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Agricultural expansion and land use land cover changes in the Mount Bamboutos landscape, Western Cameroon: implications for local land use planning and sustainable development

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ABSTRACT

This paper reports the extent of degradation and pattern of land use land cover change (LULCC) in the Mount Bamboutos landscape in Western Cameroon, using Landsat satellite images of 1980, 2000 and 2018. The researchers surveyed 261 household farmers to understand the different agricultural activities in the landscape. Grassland, sparse primary forest and sparse secondary forest decreased by a magnitude of 818%, 101% and 53%, respectively, from 1980 to 2018. Farmland, tea plantation, eucalyptus plantation and built-up areas increased by 16,799.8 ha (69%), 1009.6 ha (84%), 3757 ha (94%) and 3385.5 ha (97%), respectively, from 1980 to 2018. Agriculture, settlement and grazing land expansion are the key drivers of the LULCC. A conceptual model to increase inclusive stakeholder participation and sustainability in local land use planning is proposed.

KEYWORDS

Deforestation; degradation; grazing; LULCC; PLUP; restoration; sustainability

Introduction

Land use land cover change (LULCC) assessment is important for understanding the sustainable use of natural resources [1,2]. LULCC assessment concerns the dynamics of ecosystem functions and landscape environmental change [3]. Remote sensing (RS) data and geographic information system (GIS) provide the necessary tools. Several authors have used Landsat images to study LULCC in different geographical areas and at different spatial and temporal scales [1,3–8]. Population growth, uncontrolled urbanisation, and agricultural expansion are drivers of LULCC at different special scales [1,7,9–11]. LULCC affects ecosystems functions and services, such as water regulation, soil formation and protection, climate regulation, biodiversity, agricultural production [12–15], water quantity [4] and water quality [16]. Therefore, the use of satellite images is crucial, particularly in sub-Saharan African countries where subsistence agricultural production is essential to securing

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household food security and nutrition diversity [17]. Thus, research that integrates contemporary remote sensing with data on elements of food security and nutrition diversity is needed [17]. This is urgent in smaller urban areas in developing countries where most of the urban growth is taking place, but where statistical data on land use and urban land systems are scarce and often of poor quality [18].

The complexity of interaction between different land uses brings about significant changes in land use over space and time, and the need for sustainability policies in land use functions [19]. Land use functions are the private and public goods and services provided by the different land uses in a given region, and land use systems are given three classes, namely, production, living and ecological land (PLEL) [9,19–22]. This multifunctional approach to land use classification integrates understanding in regard to the possible trade-offs [19] and helps in planning development [23].

Mountainous areas forming the Western Highlands of Cameroon constitute about 8% of the total land surface of the country (from the Atlantic coastline of Limbe in the Southwest region, across the Northwest and West regions to the Adamawa plateau). This mountain stretch is endowed with high value endemic biodiversity and forest resources of global conservation and protection importance. Deforestation and forest degradation in the mountain landscape are the result of long-term progressive unregulated and uncontrolled timber harvesting, agricultural expansion, overgrazing, population growth, fuel wood and charcoal harvesting, housing development, and bush fires [1]. Land use governance remains a serious problem in Cameroon. LULCC is expanding in parts of the Western Highlands of Cameroon, where competition between land uses and land conflicts between the government and local communities and between and within village communities are widespread [1]. Land use and land conflicts between farmers and pastoralists sharpen the ecological insecurity, vulnerability and instability of the already fragile Mount Bamboutos landscape [24]. The land use and land tenure systems here are unprotected, insecure, and poorly defined and enforced; abuses of resource use rights are easy. Therefore, the Mount Bamboutos landscape was identified as a top priority area requiring actual field-based quantification and assessment, so that ecosystem restoration, conservation and participatory local land use planning initiatives may take place.

Several participatory land use planning (PLUP) projects have been undertaken in developing countries to reduce deforestation and biodiversity loss and to improve local access to resources, food security, land tenure and positive livelihood impacts [25–27], using the guidelines for land use planning developed by FAO [28]. Land use planning in Cameroon is regulated by the Orientation Law No. 2011/008 of 6 May 2011 on Land Use and Sustainable Development Planning of the national territory. The law categorises land use planning hierarchy into national, regional and council land use plans, and thus, omits local land use planning [29]. The government is still to provide guidelines methodology to guide the preparation of local, council, regional and national land use plans in Cameroon [30]. Article 6 of the 2011 Law highlights the importance of local participation in all decisions regarding land allocation and use [29,30]. Local land use and sustainable development plans are important for the preparation and adoption of council land use plans of the concerned municipalities. Because decision-making about future land use is usually contested at different levels of planning, the engagement of all stakeholders, from central Ministries who define policy and strategy, down to the level of village communities is imperative in order to address land conflicts and build consensus on land allocation and use as defined by the 2011 land use planning law of Cameroon [30].

Cameroon's Ministry of Economy, Planning and Regional Development (MINEPAT) mandated the European Forest Institute in 2016 to develop and test a methodology and a set of tools to support council land use and sustainable development planning in Cameroon. Nguti sub-division of the Southwest region of Cameroon, a forest and agriculture-dependent municipality, was chosen as a pioneer case study for the local land use planning. So far, data collection, stakeholder consultation and scenarios identification and analyses have been completed in a participatory process at village level, but an actual council land use plan has not yet been prepared [30].

The main objective of this study is to determine the actual extent of degradation and LULCC in the Mount Bamboutos landscape using satellite data from 1980 to 2018. The patterns and extent of LULCC and its effect on land use systems are derived from three different years (1980, 2000 and 2018) over the Mount Bamboutos landscape. The researchers examined the implications of the LULCC on local, council, regional and national land use and sustainable development planning. The aim is to aid the design, planning and implementation of ecosystem restoration and conservation initiatives and participatory local land use planning and zoning in the study area.

Materials and methods

Study area

The study area covers 350 km^2 in the Mount Bamboutos landscape, located between longitude 9°57′5″ E to 10°10′50″ E and latitudes 5°31′50″ N to 5°47′50″ N of the Greenwich Meridian. Mount Bamboutos is part of the Western Highlands of Cameroon, and forms a group of volcanoes based on a swell in the Cameroon Volcanic Line [31] shared by four regions of Cameroon. The Mount Bamboutos landscape in this study stretches across four divisions, eight sub-divisions, and over twenty villages located in the West, North West and South West regions of Cameroon (Figure 1). The study area consists of Lebialem division (specifically Bamumbu, Fossimundi and M'muockmbie Fondoms) of the South West region; Mezam division (Pinyin, Buchi and Menka Fondoms) in the North West region; and Bamboutos and Manoua divisions (Bangang, Babadjou and Bafou Chiefdoms) in the West region of Cameroon (Figure 1), which collectively constitute hotspots for market garden farming. The Mount Bamboutos ecosystem (highest elevation of 2740 m) is located within the Western Highlands of Cameroon, and is the third highest peak in West Africa, after Mount Cameroon (4,100 m high) and Mount Oku (3,100 m high). The Mount Bamboutos landscape is the main watershed giving rise to major rivers, such as Manyu, Nkam, Noun, Mbam and Mifi tributaries, which drain to the western part of the country. In particular, River Noun is the main source of the Bamendjin Dam and Lake Bambalang. River Manyu drains into the Cross River in Nigeria, and Menoua drains into Nkam and Wouri Rivers, which empties into the Atlantic Coast of Cameroon.

The Mount Bamboutos landscape is predominantly mountainous with cool tropical climate and high level of endemism and diversity of plants and animal species in the forest and savannah areas, and constitutes part of the Cameroon Mountains Endemic

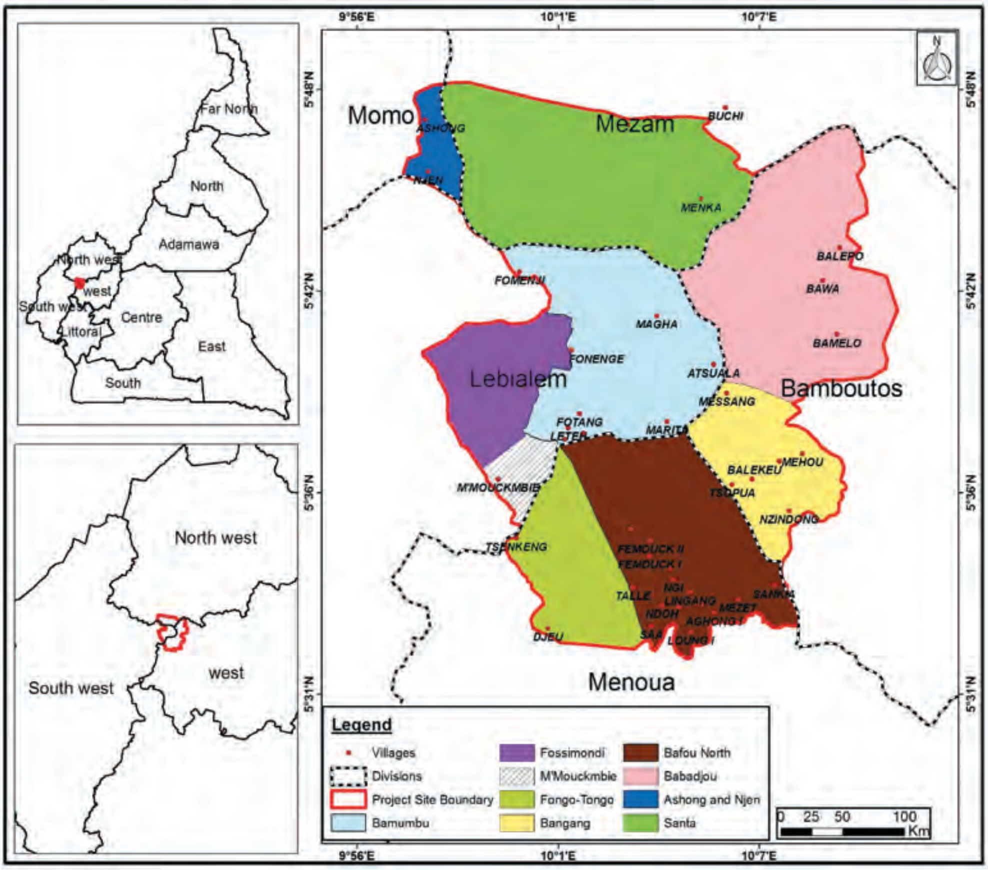

Figure 1. Location of the study area in Cameroon and the across the three regions (left) and the divisions and villages of the study area of the Mount Bamboutos landscape. The project site boundary was demarcated for ecosystem restoration purposes, and does not represent official administrative boundaries of Cameroon.

Bird Area. Some very important biodiversity species restricted to this ecosystem include the primate Preuss' Guenon (*Cercopithecus preussi*), Coopers Mountain Squirrel (*Paraxerus cooperi*), the Banded wattle-eye, (*Platysteira laticincta*) and Bannerman's Turaco, (*Tauraco bannermani*) as well as green monkeys. Other species include the endangered Cross River gorillas (*Gorilla gorilla diehli*) and the Nigeria-Cameroon chimpanzees (*Pan troglotes ellioti*) found in the South West region of the Bamboutos Mountain. Temperature ranges from 20°C to 22°C mean maximum and 13°C to 14°C mean minimum. Rainfall varies from 1780 to 2290 mm per year and mainly falls between July and September, though highly variable from year to year.

The study area has an estimated population of about 20,000 to 30,000 people in 2018 based on the 2005 census. Areas of the West and the North West regions belonging to the Mount Bamboutos landscape have higher population densities (87.7 people/km^2 compared to the national average of 37.5 people/Km^2) and together with the South West regions are the agriculture bread baskets of the country because of fertile volcanic soils and favourable climate for diverse crop cultivation. The local populations in the West, South West and North West regions are also engaged in large and small-scale livestock rearing on the hills and slopes of the Mount Bamboutos landscape. The landscape is a mosaic of degraded forest, grassland, woodland, farmland and residential land uses: a complex mix of ecological, production, and living space, comprising varied land use and land cover types, such as extensive agriculture, intensive market gardening, forests, grazing, savannah woodland, sparse degraded forest and settlements.

There are no formal land use policies in the study area. Ownership of land is by customary tenure system and is mostly acquired by inheritance. Only a few people follow legal and administrative procedures for land ownership. Land can also be acquired through lease, donation or purchase. In the Mount Bamboutos landscape, women are principal users of agricultural land, but the customary tenure system mostly denies them the right to own land. Women only have access to land resources but do not have ownership and control over land resources nor do they have equal rights in decision-making regarding the use and allocation of land and benefits from the use of land and forest resources. This continued injustice preventing land ownership by rural women is driven by the age-old local traditions and cultural beliefs on land tenure and ownership in the study area. It undermines women's social and economic empowerment and right to land and natural resource management, and thus, their contribution to the attainment of related sustainable development goals (SDGs 1, 2, 3, 5, 13 and 15) in Cameroon.

Data collection

Satellite data source and pre-processing

Assessment of land cover change was made using Landsat 3 MSS (Multispectral Scanner), Landsat 7 ETM+ (Enhanced Thematic Mapper Plus), and Landsat 8 OLI (Operational Land Imager) images taken in 1980, 2000 and 2018, respectively, representing different periods of increasing human activities on the environment in Cameroon. Imagery data were downloaded from the United States Geological Survey (USGS) website [32]. Landsat images were subjected to image enhancement activities, such as radiometric correction (to calibrate images acquired by satellite optical sensors to radiance or reflectance values), pan sharpening (a process of merging high-resolution panchromatic and lower resolution multispectral imagery to create a single high-resolution colour image), layer stacking (a process for combining multiple bands into a single image). Colour composition activities were carried out to ameliorate the brightness, contrast and visibility of objects, to reduce omission and confusion errors and to increase accuracy in spectral differencing of objects during classification. Extraction of the study zone was made using a geo-rectified vector of the project site. Table 1 shows the specifications of the satellite data used in this study. Figure 2 shows the procedure for the acquisition, pre-processing, classification and accuracy assessment, of the ground truth data and visual interpretation of the satellite images for the LULCC maps.

Hybrid image classification method: unsupervised classification and supervised classification (maximum likelihood and super vector machine)

A hybrid image classification method consisting of unsupervised and supervised image classification was executed. Unsupervised classification (k-means) was conducted to determine spectral differences in land cover classes for the creation of training parcels for field verification and eventual use for a supervised image

Table 1. Classification and specification of satellite data for the acquisition of the LULC maps.

Landsat	Sensor	Date	Spectral bands	Spatial resolution (metres)	Row number	Path number
3	MSS	14 January 1980	4, 5, 6	60 m	200	056
7	ETM+	3 December 2000	1, 2, 3, 4	30 m (15 m Pan)	186	056
8	OLI	27 January 2018	2, 3, 4, 5	30 m (15 m Pan)	186	056

MSS: Multispectral Scanner; ETM+: Enhanced Thematic Mapper Plus; OLI: Operational Land Imager.

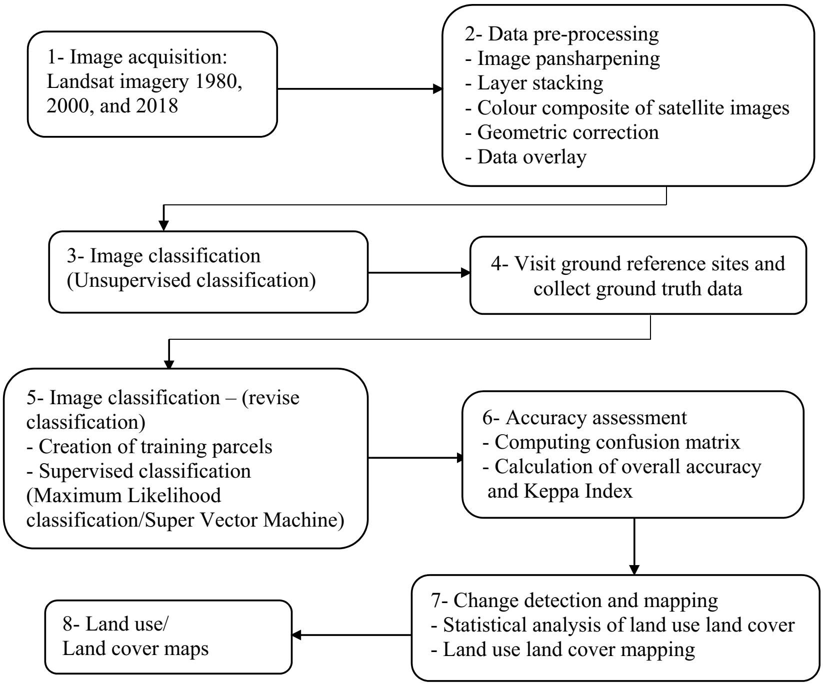

Figure 2. Flow chart of the image processing and land cover change analysis methodology (Adapted from Ewane and Lee, 2020).

classification. The supervised image classification via maximum likelihood (MLC) algorithm and super vector machine (SVM) were used to classify all Landsat scenes [33]. The MLC is based on the probability that a pixel with a particular feature vector belongs to a particular land cover class based on the training of a visual classifier. The SVM is a linear binary classifier that assigns a given test sample a class from one of the two possible labels. The hybrid approach was chosen to increase the overall classification accuracies [34].

The methodology for the identification and classification of the main and sub-land use systems and functions (Table 2) and the functional index model for the PLEL functions were used [20]. Ecological land represents land uses capable of sustaining ecological functions such as carbon sequestration, climate regulation, pollutant treatment, water regulation, soil formation and protection, nutrient cycling, and biodiversity conservation. The production land represents land uses capable of meeting human production needs for subsistence and commercial purposes. The living land represents land uses for residential and road infrastructure functions [20].

Table 2. Identification and classification system of PLEL in the Mount Bamboutos landscape.

PLEL Class 1	Cluster group	PLEL Class 2/Land use type
Ecological land	1	Open primary forest Open secondary forest Grassland Bare rock
Production land	2	Tea plantation Eucalyptus plantation Farmland
Living land	3	Built up area

PLEL: Production-living-ecological land.

Accuracy assessment (overall statistics and Kappa statistics)

The land use land cover (LULC) assessment was completed for three different years covering three periods, i.e. 1980, 2000 and 2018. Accuracy assessment simply quantifies how good a classification was done by the classifier. The accuracy of a classification is a validation process conducted by comparing the classification results with ground truth referenced data that accurately reflects the true land-cover of the study area [35]. The post-classification change detection method was used to compare independently produced classified images. This was achieved via an extraction of statistics for time-series analysis and trends of change of the different identified land uses and land cover classes. Error matrices to assess the accuracies and errors of the classification were computed. The Kappa index (the ratio of the number of well-ranked pixels to the total of the pixels surveyed) was calculated (Table 3) to measure the extent of accuracy of the classification, as it accounts for all the elements in the confusion matrix [36].

Field survey data collection

The study area is composed of nine Chiefdoms/Fondoms, including Bamumbu, Fossimundi and M'muockmbie Fondoms in the South West region; Pinyin, Buchi and Menka Fondoms in the North West region; and Bangang, Babadjou and Bafou Chiefdoms in the West region of Cameroon (Figure 1). Each of the nine Chiefdoms/Fondoms has several sub-villages and/or quarters, which make up the Chiefdom or Fondom. A representative baseline survey was conducted via participating households in the community-led restoration project. The questionnaires contained questions about the socio-economic characteristics of respondent household farmers, the farming systems and farming inputs, types of crop produced, and major challenges faced in crop production and livelihood sustenance. A total of 261 household farmers were purposefully sampled using mainly closed-ended questions in the questionnaire. Among these, 26 were sampled in Bafou, 32 in Bangang, 37 in Babadjou (West region); 20 in Pinyin, 15 in Menka, 20 in Buchi (North West region); 59 in Bamumbu, 33 in Fossimundi, and 19 in

Table 3. Satellite image processing statistics.

Years	Overall errors (%)	Kappa index	Overall accuracy (%)
1980 (Landsat 3 MSS)	12.5	0.83	87.5
2000 (Landsat 7 ETM)	7.7	0.88	92.3
2018 (Landsat 8 OLI)	6.3	0.89	93.7

MSS: Multispectral Scanner; ETM+: Enhanced Thematic Mapper Plus; OLI: Operational Land Imager.

M'muockmbie (South West region) of the study area in Western Cameroon. The distribution of the number of questionnaires per Chiefdom/Fondom was based on the total number of sub-villages and population of the Chiefdom/Fondom. The Mbororo community (a minority group), who are mostly found in the Bangang and Babadjou Chiefdoms of the West region of Cameroon, constituted part of the representative sample population of the study.

Results

Classification system of the production-living-ecological land

Table 4 shows a two-level classification system and quantification of the production-living-ecological land based on the identification and grouping of the land use functions. By 1980, the ecological space function occupied 82.9% of the land, but this ratio decreased to 30% in 2018, indicating a 52.9% decrease in ecological land from 1980 to 2018 (Table 4). The area occupied by production land was 16.9% in 1980 and increased to 62.6% by 2018, indicating a 45.7% increase in production land from 1980 to 2018 (Table 4). Built area occupied the lowest land cover in 1980 (0.2%) and increased to 7.4% in 2018, indicating a 7.2% increase in living land from 1980 to 2018 (Table 4).

Land use land cover assessment

The main LULC types identified included built-up areas, tea and eucalyptus plantations, bare rock areas, farmlands, grassland, opened primary forest and opened secondary forest (Table 5). Grassland and opened secondary forest dominated the land cover in the 1980s when human pressure on the land was still low, and farmlands occupied an overwhelming 52% of the study area as at 2018 (Table 5). In the study area, farmlands are areas of cultivated land of both extensive and intensive cropland. Opened primary forests are areas of degraded forest with sparse trees; opened secondary forests are areas of degraded secondary forest and associated woodlands undergoing natural regeneration (Table 5). Bare rocks are areas of rock outcrops mostly found in the upper slopes of the mountain (Table 5). Changes in the LULC were assessed based on the change in the

Table 4. Results of classification system and quantitative structures of PLEL in the Mount Bamboutos landscape.

Main PLEL classes		1980		2000		2018		1980–2018	
PLEL Class 1	PLEL Class 2	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)	Area (ha)	Ratio (%)
Ecological land	Open primary forest land Open secondary forest land Grass land Bare rock area	39,095.6	82.9	18,029.7	38.2	14,143.7	30.0	−24,951.9	−52.9
Production land	Tea plantation Eucalyptus plantation Farmland	7970.3	16.9	28,738.1	60.9	29,536.7	62.6	21,566.4	45.7
Living land	Built up area	99.1	0.2	397.4	0.8	3484.6	7.4	3385.5	7.2

PLEL: Production-living-ecological land.

proportion of the land cover classes [4] throughout the period of 1980–2018 within the study area. Cloud was not an important cover in the study area despite an altitude of 2740 metres mainly because the landscape is located further inland from the Atlantic Ocean compared to mountainous and lowland areas closer to the Cameroon's Atlantic coast.

Land use land cover change analysis

The LULC in the study area has undergone significant modifications from 1980 to 2018. Built-up areas increased by 97% from 1980 to 2018. Tea and eucalyptus plantations increased by 85% and 94%, respectively (Table 6), associated with significant increases in human population and increased construction of housing and related infrastructures. There was significant conversion of grassland and forest areas to tea and eucalyptus plantations, built-up area and farmland (Table 6). The area of grassland decreased most of all, by an incredible 818%. Areas of primary and secondary forest decreased by 100% and 53%, respectively, from 1980 to 2018 (Table 6). Even bare rock areas were degraded and converted to other land uses such as farmland, evident by a decrease of 144% from 1980 to 2018 (Table 6). Interestingly, the area of farmland decreased by 13% from 2000 to 2018, suggesting the conversion of farmland to other land uses such as eucalyptus plantation and settlements within this period (Table 6).

The eucalyptus and tea plantations were developed for commercial purposes to supply ready market electricity poles for the national electricity company and beverage consumption, respectively, over the past 30 years. The eucalyptus planting increased significantly from 1980 to 2018 to meet the need for electrification (Figure 3(a-c)). The expansion in the areas of eucalyptus plantation and farmlands was indiscriminate and scattered all over the study landscape, even in the upper slopes of the mountain, and showed no trend in the spatial pattern of distribution (Figure 3(a-c)). The cool tropical climate of the study area favours tea cultivation leading to an increase in the area cover of tea plantation by 2018 compared to 1980. The spatial pattern and distribution of tea plantation is highly localised at the lower slopes of the Mount Bamboutus landscape (Figure 3(a-c)).

The rapid degradation of grassland is associated with the prevalence of extensive and open livestock grazing by the minority pastoral Mbororo (Fulani) communities within the study area. The small remnants of the primary and secondary forest are clearly localised and are mainly found on the upper slopes of the western sections of the landscape located in the Southwest region of the study area, where population densities are lower (Figure 3(a-c)). This is compared to the north, east and south sections of the study landscape located in the Northwest and West regions showing little evidence of primary forest even as at 1980, with significantly decreasing secondary forest and grassland in the 2000 and 2018, associated with higher population densities (Figure 3(a-c)). Bare rock areas on the lower slopes of the mountain were increasingly degraded and significantly converted to other land uses such as farmland, eucalyptus plantation and built-up areas (Figure 3(a-c)). There are no clear transition zones between land cover types or trends in the spatial pattern of distribution of land use types, suggesting long-term (Pre-1980) man-induced LULCC events, following uncontrolled and unregulated activities in the study area.

Table 5. Land use/land cover class assessment within the Mount Bamboutos landscape in Cameroon.

LULC area	Built-up area	Tea plantation	Eucalyptus plantation	Farmland	Grassland	Open primary forest	Open secondary forest	Bare rock area	Total
1980									
Area (ha)	99.1	180.6	227.2	7562.5	18,850	4501.4	13,987.2	1757	47,165
Area (%)	0.21	0.38	0.48	16	40	9.54	29.7	3.73	100
2000									
Area (ha)	397.4	544.8	683.4	27,509.9	3995.8	2790.9	10,084.9	1158.1	47,165
Area (%)	0.84	1.16	1.45	58.3	8.47	5.92	21.4	2.46	100
2018									
Area (ha)	3484.6	1190.2	3984.2	24,362.3	2052.5	2243.5	9129.1	718.6	47,165
Area (%)	7.39	2.52	8.45	51.7	4.35	4.76	19.4	1.52	100

Table 6. Magnitude of land use/land cover change within the Mount Bamboutos landscape in Cameroon.

LULCC area	Built up area	Tea plantation	Eucalyptus plantation	Farmland	Grassland	Opened primary forest	Opened secondary forest	Bare rock area
1980–2000								
Area (ha)	298.2	364.2	456.2	19,947.3	−14,854.3	−1710.5	−3902.3	−598.9
Area (%)	75	66.9	66.8	72.5	−371.7	−61.3	−38.7	−51.7
2000–2018								
Area (ha)	3087.3	645.4	3300.8	−3147.5	−1943.2	−547.4	−955.8	−439.6
Area (%)	88.6	54.23	82.85	−12.92	−94.67	−24.4	−10.47	−61.17
1980–2018								
Area (ha)	3385.5	1009.6	3757	16,799.8	−16,797.5	−2257.9	−4858.1	−1038.4
Area (%)	97.15	84.83	94.3	68.96	−818.38	−100.64	−53.22	−144.51

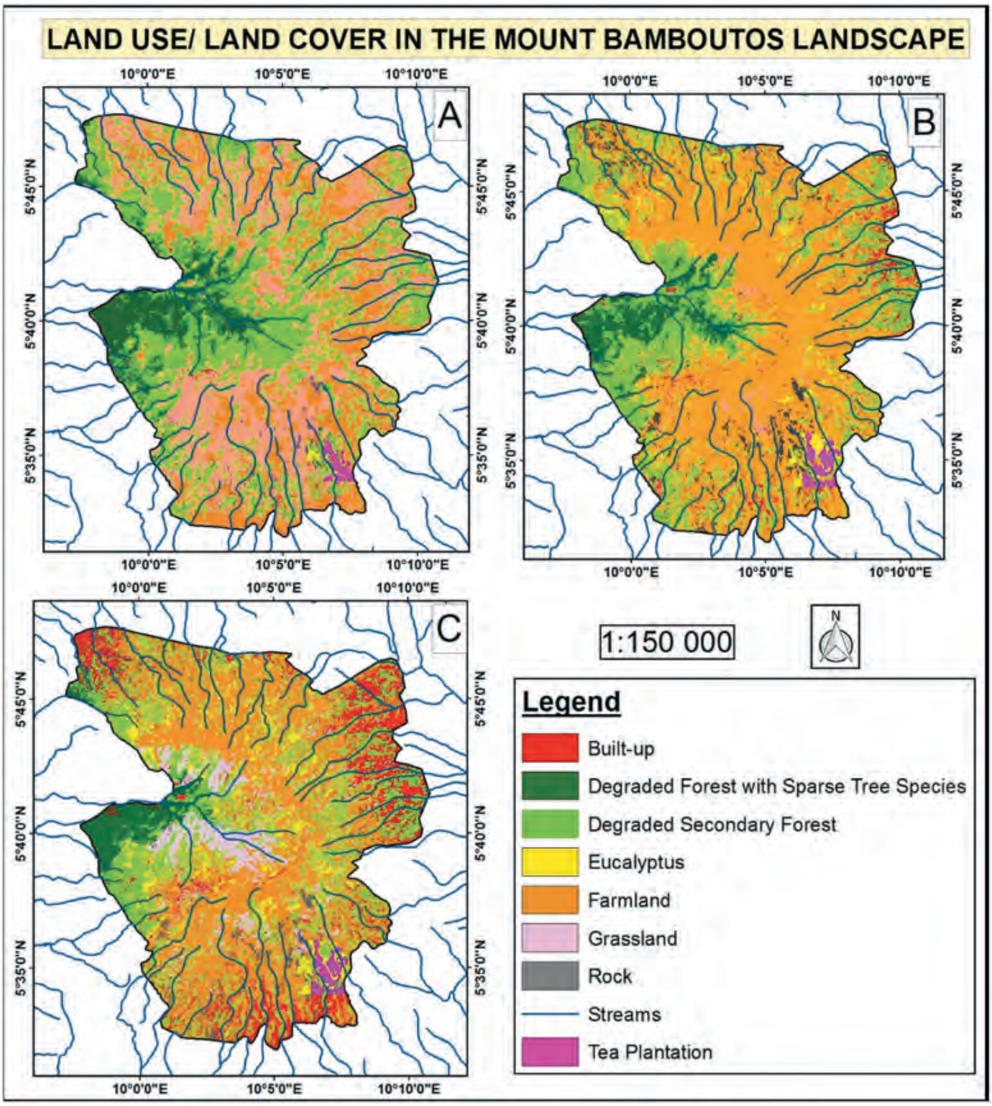

Figure 3. Land use land cover map for the Mount Bamboutos landscape in Cameroon for the year (a) 1980, (b) 2000 and (c) 2018.

Population growth and agricultural expansion as main drivers of land use land cover change

The main drivers of the LULCC in the Mount Bamboutos landscape are expansion of agricultural land for plantations of tea (85%) and eucalyptus (94%) and intensive subsistence farmlands (69%) and increase in settlement development (97%) from 1980 to 2018. This results from increasing population, land scarcity, increasing consumption, and efforts to attain household-level economic resilience. The population of the project divisions increased from 215,523 to 292,410 people in the Bamboutos division, 97,484 to 113,736 people in the Lebialem division, 251,616 to 285,764 people in the Menoua division and 313,043 to 524,127 people in Mezam division from 1987 to 2005 [37]. Field observations revealed that unregulated livestock grazing (cattle, sheep and goats) and deliberate bush fires to prepare land for new pasture by pastoralists and for farming by farmers are also important drivers of LULCC in the Mount Bamboutos landscape. A survey of 261 households across nine selected Chiefdoms/Fondoms found that the villagers are overwhelmingly engaged in intensive market gardening for subsistence and commercial purposes using traditional irrigation techniques and chemical fertilizers such as 20-10-10, 11-11-22 and Urea. The survey results show that most households (97.7%) depend on crop production followed by livestock production (1.94%) as the main source of income. Only a few people (0.39%) depend on off-farm activities. The total farm area per household varies from as little as 0.02 ha to 10 ha (98.9% of land owners) and to as large as 80 ha (1.1% of land owners) in the study area. Most of the farmers have one hectare of farm land on average. The main food crops cultivated include potatoes, sweet potato, cabbage, carrot, maize, beans, leeks, tomatoes, onions, green pepper, celery, yams, and tree crops such as avocado and coffee, using mainly traditional methods of production. Areas of warm microclimate support the cultivation of cocoyam, banana and cocoa in smaller quantities. Potatoes (*Solanum tuberosum* L.) are extensively cultivated (68.95%) compared to the other food crops to meet high demand in the local and national markets.

Crop yields have declined over the years through a decline in soil fertility caused by aggravated soil erosion and over-cultivation of the land, coupled with increasing incidence of pest and diseases, thereby increasing the risk of food insecurity. In general, the soils are acidic, low in phosphates and relatively poor in crop nutrients [38]. This scenario of relatively poor soils has attracted and triggered the increased use of chemical fertilisers such as 20–10-10, urea, foliar fertiliser, and 11–11-22 to boost soil fertility and increase food production, thereby increasing the risk of water quality degradation. The organic fertiliser commonly used by the sample farmers is poultry manure. Compost and pig dung are little used for crop production. Population growth is increasing settlement development in the Mount Bamboutos landscape, where more farmers construct mud brick houses (85% of the houses) mostly at the lower and middle slopes of the Mountain. Expansion of farmland through slash-and-burn and clear-cutting of the forest, woodland and grassland has led to high rates of deforestation, destruction of water catchments, disappearance of fuel wood and loss in soil fertility in the Western Highlands of Cameroon [39].

Discussion

LULCC and implications for local land use planning and sustainable development

Landscapes in developing countries are undergoing unprecedented change. This is because of uncontrolled and unregulated agricultural expansion, population growth, and infrastructural development such as settlement and roads [1,2,7,20,40]. The Mount Bamboutos landscape has been transformed into a mosaic of heavily degraded forest, grassland, grazing land, tea and eucalyptus plantations, and farmlands. The results reveal significant conversion and thus reduction in forest and grassland areas to farmlands and built-up areas from 1980 to 2018. Accordingly, croplands, buildings and bare lands increased by 4%, 0.43% and 5.7%, respectively, and grassland and natural forest decreased by 4.4% and 5.8%, respectively, from 1980 to 2016 in the Mount Bamboutos Caldera section within Wabane sub-division (Lebialem division) of Southwest region of Cameroon [41]. Significant decrease (90.2%) in dense forest cover because of a 188.6% and 18.25% increase in settlements and farmlands, respectively, from 2000 to 2014 was reported for the Rumpi hills forest protected area of Cameroon [40], indicating significant conversion of ecological land to production and living land. Similarly, significant conversion of forest areas to urban areas and agricultural areas from 1992 to 2012 caused varied and extensive environmental degradation problems in Islamabad, Pakistan [7]. A decrease in open forest, agriculture and barren land by 3.98%, 2.83%, and 1.82%, respectively, highlighted the need for the sustainable LULC management in the Rani Khola watershed of the Sikkim Himalaya [5].

In the Mount Bamboutos study area, in the context of the PLEL framework, ecological land decreased by 52.9% and production land and living land increased by 45.7% and 7.2%, respectively, from 1980 to 2018. These results suggest that the ecological stability, diversity, functioning and resilience of the mountain ecosystem have been significantly undermined over the past 40 years. There is an urgent need for the sustainable management of the LULC, restoration of degraded ecosystems in the study area, and policy reforms promoting local land use planning and their integration into council, regional and national land use plans. Production land (66.1%) dominated the land use system in a hilly area of Sichuan Province in China, and living land and ecological land accounted for 7.6%, and 26.3% of the study area, respectively [20]. Most of the remnants of the ecological land are located in the western section of the mountain peak. Production land and living land are mostly interspersed in the hill slopes and low-lying areas. This is consistent with the findings that most of the ecological space in mountainous landscapes is located in higher elevation areas, and plays an important role in regulating and maintaining ecological security [23].

The results suggest that land use in mountainous areas can be dominated by human production activities where the adjacent communities depend solely on the mountain resources for their livelihoods. The field survey indicates that households with older heads tend to occupy lower altitudes; devote larger land surface areas to perennial crop cultivation; and keep land fallow for longer periods. Younger households occupy higher altitudes, are more recent inhabitants and practise shorter fallow periods. This is consistent with the observed trend towards increased use of the upper slopes for intensive horticulture, using local irrigation techniques and chemical fertilizers during the dry seasons.

The significant conversion of forest and grassland areas to farmland, plantations and built-up areas suggests that there is urgent need for assessment of the different priority ecological areas requiring restoration interventions and for PLUP and zoning to reverse the observed trend in LULCC, land use conflicts, and land conflicts within and between village communities and between village communities and the government. Cattle grazing is a common practice of land use on the upper slopes where food crop cultivation is uneconomical [24,38] and enforces fierce land use competition with subsistence agricultural land. Long-term progressive deforestation, aggressive expansion of agricultural cultivation on the lower slopes and riparian areas, and expansion of grazing land have contributed to accelerated soil erosion, shallow landslides, and land degradation and a decline in local crop yield. As a consequence, farmers engaged in intensive market gardening depend on the use of chemical fertilisers to increase food production. The extensive use of chemical fertilisers is further explained by the fact that the soils are acidic, low in phosphates and increasingly and relatively poor in crop nutrients [38].

Following the ecosystem restoration and conservation initiatives in the study area, projects funded by external agencies such as Darwin Initiative and TreeSisters (UK) have trained farmers on tree cropping, particularly sustainable diversified farming with agroforestry, contour farming, cultivation of fruit and NTFP trees on-farm and Conservation Agriculture techniques, especially for market gardeners. The practice of Conservation Agriculture (with annual cropping and perennial cropping as best sustainable systems) has become widespread [42,43]. More than a thousand farmers have also been trained on how to establish their own small agroforestry tree nurseries, pegging, grafting, marcotting, composting, harvesting and tree treatment. There is continued monitoring of the uptake and progress in the practice of sustainable and conservation agriculture techniques by trained extension workers in the project landscape.

The aim is to reduce soil erosion, improve soil productivity and crop yield, and enhance food security, nutrition diversity and local economic resilience for the farming households. The Mbororo pastoral community has been trained on value addition opportunities and cost-benefit analysis for their priority products as a way to reduce grazing pressure in the woodland-grassland mosaic and in riparian areas during such projects. The priority assessment for participatory ecosystem restoration and land use planning in the study area follows the PLEL functioning framework to ensure an integrated ecological, social and economic land system. Following this PLEL framework, areas reserved for ecological conservation, areas reserved for agricultural production including agro-industrial plantations, and areas reserved for housing development and settlements should collectively be identified, delineated, and mapped using the participatory mapping and land use planning and zoning approach.

The 2011 Law on the orientation of land use and sustainable development planning in Cameroon focuses on national, regional, and council land use planning [29], with no considerations or provisions for local land use planning. The Ministry of Economy, Planning and Regional Development (MINEPAT) is expected to develop a national framework document for PLUP. A national land use plan has not yet appeared. Local land use plans are the lowest in the land use planning hierarchy and present an opportunity to reconcile top-down planning to meet not just local development goals based on the needs of local communities but also national and regional development goals [30].

A PLUP project was initiated in the Mount Bamboutos landscape in 2018, funded by le Fonds français pour l'environnement mondial (FFEM), viz., FFEM small grants project – PPI5. This project has technical support from the IUCN-French Committee. The PLUP activities were continued by the Darwin Initiative funding with technical support from the International Tree Foundation (ITF) and implemented by the Environment and Rural Development Foundation (ERuDeF) till March 2021. Two regional dialogue platforms of the PLUP in the West and Southwest components of the landscape have been put in place, and a platform model defining the functioning and mandate of the dialogue platforms was adopted by all stakeholders. Land use maps based on participatory mapping and stakeholder zoning of desired land uses in Bangang-north, Bafou-north and Bamumbu villages were validated by all stakeholders in the local land use planning pilot project villages in February 2020. Proposed land use plans were validated at the village level in Bangang-north and Bafou-north by all stakeholders in March 2021.

Progress in the PLUP for the entire Mount Bamboutos landscape has been slow mainly because of limited funding, coupled with the dispersed rural communities, complex local land tenure systems and existing land tenure and land use conflicts within and between village communities and between village communities and the government. Soliciting the free, prior and informed consent (FPIC) of the local population in village communities, continuous multiple stakeholder consultations, available and sustainable technical and financial resources, paying attention to customary land tenure conditions, etc. are invaluable for increasing participation in the local land use planning process to ensure sustainability in the land use planning in a proposed conceptual model (Figure 4).

In addition, successful preparation, implementation and integration of local land use and zoning plans should ensure sustainability of the land use planning and increase land tenure security, ecosystem restoration and conservation success and sustainability, and reduce deforestation in the long run. This should attract public and private partnerships (PPPs) and investments, envisaged in cooperatives and factory-based industries that will promote sustainable local development and reduce poverty, food and nutrition insecurity in the study area (Figure 4). In general, critical factors to successful land use planning include effective data collection, awareness raising, capacity building, gender inclusiveness, institutionalisation, formal approval, a legally binding status and a bottom up consultation with top down participatory process that merge goal setting and scenario analysis [30,44].

The local land tenure systems are highly complex and conservative, linked to local traditions and cultural beliefs. For example, men object to attending meetings and training workshops with women, and women cannot implement recommended diversified and sustainable agricultural practices without approval from their men or husbands. Researchers have engaged in education and sensitisation activities to inform men about the important role women play in natural resource management and land use planning. The purpose has been to show that women should have ownership, decision-making and control rights over land, but results are still meagre. This undemocratic injustice to prevent rural women from owning land is rooted in the age-old local land tenure systems, traditions and cultural beliefs. A national reform on local land tenure systems promoting land ownership for rural women, particularly in the study area, is crucial to achieving progress. Rural women need social, cultural, economic and political empowerment in land ownership and governance and natural resource management. This change will be crucial to sustainable development in Cameroon.

Therefore, the initiative on PLUP in the Mount Bamboutos landscape is a part of the preliminary phase of national land use planning, to ensure that the planned units (allocation zones) of the proposed local land use plans are integrated into the council, regional and national land use plan documents. According to the 2011 Orientation Law on Land Use and Sustainable Development Planning of Cameroon, local land use and sustainable development plans are prepared at the level of the village communities and adopted by the council of the municipalities concerned, for integration into the regional and national land use plans [29]. Early evidence suggests that successful development,

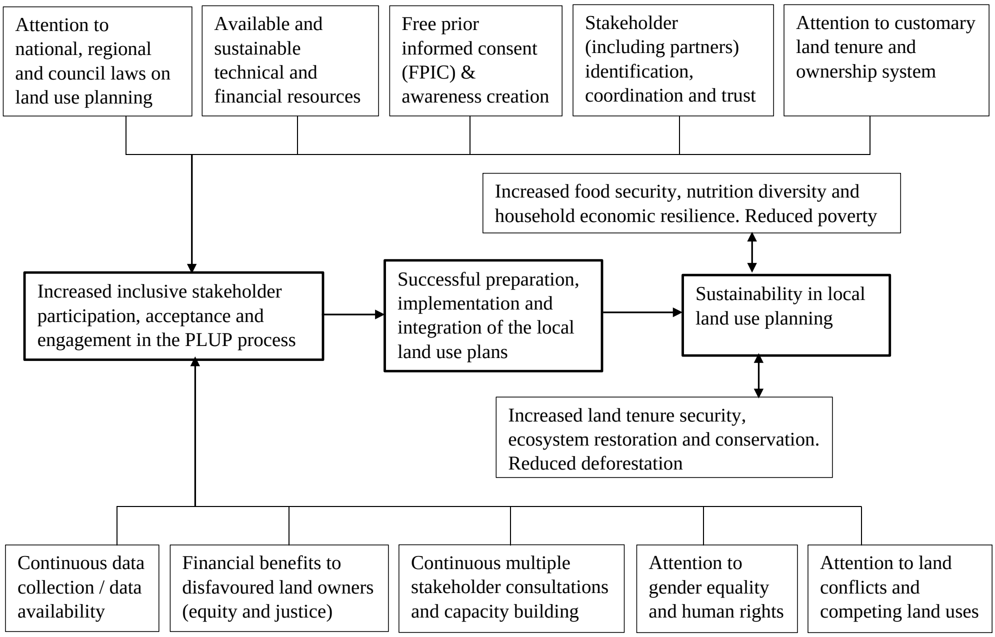

Figure 4. A proposed conceptual model to increase inclusive stakeholder participation and sustainability in local land use planning in Cameroon.

validation and integration of local land use plans into council, regional and national land use plans can stimulate land tenure security towards achieving REDD+ and sustainable development in Cameroon [30]. It also appears that carefully negotiated land use plans at the relevant jurisdictional scale offer a means of reducing deforestation, supporting biodiversity conservation and sustainable forest management, and promoting economic development in Central Africa countries [45]. Therefore, the results on the LULCC, PLEL and PLUP frameworks and information on the PLUP in the Mount Bamboutos landscape are useful baseline information to guide participatory local, council, regional and national land use planning to achieve sustainable development in Cameroon. Based on current experience in the PLUP process, a budget to complete the preparation, validation and integration of the local land use plans of the Mount Bamboutos landscape into the council and regional land use plans is estimated at £136,690 (approximately 99,783,554 XAF) (Please see supplementary material).

Conclusion

The study aimed to determine the actual extent of degradation and pattern of LULCC in the Mount Bamboutos ecosystem in the Western Highlands of Cameroon. Landsat images of three different years, including one Multispectral Scanner (MSS) from 1980, Enhanced Thematic Mapper Plus (ETM+) scene from 2000 and Landsat 8 Operational Land Imager (OLI) scene from 2018, were acquired and processed. The spatial and temporal data from the Landsat images were complemented with extensive ground-based survey data to verify and improve differences in the identified LULC categories. The achieved classification accuracies were 83% in 1980, 92% in 2000 and 93% in 2019. The study results showed that the areas of grassland, degraded primary forest and degraded secondary forest decreased by 818%, 101% and 53%, respectively. The areas of farmland, tea plantation, eucalyptus plantation, and built-up area increased by 69%, 84%, 94% and 97%, respectively, from 1980 to 2018 in the Mount Bamboutus landscape. Grassland dominated the land use land cover (40%) in the 1980s and farmland dominated the land use land cover (52%) in 2018.

This indicates significant conversion of the forest and grassland to farmland and built-up areas from 1980 to 2018, revealing a significant increase in areas of production land and living land and significant decrease in ecological land. Therefore, the stability, diversity, functioning and resilience of the Mount Bamboutos ecosystem have been disturbed for more than 40 years with significant degradation of the biodiversity and forest resources. The results provide important baseline information to land managers, land users, and large land owners on the urgent need for land use planning of the Mount Bamboutos landscape. The ecosystem restoration and conservation initiatives should include extensive tree planting in the different production, living and ecological systems. Land tenure reforms should be developed, followed by policies and strategies for effective implementation to increase and promote the rights of rural women in land ownership, decision-making and control, and overall governance of land and natural resource management for sustainable development. The Conservation Agriculture approach should be followed for sustainable development. Local land use planning and successfull ecosystem restoration initiatives should enable Mount Bamboutos Integral Ecological Reserve to be reconstituted.

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