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Monitoring Environmental Changes and Their Drivers: The Case Study of Central Ethiopian Highlands

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Abstract The central Ethiopian highlands, which are attracting massive population influx from the surrounding areas, are being subjected to myriad environmental changes and impacts thereof. Hence, an in-depth understanding of the statuses, and trends of the environmental resources on the highland is critical. This study used archived remotely sensed Landsat data to produced Land Use and Land Cover maps of the highlands and changes over 32 years (1985 – 2017). The Hybrid Maximum Likelihood Algorithm and image segmentation techniques; and Land Change Modeler were deployed. Accordingly, Agricultural lands, Grass/Bare lands, Lakes/Ponds, Scrublands, Settlement/Urban areas, Vegetation areas, and Wetlands were detected and mapped. Overall mapping accuracies and kappa statistics ranged between 84% - 87.6% and 95.7% - 94.4%, respectively. Agriculture is the dominant Land Use and Land Cover type throughout, though the compositions of the remaining Land Use and Land Cover types have changed since 1985; except for Lakes/Ponds, and Wetlands. Settlement/Urban areas have grown by 546%, at the expense of agricultural lands and vegetation areas, a condition that is exposing farmers to the loss of massive cropland and woodlands. Additionally, Agricultural lands have changed into Grass/Bare lands and Scrublands, as shreds of evidence of the environmental impacts of the rapid urbanization. Therefore, with an anticipated growing population and urban expansion on the highland, it is essential to promote practices of sustainable land resource management and development in the region.

Keywords: *land use land cover, environmental change, change analysis and modeling, remote sensing, central Ethiopian highlands, Ethiopia*

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1. Introduction

Ethiopian highlands are characterized by alternating dissected, rolling terrains and extensive plateau often raise as high as 1500m above sea-level or higher. It constitutes Africa's largest continuous highland system and 80% of all the tallest mountains and hence known as "the Roof of Africa". Additionally, by orographically trapping moisture from prevailing winds, the highland creates a unique hydrologic state and processes responsible for forming various river systems flowing downwards to neighboring downstream countries such as Egypt, Sudan, Kenya, Somali, and Djibouti; and therefore, referred to as "water tower of Africa". The rivers are significant for supplying drinking water for the downstream population and their domestic animals, ancient civilizations, and economic development in these countries. Great East African rift valley split Ethiopian highland into two systems: the western (Abyssinian massif) and eastern highlands (Harar massif). And the central Ethiopian highland lies at the heart of this western highland system.

However, the hydro-ecological and bio-physical functions of the highland are being exposed to alarming pressure from heightened population growth. Ethiopia's population was 35million in 1980, 66million in 2000 and currently, it is estimated to be 114million, indicating a trend of Ethiopia's rapid population growth [1,2]. If this trend continues, Ethiopia will be among the nine countries worldwide contributing to more than half of the world population growth by 2050 [3]. Ethiopia's highlands, though constitute only 52% of the country's land area and bear the largest share of the burden of population growth and socio-economic needs thereof. Approximately, 90% of Ethiopia's population resides on the highlands and so are 95% and 2/3 of the country's croplands and livestock productions, respectively [4,5]. Reasons are that the highlands are livable for their hospitable climatic conditions, fertile soils for agricultural production, and absence of several African vector-borne diseases such as malaria, trypanosomiasis, yellow fever, and etc.… vis-à-vis the lowlands. As a consequence, there is resultant aggravated land degradation and resultant accelerated soil erosion amid extensive agricultural expansion into vulnerable and/or forested lands to feed the growing population [6,7].

Appropriate Land management policy including its sustainable use planning and development is critical to reverse the situation. Such policy would require an in-depth understanding of the current state, trends of environmental changes over time, and factors controlling. Appraisal of the current state of highland can easily be achieved through Land Use Land Cover (LULC) mapping, while trends of land changes can be accomplished through multitemporal land resources analysis and modeling. LULC mapping is a process that digitally detects, recognizes, and classifies electromagnetically discernable characteristics of the satellite imagery into a list of thematic categories. On the other hand, multitemporal analysis and modeling is a process of detecting and monitoring land changes to and from these thematic categories using archive time-series satellite imagery

Archives of remotely sensed data of the National Aeronautics and Space Administration's (NASA's) Landsat mission have a proven record of constructing historical as well as contemporary environmental resources and trends on diverse landscapes. For example, several studies have been conducted using Landsat satellite imagery to map distinct LULC categories on extremely mosaic landscapes of developing countries, a semblance of central Ethiopia's highland [8,9,10,11]. Similarly, multitemporal analysis of LULC studies has been also conducted to model and monitor environmental changes on the comparable landscape [12,13,14,15]. Hence, the main goal of this study is to appraise the current state of LULC inventory using 2017 Landsat imagery and the trajectory of land change with archived time-series data from 1985 to 2017. This is to help understand the rapidly growing population and impacts thereof on the environmental resources of the central highland of Ethiopia, which also contain Addis Ababa, the nation's capital.

2. Materials and Methods

2.1 Explore Importance of the Problem

The study area covers, approximately, 4,326 km^2 (1,670miles square) on central Ethiopian highlands. It encompasses the city of Addis Ababa and six woredas (i.e., sub-cities) of Oromia Special Zone Surrounding Finfinne, namely: Sululta, Bereh, Akaki, Alem Gena, Walmara, and Mulo (Figure 1). Addis Ababa, the most populous city of Ethiopia, is the capital city of the nation as well as of the Oromia regional state. This centrally located area is bound between 08 ° 32' 0'' N, 09 ° 03' 10'' N latitude, and 38 ° 02' 70'' E, 39 ° 09' 0'' E longitude. Topographically, the study area is an integral part of the massive raised plateau and chains of mountains of the western Ethiopian Highlands (i.e., Abyssinian massif). The elevation ranges from 1,531m above sea-level in the northwest and southeast to 3,457m above sea-level in the northeast. Climatically the region exhibits a tropical monsoon, i.e., an intermediate climate between tropical rainforest and savanna. Because of its elevation, it is unusually cooler relative to tropical regions with the same latitude. The highland is agriculturally fertile and capable of providing up to three harvests a year.

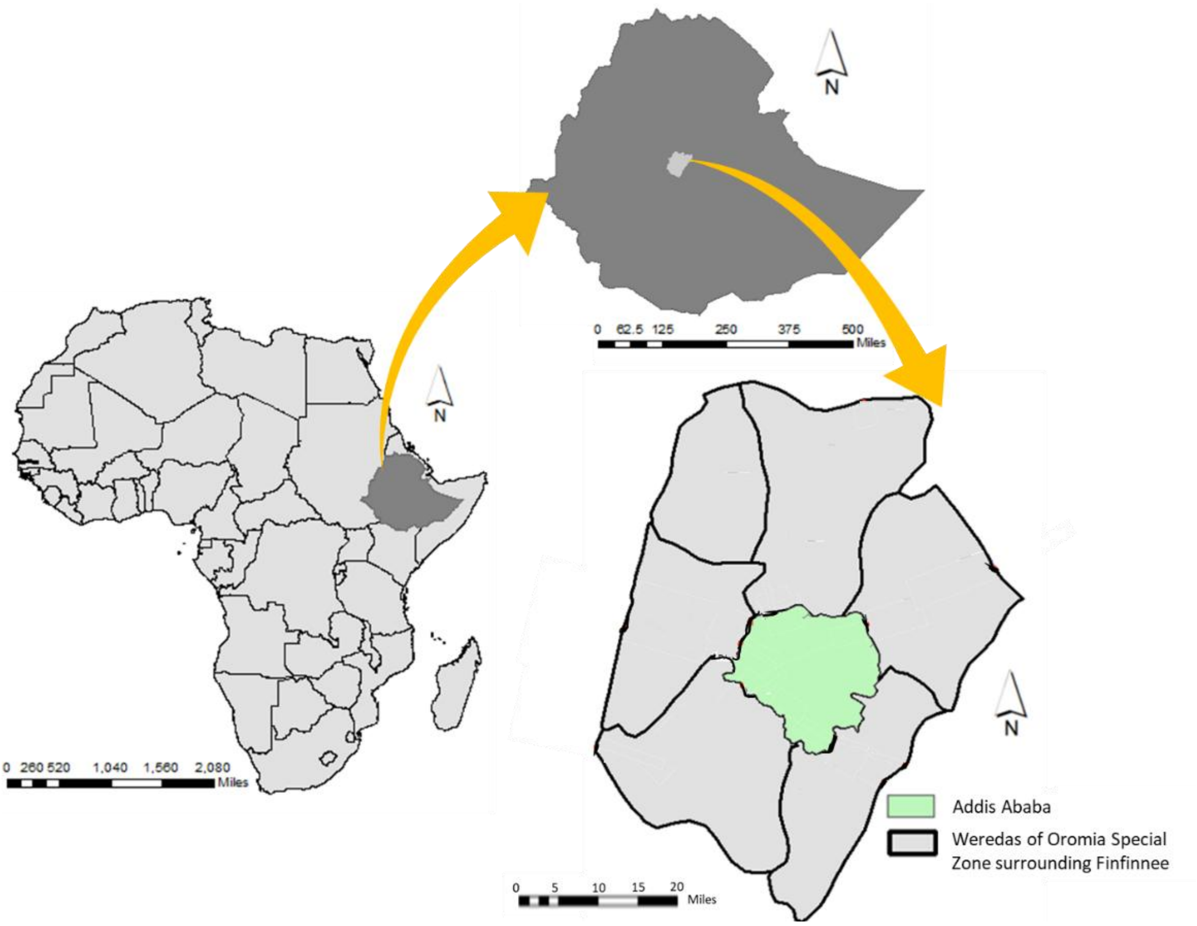

Figure 1. Study area

Table 1. Specifications of Landsat Thematic Mapper TM Images

Year	Date of Image Acquisition (mm/dd/yyyy)	Sensor	Cloud cover (%)	Image Quality	Swath Width	Spatial Resolution
1985	01/02/1985	Landsat 4-5 Thematic Mapper (TM)	0	9	185km*185km	30mx30m
2003	01/12/2003	Landsat 7 Enhanced Thematic Mapper Plus (ETM+)	0	9	185km*185km	30mx30m
2017	01/08/2017	Landsat 8 Operational Land Imager (OLI)	0	9	185km*185km	30mx30m

2.2. Data Acquisition and Pre-processing

Landsat has an archive of images of continuous earth observation datasets for over 4 decades. A total number of 3 near-anniversary images of 1985, 2003, and 2017 were downloaded from the United States Geological Survey for this study. The images were the Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI) (Path 168, Row 54). The images, which had the spatial resolution of 30mx30m and a swath width of 185km*185km, were of high quality (i.e., zero percent cloud cover) and delivered after been spatially referenced into World Geodetic System 1984 (WGS84) datum and projected onto Zone 17 Universal Transverse Mercator (UTM). As part of the image pre-processing activity, the separate bands of Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI) were stacked and cropped into the boundary of the study area obtained from map library. Map Library is Scotland based GIS clearinghouse, which provides basic boundary maps concerning Africa. Detailed specifications of the images were listed in Table 1.

2.3. Identification of the Information Class

Several LULC categories were identified for the study area using high-resolution Google Earth images (Table 2). These are Settlement and Urban areas, Vegetation Areas, Agricultural lands, Grass/Barren lands, Lakes/Ponds, Wetlands, and Scrublands. Settlement and Urban areas are cities, towns, and infrastructural facilities; while Vegetation areas are landscapes dominated by trees and shrubs, and Grass/Barren lands are degraded lands covered with low or no vegetation, gravel pits, pavement, etc… Lakes and Ponds are lands with open water such as ponds, lakes, and reservoirs; whereas, Wetlands are some transitional areas between open water and the surrounding terrestrial ecosystem. The LULC categories were developed following a layout presented by Anderson et al., [16].

2.4. Land Use Land Cover Mapping

The combined Maximum Likelihood Classifier (MLC) algorithm of the supervised image classification and image segmentation was used for the LULC mapping. The approach followed step-by-step classification techniques, where first MLC used for training samples and classifying the image into relatively homogenous categories of LULC types. Efforts were made to collect multiple samples for each information class, so as it accommodates spectral variability within classes and to assume adequate representation. The MLC is commonly used classification algorithm and involves selecting training sites for each LULC classes and developing the probability density function of DN of each training sites. The algorithm evaluates the brightness values of every pixel on the image and assigns pixels to LULC categories based on their highest likelihood of membership to categories. The probability density function (p) for a training site Wi is given by Eq. 1 [17].

$$\hat{P}(\mathrm{X} \mid \mathrm{Wi}) = \frac{1}{(2\pi)^{1/2}\,\hat{\sigma}_i}\,\mathrm{e}\left[-\frac{1}{2}\frac{(x-\hat{\mu})^2}{\hat{\sigma}_i^2}\right] \qquad (1)$$

Where e = the natural logarithms, x is the brightness values, µ = the estimated mean of the values of the category and σ = the estimated standard deviation of the values in the category.

For a multispectral image, the n-dimensional density function is given by Eq. 2.

$$\mathrm{P}(\mathrm{X} \mid \mathrm{Wi}) = \frac{1}{(2\Pi)^{\frac{n}{2}}\,|v_i|^{1/2}}\,\mathrm{e}\left[\frac{1}{2}(x-M_i)^T\, v_i^{-1}(x-M_i)\right] (2)$$

Where $|v_i|$ = the determinant of the covariance matrix, v_i^{-1} = inverse of the covariance matrix, $(x-M_i)^T$ = the transpose of the vector $(x-M_i)$ the mean of the vectors μ_i and variance matrix (v_i) for training sites of each category.

Table 2. Specifications of the major LULC types identified in the study area

Role No.	LULC Categories	Descriptions
1	Vegetation areas	Lands dominated by density populated trees and shrubs.
2	Built-up areas	Lands modified by human settlement including cities, towns and other infrastructural facilities such as road network.
3	Agricultural lands	Lands modified crop cultivation such as teff, corn, maize, beans and other crops. Lands covered by low vegetation (grasses) or no grasses.
4	Barren Lands	Lands covered by gravel pits, pavement, soils or other earthen material etc. It is land areas that are degraded and/or not fertile enough for vegetation growth.
5	Waterbodies	Lands covered with rivers or inundated open water areas mainly lagoons, ponds, lakes and reservoirs (dams) or Lands in transition zones between inundated ponds and surrounding uplands where a hydrologic characteristic produced unique ecosystems.
6	Scrublands	Lands covered by low vegetations, extremely dispersed trees, bushes or shrubs. It is a portion of land (infertile) where plant growth may be sparse, stunted and/or contain limited biodiversity.

Therefore, the maximum likelihood decision of X is a member of Wi when, using Eq. 3.

$$P\left(x\middle|\omega_i\right)\cdot P\left(w_i\right) \geq = P\left(x\middle|w_j\right)\cdot P\left(w_j\right) \qquad (3)$$

Where i and j are possible training sites of LULC classes under consideration.

After MLC's initial image categorization, image segmentation is applied to separate and mask well-classified regions of the study area. A subsequent MLC classifier was again applied on the remainder of the image to produce a news LULC map for additional segmentation. The process continued, iteratively, until eventual better spectral separability and categorizations are produced. The final LULC map was produced by combining the results of each iteration using image algebra.

A stratified random sampling of 150 randomly selected points was used to evaluate and verify the accuracy of the produced maps. It was stratified such that each LULC type has at least 20 randomly selected points for evaluation. The 150 random points were ground truth data referenced from high-resolution Google Earth imagery. Four statistical indices namely: Error matrix, Producer and User accuracies, and Kappa statistics were used for assessing the mapping accuracy of the maps [17]. Error matrix is the ratio of correctly classified pixels to the total number of pixels, while producer's accuracy is the proportion of that a land cover of an area is as correctly classified as the ones produced on the map. User accuracy is the probability that a LULC mapped corresponds to the types on the ground. Error matrix, Producer, and User accuracies are expressed as percent ranging from 0 – 100%. A hundred percent signifies good mapping accuracies, while 0% means bad accuracies. On the other hand, the Kappa analysis is used for measuring if the accuracy of the map is above and beyond the one expected by chance [18].

Lastly, the verified LULC maps were smoothed from noises of "salt and pepper" appearances also known as speckles for the final map production. The most common smoothing operation, the majority filter [19], was deployed with a 7 X 7 filter window to 'clean up' the image and produce smoother and visually attractive publishable maps. The smoothed images were then clipped into sizes of the study area.

2.5. Change Detection and Analysis

Change detection is consisted of making a comparison of change between "from" and "to" classes for each pixel over time (i.e., 1985 versus 2003 and 1985 versus 2017 LULC maps). Several change detection methods e.g. image ratioing, image differencing, Principal Component Analysis (PCA) are available [12,20,21,22]. In this study, change detection was made using the post-classification detection technique in IDRISI Land Change Modeler (LCM). LCM produces various graphs and maps such as but not limited to cross-tabulation tables, change the from-to map, gains and losses maps, all are important for detecting and analyzing LULC changes [23].

3. Results and Discussion

3.1. LULC Maps of Central Ethiopian Highlands

According to the classification result of the 1985 image (See Figure 2a), 7 LULC types were detected, recognized, and mapped in the study area. These are Agriculture, Grass/Bare land, Lakes/Ponds, Scrublands, Settlement/Urban areas, Vegetation, and Wetlands. The dominant LULC type of the area was Agriculture, which stretched over 3,372 km2 (i.e., 77.9%), followed by Vegetation, which occupied 759 km2 (i.e., 17.5%) and Settlement areas were 115 km2 (i.e., 2.7%). The remaining less than 2% of the study area was covered by Grass/bare lands (i.e., 1.4%), Lakes/Ponds (0.4%), Scrublands (0.06%), and Wetlands (0.02%). Similarly, the classification of Landsat 2003 image discovered the same 7 LULC types (See Figure 2b). Still, the dominant LULC type of the area was Agricultural land, and it was stretched over 3,232 km2 (i.e., 75%) of the study area, which is 40 km2 less than the size in 1985. This was followed by Vegetation areas, which occupied 516 km2 (i.e., 12%), whereas Settlement/Urban areas expanded over 276 km2 (i.e., 6%) of the landscape. Agricultural, Vegetation, and Settlement lands combined constituted 93% of the landscape, and the remaining four LULC types covered only 7%. Accordingly, Grass/Bare land covered 5%, while Scrubland covered 2%, Lakes/Ponds (0.34%) and Wetlands (0.04%).

In 2017, Agriculture land is still the dominant LULC type and covers areas which stretch over 2,961 km2 (i.e., 68.40%) (See Figure 2c), followed by Settlement/Urban areas 743 km2 (i.e., 17.14%) and Vegetation lands 331 km2 (i.e., 7.7%). Vegetation LULC type, which ranked second in 1985 and 2003 classified images, was overtaken by Settlement/Urban areas as an indication of massive urbanization and population growth. Agricultural land, Settlement/Urban areas, and Vegetation lands constitute 93.24%, whiles the remaining four LULC types cover only 6.76%. Grass/Bare lands covered 185 km2 (i.e., 4.3%) of the study area, Wetlands also covers 1.1 km2 (i.e., 0.03%), Lakes/Ponds occupied 10 km2 (i.e., 0.23%) and finally Scrublands occupied 95 km2 (i.e., 2.20%). The historical and contemporary LULC types inventories have detected and mapped typically heterogeneously complex Ethiopian [24,25,26], as well as related East African highlands [14]. For instance, the 7 LULC types documented in this study is similar to the 6 LULC types (i.e., forested lands, Bare lands, Grasslands, Croplands, Shrublands, and Urban built-up areas) documented by Miheretu and Yimer [25] on Gelana sub-watershed, Wollo region, North Central Ethiopian highlands.

3.2. Validation of LULC Maps Accuracies

Table 3 summarizes the results of the classification accuracy assessments. Accordingly, there was an overall mapping accuracy of 84.0% and Kappa Statistics of 0.88% for the map of 1985. Similarly, the overall accuracy and

Kappa statistics of the 2003 map were 91.77% and 0.89%, respectively, whereas, for the 2017 image, they were 95.7% and 0.95%. With overall classification accuracy ranging from 84% to 95.7%, the resulting LULC maps were deemed accurate. Additionally, with the overall Kappa statistics ranging from 0.88% to 0.94%, the agreement between the classified images and actual LULC types on the ground is satisfactory. In general, the progressing increments of the accuracy indices (i.e., from 1985 to 2017) perhaps indicate uncertainty and challenges associated with constructing historical reference data. The validation results of the LULC maps were comparable with the results of Friehat et al.., [22].

The most accurately classified LULC types are Settlement/Urban areas and Lake/Ponds. Both had producer and User accuracies of 100%. These mapping accuracies of Urban/Settlement areas may have to do with unique attention applied in selecting the training sites and subsequent classifier-training from this area as it was the main theme of the study. On the other hand, the superior accuracy of Lakes/Ponds could be due to conspicuous spectral absorption of open water bodies at visible and near-infrared regions of the electromagnetic spectrum. Agricultural lands and vegetation areas were also mapped with very good Users and Producers accuracies (i.e., 84% to 94%), respectively. The accuracy of scrublands, wetlands, and bare/grasslands were least (see Table 3) indicating the impact of diversity in these LULC types' categories and spectral heterogeneity thereof. Mixed pixels and spectral heterogeneousness would pose challenges to remote sensing data classification for LULC mapping [27]. All the information associated with the analysis of mapping accuracy is presented in Table 3.

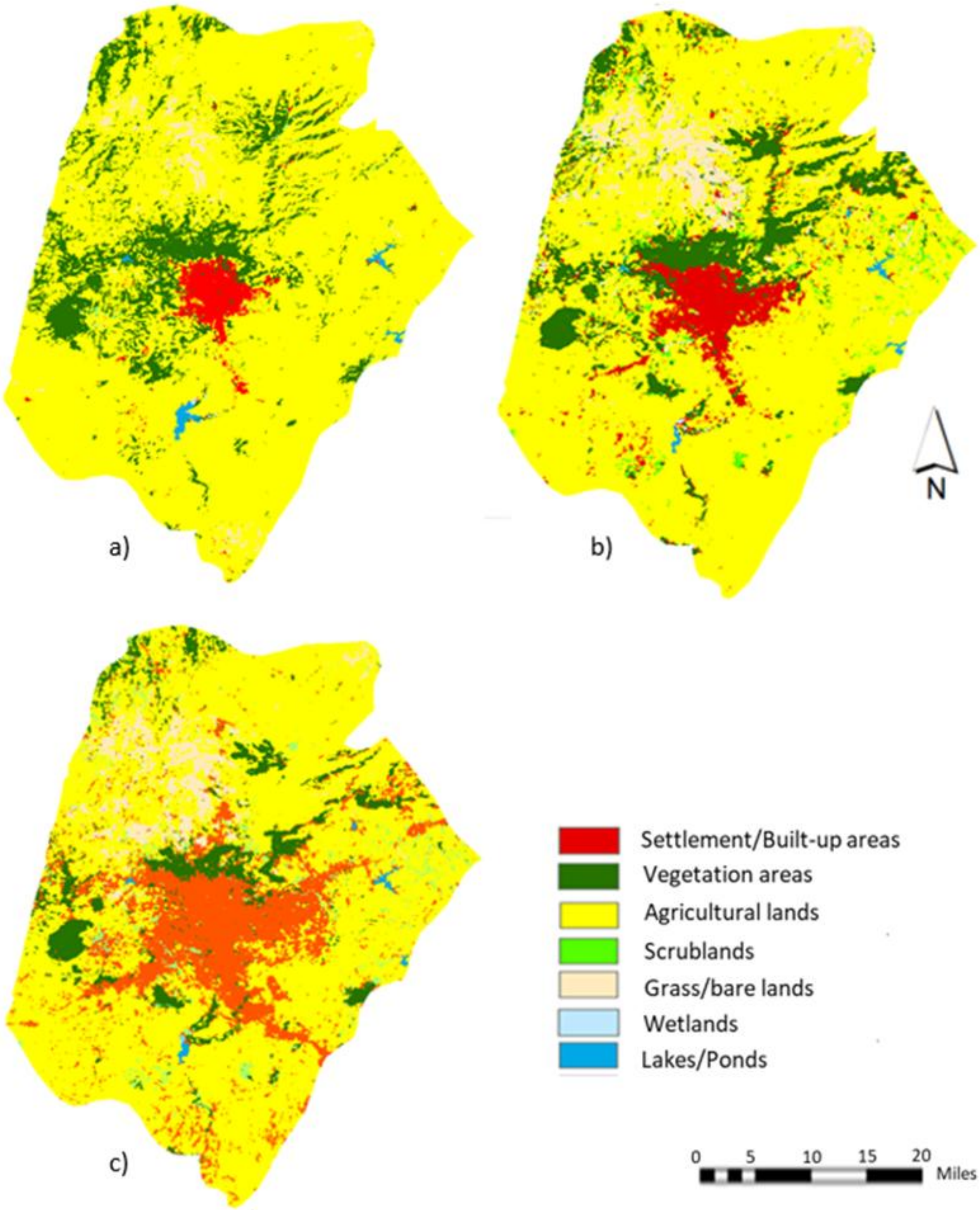

Figure 2. Classified LULC Map of Central Ethiopian Highland: a) 1985; b) 2003 and c) 2017

Table 3. Summary of error matrices for the classified images of 1985, 2003 and 2017

Year	LULC Categories	Producer Accuracy	User Accuracy	Kappa
1985	Vegetation areas	83.3%	93.75%	0.93
	Settlement/Urban areas	100%	100.0%	1.00
	Agricultural lands	92.0%	88.46%	0.80
	Grass/Bare lands	72.7%	72.73%	0.70
	Wetlands	100.0%	70.0%	0.68
	Lakes/Ponds	100.0%	100.0%	1.00
	Scrublands	72.73%	80.00%	0.78
	Overall accuracy		84.0%	
	Overall KIA		0.88	
2003	Vegetation areas	83.3%	93.75%	0.98
	Settlement/Urban areas	100%	100.0%	1.00
	Agricultural lands	92.0%	88.46%	0.80
	Grass/Bare Lands	72.7%	72.73%	0.70
	Wetlands	100.0%	70.0%	0.68
	Lakes/Ponds	100.0%	100.0%	1.00
	Scrublands	72.73%	80.00%	0.78
	Overall accuracy		91.77%	
	Overall KIA		0.89	
2017	Vegetation areas	83.3%	93.75%	0.93
	Settlement/Urban areas	100%	100.0%	1.00
	Agricultural lands	92.0%	88.46%	0.80
	Grass/Bare Lands	72.7%	72.73%	0.70
	Wetlands	100.0%	70.0%	0.68
	Lakes/Ponds	100.0%	100.0%	1.00
	Scrublands	72.73%	80.00%	0.68
	Overall accuracy		95.7%	
	Overall KIA		0.95	

3.3. Change Detection and Analysis

Figure 3 shows the LULC changes from 1985 to 2017. According to this finding, out of the study area's 4326.4 km^2 landmass, 1220.7 km^2 experienced LULC types changes, in one form or the other. Conversely, LULC change was not detected in 3105.6 km^2 of the landscape. In general, environmental resources have changed on 28% of the landscape during the study period, while the remaining 72% has not unchanged.

Table 4 shows specific types of change for the highland's LULCs. Accordingly, while Wetlands and Lakes/Ponds have experienced the infinitesimal change (i.e., combined less than 0.05% of the change), the remaining LULC types have significantly changed during the 32 years' study period (1985 – 2017). The largest proportion of the land transformation was due to Settlement/Urban areas, which accounted for 41% of the changed landscape followed by Vegetation areas (i.e., 28%). Land changes as a consequence of Agricultural lands, Grass/Bare lands and Scrublands accounted for 27%, 8%, and 6% transformations, respectively. Settlement/Urban areas, Scrublands, and Grass/Bare lands experienced gains in the land. Settlement/Urban areas have gained land from 115 km^2 in 1985, to 276 km^2 in 2003 and 743km^2 in 2017, which were increases by 140, 169%, and 546%, respectively. Additionally, Scrublands and Grass/Bare lands have gained land from 2.4 km^2 and 59 km^2 in 1985; to 86 km^2 and 202 km2 in 2003 and 95 km^2 and 185km^2 in 2017; respectively. The fivefold increase in Settlement/Urban area is a typical urban growth rate for developing countries [13,28,29,30,31]. For instance, Habila [30] documented Abuja and metropolitan area growth of 467% over 28 years (i.e., 1988 – 2016), while similarly, Oyugi et al., [29] reported Urban/Settlement area growth of 238% over 22 years (i.e., 1988 – 2010) for Nairobi and its environs.

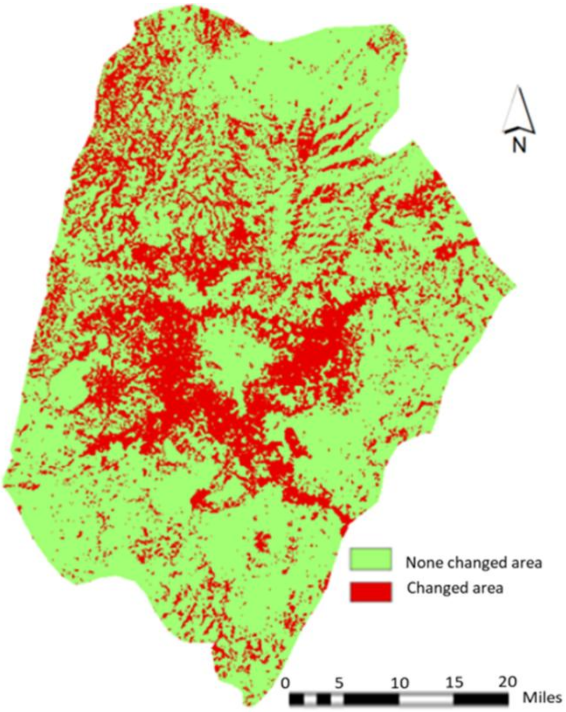

Figure 3. Map of Changed and Unchanged areas during the study period (1985 – 2017)

Table 4. LULC Changes that occurred between years 1985, 2003 and 2017

LULC Types	1985 Area	2003 Area	2017 Area	Change in Area (1985 to 2003)		Change in Area (1985 to 2017)		Total change
	Km^2	Km^2	Km^2	Km^2	%	Km^2	%	%
Vegetation	759	516	331	-243	-32%	-428	-56%	28%
Settlement/ Urban Areas	115	276	743	161	140%	628	546%	41%
Agriculture	3372	3232	2961	-140	-4%	-411	-12%	27%
Grass/Bare Lands	59	202	185	142	242%	125	214%	8%
Wetlands	1.12	1.8	1.1	0.67	61%	-0.02	-2%	0%
Lakes/Ponds	17.3	12	10	-4.9	-31%	-7.2	-42%	0.5%
Scrublands	2.4	86	95	83.6	3483%	92.8	3858%	6%

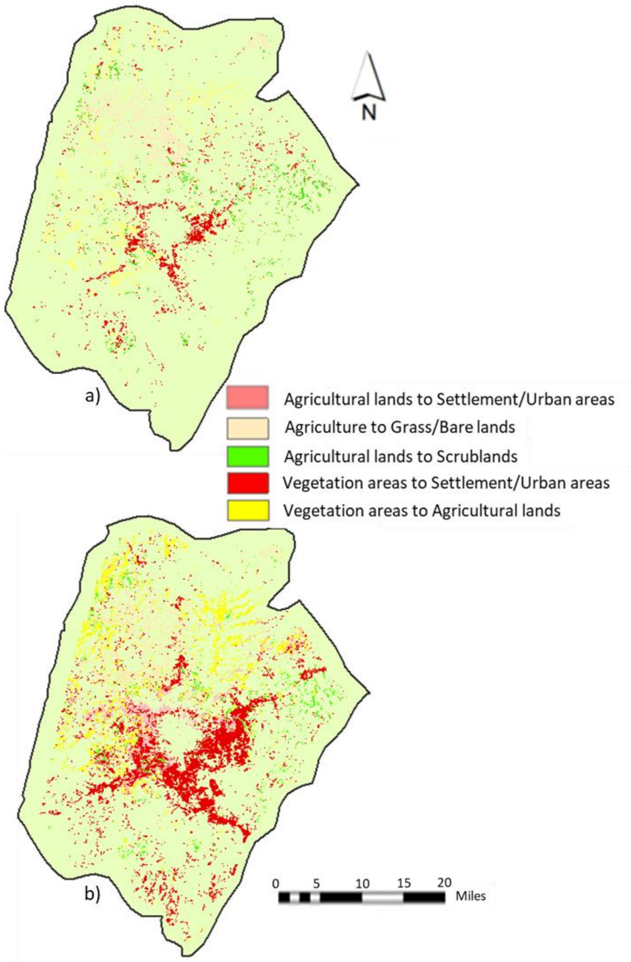

Figure 4. Spatial distribution and analysis of Major LULC changes a) between 1985 and 2003 and b) between 1985 and 2017

The largest land transformation, between 1985 and 2003 (i.e., 175 km^2) was a conversion of Vegetation areas into Agricultural lands, followed by a conversion of Agriculture lands into Grass/Bare lands (i.e., 151 km^2) (Figure 4). Moreover, Agriculture lands have been converted into Settlement/ Urban areas by 128 km2 and scrublands by 66 km^2. Similarly, between 2003 and 2017 Agricultural lands and Vegetation areas continued losing lands to other LULC types. While Vegetation continued losing lands to Agriculture (i.e., 141 km^2), it was Agricultural lands that dominated the conversion by losing lands mainly to Settlement/ Urban areas (i.e., 400 km^2) and Grass/ Bare land (i.e., 58 km^2). Settlement/Urban areas have also taken lands (i.e., 107 km^2) from what had been Vegetation areas in 2003. Similar patterns of land transformations were noted on other comparable landscapes [11,22,26,28,30]. To monitor 40 years of LULC change, Prakasam, [30] detected a transformation of vast Agricultural lands into built-up areas in Kodaikanal Taluk, India; whereas, with a twenty-five-year (1985 – 2010) observation of LULC changes in northeastern Illinois, Friehat et al., [22] reported losses of Agricultural lands to Chicago urban growth; indicating agricultural land transformation amid the expansion of urban and settlement areas.

Consequently, three major drivers are causing the land transformation on Central Ethiopian highlands. These are urbanization, agriculturalization, and environmental degradation. Urbanization is the main driver as it is found responsible for the conversion of 459 km^2 Agricultural lands as well as 171 km^2 Vegetation areas, indicating a clear sign of urban encroachment into surrounding physical environments. The second major driver of the land transformation is agriculturalization. It has taken 275 km^2 of Vegetation areas, signifying the activities of displaced farming communities. Farmers displaced by urbanization are encroaching the natural environment by cutting trees and clearing lands and putting them under crop production. Lastly, the third major driver is environmental degradation. During the study period, 132 km^2 of Agricultural and 70 km^2 of Vegetation lands transformed into land showing signs of environmental degradation and/or perhaps fallow lands left for recuperating its degraded fertility.

4. Conclusion

Owing to the hydro-ecological and bio-physical functions of the central Ethiopian highlands and its extensive degradation from growing population and impacts, therefore, regular monitoring of the highlands is important. Archived remotely sensed satellite imagery has shown a capability to retrieve the current state as well as trends of environmental resources on a mosaic landscape such as the Central Ethiopian Highland. This study used archived Landsat data of over 32 years and identified 7 LULC types (Agricultural lands, Settlement/Urban areas, Vegetation areas, Lake/Pond, Scrublands, Grass/Bare-lands, and Wetlands) with overall accuracies and Kappa statistics ranging between 84% and 87,6% to 95.7% and 94.4%; respectively. Agriculture is the dominant LULC types of Addis Ababa and Surrounding Oromia zones (i.e., 68.4%), following by Settlement/Urban (17.14%) and Vegetation areas (i.e., 7.7%). The remaining 6.76% of the study area is consisted of Grass/Bare lands (i.e., 4.3%), Wetlands (i.e., 0.03%), Lakes/Ponds (i.e., 0.23%) and Scrublands (i.e., 2.20%).

The current LULC types of the highland show a departure from what it was in 1985. In general, land transformations were detected on 28% of the study area and the majority of the changes were Settlement/Urban areas, followed by Vegetation areas and Agricultural lands. Settlement/Urban areas increased approximately 5 folds of the size it was in 1985, substantiating rapid population growth and urbanization on the highland. Settlement/Urban expanded on the lands that were originally Agricultural lands and Vegetation areas. Additionally, although land degradation characterized by Grass/Bare lands and Scrublands took place only at 8% and 6% of the study area, respectively; they have increased by 2 and 30 folds over the study period, indicating the environmental impacts of Settlement/Built-up areas expansion. The land degradations occurred mainly on the lands that were historically under agricultural production. Loses of Agricultural lands to both Settlement/Urban areas and degraded lands in this cumulative margin are significant considering food production and security to the growing population on the central highlands. It is possible that farmers, who were once known for surplus agricultural production, are perhaps experiencing a food shortage, land scarcity, and poor soil fertility.

Last but not least, the LULC mappings exercises of the study were based on ground truth data collected with the help of high-resolution images of Google Earth. It is done without visiting the study area to view these LULC types visually. The results shall further improve with future works involving visitation to the study area for ground reference data (ground truth).

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Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript. Besides, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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