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Assessment of land use and land cover changes in Kenya's Mt. Elgon forest ecosystem

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Abstract

Current land-use trends in Kenya's montane forest ecosystems show that land uses are changing fast due to natural and anthropogenic factors and these changes could have devastating effects on the environment. One such montane forest is the transboundary Mt. Elgon forest located in western Kenya. This study analysed trends in land use–land cover changes in Mt. Elgon forest ecosystem over the last 45 years. Landsat imageries downloaded from the United States Geological Survey archives were used to assess land use–land cover changes between 1973 and 2019 by applying supervised classification using Arc GIS 10.5. The IDRISI Selva 17.0 was used to calculate area under different land uses and generate change maps. The major Land Use–Land Cover (LULC) classified were mixed farming, natural forests, planted forests, bamboo forest, fallow land, tea plantation. The landsat images had an average overall classification accuracy of 87.12% and kappa coefficient (K) of 0.84. The kappa coefficient was rated as substantial and the classified images qualified for further analysis. Results established that there was an 18% decline in the natural forest cover between 1977 and 2019. There was a similar decline of 15.19% in bamboo forest cover. Plantation forests established in the 1990's also showed a 15.6% decline between 1999 and 2019. There was, however, a 29% increase in mixed farming, a 10% increase in fallow land and a 0.13% increase in tea plantations. These changes in land uses and land cover call for an urgent need to develop sustainable management plans to protect and conserve the Mt. Elgon forest ecosystem. Sustainable land management strategies to be used in the future may include education on the significance of the forest ecosystem, community participation in sustainable utilisation of forest eco-services and the introduction of sustainable alternative sources of livelihoods, such as bee farming.

KEYWORDS
ecosystem changes, indigenous forests, land cover, land-use changes, Mt. Elgon

Résumé

Les tendances actuelles d'utilisation des terres au sein des écosystèmes forestiers de montagne du Kenya montrent que l'utilisation des terres change rapidement en raison de facteurs naturels et anthropiques et que ces changements pourraient avoir des effets dévastateurs sur l'environnement. La forêt du mont transfrontalier Elgon, située

dans l'ouest du Kenya, est l'une de ces forêts de montagne. Cette étude a analysé les tendances des changements d'utilisation des terres et de la couverture terrestre au sein de l'écosystème de la forêt du mont Elgon au cours des 45 dernières années. Les images Landsat téléchargées à partir des archives du « United States Geological Survey » (Service géologique des États-Unis) ont été utilisées afin d'évaluer les changements survenus dans l'utilisation des terres et dans la couverture terrestre entre 1973 et 2019, en appliquant une classification supervisée à l'aide d'Arc GIS 10.5. Idrisi Selva 17.0 a été utilisé pour calculer la superficie des zones soumise à différentes utilisations des terres et générer des cartes représentant les changements. Les principaux types d'utilisation des terres et de couverture terrestre étaient l'agriculture mixte, les forêts naturelles, les forêts plantées, les forêts de bambous, les terres en jachère et les plantations de thé. Les images Landsat avaient une précision de classification globale moyenne de 87,12% et un coefficient kappa (K) de 0,84. Le coefficient kappa a été jugé important et les images classifiées remplissaient les conditions requises aux fins d'analyse plus approfondie. Les résultats ont établi qu'un déclin de 18% du couvert forestier naturel s'était produit entre 1977 et 2019. Une baisse similaire de 15,19% du couvert forestier de bambous s'est également produite. Les plantations forestières établies dans les années 1990 ont également accusé une baisse de 15,6% entre 1999 et 2019. Il y a cependant eu une augmentation de 29% de l'agriculture mixte, de 10% des terres en jachère et de 0,13% des plantations de thé. Ces changements dans l'utilisation des terres et la couverture terrestre mettent en évidence un besoin urgent d'élaborer des plans de gestion durable afin de protéger et de conserver l'écosystème forestier du mont Elgon. Les stratégies de gestion durable des terres à utiliser à l'avenir peuvent notamment inclure une sensibilisation sur l'importance de l'écosystème forestier, la participation de la communauté à l'utilisation durable des éco services forestiers et l'introduction de sources alternatives durables de moyens de subsistance, telles que l'élevage des abeilles.

1 | INTRODUCTION

Land-use change involves the arrangements, activities and inputs people make in a particular land cover type to produce and maintain change. The negative impacts often associated with land-use changes worldwide have become a global concern (Lambin & Meyfroidt, 2011). These changes have been increasing at a high rate in the past few decades. Land-use changes may involve the expansion of one land use at the expense of other land-use type. One of the main causes of land use/cover changes is population increase and the expansion of agricultural land (Berihun et al., 2019).

Dynamics of Land use and land cover (LULC) change have not been uniform in all parts of the world as a result of different driving forces (Berihun et al., 2019). The acquisition of natural resources for immediate human needs, often at the expense of degrading environmental conditions is often the ultimate goal of land use change (Foley et al., 2005). Many land-use practices are essential for humanity because they provide critical ecosystem services, such as food, fibre, herbal medicines, shelter and freshwater. On the other hand, some forms of land-use changes undermine the ability of the ecosystem to sustain food production, maintain fresh water and forest resources, regulate climate and air quality and ameliorate infectious diseases (Foley et al., 2005). Kanianska et al. (2014) indicated that changing land-use practices have enabled world grains harvest to double from 1.2 to 2.5 billion tonnes per year between 1970 and 2010. Smith et al. (2014) confirmed that globally since 1970's, a 1.4-fold increase in number's of cattle, buffalos, sheep and goats and a 1.6- and 3.7-fold increase for pigs and poultry, respectively. Land-use changes such as afforestation could be associated with the improvement of atmospheric condition and increase in biodiversity. Pejchar et al. (2005) observed that plantation forests play an important role in biodiversity conservation and restoration of forest species and that enhanced biodiversity outcomes are expected with plantations that utilise indigenous tree species.

Although land use change to modern agriculture has been effective in increasing food production, it has also extensively degraded the environment thus gaining a lot of interest because of its role in driving environmental changes (Hosea et al., 2017). One of the

worrying land-use changes is the conversion of forests to other uses. Kees and Navin (2010) reported that in the past 300 years, land-use changes, for agricultural production and timber extraction, have led to a global net loss of 8–13 million km^2 of forest. Gibbs et al. (2009) established that across the tropics, between 1980 and 2000 more than 55% of new agricultural land came from intact forests, and another 28% came at the expense of disturbed forests. Despite various initiatives to reverse forest decline, the world has continued to lose some 15 million hectares of forests annually (Nzeh & Emeka, 2012). For instance, deforestation in the 1980's and 1990's reached 8.2% of total forest area in Asia, 6.1% in Latin America and 4.8% in Africa (Arnoldo, 2000). Odada et al. (2020) reported that the most significant changes on the earth surface include increased degradation of land, siltation of water bodies, deforestation and extinction of key terrestrial and aquatic species and majority of these changes are mostly associated with over-exploitation of natural resources, extensive land degradation, agricultural land expansion and increase in human and livestock populations.

Land scarcity in the highlands of East Africa has converted forested lands to agriculture, reducing forest cover. Olson et al. (2004) reported that during the last few decades, the area under cultivation has more than doubled in East Africa. FAO (1993) estimated that between 1980 and 1990, natural forests decreased by about 12.7% in Tanzania. Kenya has the most diverse but highly fragmented forests in East Africa (Kenya, Uganda and Tanzania). The increase in fragmentation is caused by both natural and anthropogenic factors (Lung & Schwab, 2004). Anthropogenic activities include road construction, logging, conversion to agriculture or wildfire (Wade et al., 2003). Kenya's indigenous forest canopy is approximately 6.9% (3,467,000 ha) (Cheboiwo et al., 2018). This forest cover is low as compared to forest covers of 55% for Tanzania, 43% Mozambique, 12.4% Uganda, respectively (Mwangi et al., 2018). This current coverage is below the globally recommended ten percent (10%) (GOK, 2010). Kenya has been losing forest cover at the rate of approximately 1900 ha per year for the last 20 years (CBS, 2004). The country's forests decreased by 0.34% (12,050 ha) per year between 1990 and 2000 and a 6.5% (241,000 ha) forest loss between 1990 and 2010 (FAO, 2010). The degradation of the forest has been attributed to various factors that include illegal logging and encroachment on forest land for farming and charcoal-burning. Current land-use trends in Kenya's montane forest ecosystems shows that land uses are changing fast and this speed of change could have a devastating effect on the environment both locally and globally (Liu et al., 2003). Mt. Elgon forest ecosystem has been experiencing land-use changes that have the potential to negatively affect forest biodiversity and livelihoods of forest adjacent communities. According to the Indigenous Information Network (2008), the Mt. Elgon forest resources are of crucial significance to the livelihoods of the Sabaot, Ogiek and other forest adjacent communities. The forest is also an important habitat to fauna and flora of the region. The forest ecosystem is vital to the socioeconomic functioning of the Mt. Elgon region. Mt. Elgon forest is a water tower that forms the upper catchment of river Nzoia which forms one of the country's major rivers. Unsustainable land-use changes in this region may result in the drying up of rivers which could impact disastrously, the agricultural sector, leading to serious food insecurity challenges. Majority of people in sub-Saharan Africa depend on natural resources for their livelihoods and therefore understanding land use change (LUC) dynamics is crucial for sustainable land resource management (Wood et al., 2004). This study sought to assess and document land use land–cover changes that have occurred in the Mt. Elgon forest ecosystem between 1973 and 2019. This time frame was preferred because it is during the year 1973 that Mt. Elgon region experienced severe land use change due to resettlements (GOK, 2019). These resettlements resulted in the development of agriculture adjacent to the primary forest that covered the slopes of this dormant volcano. There has been scant unreported research to investigate the time-series changes in land uses after this resettlement program. Mt. Elgon Integrated Conservation and Development Project MEICDP (2001) carried out Aerial photography and land cover mapping of Mt. Elgon between 1960 and 1999. They, however, did not address the relationship between land cover and land-use changes. Similarly, they indicated that the aerial photographs utilised in the project were not fully exploited. They recommended that more could be done on the vegetation and ecological associations on Mt. Elgon. The Kenya Water Towers Agency (2016) studied land use–land cover change of Mt. Elgon forest between 1990 and 2016. They, however, looked at forest as a single block and did not distinguish between changes in natural and planted forests. A similar omission was made when they focussed on cropland with no distinction between the monocultural tea plantation and mixed farming. Therefore, this study has investigated the trends in land use and land cover in Mt. Elgon forest ecosystem between 1973 and 2019. The study has specifically distinguished the changes in indigenous forests and planted forest. Similarly, the study has explored the changes in monocultural tea farming and mixed farming.

2 | METHODS

The Mt. Elgon forest is a transboundary ecosystem in Northwestern Kenya and Eastern Uganda. In Kenya, it is surrounded by Bungoma County to the south and Transnzoia County to the east. On the Ugandan side, Mbale district is to the south-eastern part, Sironko district to the west and Kapchorwa district to the north. The study was carried out in the Kenya's Mt. Elgon forest ecosystem and the adjacent regions (Figure). The study covered a total area of 1860.5 km^2.

Mount Elgon Ecosystem is located approximately 150 km northeast of Lake Victoria, at latitude 1° 08’ N and 34°45'E. The climate of the area is mainly tropically humid, with mean annual rainfall of 1400–1800 mm and an average temperature range of 14–24°C, though both climate parameters vary strongly with elevation. The annual rainfall pattern is bimodally distributed, with long rains between March and June, and short rains from September to November. Mean temperature is lowest in June to September (Musau et al.,

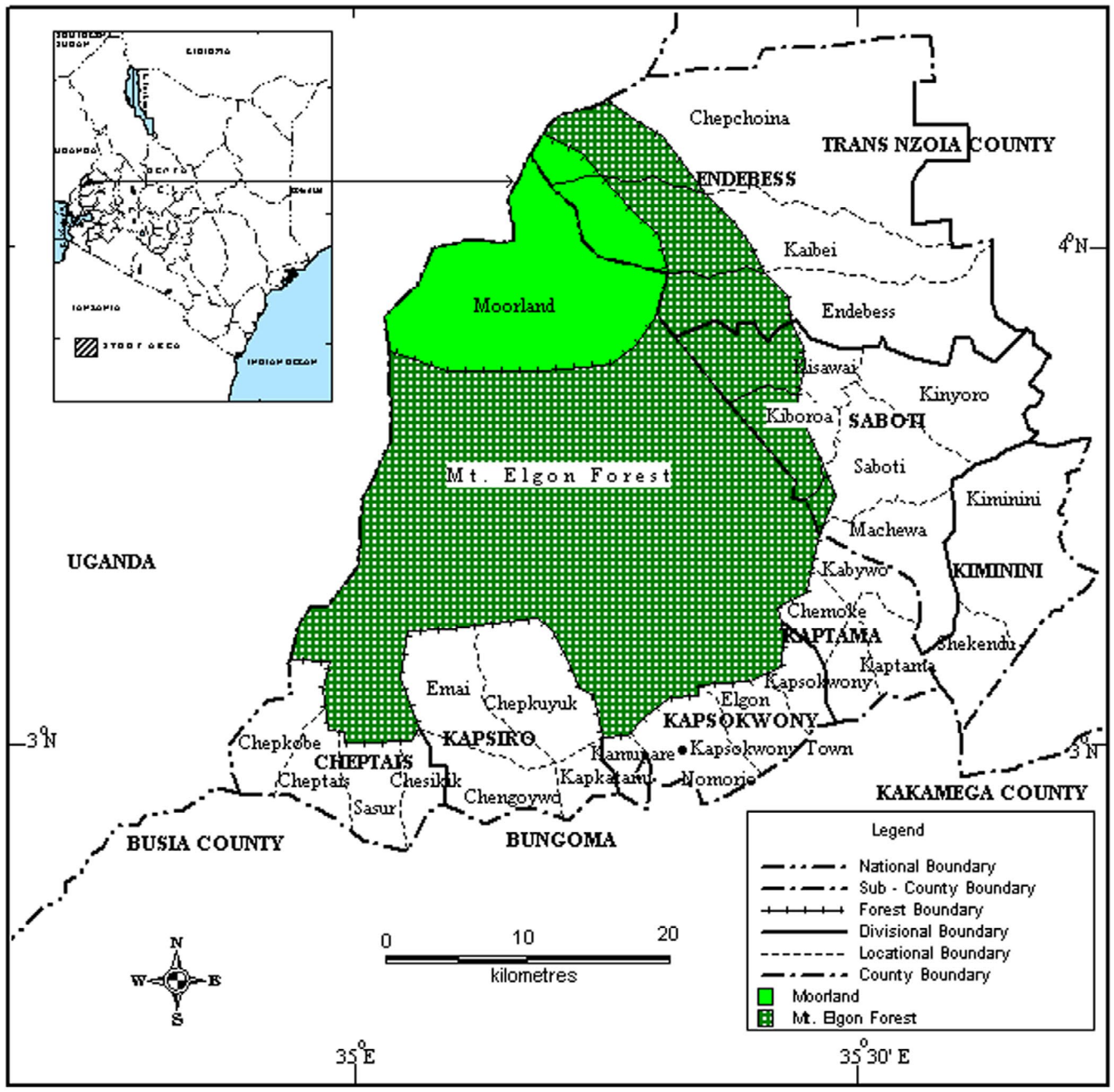


FIGURE 1 Map of Mt. Elgon forest ecosystem and adjacent regions. (Source: Moi University Department of Geography GIS Lab)

2015). The region also receives a minimum and maximum temperature of 9°C and 22°C, respectively. The soils are poorly drained dark peaty loams, ranging in colour from reddish-brown to black. They are shallow with rock outcrops (Ongugo et al., 2001).

2.1 | Data collection and analysis

Data were collected by use of satellite imageries, observation and secondary theoretical data. Satellite imageries were downloaded from the USGS website. Land-use changes between 1973 and 2019 were analysed using satellite imagery for 1977, 1986, 1999 and 2019. The 1977 Multi-Spectral Scanner (MSS) satellite image that was used was taken on 28th December 1977 and had (Path/Row 170/59). The image had a resolution of 60 m. Other images used included the Landsat 4–5 Thematic Mapper™ for 1986 and 1999 taken on 18th March 1986 and 17th December 1999, respectively. For the 1986 and 1999 images, Path/Row 170/59 was used. Landsat images for 1986, 1999 and 2019 consisted of seven spectral bands with a spatial resolution of 30 m for Bands 1–5. Acharya and Yang (2015) reported that Landsat™ satellite images are a good tool for mapping vegetation. For the 2019 Landsat image, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images (Path/Row 170/59) were used. It consisted of eight spectral bands with a spatial resolution

TABLE 1 Land Use–Land Cover Classes of Mt. Elgon Forest Ecosystem

Land Use	Description
Mixed Farming	A farming system that involves growing of a mixture of a variety of crops on the same piece of land
Planted Forest	forests established through human planting
Natural Forest	A forest that has reproduced naturally, consisting of naturally immigrant or indigenous tree species and strains
Grasslands	A large open area of land covered with grass, especially one used for grazing. Included moorland
Fallow Land	Bare Land awaiting the growing of crops
Bamboo	a giant woody grass
Tea Farming	Area covered by tea plantation

of 30 m for Bands 1–7. In this image, bands 2–5. Acharya and Yang (2015) suggest that the best bands for mapping vegetation is colour infrared of the band 5, 4 and 3. The downloaded satellite images from https://earthexplorer.usgs.gov/ had the global reference system World Geodetic System 1984 (WGS84) and the projection Universal Transverse Mercator (UTM) 37 N.

Pre-processing involved clipping and compositing. The administrative state boundary map for the area of study was also brought to Universal Transverse Mercator project in zone 37 and later the satellite imageries were clipped with the administrative boundary of Mt. Elgon forest and the adjacent region (Figure 1). The different False Colour Composite (FCC) of the Mt. Elgon region for the different stated periods were prepared. The preparation ensured that the pixel grids of the images for the year 1977 conform to the corresponding images of the year 1986, 1999 and 2019. This enabled pixel by pixel comparison of the images. Ground-truthing on land uses changes was carried out for seventy points obtained in the field with a Garmin Etrex30x Global Positioning Systems (GPS).

A supervised multispectral classification was performed using Arc GIS 10.5 to distinguish between the seven possible classes which included natural forests, planted forests, tea plantation, mixed farming, grasslands, bamboo forest and fallow land. Table 1 below shows the various land use and land cover classes that were used.

Some 50 training samples were created for each land use. Change analysis was run between 1977 and 1986, 1986–1999, and 1999–2019 imageries which created change maps. Change analysis was done by use of IDRISI Selva 17.0 software. These maps showed the changes that have occurred over the periods under study. An accuracy assessment via ground-truthing and the use of Google Earth Pro was done from the change maps so as to verify any land use change that may not have been clear. The accuracy of the classification system was evaluated by use of 70 reference test pixels identified and widespread on the 2019, 1999, 1986 and 1977 landsat images of the research site. Validation was then performed, by comparing data from Google earth and ground check. The accuracy of land use classification was assessed by using Kappa accuracy assessment, consisting of overall accuracy (OA), Producer's accuracy (PA), user's accuracy (UA) and Kappa statistic (Congalton and Green, 1999). The probability that a classified pixel from the (LC) map accurately corresponds with the referenced data is determined by the user's accuracy (Jensen, 2005), while the Kappa statistic measures the difference between the true agreement of classified map and chance agreement of random classifier compared to reference data (Lillesand et al., 2004). It is stated that Kappa values of more than 0.80 indicate good classification performance. To validate data from satellite images, secondary literature of previous scientific studies on Mt. Elgon ecosystem were used. Data were presented in the form of diagrams, time-series maps, tables and bar graphs.

3 | RESULTS

Analyses revealed that in 1977, there were five major land uses which included natural forests, bamboo forests, grasslands, mixed farming and fallow land (Figure 2). The assessment showed an overall accuracy derived from the stratified random sampling method for the 2019 classified images was 90% with an overall kappa statistic of 0.85. As for the 1999 Landsat image, the overall accuracy was 88.57% and the kappa statistics was 0.86. The 1986 Landsat image revealed an overall accuracy of 86% and a kappa-statistics value of 0.83. Finally, the overall accuracy for the 1977 Landsat image was 84% with a kappa statistics of 0.80 (see Appendix 1 and 2).

In 1977, natural forest was the dominant land use/ land cover in the Mt. Elgon forest ecosystem accounting for 36.08% (671.37 km^2) of the total land area. Grasslands were the second most dominant land use with 28.23% (525.35 km^2). Bamboo forest accounted for 16.60% (309.7 km^2) of the land use while fallow land and mixed farming accounted for 17.68% (328.9 km^2) and 1.37% (25.39 km^2), respectively.

In 1986, the region still had five major land uses which included natural forests, bamboo forests, grasslands, mixed farming and fallow land (Figure 3). The major land use in 1986 was natural forest that was 31.07% (578.11 km^2) of the total land area of 1860 km^2. Grasslands covered some 29.38% (546.52 km^2) that were mainly used for grazing domestic animals in the forest. Fallow land and mixed farming occupied 21.4% (398 km^2) and 12.65% (235.42 km^2) of the Mt. Elgon forest ecosystem, respectively. Bamboo forests covered some 5.46% (101.79 km^2).

Analyses further revealed major changes in sizes of the various land use and land cover types. Between 1977 and 1986, there was

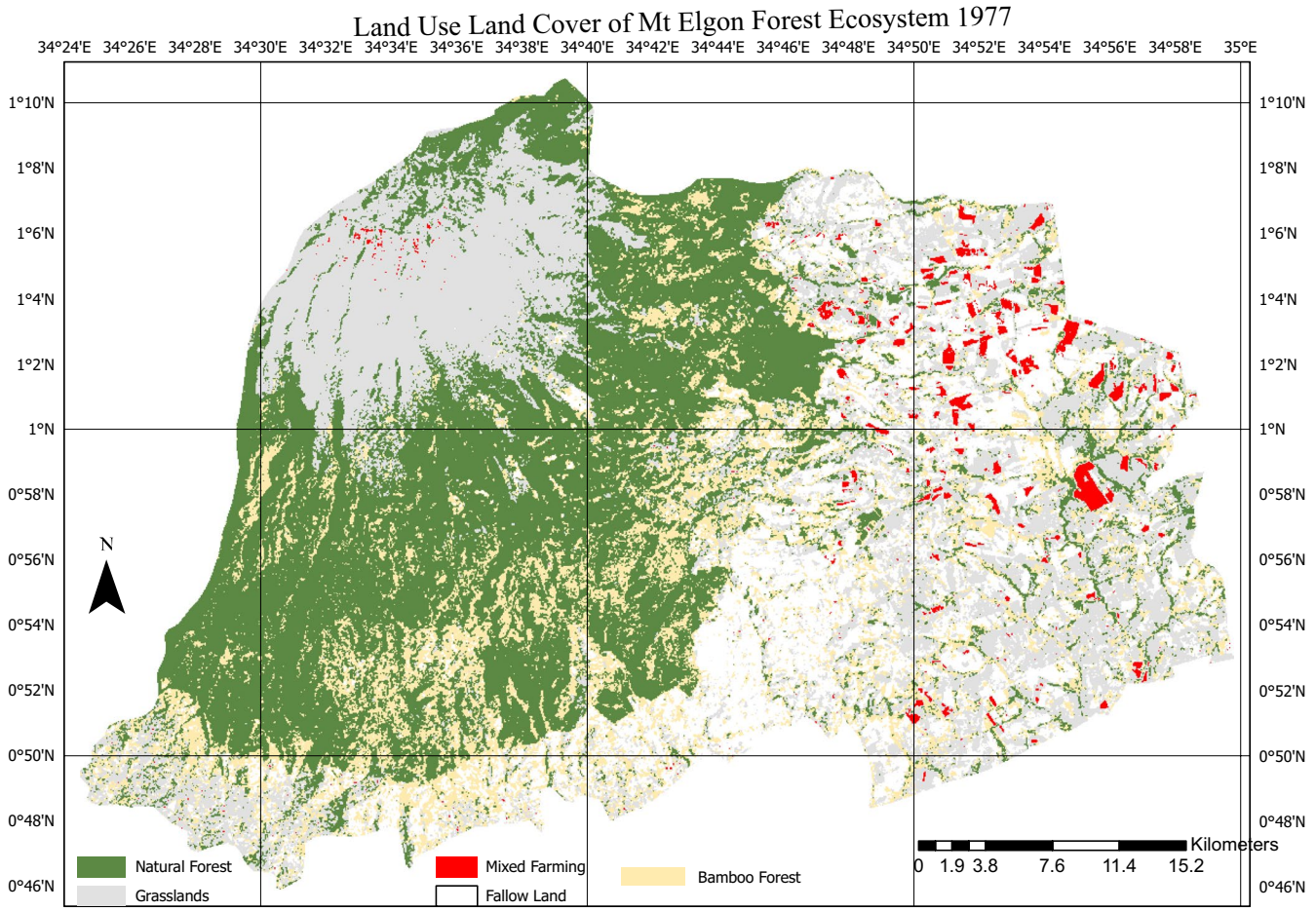


FIGURE 2 Land Use Land Cover Changes in Mt. Elgon forest ecosystem and adjacent areas (1977)

a significant decline of 11.14% in the area under bamboo and a 5% in natural forest. There was a corresponding increase of 11.29% in mixed farming, fallow land showed a slight increase of a 3.76% increase, and a 1% increase in grasslands (Figure 4).

Further analysis revealed that between 1977 and 1986, 120.33 km^2 of the natural forest was transformed into grasslands, some 30.61 km^2 of natural forest was transformed into fallow land and 10.16 km^2 of natural forest was transformed into mixed farming. Similarly, grasslands were transformed with 138.28 km^2 and 89.88 km^{2}transformed into fallow land and mixed farming, respectively, while some 93.32 km^2, 27.83 km^2 and 69.02 km^2 transformed into grasslands, mixed farming and fallow lands, respectively, over the same period (Figure 5).

Analyses of the Landsat Images of 1999 established plantation forests and tea plantation were the added land uses in the Mt. Elgon ecosystem. The areas of land under plantation forest increased by 23% to 407.67 km^2. The plantation forests were introduced by the Kenyan government and comprised of both indigenous and exotic plantations. Previous studies revealed that the main indigenous tree species included Elgon teak while the exotic tree plantations mainly consisted of Cypress and eucalyptus trees. Plantations forests were adopted by the Kenyan government as an initiative to expand the countries forest cover to international acceptable standards of 10%. The decision to introduce plantation forests was made on the basis that a large portion of the Mt. Elgon forest had undergone excision and deforestation caused by both the local communities and the government officials. The local communities mainly venture in logging and deforestation so as to get wood fuel, wood for trade and wood for building and construction. The region had also experienced forest encroachment by the local communities to increase land for settlements and fertile lands for agricultural activities. Secondary data further revealed that the government of Kenya had in the 1970's excised large tracts of forest land of about 3686 ha from the Mount Elgon Forest in areas such as Chebyuk, to resettle 600 families of Elgonyi Dorobo from Elgon native land who had been rendered landless due to cold weather in their original homeland. Similarly, commercial logging authorised by government officials was also carried out in the Mt. Elgon forest so as to generate wood for industrial purposes.

Tea plantation covered some 0.10% (1.81 km^2) of the total land area. Previous studies further revealed that tea plantation was cultivated by the Kenyan government as a buffer around the natural forest by the Nyayo Tea Zone Corporation (Ongugo et al., 2014). Tea plantation was initiated by the government as an initiative to curb against further degradation of the forest. This could have resulted into the decline in the sizes of land under other land uses. For instance, fallow land declined by 18% (Figure 6).

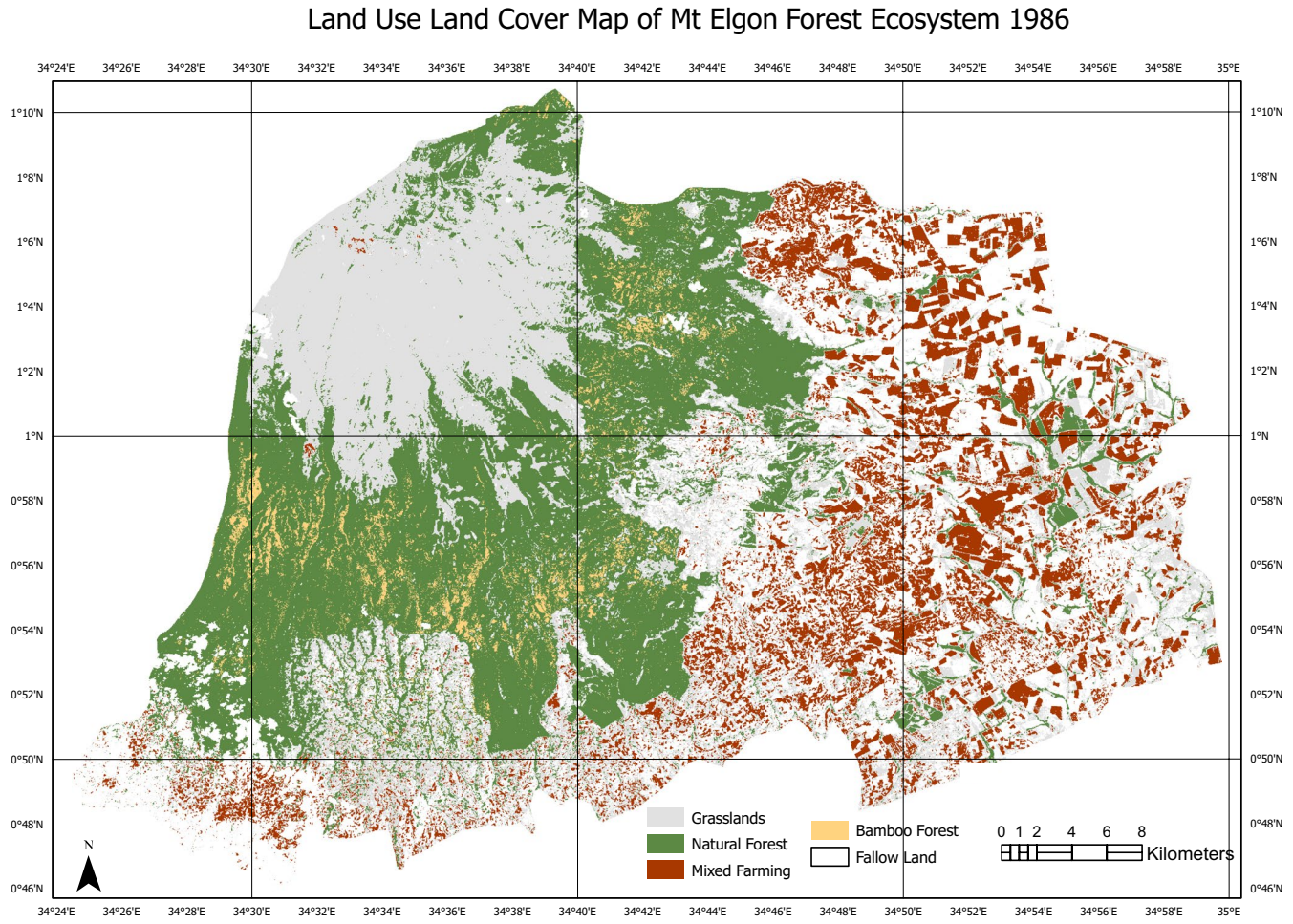
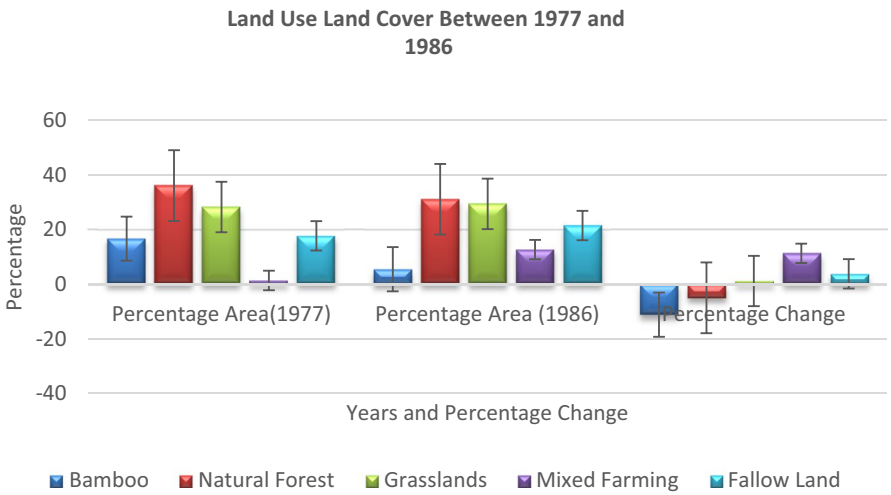


FIGURE 3 Land use land cover changes in Mt. Elgon forest and adjacent regions (1986)

FIGURE 4 Percentage change in size of land under different Land Uses between 1977 and 1986



There were further changes in land use/land cover changes between 1986 and 1999. There was a decline of 18.09% in fallow land, 11.16% in natural forest, 10.9% in grasslands and a 0.89% decline in bamboo. The area under mixed farming expanded by 17.48% over the same period (Figure 7). Further analyses of Landsat images revealed that between 1986 and 1999, 102.81 km^2 of grasslands was transformed to plantation forests, some 106.11 km^2 of grasslands was transformed into mixed farming while about 0.28 km^2 of grasslands was transformed into tea plantations. About 152.32 km^2 was transformed into plantation forest, 59.87 km^2 into mixed farming and 1.05 km^2 into tea plantation. Some 12.14 km^2 and 0.21 km^2 of bamboo forest was transformed into plantation forests and tea plantation, respectively (Figure 8).

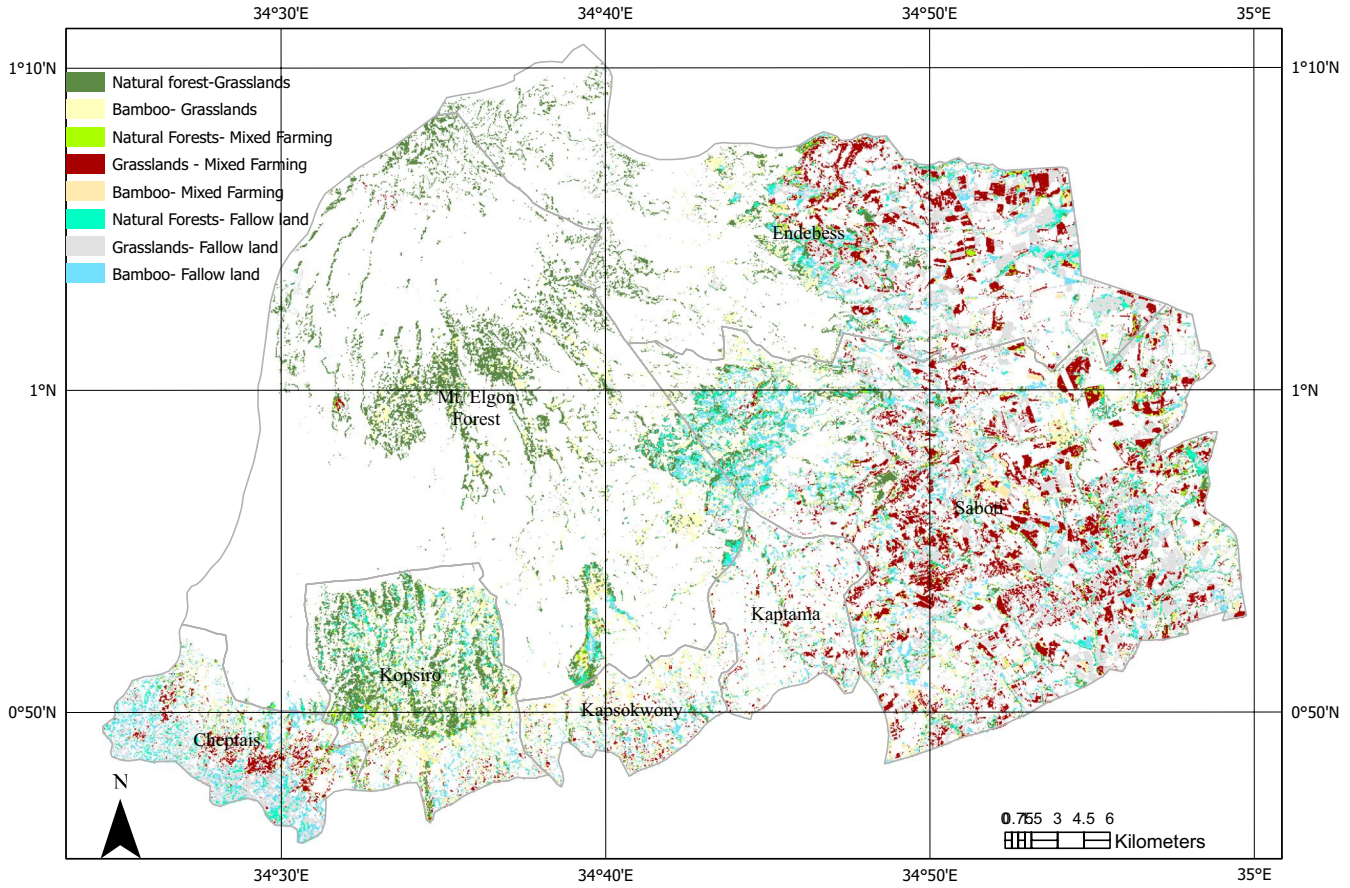


FIGURE 5 Changes in land use in the Mt. Elgon forest ecosystem between 1977 and 1986

The introduction of plantation forest could have led to an increase in forested land and thus improved forest health over this period. This increase, however, led to a decline in other land uses such as grasslands and fallow land. Similarly, the introduction of tea plantation (Nyayo Tea Zone) not only played a key role in the conservation of the Mt. Elgon forest, but it also played a key role in the economic development of the region. Field observation revealed that many members of the local community are employed in the tea plantation and the Mt. Elgon Tea factory.

Between 1999 and 2019, there was a continued change in land uses in the Mt. Elgon ecosystem. For instance, land under natural forests declined by 2% from 19.91% (370.72 km^2) to 18% (336.88 km^2) in 2019. Plantation forests declined by 15.43% that is from 21.89% (407.67 km^2) in 1999 to 6.49% (120.44 km^2) in 2019. The size of land under bamboo forest and grasslands declined by 3% from 4.58% (85.22 km^2) in 1999 to 1.46% (27.12 km^2) in 2019 while grasslands declined by 3% from 18.51% (344.71 km^2) to 15.19% (282.89 km^2) in 1999 and 2019, respectively. There were, however, a 24.55% increase in mixed farming to 30.7% (570 km^2) in 2019 and 0.5% increase in fallow land to 27.93% (520.27 km^2), respectively. Land under tea plantation increased by a mere 0.03% (Figure 9). Further analysis of Landsat imageries confirmed that 16.45% (61.01 km^2) of land previously under natural forests was transformed into fallow land. Between 1999 and 2019, a number of land uses were transformed into fallow land. These included, 34.28% (139.78 km^2) of plantation forest, 35.64% (122.88 km^2) of grasslands, 23.19% (19.77 km^2) of bamboo forest and some 27.26% (153.01 km^2) land under mixed farming (Figure 10). The expansive increase in fallow land may explain why other land cover types and land uses declined in the region over that period. Analysis of trends in land use/land cover changes between 1977 and 2019 clearly shows that there were notable changes in land uses during this period. Natural forests, bamboo forests and grasslands showed a declining trend while tea plantation, mixed farming and fallow land showed an increasing trend (Figure 10).

Between 1977 and 2019, the size of land under natural forest also declined by 18%, bamboo forests declined by 15.19%, while grasslands declined by 13% (Figure 10). On the contrary, land under mixed farming increased by 29.27%, fallow land increased by 10.25%, plantation forests increased by 6.47% while land under tea plantation increased by a mere 0.13% (Figure 11). Table 2 below gives a summary of the land use and land cover change between 1977 and 2019.

4 | DISCUSSION

Results of this analysis on trends of land use/land cover changes between 1973 and 2019 clearly show that there were notable changes

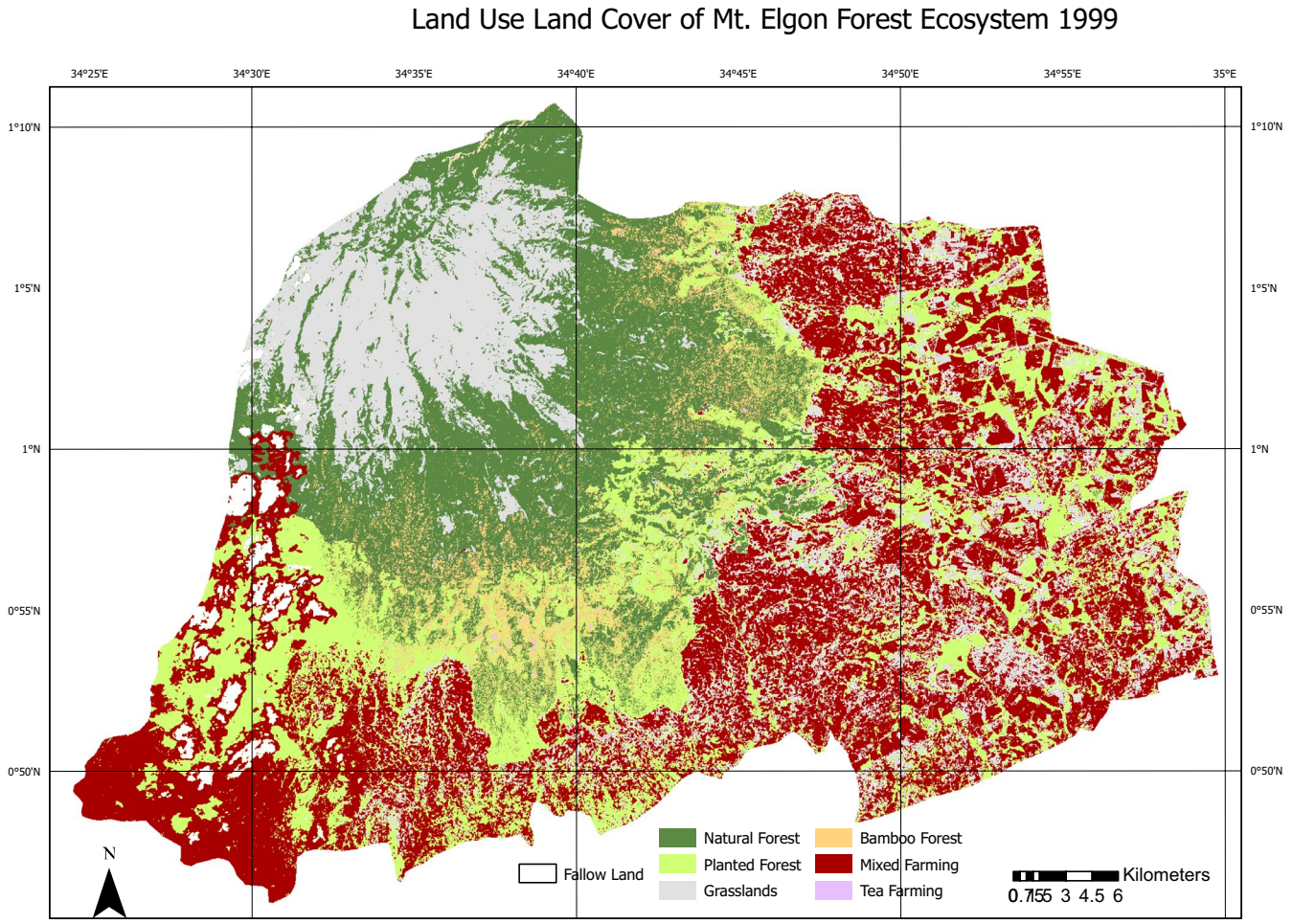
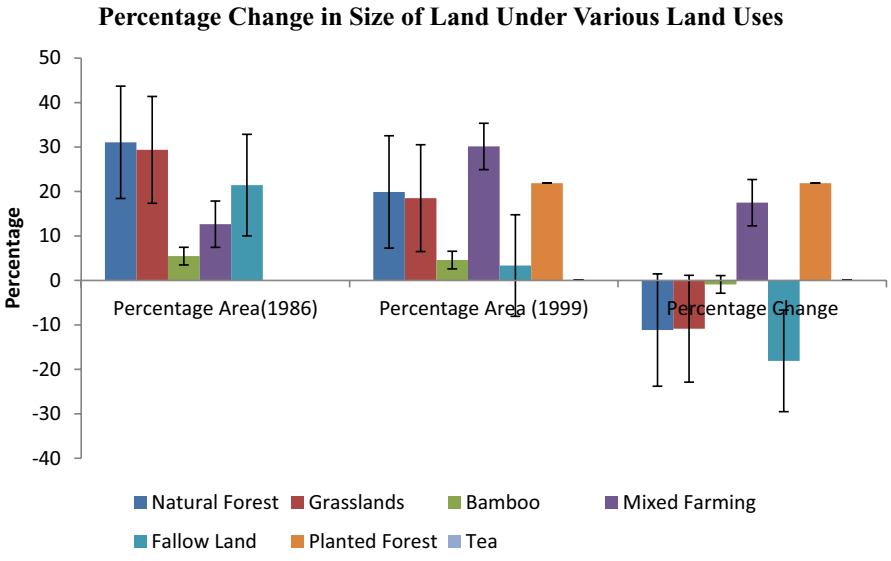


FIGURE 6 Land use land cover map of the Mt. Elgon forest region in 1999

FIGURE 7 Change map of Mt. Elgon forest ecosystem displaying changes in land use between 1986 and 1999



in land uses during this period. Land under natural forests, bamboo forests and grasslands show a declining trend while land under mixed farming and fallow land show an increasing trend. This study confirmed that between 1977 and 2019, natural forests declined by 18% translating to an annual average decline of 0.43%. The 15.19% decline in bamboo translates to an annual average decline of 0.36% while a 13% decline in grasslands translates to an annual average decline of 0.3%. The highest decline in bamboo was reported between 1977 and 1986

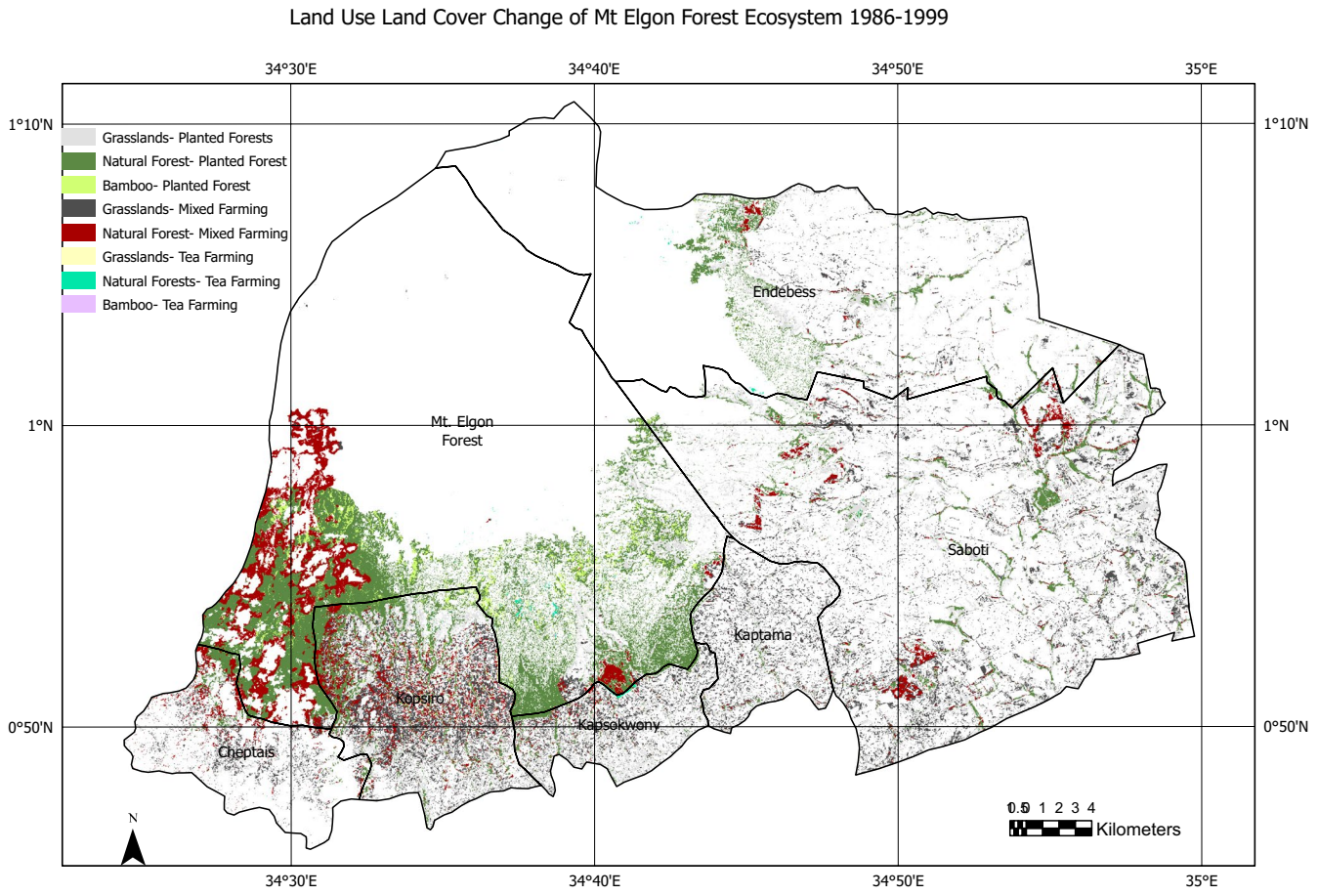


FIGURE 8 Land uses land cover changes in Mt. Elgon forest ecosystem between 1986 and 1999

with an annual average decline of 1.24%. The introduction of the first phase of Chepyuk settlement scheme in the region that was predominantly covered by bamboo could explain the major decline in bamboo during this period. On the contrary, the study revealed a 0.69% annual average increase in mixed farming, 0.24% annual average increase in fallow land and a 0.15% annual average increase in plantation forest. The result imply that increase in the size of land under agriculture is the major contributor to a decline in natural forests, grasslands and bamboo forests in the Mt. Elgon forest ecosystem.

The study revealed that land use change from natural forests to mixed farming and fallow land could explain the decline in the size of natural forest of the study area. Secondary data indicated that increase in population and change in livelihoods sources from nomadic pastoralism to crop farming could explain the increase in land under mixed farming. In the 1973, the government agreed to resettle the Elgon Dorobos to an area covering 3686 ha at the lower slopes in an area currently known as Chepyuk through legal notice no 51 of 1974 (Ongugo, 1996). The immigrants influenced the local communities who were primarily livestock herders to be agriculturists. This change in the lifestyle of the people has led to encroachment of the forest for cultivation and exploitation of the forest products (Ongugo, 1996). The second and third phase of the Mt. Elgon resettlement scheme was established in 1992. Phase two covered an area of 1741.99 ha while phase 3 covered an area of 2865.42 hectares (Simiyu, 2008). This resettlement could partly explain the increase in mixed farming and fallow land in the region.

The results of this study are in agreement with the findings of Gunlycke and Tuomaala (2011) who reported a 200 percent increase in cropland between 1900 and 1990 at the expense of tropical forests. This corresponds to an annual average annual increase of 2.22% in cropland. However, this study revealed a lower annual average increase of 0.94% in cropland (mixed farms and fallow land) between 1977 and 2019. The main reason for the variation could be partly due to the fact that the Ndorobos, who are the native community in the region are predominantly nomadic pastoralists. Our results contribute to the ongoing debate on the usability of the global forest change data set in conservation efforts at a local level (Hansen et al., 2013). The data set on forest change is specifically valuable in understudied regions such as Mt Elgon forest ecosystem where few technical and financial resources are available for rigorous field research. In Tanzania, FAO (1993) estimates that natural forests reduced by about 12.7% between 1980 and 1990. Land-use changes in Tanzania that led to depletion of forests were associated with population increase, intensification of agriculture and increased demand of forest products (Misana & Nyaki, 1993). Olson et al. (2004) affirmed that during the last few decades, the area under cultivation has more than

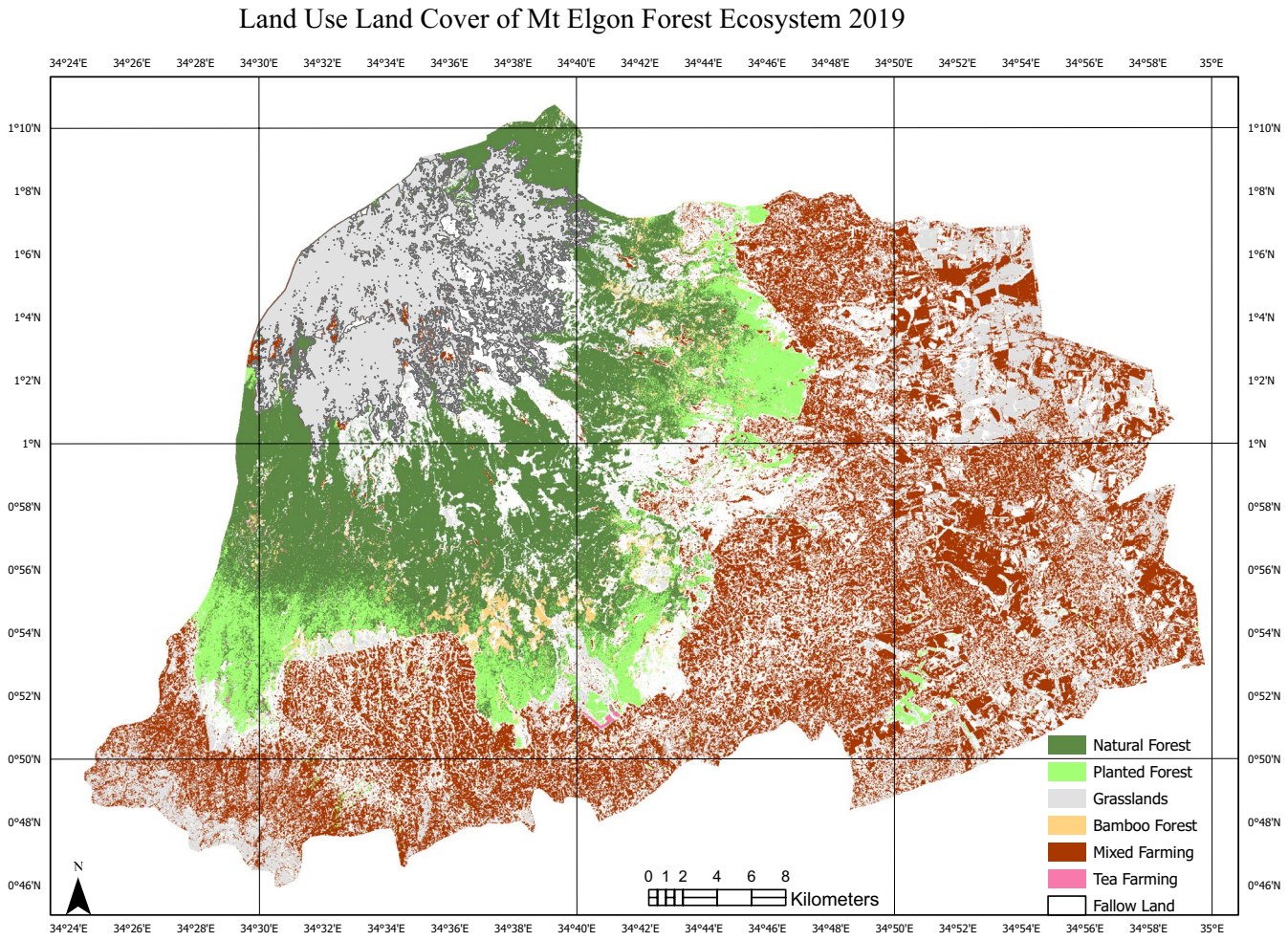


FIGURE 9 Land use in Mt. Elgon for the year 2019

doubled in East Africa. Ball (2001) reported that about 8000 years ago forests covered about 50% of the earth's land area, compared to 30% today. FAO estimated that during the 1990's, tropical regions lost about 15.2 million hectares of forests per year. Myers (1994) reported that about 60 percent of the tropical moist forests cleared were for agricultural and settlement.

Nield et al. (2000) reported that the levels of degradation and depletion of forest resources in Mt. Elgon have been difficult to quantify, due to poor reporting by the Kenya Forest Service and the Kenyan Wildlife Service. The then Ministry of Environment and National Resources reported that, despite the forest being one of the major five national water towers that contain species that are globally threatened, it is among one of the forest ecosystems that is least studied in the country (Hitimana et al., 2010). MEICDP (2001) reported that the major change in vegetation cover in Mt. Elgon forest from the 1960's to 1999 has been the decline in area of indigenous forest. It is reported that one-third of the indigenous forest cover has disappeared during this period. They further confirmed that during this period plantations and bamboo forests expanded. Findings differ from MEICDP (2001) findings who reported an increase in grasslands over this period. Ongugo et al. (2014) asserts that overall, the area under indigenous forests in Kenya has declined by 8.1% between 1990 and 2010 translating into an annual average decline of 0.4%. This study revealed a higher annual average decline of 0.43% in natural forest an indication that if the trend is allowed to continue, the future of the forest will be at stake.

Ongugo et al. (2014) further reported that in the late 1990's and early 2000's, there were several excisions of Mau and Mount Elgon forest that were politically motivated and which happened without regard to legal process (EMCA, 1999). In 2001, a total of 67,000 ha were cleared (Mathu, 2007). The creation of Nyayo Tea Zone Corporation in 1986, was intended to deter encroachment and support local communities through employment creation (Mathu, 2007). The increase in the Nyayo Tea Zone, therefore, plays a crucial role in the conservation of the Mt. Elgon forest ecosystem.

In Myanmar, Schneider et al. (2020) reported that land-use changes include deforestation, creation of large monocultural plantations (oil palm, maize, rubber), special economic zones and increasing presence of NGOs concerned with the conservation of Myanmar's forests, which belong to the biodiversity hot spots. Schneider et al. (2020) further reported that compared with the 1990's, when the landscape in northern Tanintharyi was predominantly under forest and shifting cultivation, land-use changes have led to the decline in the availability of essential ecosystem services

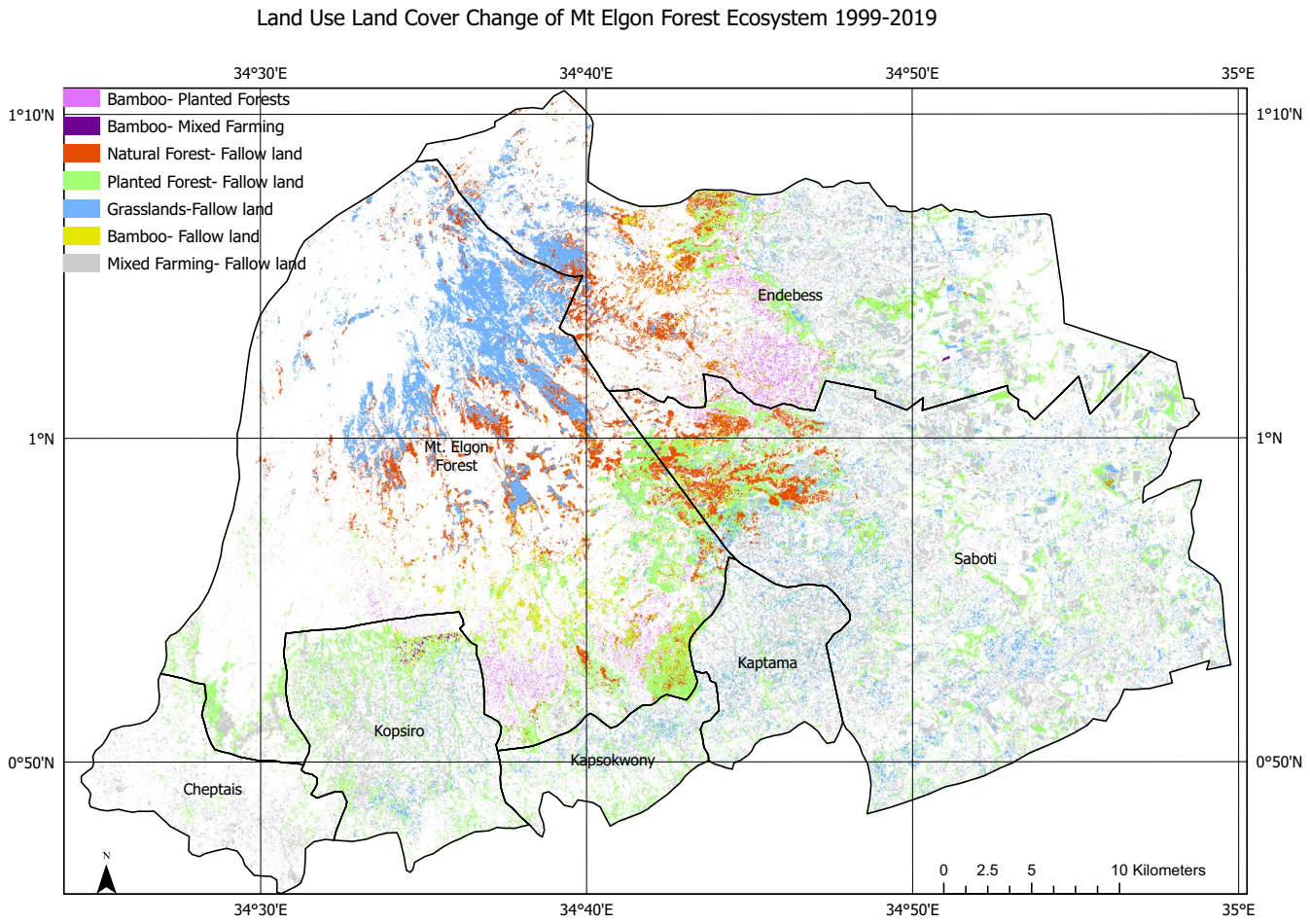


FIGURE 10 Changes in land use land cover in Mt. Elgon forest ecosystem between 1999 and 2019

such as biodiversity, water, regulation of microclimate, wild plants, wood fuel and livestock while a few have increased (mainly commercial crops such as cashew, rubber, betelnut and lime). Land-use changes are therefore very complicated since increase in agricultural land would reduce the availability of non-timber forest products, firewood and increase global greenhouse gases. On the contrary, it greatly increases the availability of financial resources to the land users.

Land-use changes have not always led to decline in forested land. For example in Madagascar, Zaehringer et al. (2019) reported that in 1997 and 2012, the establishment of Makira Natural Park and Masoala National Park respectively, led to the closure of large tracts of agricultural frontier, making many local land users to lose current and future access to agricultural land and financial resources associated with agriculture. Particularly in Beanana, secondary forest increased from 0–49.3 ha whereas in Fizono, secondary forest increased from 0.2 to 46.6 hectares between 1990 and 2017. Bamboo forest increased from 0.2 hectares to 0.3 hectares between 1990 and 2017 in Beanana over the same period (Zaehringer et al., 2015). The analysis of this study had an overall accuracy of 87% and a producer accuracy of 86%. Allnutt et al. (2013) revealed that in Masoala National Park the annual rate of forest change increased from 0.99% during 2005 and 2008 to 1.27% from 2010 to 2011. In Manompana forest corridor, Eckert *et al.* (2011) reported that the annual deforestation rate remained almost stable with 1.07% between 1991 and 2004 and 1.09% between 2004 and 2009.

5 | CONCLUSIONS AND RECOMMENDATIONS

Mt. Elgon forest ecosystem has experienced major land-use changes between 1973 and 2019. In the period of land use analysis for the study, the highest decline has been in natural forest. This decline is higher than the annual average decline for Kenya. The second most affected land use is the plantation forest, which provides almost similar ecosystem services as the natural forest. The land-use changes have also led to increased land area under mixed farming and tea plantation, especially due to financial motivations. Land use change tends to negatively affect natural forests because of the ever-increasing social, demographic and economic demands of people. Basing on these findings, I propose two recommendations. First, the study recommends an increase in afforestation program with the use of indigenous trees so as to provide a suitable habitat, conserve and protect the endemic species of the Mt Elgon forest

TABLE 2 Trends in Land Use, Land Cover Changes in Mt Elgon forest ecosystem

	1977		1986		1999		2019	
Land Use	Area (Km^2)	% Area	Area (Km^2)	% Area	Area (Km^2)	% Area (Km^2)	Area (Km^2)	% Area
Natural Forest	671.37	36.08	578.11	32.13	370.72	19.91	336.88	18.08
Planted Forest	-	-	-	-	407.67	21.89	120.44	6.46
Grasslands	525.35	28.23	546.52	29.38	344.71	19.99	282.89	15.18
Bamboo	309.72	16.64	40.44	5.46	85.22	4.58	27.12	1.5
Mixed Farming	25.39	1.37	235.42	12.65	561.19	30.14	570.76	30.64
Tea	-	-	-	-	1.81	0.1	2.42	0.13
Fallow Land	328.93	17.68	398.94	21.44	62.39	3.35	520.27	27.93

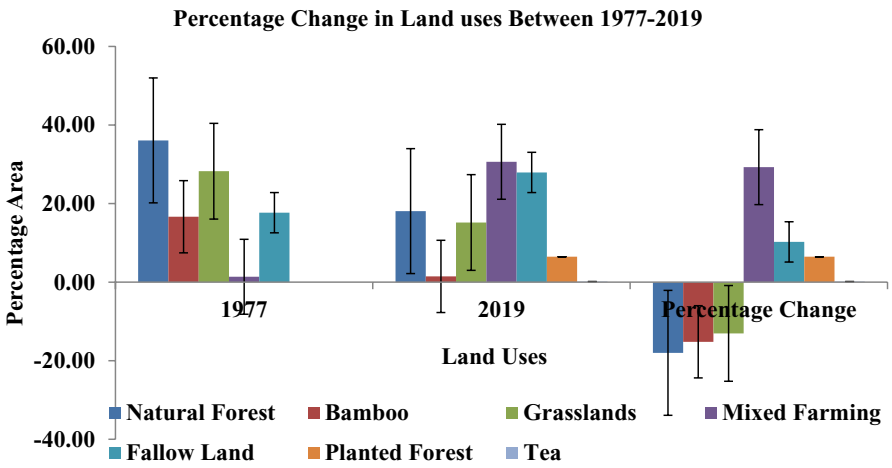


FIGURE 11 Percentage change in land uses between 1977 and 2019

Ecosystem. Second, I propose future management strategies that include educating and encouraging of community participation on the importance of forest conservation and the introduction of alternative sustainable sources of livelihood, such as beekeeping. This will minimise the reliance on the forest resources for livelihood.

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CONFLICT OF INTEREST

The author did not receive any funding. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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APPENDIX 1
USER ACCURACY

User Accuracy(UA)	2019	1999	1986	1977	Average User Accuracy
Natural Forest	90	80	80	90	**85**
Grasslands	80	90	90	80	**85**
Bamboo	80	90	90	100	**90**
Mixed Farming	100	90	90	80	**90**
Fallow Land	80	80	80	70	**77.5**
Tea	100	100	-	-	**100**
Planted Forest	100	90	-	-	**95**
Overall Accuracy	**90**	**88.5**	**86**	**84**	
Kappa Coefficiency	**0.88**	**0.87**	**0.83**	**0.8**	**0.845**

APPENDIX 2
PRODUCER ACCURACY

Producer Accuracy	2019	1999	1986	1977	Average Producer Accuracy
Natural Forest	81.8	88.8	88.8	100	89.85
Grasslands	100	90	75	80	86.25
Bamboo	100	100	100	90.9	97.725
Mixed Farming	71.4	75	75	66.6	72
Fallow Land	100	100	100	87.5	96.875
Tea	100	100	-	-	100
Planted Forest	90.9	75	-	-	82.95