


Spatio-Temporal Dynamics of Land Use/Land Cover in the Western Highlands of Cameroon (WHC) and Its Implications on Water Resources Management

Beatrice Abuiga Fonda¹, Neculina Anyinkeng¹, Coleen Mumbang¹, Lucy Deba Enomah², George Bindeh Chuyong^{1*}

¹Department of Plant Science, University of Buea, Buea, Cameroon

²School of Geoscience, University of South Florida, Tampa, USA

Email: *georgehuyong@gmail.com

How to cite this paper: Fonda, B.A., Anyinkeng, N., Mumbang, C., Enomah, L.D. and Chuyong, G.B. (2026) Spatio-Temporal Dynamics of Land Use/Land Cover in the Western Highlands of Cameroon (WHC) and Its Implications on Water Resources Management. *Natural Resources*, 17, 1-26.

<https://doi.org/10.4236/nr.2026.171001>

Received: November 29, 2025

Accepted: December 28, 2025

Published: December 31, 2025

Copyright © 2026 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

As human populations continue to grow rapidly, natural resources are becoming increasingly scarce, either being depleted or exhausted. Forests are a natural resource that provides goods and services essential for human welfare. Despite their importance to mankind, they are highly prone to fragmentation and destruction due to human impact, causing a great threat to water resources. This study aimed at evaluating changing trends in Land-use Land-cover (LULC) and its implications on water resources of the Western highlands of Cameroon over a 36-year period. Spatio-temporal dynamics of the landscapes were studied from the diachronic analysis of four Landsat scenes: Landsat TM of 1984, Landsat ETM+ 2001 and 2010, and Landsat 8 for 2020, complemented by verification missions and socio-economic surveys on the field. The satellite images were processed using ArcGIS and ERDAS Imagine® software. The results revealed that between 1984 to 2020 the extension of agricultural land (from 8752 ha to 24425 ha), built-up areas (from 2502 to 8965ha), degraded forest (from 9000 ha to 20016 ha), Savannah (from 37258 ha to 49898 ha) and bare soils (from 71 ha to 342 ha) could have accounted for the disappearance of much of the dense, montane and gallery forest area and water bodies which within the period recorded losses of -26455ha, -6113 ha, -10972 ha and 3660 ha respectively. Results from surveys revealed that farming (50.7) and collection of fuel wood and NTFPs (28.4) were the main activities carried out around forests, which resulted in the degradation of forests in general and gallery forest in particular. The reduction in the area of water bodies owing to land use and climate change probably accounted for the reduction in surface area and

water volume of the Bamendjin reservoir, a proxy for available water resources of the area. Therefore, the need for service and fuel wood, agricultural land to ensure food security, and settlements to accommodate the increasing population is at the heart of the multifaceted pressures on forests, land cover change, and water resources. The rapid population growth of the Western highlands of Cameroon could have accounted for these pressures. There is an urgent need to implement an appropriate land use policy in this area.

Keywords

Western Highlands of Cameroon, Land Use/Land Cover, Remote Sensing, GIS, Spatio-Temporal Dynamics, Water Resources, Climate Change

1. Introduction

For a long time, environmental issues have not been taken seriously, with concern restricted to the scientist or activist communities, with no one taking responsibility for the damage being done [1]. Cities in Sub-Saharan Africa (SSA) are expanding at unprecedented rates, dramatically altering the landscape with resources either being changed or exhausted [2]. The current world population of 7.6 billion is expected to reach 8.6 billion in 2030, 9.8 billion in 2050, and 11.2 billion in 2100 [3]. This increase will therefore require increased food production, which will need to occur in the context of mounting water scarcity, likewise decreasing the area under forest cover due to deforestation and environmental degradation.

Forests are one of the great inherited resources of the earth and play a key role in the economic development of many countries through the provision of goods and services for human welfare. Forests are valuable in providing food, shelter, fuel, medicinal ingredients, and paper that human beings and other animals depend on [4]. They provide habitat for the largest assemblage of species of any terrestrial ecosystem and store about 25 % of the total carbon in terrestrial systems, which otherwise would reside in the atmosphere as greenhouse carbon dioxide (CO₂) gas [5]. Moreover, they also provide a unique habitat for a number of rare and endangered species [6]. Besides fuel wood and timber, the forest ecosystem also supports a wide range of Non-Timber Forest Products (NTFPs), such as wild fruits, nuts, rattan, and medicinal plants, which support the livelihood of many indigenous forest dwellers [7]. Forests play a direct role in nutrient cycling and soil formation as well as pest and pollution control. They also play a very important role in the hydrological cycle as their presence or absence affects the amount of runoff and the amount of water infiltrating into the soil [8]. Susswein *et al.* [9] also reported that forests regulate climate through the exchange of water, energy, and momentum with the atmosphere as well as maintain water supply and quality by protecting watersheds from soil erosion, floods, and drought. They therefore supply, store, and retain water in watersheds and natural reservoirs by regulating the water flow and protecting against storms, erosion, and floods [10].

Savanna regions may contain significant areas of forest, usually in riparian environments [11]. Gallery forests represent one of the few examples of naturally fragmented tropical forest patches [12]. These are narrow strips of forest associated with creeks and rivers, forming continuous strips along streams in an otherwise unforested landscape [11]. They are highly prone to fragmentation and destruction due to human impact, causing a great threat, owing to Land Use Changes [13].

According to FAO [14], global forest cover drastically decreased from 4128 million hectare in 1990 to 3999 million hectare in 2015, corresponding to a drop from 31.1 to 30.6% (1.5% loss); This trend has been recorded in Cameroon with a 1.53 million ha loss from 2001-2020 corresponding to a 4.9 % decrease due to Land Use changes.

The WHC is considered the breadbasket of Cameroon due to its agricultural and livestock rearing potential. However, this is one area of the country noted for a gradual degradation of the agro-sylvo-pastoral resource base because of irrational exploitation. It is estimated to have a surface area of 31,192 km² [15] and has been witnessing massive population growth in the last decades, with a density of about 128 persons/km² [16].

The reservoir in the Bamendjin area, which constitutes a major watershed, has been very useful to the growing local population in the pursuit of their developmental activities. The Bamendjin Dam, which is built across the River Noun, reinforces the hydroelectric plant and is meant to boost the main electricity production plant on the River Sanaga at Edea by holding back the River Noun and its braided tributaries in the flood plain during the dry season. It constitutes an abundantly vast “water empire” [17] which serves not only as a major reservoir for water supply but also fosters agriculture, grazing, and fishing activities [18]. Since its construction, waters held behind have generated a number of problems on the one hand, and set into motion a number of competing water and land use systems on the other hand [19].

Owing to the combined effect of increasing population, uncontrolled urbanization, agricultural expansion, climate change, and the persistent aggressive cycles of poverty, people are compelled to encroach on forests and water sources for livelihood sustenance [14]. Regardless of their importance, irrational exploitation has resulted in unprecedented destruction and continued degradation of these natural resources [12]. The watershed in the Bamendjin area has been witnessing remarkable degradation, which stems largely from the drivers of LULCC. These drivers at different spatial scales [20] affect ecosystem functions and services, such as water regulation [21], water quantity [22], and water quality [23]. There is thus an urgent need to assess the status of forests in this priority area in a bid to understand land cover types that may have been affected over time by different drivers. This will help in awareness raising and capacity building of the population of this priority area, as well as streamline policy efforts towards specific sustainable development goals 6 (sustainable water resources), 6.6

(catchment restoration), 11 (sustainable cities and communities), and 15 (land sustainability). This study, therefore, sought to evaluate relative changes in land use/ land cover, identify drivers of change in areal extent, and assess the effects of these changes on water resources of the Western highlands of Cameroon (WHC) over a 36-year span.

2. Materials and Methods

2.1. Description of Study Area

WHC is situated in the Savanna ecological zone of Cameroon, specifically in the highland plateaus of the West and Northwest regions. It is located between Latitudes $5^{\circ}40'' - 6^{\circ}80''$ North and Longitudes $10^{\circ}20'' - 10^{\circ}40''$ East [24] (Figure 1).

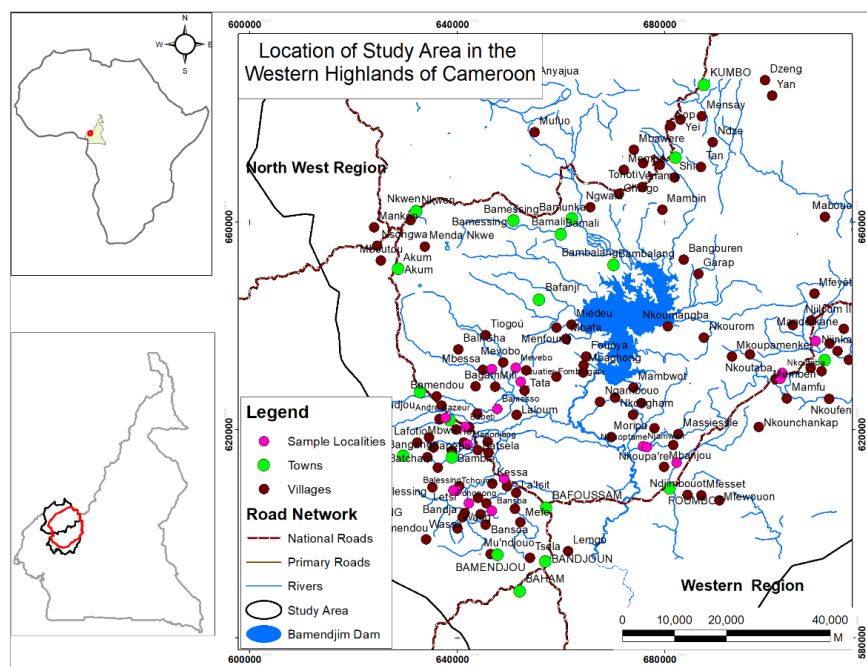


Figure 1. Location of study area in the western highlands of Cameroon.

The climate is a tropical Soudanian type with annual average rainfall from 1500 - 2600 mm and an annual average temperature range of 14°C and 28°C [25]. Altitude ranges from 1500 m - 2500 m asl [26]. The soils are Sandy clay ferruginous soils with pH range of 4.5 - 5.0. Vegetation varies from the low plateaus to the high plateaus due to altitudinal zonation in the drainage basin. The principal vegetation consists of Grasses with herbs [27] and is usually dominated by *Pennisetum purpureum*, *Imperata cylindrical* [28], and arboreal plants. On the high plateaus (above 1,500 meters), remnants of dense vegetation dominated by *Symphonia globulifera*, *Strombosia schefflera*, *Albizia gumnifera*, and *Allophylus bullatus*, exist in inland valleys and slopes [29]. A large part of the plateau is covered by “prairie” vegetation, which makes this area one of the main valuable grazing lands in Cameroon. On the low plateaus (1,000 - 1,500 meters), remnants of humid for-

ests occur and are protected in some areas as sacred places for traditional sacrifices typically found around palaces [30].

The economy of the region depends largely on agriculture and livestock, which are the major activities carried out and occupy almost the totality of the land. Traditional or subsistence agriculture, which entails slash and burn shifting cultivation, is the most common agricultural practice dominating. Approximately 80% of the entire population is engaged in this agricultural practice, while approximately 6% of the industrious population practices livestock farming [16]. The Project area is approximately 2025 km² around the Bamendjim reservoir. It is situated within six divisions in Cameroon: Ngoketunjia, Mezam, Noun, Mifi, Bamboutos, and Menoa.

2.2. Land-Use and Land Cover Assessment

2.2.1. Data Acquisition and Image Pre-Processing

Satellite images selected for the time series analysis of LULCC in the Western Highlands of Cameroon included Landsat Thematic Mapper (5TM, 1984), Landsat Enhanced Thematic Mapper Plus (7ETM+, 2001, 2010), and Landsat Operational Land Imager with Thermal Infrared Sensor (8OLI-TIRS, 2020) (Table 1). These images were accessed freely from the Global Visualization Viewer of the United States Geological Survey (USGS) (<http://www.usgs.gov/> downloaded on 18th and 23rd December 2021) and geo-rectified to UTM (Universal Transverse Mercator) WGS (World Geodetic System) 84 with radiometric corrections and spatial resolutions of 30 m and 15 m for the Panchromatic band. These are orthorectified Landsat images that were easily integrated into a Geographic information system (GIS). The images were acquired approximately at the beginning of the dry season of the selected years, ensuring low cloud cover and minimizing variabilities in phenological stages of plant cover. Figure 2 summarizes all the methods and analyses used in producing the land use and land cover maps and change detection.

The downloaded images were imported into ERDAS Imagine[®] version 10.1 band after band for different band combinations. Darkest pixel corrections were done to enhance radiometric and geometric values and image visualization. Co-registration was done using the 1984 image as the base image, onto which the other images were warped using the image-to-image registration method and first-order polynomial warping function in ERDAS Imagine[®] version 10.1. False colour composites bands (752) of the different years depicting the vegetation image pixels were trained and categorized into appropriate classes [31]. Images were then resized to the same spatial resolution and later subsetted into the study area to determine the land use and land cover types by classifying images.

Table 1. Characteristics of images used for a time series analysis.

Sensor	Acquisition Date	Spatial Resolution	Path/Row
Landsat TM 5	29/11/1984	30m	186/56

Continued

Landsat ETM 7	05/02/2001	30m	186/56
Landsat ETM 7	16/01/2010	30m	186/56
Landsat 8	04/02/2020	30m	186/56

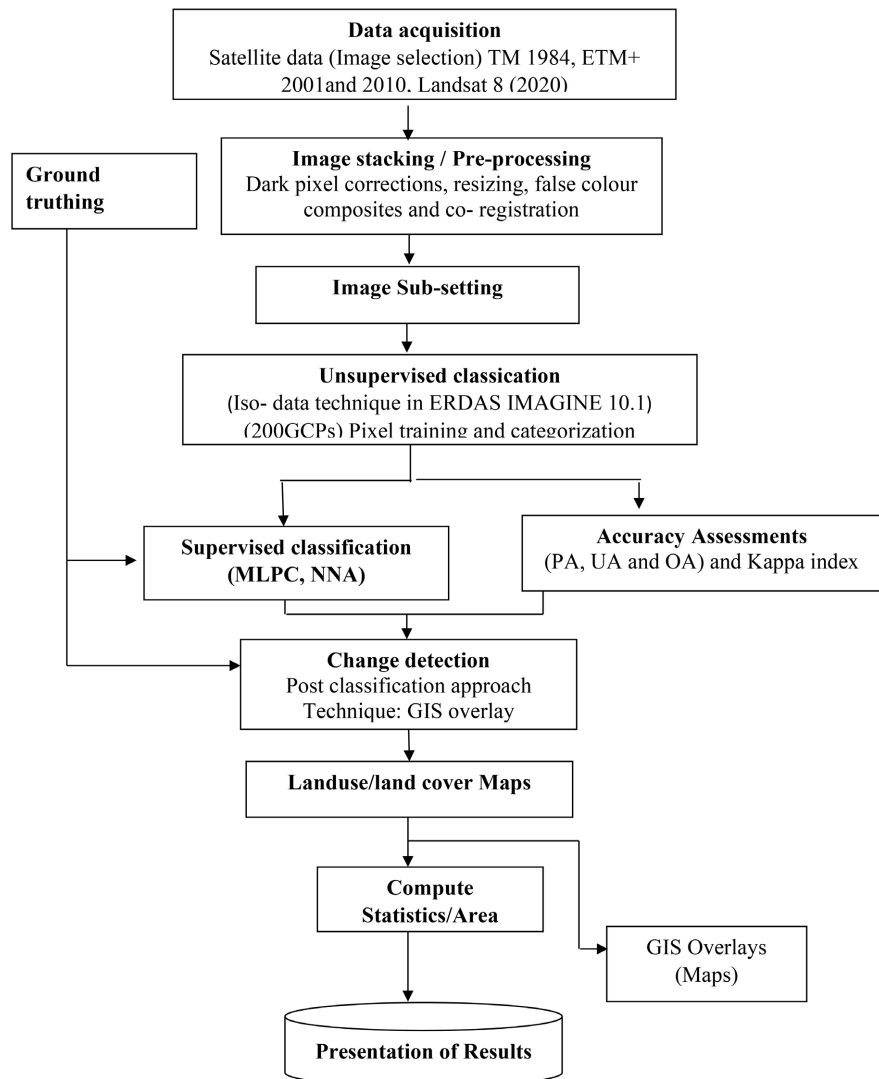


Figure 2. Methodological flow chart used in producing the land-use land cover maps and change detection.

2.2.2. Image Classification and Accuracy Assessment

Unsupervised classification was done using the ISO-Data technique in ERDAS Imagine® version 10.1. with computerized assignment of spectral signatures to the various land use and land cover types. At least 200 Ground Control Points (GCPs) were automatically generated and used during the field phase for land use land cover verification. A ground truthing survey was done to obtain ground reference data to test the reliability of the unsupervised classification and understand the general land cover classes of the study area. During the survey, GPS coordinates

of ground points were recorded in the different land use and land cover types and later used to transform former land use and land cover types before performing a supervised classification. Data (GCPs) obtained from field visits were input into the supervised classification using the Maximum Likelihood Parametric Classifier (MLC) and Nearest Neighbor Algorithm (NNA) to identify various features and/or land use classes on the images based on assigned spectral signature [32] [33]. These training signatures were created with at least 10,000 pixels per land use and land cover class (Heo and Fitzhugh 2000) and automatically classified all pixels in an image into nine (9) land use and land cover categories. These categories included: (1) Dense Forest, (2) swamps and Gallery Forest, (3) montane forest, (4) Built up areas, (5) Farmlands, (6) water bodies, (7) Savanna, (8) degraded forest, and (9) Bare soils (**Table 2**).

The classification was later polygonised and exported to ArcGIS version 10.1 for further processing using Ground Control Points as validation set. All ground control points were overlain on the classified maps for verification and determination of the accuracy of fit according to the method of Cogolton [34]. The producer, user, and overall accuracies, as well as the Kappa coefficient statistic, were computed from the resulting confusion or error matrix to test the accuracy of the classified maps of 1984, 2001, 2010 and 2020 following the method of Disperati and Viridis [35];

$$\text{Producer Accuracy} = \frac{\text{Total number of pixels in a category}}{\text{Total number of pixels of that category derived from the reference data (i.e. row total)}} \quad (1)$$

$$\text{User's Accuracy} = \frac{\text{Total number of pixels in a category}}{\text{Total number of pixels of that category derived from the reference data (i.e. column total)}} \quad (2)$$

$$\text{Overall Accuracy} = \frac{\text{Sum of the diagonal elements}}{\text{Total number of sites pixels (column total)}} \quad (3)$$

The kappa statistic value is a measure of the agreement between classification and reference data [36].

$$\text{Kappa coefficient statistics} = \frac{P_0 - P_e}{1 - P_e} \quad (4)$$

where: P_0 = Probability of agreement and P_e = Probability of random agreement.

Table 2. Land use/Land cover categories and their descriptions.

S/N	LULC Category	Description
1.	Dense forest	Naturally occurring stands of continuous cover of evergreen and semi-deciduous trees clustered together. The forest is intact, high-stemmed with relatively little or no disturbance.
2.	Gallery forest and swamps	Forests that form as corridors along rivers or wetlands and dominated by Raphia, mature natural trees, and tall grasses.

Continued

3.	Montane forest	Forest types situated at high altitudes and on mountain slopes with a mixed species of broad leaf evergreen trees and epiphytic plants.
4.	Built-up Areas	Consist of human construction dedicated to residential and commercial sectors, as well as infrastructure (roads, playgrounds, etc.)
5.	Farmland	All Cultivated lands for both annual and perennial crops, as well as juvenile cash crop plantations.
6.	Water bodies	Rivers, streams, lakes, dams, reservoirs in wetlands, and fish ponds.
7.	Savanna	Grassland ecosystem characterized by the stunted trees sufficiently spaced with little or no canopy cover.
8.	Degraded forest	Forestland with sparse crown cover of 15% - 60%, with relatively low stem density indicating degradation caused by planned or uncontrolled logging, and agricultural activities.
9.	Bare ground	Areas void of vegetation, water, settlements or farmlands with little or no vegetation cover, including open fields, bare slopes, and exposed rocky escarpments, bare soils, quarry areas, exposed sand bands, and eroded soil deposits.

2.2.3. Post Classification Change Detection

LULCC detection was performed using change detection analysis in a post-classification approach. The technique used the GIS overlay in ArcGIS version 10.1 based on generated vector themes of the different years. LULC change over time was quantified by evaluating gains and losses of specific LULC categories. Change detection was computed for the different LULC category in terms of (i) surface area (ha) for the years 1984, 2001, 2010 and 2020, (ii) area change (ha) for 4 periods (1984-2001, 2001-2010, 2010-2020 and 1984-2020), (iii) % area change per period. Since the duration per period vary, the change estimates were annualized for easy comparison and evaluation as follows: (iv) annual rate of change, and (v) % annual rate of change. These estimations of change were computed based on the formulae of Kashaigili [37]:

$$\% \text{ Cover change} = \frac{Area_{i \text{ year } x} - Area_{i \text{ year } x+1}}{\sum_{i=1}^n Area_{i \text{ year } x}} \times 100 \quad (5)$$

$$\text{Annual rate of change} = \frac{Area_{i \text{ year } x} - Area_{i \text{ year } x+1}}{t_{\text{years}}} \quad (6)$$

$$\% \text{ Annual rate of change} = \frac{Area_{i \text{ year } x} - Area_{i \text{ year } x+1}}{Area_{i \text{ year } x} \cdot t_{\text{years}}} \times 100 \quad (7)$$

where

$Area_{i \text{ year } x}$ = area of cover i at the first date,

$Area_{i \text{ year } x+1}$ = area of cover i at the second date,

$\sum_{i=1}^n Area_{i \text{ year } x}$ = total cover area at the first date and

t_{years} = period in years between the first and second scene acquisition data.

2.3. Assessment of Drivers of LULC Changes within Local Communities in WHC

Based on the hydrological map of the study area, some main streams identified were selected, and the population around these streams was targeted for assessment of impacts of LULCC on water resources through the use of semi-structured, open-ended questionnaires. A total of 201 questionnaires were administered purposefully and proportionally to respondents in 12 localities in 4 divisions namely; Foumban (35), Foumbot (35) and Mangoum (20) (Noun Division), the Baleng community made up of Tchada (15), Dionku (15), Fampi (15) and Tyo (15) (Mifi Division), Bameboro (20), Batsuetim (15), Batossusong (15) and Galim (30) (Bamboutos Division) and Bamendou (20) (Menoua Division). These localities were chosen to represent the full range of LULC changes observed and for their proximity to key water bodies. Mostly people of 45 years and above, and considered to have a good knowledge of the area, were targeted. The questionnaires were partitioned into three themes with specific indicator variables for assessment: (a) General demography (b) Local perception of LULCC and water resource management, and (c) Assessment of drivers of change (farming, NTFP, and forest exploitation) that affect water supply. The Chi-Square statistic (χ^2) was used to evaluate a significant difference ($p \leq 0.05$) between indicator variables for a given theme.

3. Results

3.1. Land Use/Land Cover in the WHC

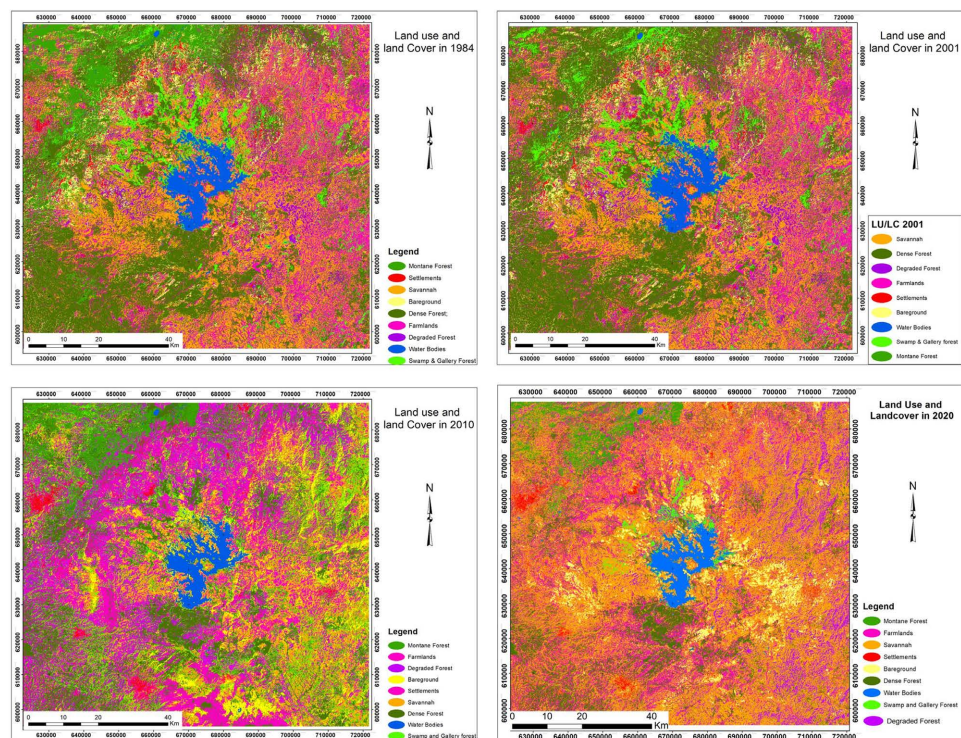


Figure 3. Classified land use and land cover maps of the Western Highland Cameroon (WHC) for the year 1984 (a), 2001 (b), 2010 (c), and 2020 (d).

The overall accuracy assessment of the supervised maps was 98.14%, 93.32%, 89.85% and 88.77%, respectively, for years 1984, 2001, 2010, and 2020 with a Kappa index of 0.95, 0.93, 0.89, and 0.93, respectively (**Table 3**). These values indicate a significant agreement with reference data and satisfy the minimum accuracy threshold of 85% needed for efficient land use/cover change analysis and modelling [38]. Supervised classification maps of the nine major LULC categories for the years 1984, 2010, 201, and 2020 are presented in **Figure 3**, and their respective surface area and percent contribution are in **Table 4**. In 1984, the dense forest (48100 ha), savannah (37258 ha), and swamps and gallery forest (32000 ha) were dominant LULC, accounting for 73.4% of the total area. There was a complete shift in 2020, with savannah (49898 ha), farmland (24425 ha), and degraded forest (20016 ha) accounting for 59.0% of the total area. Over the years, farmland, settlement, bare ground, and degraded forest increased steadily in surface area in the classification maps of 1984, 2001, 2010, and 2020 (**Figure 4** and **Table 3**). On the contrary, the dense forest, swamp, and gallery forest, water bodies, and montane forest were on the decline.

Table 3. Accuracy assessments for classification maps of the different land use/land cover classes for 1984, 2001, 2010, and 2020.

LU/LC classes	1984		2001		2010		2020	
	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)	PA (%)	UA (%)
Dense Forest	98.23	97.88	91.55	92.44	89.43	83.79	91.35	93.63
Savannah	98.77	98.55	95.57	96.62	88.20	91.98	94.89	96.07
Settlements	99.92	97.52	94.18	97.17	94.31	97.43	94.18	97.22
Swamp & Gallery Forest	98.54	96.48	89.07	90.87	83.39	89.95	89.93	89.63
Farmland	99.05	96.41	90.28	95.63	86.33	88.01	90.29	95.62
Water Bodies	100.00	100.00	100.00	94.97	100.00	95.34	100.00	95.06
Bare ground	92.08	99.58	90.37	85.60	86.73	86.01	90.41	85.60
Montane Forest	98.15	98.40	93.32	91.80	88.42	91.68	94.16	92.82
Degraded Forest	97.40	98.95	95.70	92.93	91.95	86.85	95.42	92.48
Overall Accuracy	98.14		93.32		89.85		93.32	
Kappa Index	0.95		0.93		0.89		0.93	

Note: PA = Producer's Accuracy, UA = User's Accuracy.

Table 4. Area of land-use/land cover category in the WHC (1984-2020).

LULC category	1984		2001		2010		2020	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Dense Forest	48,100	30.1	39,259	24.5	32,218	20.1	21,645	13.5
Savannah	37,258	23.3	40,167	25.1	44,848	28.0	49,898	31.2

Continued

Settlement	2502	1.6	3789	2.4	4210	2.6	8965	5.6
Swamp and Gallery Forest	32,000	20.0	29,789	18.6	25,400	15.9	21,028	13.1
Farmland	8752	5.5	15,298	9.6	20,410	12.8	24,425	15.3
Water Bodies	10,247	6.4	9612	6.0	7897	4.9	6587	4.1
Bare ground	2577	1.6	2872	1.8	3687	2.3	3985	2.5
Montane forest	9564	6.0	7982	5.0	4521	2.8	3451	2.2
Degraded Forest	9,000	5.6	11,232	7.0	16,809	10.5	20,016	12.5

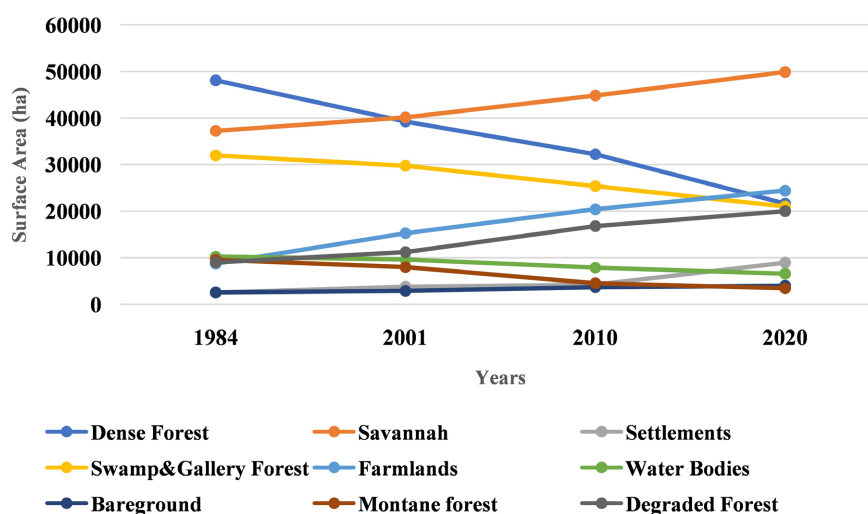


Figure 4. Trends in LU/LC categories for the years 1984, 2001, 2010, and 2020.

3.2. Patterns of LULC Change in the Western Highland of Cameroon (WHC)

Land cover statistics throughout the time span of 36 years showed varying dynamics, with all nine categories recording above 33% net change (loss or gain). Settlement, farmland, Bare ground, degraded forest, and bare soil and savannah recorded positive change of 258.31%, 179.08%, 122.40%, 54.64% and 33.93% respectively (Table 5). This gain probably resulted from a loss in montane forest (−63.92%), dense forest (−55.00%), and swamp and gallery forest (−34.29%). Water bodies equally recorded a total area loss of 3660 ha (−35.73%) throughout the period (Table 5, Figure 5).

Table 5. Surface Area change of the different land-use/land cover categories in the WHC (1984-2020).

LULC category	1984-2001			2001-2010			2010-2020			1984-2020		
	Area change (ha)	%	Annual rate (%/yr)	Area change (ha)	%	Annual rate (%/yr)	Area change (ha)	%	Annual rate (%/yr)	Area change (ha)	%	Annual rate (%/yr)
Dense Forest	−8841	−18.38	−1.08	−7041	−17.93	−1.99	−10573	−32.82	−3.28	−26455	−55.00	−1.53
Savannah	2909	7.81	0.46	4681	11.65	1.29	5050	11.26	1.13	12640	33.93	0.94

Continued

Settlements	1287	51.44	3.03	421	11.11	1.23	4755	112.95	11.30	6463	258.31	7.18
Swamp and Gallery Forest	-2211	-6.91	-0.41	-4389	-14.73	-1.64	-4372	-17.21	-1.72	-10972	-34.29	-0.95
Farmland	6546	74.79	4.40	5112	33.42	3.71	4015	19.67	1.97	15673	179.08	4.97
Water Bodies	-635	-6.20	-0.36	-1715	-17.84	-1.98	-1310	-16.59	-1.66	-3660	-35.72	-0.99
Bare ground	295	11.45	0.67	815	28.38	3.15	298	8.08	0.81	1408	54.64	1.52
Montane forest	-1582	-16.54	-0.97	-3461	-43.36	-4.82	-1070	-23.67	-2.37	-6113	-63.92	-1.78
Degraded Forest	2232	24.80	1.46	5577	49.65	5.52	3207	19.08	1.91	11016	122.40	3.40

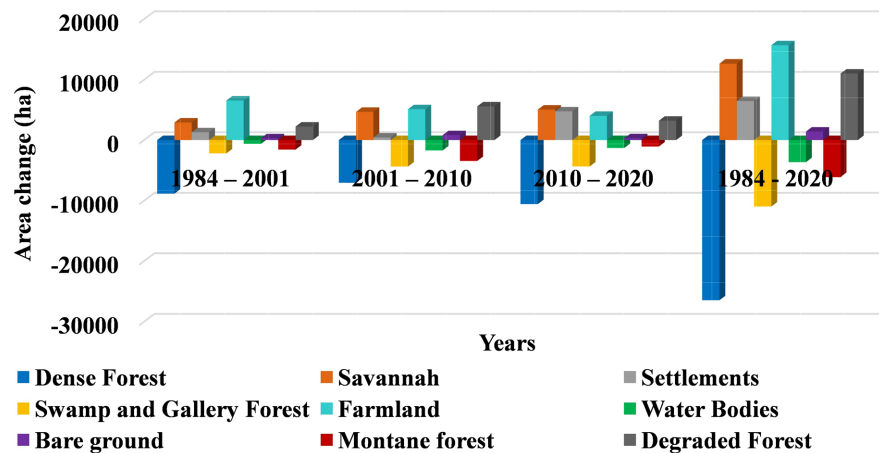


Figure 5. Change in surface of the different LULC categories within WHC.

Between 1984 and 2001, farmland and settlement recorded the highest increase in surface area of 6546 ha (74.79%) and 1287 ha (51.44%), respectively (Table 5, Figure 5). This was followed by degraded forest with an increase of 2232 ha (24.80%) and bare ground 295ha (11.45%). Savannah, with the second-highest surface area, also witnessed an increase of 2909 ha (7.81%). All three categories of forest witnessed reductions in surface area, with dense forest losing 8841 ha (-18.38%), montane forest 1582 ha (-16.54%), and swamps and gallery forest 2211 ha (-6.91%). Water bodies equally recorded a reduction of 635 ha (-6.20%). Surface area of degraded forest, bare ground, and savannah approximately doubled between 2001 and 2010 with an increase of 5577 ha (49.65%), 815 ha (28.38%), and 4681 ha (11.65%). Farmland and settlements equally increased in surface area by 5112 ha (33.42%) and 421 ha (11.11%), though less than previous estimates (Table 5, Figure 5). Loss in surface area was almost threefold for montane forest, swamp, and gallery forest, and water bodies recording 3461 ha (43.36%), 4389 ha (14.74%), and 1715 ha (17.84%) respectively. Loss in the dense forest was not different from the 1984-2001 estimate (Table 5). The greatest changes were recorded in all LULC categories between 2010 and 2020, with a very high increase in settlement of 4755 ha (112.95%) and relatively lower for degraded forest and farmland, and savannah. Loss in dense forest of 10573 ha (32.82%) between 2010 and 2020 was, however, the highest record in the 36-year span.

The overall annual rates of change show that settlements (7.18%/yr), farmland (4.97%/yr), and degraded forest (3.40%/yr) accounted for the dynamism of the LULC (**Table 5, Figure 6**). These gains were accounted for by losses in the montane forest (-1.78%/yr), dense forest (-1.53%/yr), water bodies (-0.99%/yr), and swamp and gallery forest (-0.95%/yr). This trend was the same for the different periods (1984-2001, 2001-2010, and 2010-2020), though at varying rates. The period 2001 - 2010 recorded the highest annual rates of change (**Figure 6**).

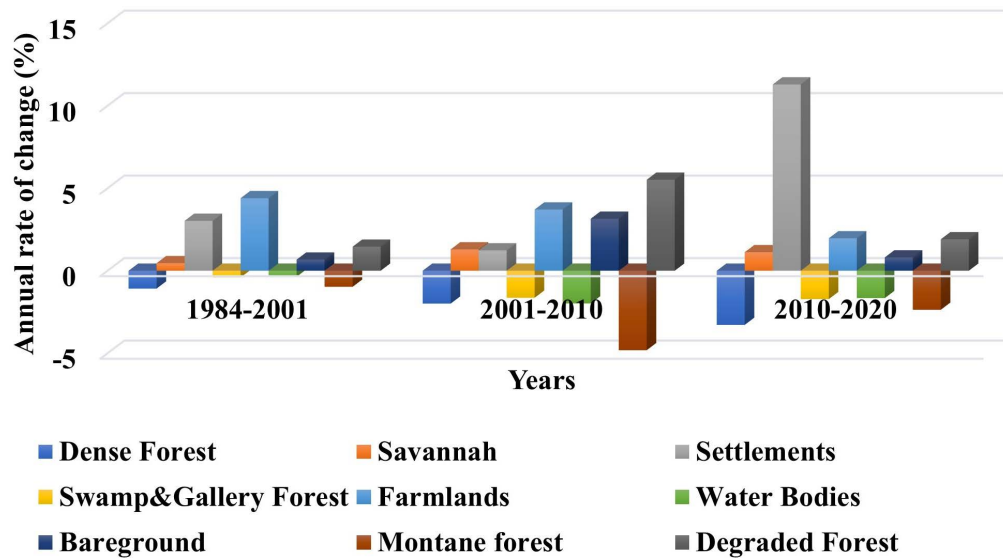


Figure 6. Annual rate of land cover change for the different LULC categories within WHC.

3.3. Assessment of Drivers of LULC Changes within Local Communities in WHC

Majority of the respondents were males (71.6%), and a good number of them had no formal education (41.8%), with farming (63.8%) as the main occupation of the population. A summary of respondents' views on local perception of LULC change and water supply is presented in **Table 6** and **Table 7**. Water source for daily needs was very variable, with the majority relying on wells (32.8%), streams (27.9), rivers (13.9%), and springs (9.5%). Supply was more acute in the dry season (93%), and the impact in terms of shortages was felt 15-25 years ago. The possible reasons for this drop in supply include: increasing local population (57.2%), poor catchment management (20.9%), and as a result of loss of some feeder streams (20.9%). The opinion of the respondents with respect to the reasons for the loss of major water sources also varied significantly ($P < 0.001$), with high concentration of houses and farmlands around major catchments (20.9%) and poor farming practices along water courses (20%) being the most cited reasons. Almost all of the respondents lamented that the water crises were affecting their personal and communal life by hampering domestic activities (39.8%), increasing disease incidence (27.5%), lateness of school pupils (17.4%), and reduction in crop yields (14.9%).

Table 6. Assessment of water supply and usage within the WHC.

Parameter	Category	Frequency	Percentage frequency	X ² -statistics	P-value
Water source for daily needs	Catchments	28	13.9	73.1	<0.001***
	Rivers	19	9.5		
	Springs	20	10.0		
	Streams	56	27.9		
	Taps	12	6.0		
	Wells	66	32.8		
Season with acute water shortages	Both	14	7.0	148.9	<0.001***
	Dry season	187	93.0		
Duration of experiencing water crises sources	15 years	71	35.3	16.1	<0.001***
	20 - 25 years	88	43.8		
	35 - 40 years	42	20.9		
Possible factors contributing to water crises	High concentration of houses and farmland around major catchments	17	8.5	133.1	<0.001***
	High temperature	15	7.5		
	Increasing local population	55	27.4		
	Loss of forest	1	0.5		
	Loss of some water sources that feed main stream	42	20.9		
	Over population	14	7.0		
	Poor catchment management	42	20.9		
	Poor farm practices around water sources	14	7.0		
	Reduced volume from source	1	0.5		
Effects of water shortage on communal life	Incidence of diseases	55	27.4	32.1	<0.001***
	lateness of school pupils	35	17.4		
	Hampers domestic activities	81	40.3		
	Reduction of crop yields	30	14.9		

A high proportion of the respondents (79.1%) noticed changes in the quality of the vegetation of the area, with more than half (56.7%) reporting a decrease in forest cover and savanna over the years. Most of the respondents (83%) affirmed the following anthropogenic activities to be responsible for the degradation of the vegetation and gradual loss of forests: opening of new farms (33.3%) and human settlement (29.9%). There was a clear indication of a lack of awareness on the link between forest cover change and water availability among the respondents (52.7%), though some were of the opinion that agricultural activities reduce forest cover (Table 7).

Table 7. Respondent views on the relationship between forest loss and provision of water.

Parameter	Category	Frequency	Percentage frequency	X ² -statistics	P-value
Notice any change in vegetation in the course of time	No idea	22	10.9	189.5	<0.001***
	No	20	10.0		
	Yes	159	79.1		
Observed changes in vegetation	Forest cover is decreasing, and the savannah is decreasing	114	56.7	138.4	<0.001***
	Forest cover is decreasing, and savannah is increasing	61	30.3		
	Forest cover is increasing, and savannah is increasing	12	6.0		
	No response	14	7.0		
Reasons for observable changes in vegetation	Construction of houses	60	29.9	14.8	0.002**
	Opening of new farms	67	33.3		
	Over grazing	34	16.9		
	Poor farming practices	40	19.9		
Possible link between forest cover change and water availability	No	39	19.4	36.2	<0.001***
	No idea	106	52.7		
	Yes	56	27.9		
Agricultural practices affect forest cover	No	48	20.9	7.8	0.008**
	No idea	69	37.3		
	Yes	84	41.8		

Farming and extractive use of the surrounding forest were considered the key agents of change, and a summary of the respondents' views is presented in **Table 8** and **Table 9**, respectively. Approximately 60.7% of respondents were involved in farming and had 4 - 6 farms (46.8%) per household, with farm sizes of 0 - 1 ha (53.2%). The majority of these farms were aged 15 years and above (46.8%). Acquisition of these farms was either inherited (66.7%), bought (20.4%), or rented (12.9%), with slash/burn being the most cited method of establishment (62.2%). Agroforestry was also a common practice carried out by the majority (60.7%) of the farmers with intercropping of fruit trees and other valuable tree species for bee farming.

Table 8. Assessment of farming as key drivers of change in the western highland Cameroon.

Parameter	Category	Frequency	Percentage frequency	X ² -statistics	P-value
Dependence on the forest as a source of livelihood	No	69	34.3	19.74	<0.001***
	Yes	132	65.7		
Main activities carried out around the forest	Farming	122	60.7	76.87	<0.001***
	Fuelwood and NTFPs	57	28.4		

Continued

	Tapping	22	10.9		
Number of farms cultivated per household	1 - 3	62	30.8		
	4 - 6	94	46.8	18.48	<0.001***
	6 and above	45	22.4		
Method of farm acquisition	Bought	41	20.4		
	Inherited	134	66.7	0.102.18	
	Renting	26	12.9		
Duration of farming	0 - 5 yrs	49	24.4		
	15 yrs and above	94	46.8	16.93	<0.001***
	5 - 10 years	58	28.9		
Approximate size of farm	0 - 1 ha	107	53.2		
	1 - 3 ha	75	37.3	59.22	<0.001***
	above 5 ha	19	9.5		
Method used to establish farms	Clearing	33	16.4		
	Ploughing	12	6.0		
	slash/burning	125	62.2	153.61	<0.001***
	Spraying	31	15.4		
Location of farm(s)	Around houses	65	32.3		
	Around the forest	45	22.4		
	flood plains	37	18.4	8.65	0.034*
	Savannah	54	26.9		
Approximate distance to the farm(s)	0 - 500 m	65	32.3		
	1 - 5 km	54	26.9	5.94	0.051 ^{ns}
	500 - 1 km	82	40.8		
Practice Agroforestry	No	70	34.8		
	Yes	131	65.1	18.51	<0.001***

Ethnobotanical assessment of the extractive uses of the surrounding forests affirmed high dependence on the forest as a source for livelihood (**Table 9**), medicinal plants (34.4%), and food (33.3%) being the most significant NTFPs collected. Noticeable changes in vegetation were also observed with core NTFPs on the decline (42.8%) or had disappeared (33.0%), resulting in non-significant shifts of collection points either at the forest centre (40.8%), forest edge (30.8), or at random (28.4%).

Table 9. Ethnobotanical assessment on extractive use of surrounding forests.

	Category	Frequency	Percentage frequency	X ² -statistics	P-value		
Dependence on the forest as a source of livelihood	No	69	34.3	39.50	<0.001***		
	Yes	132	65.7				
End-use of NTFPs collected from forests	Crafts	14	7.0				
	Food	70	33.3				
	fuel wood	50	24.9				
	medicinal plant	67	34.8				
Types of NTFPs collected from the forests	Bamboo	24	10.7				
	Medicinal plants	103	46.2				
	Mushroom and snails	70	31.4				
	Raffia wine	26	11.7				
Plant forms harvested for medicinal uses	Herbs	73	36.3			0.925	0.630 ^{ns}
	Shrubs	66	32.8				
	Trees	62	30.8				
Plant parts used	Barks	43	21.4				
	Leaves	71	35.3				
	Rhizomes	13	6.5				
	Roots	6	3.0			112.3	<0.001***
	Sap	13	6.5				
	Seeds	17	8.5				
	Whole plant	38	18.9				
Collection points	Forest centre	82	40.8	5.22	0.073 ^{ns}		
	Forest edge	62	30.8				
	Random	57	28.4				
Noticeable changes in availability of plants in forest	No	45	22.4	137.0	<0.001***		
	No response	13	6.5				
	Yes	143	71.1				
Level of availability	Decreasing	92	42.8	61.6	<0.001***		
	Disappeared	71	33.0				
	Increasing	24	11.2				
	Undecided	28	13.0				

4. Discussion

4.1. Land-Use Land Cover Dynamics

Nine principal land use/ cover classes were identified in this study, with some showing gains in surface area while others showing losses. The decrease in forest cover (dense, montane, and swamp, and gallery forests) observed in this study

could be attributed to their conversion to agricultural fields and settlement to ensure food security and accommodate the increasing human population, respectively. Population growth, coupled with land scarcity, has forced farming households to expand their agricultural fields into natural environments in order to increase their agricultural production and cover their daily household needs. Similar outcomes were observed by Ewane *et al.* [20], who examined implications of agricultural expansion and land use/ cover change on local land use planning and sustainable Development, and reported an increase in built-up areas and farmland as a result of an increase in human population. There has been continuous farming on the slopes around the mountain, as Ndzeidze [29], also reported that very little of this highland montane forest remains, as the forests have been cleared over the years in the quest for farming, settlements, and grazing land. A study in the Bamboutos watershed to assess the impact of land use/ cover change on water quality reported the conversion of gallery forest, wetlands and swamp, into farm land, commercial vegetable farming and market gardening with residential settlement as well, while the savanna vegetation is transformed into animal grazing sites [39]. In this same study, although the natural forest was being converted to arable farming and settlement expansion, the natural forest was also highly regarded and protected for its cultural values, as families' shrines and the village's secret forest were used for rituals and sacrifices. In addition to being lost to farmland and settlement areas, ecological land (open primary forest land, open secondary forest land, grass land, and bare rock area) has been transformed into tea and eucalyptus plantations that were established for commercial purposes to supply ready-to-consume beverages and market electricity poles for the national electricity company over the past 30 years [20]. Almayehu *et al.* [31] delineated the following as direct causes of land use and land cover change in the Somodo watershed; illegal logging and fuelwood extraction, expansion of plantation, expansion of settlement, agricultural expansion, and construction of infrastructures such as schools, roads, and research center.

Land scarcity largely accounts for intensive cultivation with no fallow periods. The massive decline in forest cover is often associated with agricultural expansion in the periphery of the forest, while timber exploitation and charcoal production are other problems that contribute to the decline in forest cover [40]. Forests remain potential sites for opening new farms, as the best crop yields, they reported, were obtained from farms inside the forest and at the forest edge. This could be attributed to high organic matter content in forest soils, caused by litter decomposition. Gallery forests also have alluvial soils that are far more fertile than the soils of the savannah. This is due to nutrients in the stream associated with organic matter from litter decomposition. This has resulted in a general downward trend in the area covered by these forests on a spatiotemporal basis. Owing to the scarcity of land, savannahs are also gradually being converted to farmland.

4.2. Drivers of LULC Change and Implications for Water Resources Management

From the socio-economic survey, farming, collection of fuel wood, and NTFPs were the main economic activities carried out by the population, and these activities have largely accounted for the degradation of the forest in the WHC. The main drivers of LULC in the WHC are intensive subsistence farming, collection of fuel wood, increased construction of housing, unregulated and overgrazing, unsustainable farming practices, and overexploitation of NTFPs. The increased pressure could be attributed to population growth, hence increased settlement development, expansion of farmland through slash-and-burn agricultural practices, forest clearing, and spraying has led to high deforestation rates, destruction of water catchments, and loss of soil fertility. Momo *et al.* [12] made similar observations while studying land use/ land cover and anthropogenic causes around the Koupa-Matapit area. The degradation of forests in this region is a result of the introduction of sun-loving crops, which encourages the clearing of shade, hence aggravating forest loss over time. Our result concurs with the observations made by Teshome *et al.* [41], who investigated the dynamics of land cover in the Muger sub-basin, Oromia, Ethiopia, and identified the main factors that are responsible for the land cover change as well as the effects of these changes. Their study revealed agricultural expansion ranking first as the main driver of land cover change, followed by population growth, wood extraction, expansion of settlement, and infrastructure development. The noted majority of the farmers owned farmland of sizes 0-1ha and had approximately 4-6 farms per household, which is estimated at 6ha per household. Thus, the scarcity of favourable land for farming as a result of population growth increases pressure, deforestation of the nearby forested (dense, montane, swamps and gallery forests) areas, and savannah vegetation all contribute to the degradation of the watershed and water resource. Field survey advanced reason for change in vegetation being construction of new houses, opening of new farm lands, overgrazing, and poor farming practices, noting significant differences. Our findings correspond with those of Kometa and Ebot [18], who recounted that a reduction in pasture/fresh grass for livestock resulted from overgrazing due to an increase in the number of animals, not only resulting in vegetal cover degradation, but also degradation of some watershed ecosystems. River valleys in the Bamboutos watershed are being altered into intensive marketable farming sites due to their low relief, fertile soil, and water supply availability all year round, swamps and wetlands now occupied by market garden farms [18] [38]. The nucleation of this build-up houses, coupled with the intensive farming and migration of livestock into swamps and gallery forest areas during the dry season, results in the shrinking of the water resource and land use conflict. The decrease in forested land (dense, montane, swamps, and gallery forests), with increases in farmlands, settlement, barren land savannah, and water bodies, and poor catchment management, poor farming practices around water sources highlight the need for sustainable water resource management.

The increased exploitation of the various NTFPs leaves a significant impact on the forest ecosystem and its services. Indeed, the removal of leaves, barks, and roots could cause a vulnerability of plants or extinction of rare species, which in effect could result in forest degradation through loss of biodiversity [42]. Moreover, the almost daily human presence within the forest and harvesting of NTFPs and other wood products are at the origin of the loss or the disappearance of some valuable species [43]. The main drivers of deforestation and degradation are therefore the combination of several factors, including the expansion of peasant agriculture, poor farm practices, and the construction of houses. The socio-economic survey identifies slash-and-burn as the primary method for farm establishment that must be accounting for observed increase in the surface area of degraded forests and savannah vegetation.

The increasing human population, coupled with the scarcity of favourable land for farming, grazing and construction of settlements causing the agricultural front to migrate to previously unexploited areas such as the banks of water courses [44] These activities are all taking their toll on the watershed appear to be the drivers of watershed degradation putting the supply of fresh water at risk [18]. Indicators such as the decline in water quantity and the increase in water-related illnesses are active issues that draw attention to questions on the environmental quality and degradation. Other issues, such as the seasonality of streams and scarcity of potable water in the dry season, are just part of the chain of problems originating from the degradation of the watershed. It is worth noting that the long cycles of poverty in the WHC intensify the watershed degradation process [45]. The case of the region is remarkable due to its high population density and a rural economy that depends on subsistence agriculture, which yields little income and can barely sustain livelihoods [45] [46]. The varied nature of the physical and human landscape thus constitutes the framework for the spatial processes, which considerably account for the watershed degradation [18]. These agrarian changes in response to pedoclimatic changes weaken natural ecosystems, more especially, the water ecosystems, including the gallery forests that naturally surround rivers and streams. Climate change and human induced changes are considered the two major factors impacting hydrological processes [47] [48]. Result showed that the WHC hydrological basin is faced with decreasing stream flows as evident in the shrinking of the surface area of water bodies. Climate variability has led to rising temperatures, increased evapotranspiration and changing precipitation patterns that play vital role in streamflow trends and surface area of water bodies, while human activities have changed the temporal and spatial distribution of water resources. Though the GIS analyses could not pick streams, the gradual decline in the surface area of the Bamendjin dam was witnessed.

These findings advocate that the stability, functioning, and resilience of the WHC 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, especially water resources in the study area, and policy re-

forms promoting Participatory Land Use Planning (PLUP). The orientation Law on land use and sustainable development planning in 2011 by the Ministry of Economy, Planning and Regional Development (MINEPAT), Cameroon, laid no emphasis on local land use planning; however, it is expected to develop a national framework document for the PLUP. In 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. This is according to the 2011 Orientation Law on Land Use and Sustainable Development Planning. Hence, the project on Mount Bamboutos landscape, initiating the PLUP, serves as part of the preliminary phase of the national land use plan planning, ensuring the planned allocation zones of the proposed local land use are integrated into the council, regional, and national land use plan documents. Stimulated land tenure security towards achieving REDD+ and sustainable development in Cameroon is apparent from the successful development, validation, and integration of local land use plans into council, regional, and national land use plans [20].

5. Conclusions

Over the 36 years span, there has been a constant decrease in area of the different land cover owing to an increase in area of the different drivers of change. Dense forest, montane forest, gallery forests, and water bodies witnessed a constant decrease in trend in terms of surface area, while Savannah, farmlands, built-up areas, degraded forest, and bare soils increased over the years.

Rapid population growth of the WHC in the last decades has resulted in the clearance of natural vegetation to allow room for settlement and agricultural land for food security. Therefore, the need for service and fuel wood, agricultural land, and settlements is at the heart of the multifaceted pressures on the forests and land cover change. Therefore, the stability, diversity, functioning, and resilience of the ecosystem have been disturbed for more than 40 years, with significant degradation of the forest and forest resources.

These drivers have, in effect, ushered in profound degradation of the Bamendjin watershed, putting it under serious threat. The high levels of poverty and the over-dependence on agricultural activities only worsen the situation. Water scarcity remains an issue of major concern and a hindrance to development. The fact that watersheds are zones of social and economic conflicts undermines efforts to improve the lives of large numbers of the poor who depend on these resources for their survival and economic well-being, as land users have different goals for the available natural 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 WHC. Climate change and human induced changes are considered the two major factors impacting hydrological processes. Result showed that the WHC hydrological basin is faced with decreasing stream flows as evident in the shrinking of the surface area of water bodies. The long-term data record of

monthly water-surface area and climatic can serve as base data for studies that may provide scientific foundation for understanding the potential confounding impacts of climate change and anthropogenic activities on local hydrology and providing strategies for effective control by changing local land-use practices.

The Bamendjin watershed holds much promise for the sustainable development and the sustenance of local livelihoods in the area. Given the present dispensation, the logical way forward remains the harmonious observation and management of this very crucial natural resource system. It is important that awareness be raised on the indicators of watershed degradation and the importance of watershed management. This will reflect an appropriate approach for the sustainable use and management of natural resources. Institutional and organizational agreements should be enforced and better managed in order to ensure effectiveness in the watershed programmes. A balance between population and carrying capacity of upland watersheds must be achieved with the intention to protect and conserve some of our catchments. In a diversified relief watershed like the WHC which is fast degrading, there is need for significant policy and programme responses and solutions which must not ignore the basic needs of people living in the uplands. Incentives may be needed to drop existing land-use practices for environmentally acceptable and sustainable resource utilization. Land tenure and the complexity of user rights that constrain the development of land use practices needed to stabilize forest and rangelands should be revisited. Finally, multiple use options employing agroforestry, production forests, protection of forests on critically steep slopes, capitalization of payment ecosystem services and other practices which provide needed goods and services and sustainable use of water resources must be promoted in appropriate areas of the communities.

Funding

This research received no external funding.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Author Details

Department of Plant Science, University of Buea, Buea, Cameroon and School of Geoscience, University of South Florida, Tampa, USA.

Authors' Contributions

Conceptualization, methodology and investigations: G.B.C., N.A., and B.A.F.; data curation and formal analysis, B.A.F; C.M.; L.D.A.; and G.B.C., writing—original draft preparation, B.A.F.; writing—review and editing, G.B.C., N.A., B.A.F.; C.M.; and L.D.A.; funding acquisition, B.A.F.; N.A.; and G.B.C. All authors have read and agreed to the published version of the manuscript.

Acknowledgements

The authors acknowledge with gratitude the financial, logical and material support provided by family members and friends. We are grateful to Zed Ngendoh Sanga for sourcing the images and his invaluable remote sensing techniques, Elias Ndivi, Fritz Mukow and community members for assisting during ground truthing and socioeconomic survey. We thank the staff at UNVDA Ndop and Bamendjin offices for providing long-term information vital for this study.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Green Cameroon (2013) A Local Guideline for Environmental Protection in Cameroon. <https://www.greenCameroon.org>
- [2] Seto, K.C., Reenberg, A., Boone, C.G., Fragkias, M., Haase, D., Langanke, T., *et al.* (2012) Urban Land Teleconnections and Sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, **109**, 7687-7692. <https://doi.org/10.1073/pnas.1117622109>
- [3] United Nations, Department of Economic and Social Affairs, Population Division (2017) World Population Prospects: The 2017 Revision, Key Findings and Advance Tables. ESA/P/WP/248. United Nations.
- [4] Boltz, F., Holmes, T.P. and Carter, D.R. (2003) Economic and Environmental Impacts of Conventional and Reduced-Impact Logging in Tropical South America: A Comparative Review. *Forest Policy and Economics*, **5**, 69-81. [https://doi.org/10.1016/s1389-9341\(01\)00075-2](https://doi.org/10.1016/s1389-9341(01)00075-2)
- [5] De Vries, J. and Chow, T.L. (1978) Hydrologic Behavior of a Forested Mountain Soil in Coastal British Columbia. *Water Resources Research*, **14**, 935-942. <https://doi.org/10.1029/wr014i005p00935>
- [6] Pearce, D. and Turner D. (1998) Cost Benefit Analysis and Environmental Policy. *Oxford Review of Economic Policy*, **14**, 84-100. <https://doi.org/10.1093/oxrep/14.4.84>
- [7] MEA (2005) Ecosystem and human Well-Being. Island Press, 132 p.
- [8] FAO (2006) Global Forest Resource Assessment. 2nd Edition, Food and Agricultural Organisation of the United Nations, 350 p.
- [9] Susswein, P., Noordwijk, M., Van, N. and Verbist, B. (2001) Forest Watershed Functioning and Tropical Land Use Change. ICRAF.
- [10] Blumenfeld, S., Lu, C., Christophersen, T. and Coates, D., (2009) Water, Wetlands and Forests: A Review of Ecological, Economic and Policy Linkages. Secretariat of the Convention on Biological Diversity and Secretariat of the Ramsar Convention on Wetlands, Montreal and Gland. CBD Technical Series No. 47.
- [11] Veneklaas, E.J., Fajardo, A., Obregon, S. and Lozano, J. (2005) Gallery Forest Types and Their Environmental Correlates in a Colombian Savanna Landscape. *Ecography*, **28**, 236-252. <https://doi.org/10.1111/j.0906-7590.2005.03934.x>
- [12] Momo, M.C.S., Njouonkou, A.L., Temgoua, L.F., Zangmene, R.D., Taffo, J.B.W. and Ntoupka, M. (2018) Land-Use/Land-Cover Change and Anthropogenic Causes around

- Koupa Matapit Gallery Forest, West-Cameroon. *Journal of Geography and Geology*, **10**, 56-65. <https://doi.org/10.5539/jgg.v10n2p56>
- [13] Hansen, M.C., Wang, L., Song, X., Tyukavina, A., Turubanova, S., Potapov, P.V., et al. (2020) The Fate of Tropical Forest Fragments. *Science Advances*, **6**, 74-85. <https://doi.org/10.1126/sciadv.aax8574>
- [14] FAO (2020) The State of the World's Forests. Forests, Biodiversity and People. Progress towards Sustainable Forest Management. Forestry Paper, 1-47.
- [15] Bidogeza, J.C., Afari-Sefa, V.; Endamana, D., Tenkouano, A. and Kane, G.Q. (2016) Value Chain Analysis of Vegetables in the Humid Tropics of Cameroon. *5th African Association of Agricultural Economists Conference*, Addis Ababa, 23-26 September 2016, 1-21. <https://ageconsearch.umn.edu/record/246381/files/88>
- [16] Jiotsa, A., Okia, T.M. and Yambene, H. (2015) Cooperative Movements in the Western Highlands of Cameroon. *Revue de géographie alpine*, **103**, 1-14. <https://doi.org/10.4000/rga.2764>
- [17] Lambi, C.M. (2001) The Impact of Human Activity on Land Degradation in Some Highland Regions of Cameroon: Implications for Development. In: Lambi, C.M., Ed., *Environmental Issues, Problems and Prospects*, Unique Printers, 111-113.
- [18] Kometa, S.S. and Ebot, M.A.T. (2012) Watershed Degradation in the Bamendjin Area of the North West Region of Cameroon and Its Implication for Development. *Journal of Sustainable Development*, **5**, 75-84. <https://doi.org/10.5539/jsd.v5n9p75>
- [19] Ngwa, C.A. (2003) Development Authorities as Agents of Socio-Economic Change: An Historical Assessment of the Upper Nun Valley Development Authority in NDOP Region of Cameroon, 1970-1995. *Nordic Journal of African Studies*, **12**, 220-237.
- [20] Ewane, E.B., Deh-Nji, A., Mfonkwet, N.Y. and Nkembi, L. (2021) Agricultural Expansion and Land Use Land Cover Changes in the Mount Bamboutos Landscape, Western Cameroon: Implications for Local Land Use Planning and Sustainable Development. *International Journal of Environmental Studies*, **80**, 186-206. <https://doi.org/10.1080/00207233.2021.2006911>
- [21] Tolessa, T., Senbeta, F. and Kidane, M. (2017) The Impact of Land Use/Land Cover Change on Ecosystem Services in the Central Highlands of Ethiopia. *Ecosystem Services*, **23**, 47-54. <https://doi.org/10.1016/j.ecoser.2016.11.010>
- [22] Ewane, B.E. and Lee, H.H. (2020) Assessing Land Use/Land Cover Change Impacts on the Hydrology of Nyong River Basin, Cameroon. *Journal of Mountain Science*, **17**, 50-67. <https://doi.org/10.1007/s11629-019-5611-8>
- [23] Ewane, E.B. (2020) Assessing Land Use and Landscape Factors as Determinants of Water Quality Trends in Nyong River Basin, Cameroon. *Environmental Monitoring and Assessment*, **192**, Article No. 507. <https://doi.org/10.1007/s10661-020-08448-2>
- [24] Woukokué, T.J.B., Nguetsop, V.F. and Fonkou, T. (2017) Floristic Diversity of Western Highland Savannas of Cameroon. *International Journal of Current Research in Biosciences and Plant Biology*, **4**, 7-13.
- [25] Molua, E. and Lambi, C. (2006) The Economic Impact of Climate Change on Agriculture in Cameroon. CEEPA Discussion Paper No.17. <http://www.ceepa.co.za/docs/cdpno17.pdf>
- [26] Fonjong, L.N. and Mbah, F.A. (2007) The Fortunes and Misfortunes of Women Rice Producers in NDOP, Cameroon and the Implications for Gender Roles. *Journal of International Women's Studies*, **8**, 133-147.
- [27] Mbenkum, T. (1999) Wetland Types in Cameroon: Ecological Biological and Socio-Economic Function. *Regional Workshop on the Accession and Implementation of*

- the Ramsar Convention on Wetlands of International Importance*, Yaounde, 21-24 August 1999, 21-24.
- [28] Letouzey, R. (1985) Carte phytogéographique du Cameroun, Vol. 1-5. Institut de la Carte Internationale de la Végétation, 240 p.
- [29] Asanga, C. (2002) Case Study of Exemplary Forest Management in Central Africa: Community Forest Management at the Kilum-Ijim Mountain Forest Region, Cameroon. Forest Management Working Papers, Working Paper FM/11. Forest Resources Development Service, Forest Resources Division. FAO.
<http://www.fao.org/forestry/>
- [30] Ndzeidze, S.K. (2008) Detecting Changes in a Wetland: Using Multi-Spectral and Temporal Landsat in the Upper Noun Valley Drainage Basin, Cameroon. Ph.D. Thesis, Oregon State University.
- [31] Trotter, C.M. (1998) Characterising the Topographic Effect at Red Wavelengths Using Juvenile Conifer Canopies. *International Journal of Remote Sensing*, **19**, 2215-2221. <https://doi.org/10.1080/014311698214974>
- [32] Fasika, A., Motuma, T. and Gizaw, T. (2019) Land Use Land Cover Change Trend and Its Drivers in Somodo Watershed South Western, Ethiopia. *African Journal of Agricultural Research*, **14**, 102-117. <https://doi.org/10.5897/ajar2018.13672>
- [33] Mumbang, C., Ajonina, G.N. and Chuyong, G.B. (2025) Four Decades of Cover Change, Degradative, and Restitution Stages of Mangrove Forest in Douala-Edea National Park, Cameroon. *Forests*, **16**, Article 555. <https://doi.org/10.3390/f16040555>
- [34] Congalton, R.G. (1991) A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data. *Remote Sensing of Environment*, **37**, 35-46.
[https://doi.org/10.1016/0034-4257\(91\)90048-b](https://doi.org/10.1016/0034-4257(91)90048-b)
- [35] Disperati, L. and Viridis, S.G.P. (2015) Assessment of Land-Use and Land-Cover Changes from 1965 to 2014 in Tam Giang-Cau Hai Lagoon, Central Vietnam. *Applied Geography*, **58**, 48-64. <https://doi.org/10.1016/j.apgeog.2014.12.012>
- [36] Mishra, P.K., Rai, A. and Rai, S.C. (2020) Land Use and Land Cover Change Detection Using Geospatial Techniques in the Sikkim Himalaya, India. *The Egyptian Journal of Remote Sensing and Space Science*, **23**, 133-143.
<https://doi.org/10.1016/j.ejrs.2019.02.001>
- [37] Kashaigili, J.J., Mbilinyi, B.P., McCartney, M. and Mwanuzi, F.L. (2006) Dynamics of Usangu Plains Wetlands: Use of Remote Sensing and GIS as Management Decision Tools. *Physics and Chemistry of the Earth, Parts A/B/C*, **31**, 967-975.
<https://doi.org/10.1016/j.pce.2006.08.007>
- [38] Said, M., Hyandye, C., Komakech, H.C., Mjemah, I.C. and Munishi, L.K. (2021) Predicting Land Use/Cover Changes and Its Association to Agricultural Production on the Slopes of Mount Kilimanjaro, Tanzania. *Annals of GIS*, **27**, 189-209.
<https://doi.org/10.1080/19475683.2020.1871406>
- [39] Innocent, S., Patience, U.A., Charlotte, P.M. and Lawrence, F.F. (2024) Impact of Land Use/Cover Changes on Physical Water Quality Parameters within the Bamboutos Watershed, Cameroon. *Environmental Analysis & Ecology Studies*, **12**, 1515-1528. <https://doi.org/10.31031/eaes.2024.12.000795>
- [40] Negassa, M.D., Mallie, D.T. and Gemedo, D.O. (2020) Forest Cover Change Detection Using Geographic Information Systems and Remote Sensing Techniques: A Spatio-Temporal Study on Komto Protected Forest Priority Area, East Wollega Zone, Ethiopia. *Environmental Systems Research*, **9**, Article No. 1.
<https://doi.org/10.1186/s40068-020-0163-z>

- [41] Teshome, D.S., Taddese, H., Tolessa, T., Kidane, M. and You, S. (2022) Drivers and Implications of Land Cover Dynamics in Muger Sub-Basin, Abay Basin, Ethiopia. *Sustainability*, **14**, Article 11241. <https://doi.org/10.3390/su141811241>
- [42] Tatuebu Tagne, C., Sonwa, D.J., Awono, A., Mama, M.N., Fongnzossie, E., Ngala Mbiybe, R., *et al.* (2022) Land Cover and Land Use Changes between 1986 and 2018, and Preliminary Carbon Footprint Implications for Manoka Island (Littoral Region of Cameroon). *Sustainability*, **14**, Article 6301. <https://doi.org/10.3390/su14106301>
- [43] Dan, C., Sinsin, B., Mensah, G. and Lejoly, J. (2013) Influence des activités anthropiques sur la diversité floristique des communautés végétales de la forêt marécageuse de Lokoli au Sud-Bénin. *International Journal of Biological and Chemical Sciences*, **6**, 3064-3081. <https://doi.org/10.4314/ijbcs.v6i6.8>
- [44] Ouédraogo, M. (2008) Les galeries forestières de la Réserve de la Biosphère de la Mare aux Hippopotames du Burkina Faso: Caractéristiques, dynamique et ethnobotanique. Master's Thesis, Université Ouagadougou.
- [45] Tanga, P.T. and Fonchingong, C.C. (2009) NGO-State Interaction and the Politics of Development in Cameroon in the Context of Liberalization. *International NGO Journal*, **4**, 84-96.
- [46] Akhere Gwan, S., Kimengsi, J.N. and Nji Fogwe, Z. (2021) Landscape Degradation Processes and Implications in the Western Highlands of Cameroon. *International Journal of Environment and Climate Change*, **11**, 525-535. <https://doi.org/10.9734/ijecc/2021/v11i1230606>
- [47] Saedi, J., Sharifi, M.R., Saremi, A. and Babazadeh, H. (2022) Assessing the Impact of Climate Change and Human Activity on Streamflow in a Semiarid Basin Using Precipitation and Baseflow Analysis. *Scientific Reports*, **12**, Article No. 9228. <https://doi.org/10.1038/s41598-022-13143-y>
- [48] Adeyeri, O.E., Laux, P., Lawin, A.E. and Arnault, J. (2020) Assessing the Impact of Human Activities and Rainfall Variability on the River Discharge of Komadugu-Yobe Basin, Lake Chad Area. *Environmental Earth Sciences*, **79**, Article No. 143. <https://doi.org/10.1007/s12665-020-8875-y>