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Understanding the mountainscape dynamics and its drivers using geospatial technology and indigenous knowledge in the Ado-Awaye Mountains, Nigeria

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Keywords: Ado-Awaye Mountains, transformation, fragmentation, landscape metrics

Abstract

This study quantified the mountainscape transformation and identified its drivers over the last two decades in the Ado-Awaye Mountains, Nigeria, a protected mountain area in Oyo State, managed by the State government in conjunction with communal efforts. This potential mountain tourism destination is home to a suspended lake. A supervised classifier algorithm, a post-classification method, landscape metrics and indigenous knowledge (through interviews and questionnaires) were used to determine the patterns, dynamics, fragmentation and drivers of the mountainscape. The results revealed that the rock outcrop / bare ground / built-up areas and open secondary forests covered the greatest and smallest landmasses of the entire area in the study periods (2000 and 2019), both showing an increase. Mountainscape fragmentation also increased. Three categories of underlying drivers (cultural, natural and technological) contributed to mountainscape transformation and fragmentation in the Ado-Awaye Mountains. Forest restoration programmes and eco-friendly approaches are recommended to improve the destination's serenity and mitigate the environmental impact of the underlying drivers.

Profile

Protected area and mountain range

Ado-Awaye Mountains

Country

Nigeria

Introduction

Mountains cover 24% of the earth's surface, and 12% of the global population are dependent on their ecosystem services for economic survival and livelihood improvement (Körner & Ohsawa 2005; Schild 2008; García-Llamas et al. 2019). Mountain ecosystems are characterized by topographic variety, climatic variations, diverse vegetation types, unique biodiversity, and ecosystem services (Brooks et al. 2006; Rodríguez-Rodríguez et al. 2011; Payne et al. 2020; Negi et al. 2021; Wang et al. 2022). A mountainscape is a landscape associated with a mountainous region (Körner et al. 2021; Schickhoff 2021). Mountainscapes have the potential to provide many goods and services to those who live in or in close proximity to them (Hamilton 2015; TEEB 2010; Chaudhary et al. 2017). They are important sources of eco-cultural diversity but are highly vulnerable to socio-economic and environmental changes (Balthazar et al. 2015; Zlatanov et al. 2017; García-Llamas et al. 2019). Mountainscapes and their dynamics are of growing interest in landscape ecology and work to ensure proper monitoring, planning and development of mountainous areas (Gunilla et al. 2000; Cushman & McGarigal 2019).

Many drivers (anthropogenic and climatic factors) influence land use and land cover (LULC) dynamics in mountainous regions across the globe (Hailemariam et al. 2016; Pedrono et al. 2016). Traditional agricultural practices along with other unplanned land use, unsustainable tourism, climate change and infrastructure development threaten fragile mountain ecosystems (Buytaert et al. 2006; EEA 2006; Spehn et al. 2010; Furst et al. 2011; Maxwell et al. 2016; Wu et al. 2017; Qian et al. 2019). The pattern change of these factors affects the ecosystem services provided by the sensitive mountains, resulting in ecological impact and slow ecosystem recovery (Halada 2010; Huber et al. 2013; Pedrono et al. 2016). However, past and present information on mountainscape dynamics and its drivers in the fragile landscape at a local scale is scarce (Poyatos et al. 2003; Reyers et al. 2009), most especially in sub-Saharan African countries such as Nigeria. This dearth of information poses a significant obstacle to the effective management and sustainable development of mountainscapes (Reyers et al. 2009; Balsiger & Debarbieux 2015; Chen et al. 2017).

Mountainscape transformation and fragmentation (MTF) can be understood as the spatial patterns of LULC change in a mountainous area over time (MacDonald et al. 2000; Mottet et al. 2006; Seijmonsbergen et al. 2010; Cabel & Oelofse 2012). Recently, geospatial technology (GT) and indigenous knowledge have been employed to quantify the pattern and drivers of LULC dynamics in particular mountainscapes because of their topographic variations and limited accessibility (Shrestha & Zinck 2001; Alvarez-Martínez et al. 2010). According to Turner et al. (2007), GT has enhanced understanding of the LULC dynamics. Over the years, substantial efforts and breakthroughs have been made to determine LULC using remotely sensed data and and other forms of GT (Zhang et al. 2011; Ahmad 2013). The evolution in GT has allowed for LULC change detection on temporal scales (Lu et al. 2004).

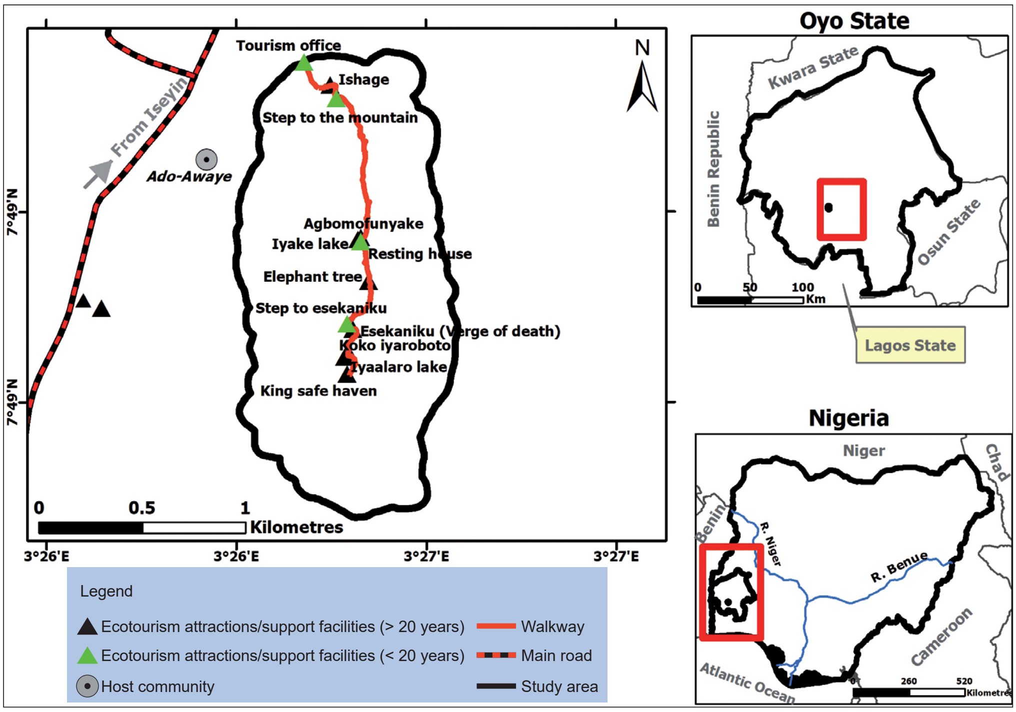

Figure 1 – The Ado-Awaye Mountains in Oyo State, southwest Nigeria.

Shrestha & Zinck (2001) and Regosa et al. (2015) enhanced the capability of Landsat images through topographic and radiometric corrections for LULC classification in mountainous regions. The image pre-processing reduced the illumination variations and atmospheric effects that limit Landsat images of mountains characterized by heterogeneous and fragmented landscapes (Alvarez-Martínez et al. 2010; Regosa et al. 2015). However, using only LULC analyses to understand the changes in heterogeneous and fragile mountain ecosystems poses limitations (Tovara et al. 2013). Many studies incorporate landscape metric changes with stratified LUCC information to address these limitations in understanding mountainscape dynamics (Kintz et al. 2006; Zomeni et al. 2008; Tovara et al. 2013).

Chaudhary et al. (2017) incorporated indigenous knowledge to determine the factors responsible for mountain landscape change. With an eye to the sustainable planning and effective management of mountain ecosystems, they employed a household survey and LULC analysis to gain indigenous knowledge related to the drivers of change and their implications for mountainscape dynamics. Indigenous knowledge of a mountain community provides cogent information for understanding the complex interactions between humans and mountain ecosystems (Corburn 2003; Pereira et al. 2005). However, Chaudhary et al. (2017) failed to explore the capability of landscape metrics to address the limitations of LULC analyses in understanding mountainscape dynamics.

The present study employed LULC analysis, landscape metrics and indigenous knowledge to determine the patterns and drivers of mountainscape dynamics in the Ado-Awaye Mountains, a unique mountainscape in southwest Nigeria. It harbours the only suspended lake in Africa, which is one of only two such lakes in the world. The mountains have intrinsic natural and cultural resources, have potential as a tourism destination, but are also subject to undue anthropogenic pressures (Olaniyi & Bada 2020). As no information existed on the patterns and drivers of the mountainscape in the Ado-Awaye Mountains, this study determined the mountainscape transformation and its drivers over the last two decades, using a combination of geospatial technology and the indigenous knowledge of the mountain community.

Materials and methods

The study area

The study was carried out in the Ado-Awaye Mountains in southwest Nigeria (Figure 1), a protected mountain area in Oyo State, managed by the State government (Oyo State Ministry of Information, Culture and Tourism) in conjunction with communal efforts. The area is home to the only suspended lake in Africa, which is also known as Iyake Suspended Lake. Ado-Awaye town sprawls around the base of the mountain, lies about 20 km west of Iseyin, Iseyin Local Government Area of Oyo State, and falls within the basement complex of southwest Nigeria (Ibrahim 2015). Its location is within latitudes 07º048’00”N and 07º054’00”N and longitudes 003º018’00”E and 003º030’00”E, with an area of approximately 190.62 hectares (Olaniyi & Bada 2020). There is no major river within the catchment (Ibrahim 2015). The mountains reach 433 m above sea level (Figure 2) and have a

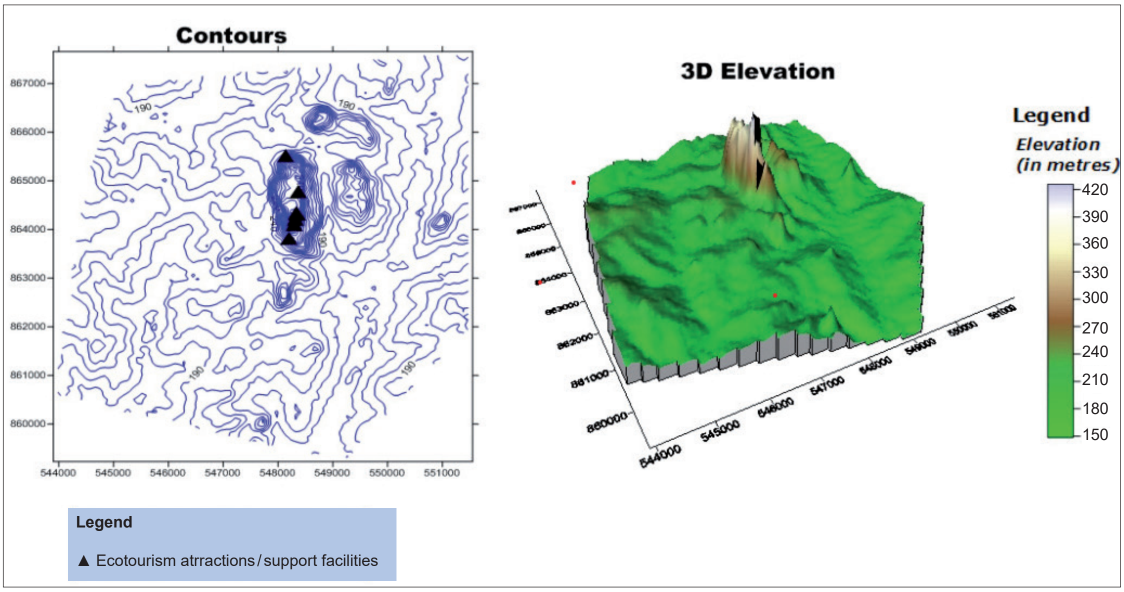

Figure 2 – The topographical characteristics of the Ado-Awaye Mountains.

maximum annual rainfall of 1,790–1,850 mm (Olaniyi & Bada 2020). The vegetation is dominated by savannah with scattered shrubs and open secondary forests (Olaniyi & Bada 2020). It is believed that the Ado-Awaye Mountains harbour a few small- to medium-sized mammals, and some bird species, including the critically endangered Hooded Vulture, Necrosyrtes monachus. Yoruba is the predominant indigenous ethnic group in the only local community (Ado-Awaye town).

Data collection and analysis

Acquisition of satellite imagery, ground truthing and image classification

Figure 3 shows the methodological framework of the various techniques used in the study. Spatial data were collected through field observations with the aid of a hand-held Global Positioning System (GPSMap 72s). Landsat 7 ETM+ and Landsat 8 OLI/TIRS images from two time series (2000 and 2019) were also acquired and pre-processed. The pre-processed images were subjected to supervised image classification: three LULC classes were identified using the adjusted United States Geological Survey land cover classification scheme (Anderson et al. 1976) in ArcGIS 10.4 software to derive the LULC types of the Ado-Awaye Mountains. The LULC classes identified include rock outcrop / bare ground / built-up area, open secondary forest, and savannah with scattered shrubs. The field observations were used as training samples for supervised image classification and accuracy assessment of the classified images. Error matrices and kappa statistics were computed using Quantum Geographic Information System software (QGIS version 3.16). The overall accuracy (kappa statistics) for the Ado-Awaye Mountains was 89.00% (0.8537).

Land use / land cover change detection and landscape analyses

Images obtained from the two time series (2000 and 2019) were classified and then compared in order to identify changes in the LULC dynamics; the post-classification method (McGarigal et al. 2002; Lu et al. 2004) was used for this. A transition matrix of the LULC dynamics of the study area was developed using the MOLLUSCE plugins in QGIS 3.16. Field observations and secondary data collection methods were employed to identify the drivers of mountainscape transformation. Changes in the landscape pattern for the three LULC classes between 2000 and 2019 were detected. These were measured to compute the landscape metrics using the LeCoS plugins in QGIS 3.16. Landscape metrics are indices to quantify the spatial characteristics of landscape pattern, composition and structure, and the dynamics of LULC, at different scales (McGarigal 2013; Wu 2013; Almenar et al. 2019; Hesselbarth et al. 2019). The landscape metrics at the class and landscape levels provide an understanding of the relationship between landscape patterns and processes (Uuemaa et al. 2009). Seven landscape metrics were computed at two metric levels (class and landscape levels).

Four landscape metrics were selected at class level, following McGarigal et al. (2002), namely edge density (ED), number of patches (NP), largest patch index (LPI), and mean patch area (MPA). Three landscape metrics at landscape level were used: the Shannon Diversity Index (SDI), Shannon Richness Index (SRI), and Simpson Evenness Index (SEI) (McGarigal et al. 2002). According to McGarigal & Marks (1995) and Gokyer (2013), ED standardizes the *"sum of the length of all patch edges per unit area"* (McGarigal & Marks 1995, p. 18; Gokyer 2013, p. 7). NP is a measure of the degree of fragmentation; LPI provides the percentage

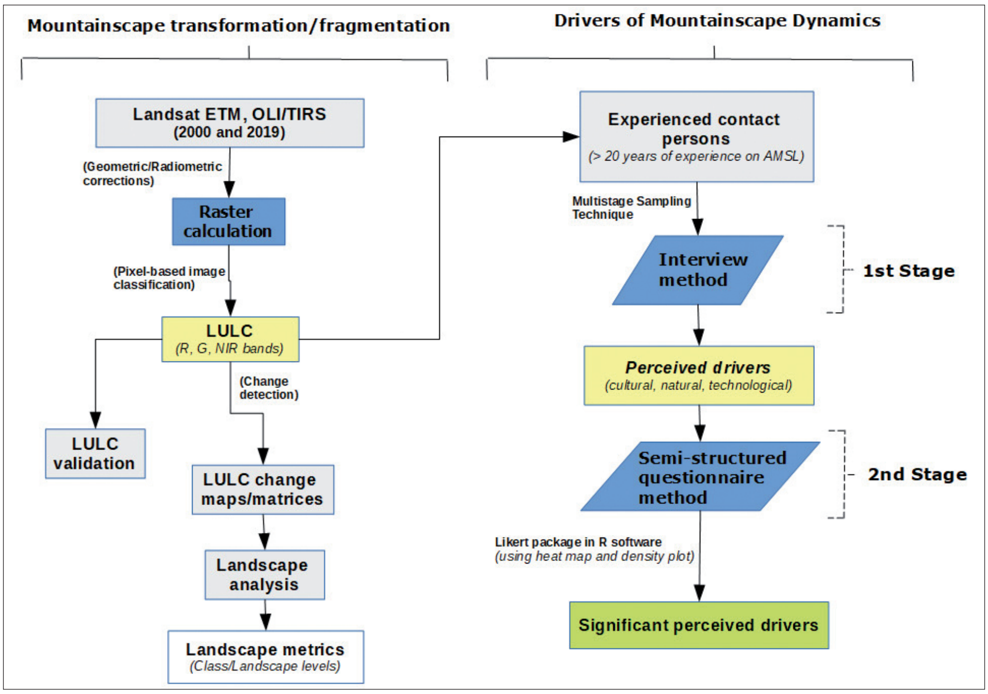

Figure 3 – Methodological framework to determine the pattern, dynamics and drivers of mountainscape transformation and fragmentation in the Ado-Awaye Mountains.

of the landscape comprised by the largest habitat patch of high connectivity; MPA quantifies *"the average patch core area at the class/landscape levels, and provides a good index to landscape suitability for species survival"* (McGarigal & Marks 1995, p. 54; Gokyer 2013, p. 12); SDI reflects the variety and abundance of various land cover types within a landscape, using a standardized value ranging from 0 to 1 (Shannon 1948; McGarigal et al. 2012). The value 0 signifies an equal proportion or a high number of LULC classes present, while 1 represents one LULC class that dominates the landscape (Ramezani 2012). SRI measures the number of patch types present in an LULC class within a landscape (McGarigal et al. 2002). SEI measures the distribution of patch types in a landscape (Scherreiks et al. 2022).

Social research setting, participants and survey

A preliminary survey was performed by researchers to familiarize themselves with the setting of the only community (Ado-Awaye town) close to the suspended lake, and to determine the choice of research sampling technique. The data collection involved a two-stage sampling technique to obtain indigenous knowledge using interviews (first stage) and semi-structured questionnaires (second stage). The perceived drivers of mountainscape transformation were determined using open-ended interview questions (see supplementary file). The Chiefs of the Ado-Awaye traditional council served as contacts. Five particularly experienced Chiefs were interviewed in order to determine the perceived drivers of mountainscape transformation in the Ado-Awaye Mountains. The interviews were conducted by the research team leader; the socio-economic data collected included age, gender, marital status, level of education, religion, occupation, place of birth and monthly income. The Chiefs also participated in choosing locals who had resided in the Ado-Awaye Mountains for more than 20 years for the second stage (questionnaire).

Because no data on the number of the local community's residents was available, information was collected from the town's head and traditional council members. The following information was gathered:

Average number of households per building = 3
Approximate number of buildings = 3,300
Total number of households = 9,900
Average household size = 6.

$$\text{The total number of inhabitants } (s) = N \times HS \qquad \text{(Equation 1)}$$

where N = the total number of households, and HS = the average household size; s = 59,400 inhabitants. 443 local community inhabitants with over twenty years' experience in the Ado-Awaye Mountains were identified by the experienced contacts. The questionnaires were administered randomly to 206 of the 443 inhabitants thus identified (46.50%). The response rate was 100%. The formula by Krejcie and Morgan (1970) was used to compute the sample size:

$$s = \frac{X^2NP(1-P)}{d^2(n-1)+X^2P(1-P)} \qquad \text{(Equation 2)}$$

where s is the required sample size; X^2 is the table value of chi-square for 1 degree of freedom at the desired confidence level (3.841); N is the total number

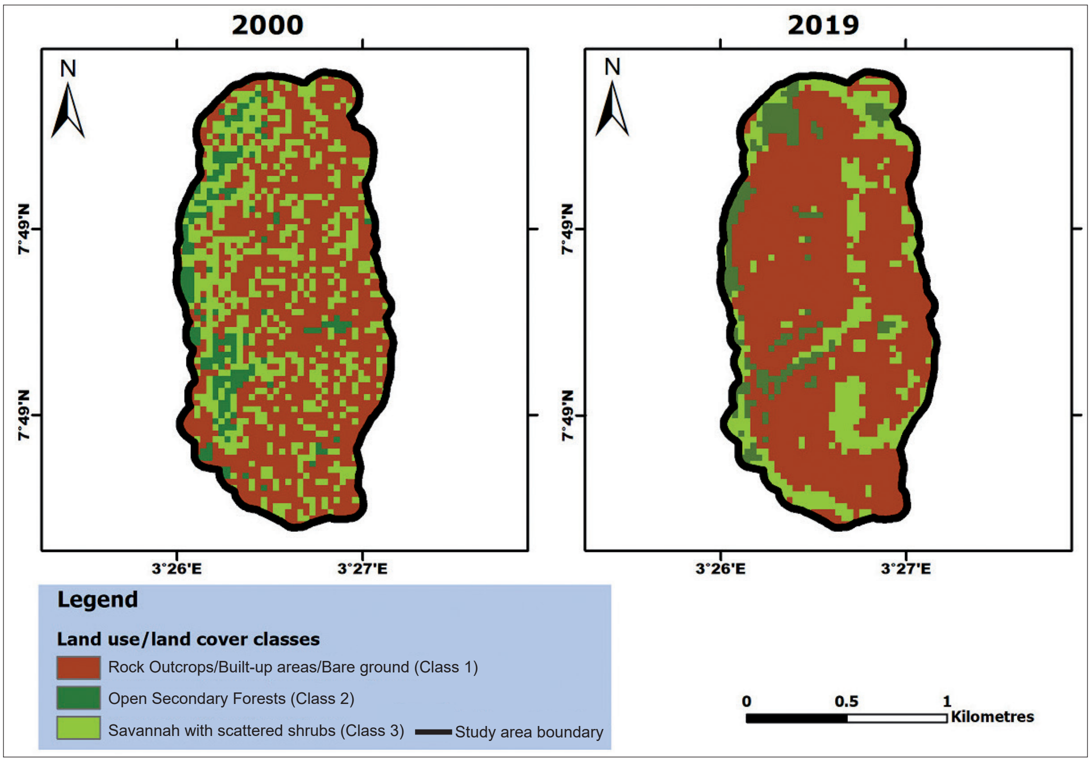

Figure 4 – The land use / Land cover of the Ado-Awaye Mountains, in 2000 and 2019.

of respondents with 20+ years' experience in the Ado-Awaye Mountains (443); *P* is the population proportion (assumed to be 0.50, since this would provide the maximum sample size); and *d* is the degree of accuracy expressed as a proportion (.05)

In the first stage, the perceived drivers of mountainscape transformation were identified through the interviews. They were categorized as cultural, natural or technological drivers according to the characterization of Burgi et al. (2004). The cultural drivers included illegal grazing, indiscriminate logging, hunting and bush burning; climate change was identified as a natural driver; the technological drivers included roads, buildings and other infrastructural facilities. The semi-structured questionnaires used in the second stage were designed and subjected to a pre-test (25 respondents) at the Obanla campus of the Federal University of Technology, Akure, Nigeria, to determine the instrument's Cronbach alpha reliability index (79.80).

The questionnaire comprised two sections: Section A, on the degree to which the perceived drivers influence mountainscape transformation (see the supplementary file); Section B, on demographic characteristics. The items in Section A (7 in total) were evaluated using a five-point Likert-type scale (i. e. strongly agree, agree, don't know, disagree and strongly disagree). The demographic characteristics included age, gender, marital status, level of education, religion, occupation, place of birth, ancestral home and monthly income. The local community were then involved in a multi-stage sampling technique. First, the local community was stratified based on the two ethnic sub-groups (Ado and Awaye people), and permanent physical features in the landscape (the Iseyin to Ado-Awaye road) were identified. A direct survey was conducted for primary data collection.

Social research data analysis

The participants' responses were coded and analysed to compute the means and standard errors of the perceived drivers. A heat map and density plot were developed to rank the underlying perceived MTF drivers in the Ado-Awaye Mountains, using the Likert package in R software. Data on the perceived drivers collected from the experienced contacts were converted to binary format (i. e. strongly agree and agree

Table 1 – Attributes of land use/ Land cover dynamics for the whole landscape of the Ado-Awaye Mountains, in 2000 and 2019. Total area of the Ado-Awaye Mountains = 190.62 hectares.

Land use/land cover classes	Area in hectares (Proportion in %)		Δ in hectares (%)
	2000	2019	
Rock Outcrops / built-up areas /bare ground (Class 1)	112.14 (58.83)	133.92 (70.25)	21.78 (11.43)
Open secondary forests (Class 2)	16.38 (8.59)	17.01 (8.92)	0.63 (0.33)
Savannah with scattered shrubs (Class 3)	62.10 (32.58)	39.69 (20.82)	−22.41(−11.76)

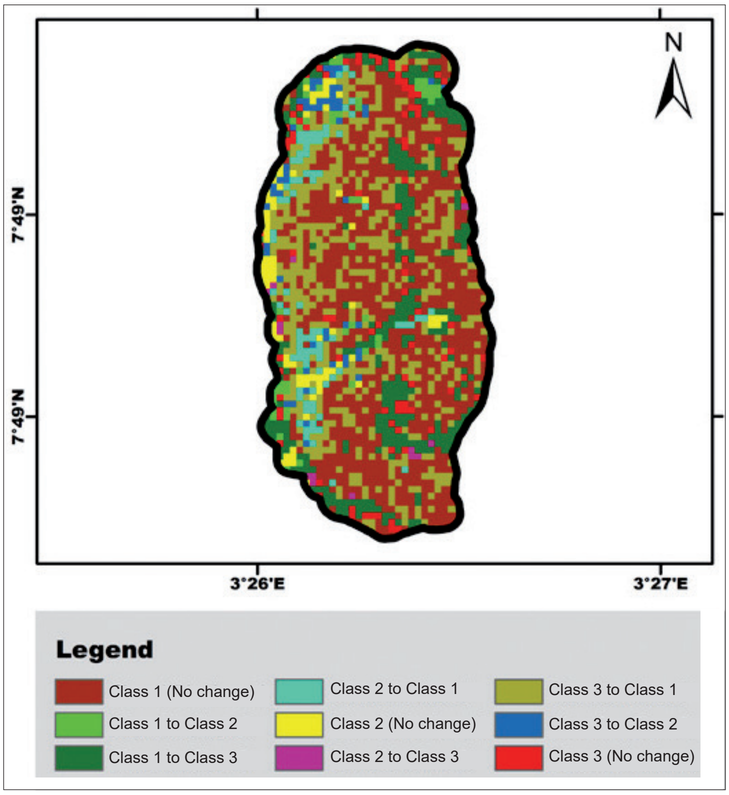

Figure 5 – Transition matrix of the land use/land cover dynamics of the landscape of the Ado-Awaye Mountains. Rock Outcrops/Built-up areas/Bare ground (Class 1); Open Secondary Forests (Class 2); Savannah with scattered shrubs (Class 3); Number of respondents = 206.

as *"Yes"*; don't know, disagree and strongly disagree as *"No"*). These were subjected to inferential statistics using the Statistical Package for Social Sciences (SPSS version 22). The pairwise comparison and significant differences between the perceived drivers of the MTF of the study area were determined using the independent-samples Kruskal-Wallis test.

The sociodemographic factors influencing the community's perceived MTF drivers locally were determined by analysing the dependent and independent variables, using the binomial logistic regression algorithm. The independent variables were age, gender, marital status, level of education, religion, occupation, place of birth, ancestral home and monthly income. The dependent variables were the perceived drivers, i. e. illegal grazing, indiscriminate logging, hunting, bush burning, climate change, roads, and buildings / other infrastructural facilities.

Results

The results for attributes of the LULC of the Ado-Awaye Mountains in 2000 and 2019 are presented in Figure 4 and Table 1. The total study area is 190.62 hectares. Three LULC classes were identified, namely rock outcrop / built-up / bare-ground, open secondary forest, and savannah with scattered shrubs. The rock outcrop / bare-ground / built-up areas were the most extensive category during the study periods: 112.14 hectares (58.83%) in 2000, and 133.92 hectares (70.25%) in 2019. The savannah with scattered shrubs decreased from 62.10 hectares (32.58%) in 2000 to 39.69 hectares (20.82%) in 2019. The open secondary forests (the lowest % land cover) covered 16.38 hectares (8.59%) in 2000 but increased to 17.01 hectares (8.92%) in 2019.

The results for attributes of the transition matrix of the LULC in the entire landscape of the Ado-Awaye Mountains are shown in Figure 5 and Table 2. Nine transition classes of LULC were observed. Savannah with scattered shrubs underwent the greatest change, with 48.24 hectares (25.30%) becoming rock outcrops / built-up areas / bare ground between 2000 and 2019. From 2000 to 2019, open secondary forests experienced the lowest change in land cover area:

Table 2 – Attributes of the transition matrix of the land use/land cover dynamics of the landscape of the Ado-Awaye Mountains. Total area of the Ado-Awaye Mountains = 190.62 hectares. Rock Outcrops/Built-up areas/Bare ground (Class 1); Open Secondary Forests (Class 2); Savannah with scattered shrubs (Class 3).

Land use / land cover transition classes	Land cover transition	
	Area cover (ha)	Proportion
Class 1 (No change)	78.03	40.93
Class 1 to Class 2	4.68	2.46
Class 1 to Class 3	29.43	15.4
Class 2 to Class 1	7.65	4.01
Class 2 (No change)	7.29	3.82
Class 2 to Class 3	1.44	0.76
Class 3 to Class 1	48.24	25.30
Class 3 to Class 2	5.04	2.64
Class 3 (No change)	8.82	4.63

Table 3 – Landscape metrics of the Ado-Awaye Mountains, Nigeria, at class and landscape scales, between 2000 and 2019.

Landscape metrics	Rock Outcrops (RO) / Built-up areas (BA) / Bare ground (B)			Open secondary forest (OSF)			Savannah with scattered shrubs (SSS)		
	2000	2019	Δ in RO/BA/B	2000	2019	Δ in OSF	2000	2019	Δ in SSS
Class level									
Edge Density (in metres/m²)	0.027	0.012	−0.015	0.007	0.006	−0.001	0.027	0.012	−0.015
Number of Patches	18	4	−14	33	24	−9	85	37	−48
Largest Patch Index (%)	57.37	68.84	11.47	1.56	2.22	0.66	11.57	4.15	−7.42
Mean patch area (in m²)	6,230.00	33,480.00	27,250.00	4,963.64	708.75	−4,254.89	7,395.88	10,727.10	3,331.22
Landscape Level	2000	2019	Δ in Value						
Shannon diversity index	0.87	0.79	−0.08						
Shannon evenness	0.81	0.72	−0.09						
Simpson richness index	0.54	0.46	−0.08						

1.44 hectares (0.76%) became savannah with scattered shrubs.

The landscape metrics of the Ado-Awaye Mountains for 2000 and 2019 are presented in Table 3. At the class level, the edge density (−0.015 metre / m²) and number of patches (−14) decreased, while largest patch index (11.47) and mean patch area (27,250.00 m²) increased in rock outcrops/built-up areas/bare ground between 2000 and 2019. The edge density (–0.001 metre / m²), number of patches (−9) and mean patch area (−4254.89 m²) decreased, while the largest patch index (0.66) increased in open secondary forest. The edge density, number of patches and largest patch index decreased, while the mean patch area increased in savannah with scattered shrubs. At the landscape level, the Shannon Diversity Index (−0.08), Simpson Evenness Index (−0.09) and Shannon Richness Index (−0.08) decreased.

The underlying perceived MTF drivers for the Ado-Awaye Mountains are summarized in Figure 6 (roads / footpaths, indiscriminate logging, illegal grazing, hunting, climate change, bush burning, tourism buildings, and other infrastructures). Most respondents perceived illegal grazing (5.00 ± 0.00) as contributing significantly to the MTF of the study area; tourism buildings / other infrastructural facilities were perceived as contributing least.

The three categories (cultural, natural, technological) of underlying perceived MTF drivers in the Ado-Awaye Mountains are presented in Figure 7. Most respondents perceived the cultural drivers, including illegal grazing, indiscriminate logging, and bush burning (4.33 ± 0.39), as significant contributors. Natural drivers like climate change (3.75 ± 0.97) were also seen as influencing the MTF. Only a few respondents perceived the technological drivers such as roads / footpaths and tourism buildings / other infrastructural facilities (1.92 ± 0.20) as contributing to the change and fragmentation. Pairwise comparison of the perceived MTF drivers was carried out using independent samples in a Kruskal-Wallis test (see Figure 8). No significant differences ($P > 0.05$) existed between three pairs of the perceived drivers (i. e. illegal grazing / hunting, indiscriminate logging / roads, and climate change / bush burning).

*Table 4 – Sociodemographic factors influencing the local community's perceived drivers of the transformation and fragmentation of the Ado-Awaye Mountains: binomial logistic regression n = 206). * = significant influence (P < 0.05); ns = no significant influence (P >0.05)*

Variables / Indicators	Significance			
	Roads	Indis-criminate logging	Climate change	Bush burning
Age	0.18ns	0.01*	0.08ns	0.52ns
Gender	0.44ns	0.07ns	0.06ns	0.95ns
Marital status	0.40ns	0.99ns	0.79ns	0.81ns
Level of education	0.07ns	0.88ns	0.33ns	0.91ns
Religion	0.00*	1.00ns	0.51ns	0.17ns
Occupation	0.00*	0.10ns	0.08ns	0.84ns
Place of birth	0.39ns	0.32ns	0.91ns	0.17ns
Family size	0.33ns	0.68ns	0.90ns	0.56ns
Monthly income	0.00*	0.30ns	0.19ns	0.14ns
Constant	0.00*	0.02*	0.00*	0.00*
Overall percentages	83.0%	77.7%	84.0%	85.4%
-2log-likelihood	161.44	198.36	137.78	133.43
Nagelkerke	0.54	0.44	0.34	0.37

The sociodemographic factors influencing the local community's perceived drivers are shown in Table 4. The results indicated that the socio-economic determinants of the local communities' perception of roads as a driver of MTF ($P < 0.05$) in the study area were religion ($P = 0.00$), occupation ($P = 0.00$), and monthly income ($P = 0.00$). As regards their perception of indiscriminate logging as a driver, the only socio-economic determinant ($P < 0.05$) was age ($P = 0.01$). No sociodemographic factors influenced the local communities' perception of climate change or bush burning as drivers of changes.

The results of the other three variables (hunting, illegal grazing, building / other infrastructural activities) were not computed because they violated the assumptions of binomial logistic regression (i. e. the dependent variable has less than two non-missing values).

Discussion

This study analysed the LULC pattern and change between 2000 and 2019 in the Ado-Awaye Mountains,

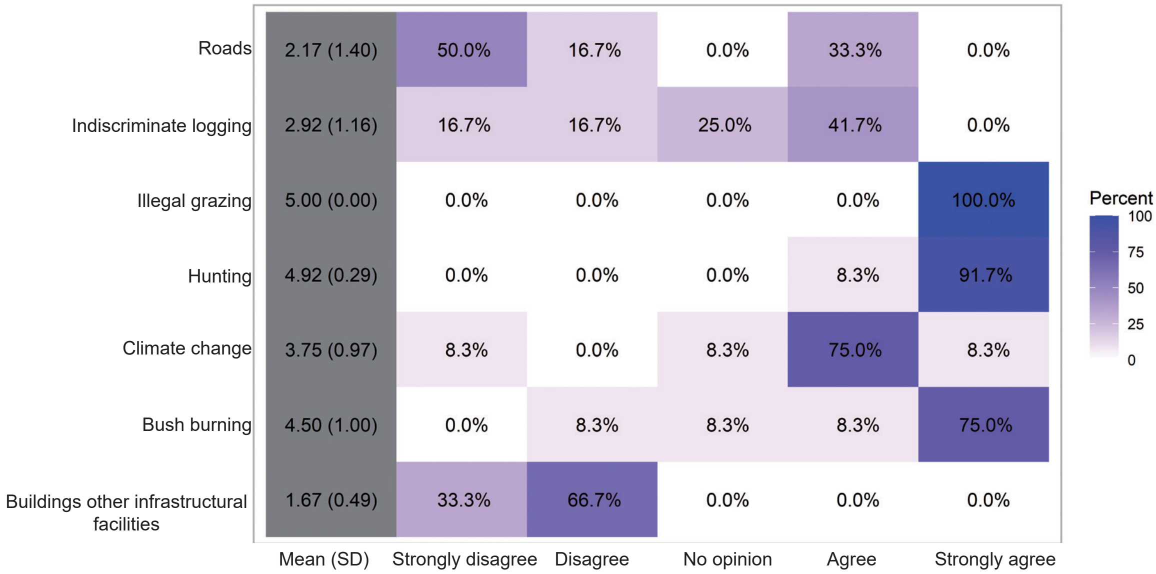

Figure 6 – Heat map showing the underlying perceived drivers of transformation and fragmentation of the Ado-Awaye Mountains.

using geospatial technology. The findings revealed that the rocky outcrops / built-up areas / bare ground are the most predominant LULC. The dominant vegetation class was savannah with scattered shrubs, throughout the mountainous region but especially on its cliffs and steep sides. This observation supported the findings of Aweto & Adejumobi (1991) and FORMECU (1998) that the area lay within the southern Guinean savannah and was characterized by grasses and scattered shrubs.

A small portion of the study area was covered by open secondary forest. The importance of forests for mental wellbeing is well documented (see e.g. Stigsdotter et al. 2011; FOREST EUROPE 2019). Mountain forests are also important as places for tourism and recreation (Price 2003). The low forest cover of the Ado-Awaye Mountains implies absence of shade for recreational purposes and makes it a less than ideal destination for mental wellbeing. Based on the LULC transition matrix, the area covered by savannah with scattered shrubs decreased over the period studied, becoming converted to rocky outcrops / built-up areas / bare ground. This change was attributed to underlying factors, including overgrazing, indiscriminate logging, bush burning, climate change, human trampling, and tourism infrastructural development.

Within the last two decades, three categories of underlying drivers – cultural, natural and technological – have contributed to transforming the Ado-Awaye Mountains. The mountainscape has changed because of overgrazing by two main actors, the Fulani herdsmen and the inhabitants of Ado-Awaye.

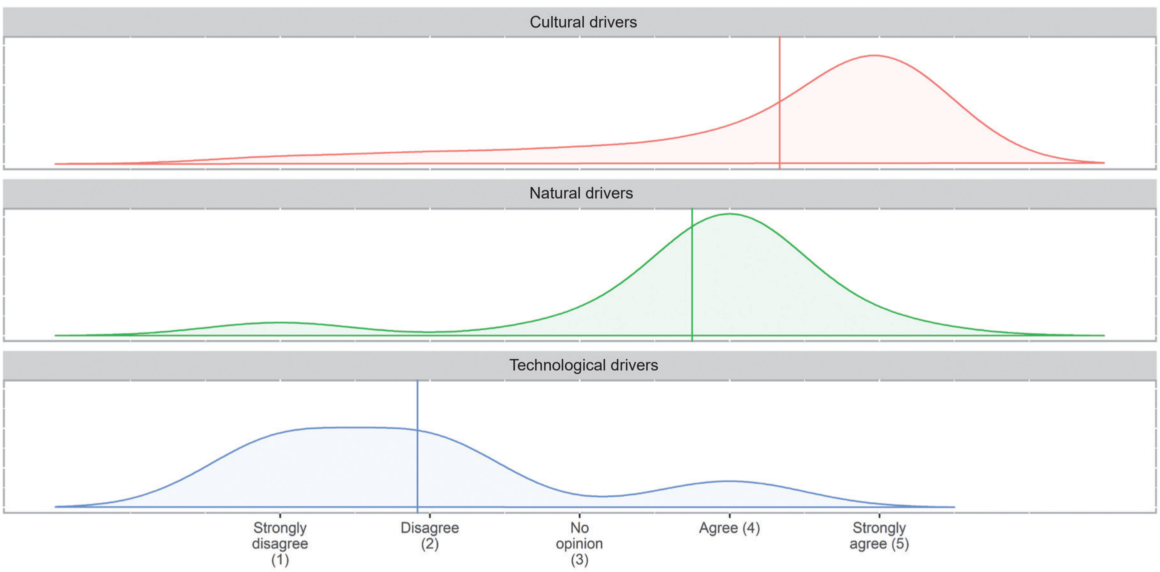

Figure 7 – Density plot showing the three categories of underlying perceived drivers of the transformation and fragmentation of the Ado-Awaye Mountains.

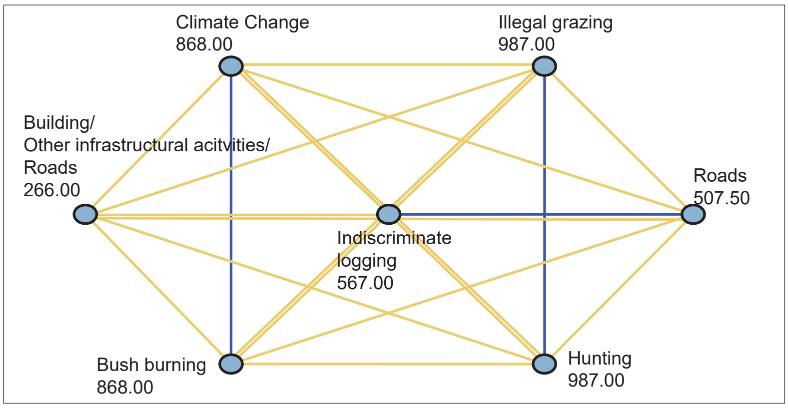

Figure 8 – Pairwise comparison of the perceived drivers of the transformation and fragmentation of the Ado-Awaye Mountains: Independent-samples Kruskal-Wallis test. Yellow line: significant difference between two perceived drivers (P < 0.05); Blue line: no significant difference between two perceived drivers (P > 0.05).

The Ado-Awaye Mountains are dominated by grasses and provide rich forage resources for domesticated animals, but the grazing has contributed to the loss of biodiversity and fragmentation of the mountainscape. This finding is consistent with Akhmadov et al. (2005), who reported that grazing affected biodiversity and resulted in the desertification of Alpine pasture in the Tajik Mountains, Tajikistan. However, this study contradicted Ingty (2021), who found that grazing enhanced biodiversity and species productivity in the Alpine Himalaya in India.

Illegal hunting and indiscriminate bush burning posed threats to the Ado-Awaye mountainscape. These activities occurred during the dry season, a period with low impedance to mountainscape accessibility. Bush burning, enhanced by climate change, helped hunters to move wild animals to a pre-determined route, making the animals more visible and thus aiding the hunters' indiscriminate activities. Such hunting combined with illegal grazing has led to resource overexploitation, transformation and fragmentation in the Ado-Awaye Mountains. Our study agrees with Chettri & Sharma (2016) on the Hindu-Kush in India, and with Marchant et al. (2019) studying mountains in east Africa, that resource over-exploitation by inhabitants because of poverty and other drivers results in biodiversity loss. Olaniyi et al. (2019) linked a high poverty rate to local communities' over-dependence on forest resources through indiscriminate hunting and other anthropogenic activities in Nigeria. This aligned with Ambe et al. (2015) and WWF (2017) who found that bush burning destroyed and fragmented the Montane vegetation of Mount Athos in Greece and the Obanliku Hills / Plateau in Nigeria. It was also consistent with the findings of Brink et al. (2014) and Jung et al. (2016) that anthropogenic pressure influenced the land-use changes in Mount Kilimanjaro, Tanzania and the Taita Hills, Kenya.

Climate change is reported as influencing the dynamics and fragmentation of Montane vegetation in various countries, including Italy, Greece and the USA (Vanneste et al. 2017; Guisan et al. 2019; Weiskopf et al. 2020; Kazakis et al. 2021). There have been a few studies on the impacts of climate change on African mountains (Nsengiyumva 2019). Climate change has recently been linked to landscape changes of some African mountains, such as Mount Kilimanjaro (Tanzania), the Ethiopian Highlands, and the Atlas Mountain (Maghreb) (Buytaert et al. 2011; Gebrehiwot & van der Veen 2013; Marchane et al. 2017; Siders 2019). In the Ado-Awaye Mountains, desertification (i.e. the reduction in savannah with scattered shrubs) may be due to increasing atmospheric temperature. An increased rate of desertification has been observed in other parts of Nigeria (Olagunju 2015; Mirzabaev et al. 2019). In mountainous regions, where conditions are particularly harsh, climate change affects vegetation distribution and shifts in biodiversity more than in other ecosystems (Tsering et al. 2010; Vanneste et al. 2017). According to Wang et al. (2016) and Zhu et al. (2017), increases in the extent of rock outcrops imply vegetation degradation and desertification, redistribution of biodiversity, and soil erosion.

In the Ado-Awaye Mountains, a few infrastructural facilities have been created to enhance cultural and mountain tourism activities. These include a 245-step walkway, a mini relaxation structure and a wooden bridge (Olaniyi & Bada 2020). Excavations during road construction contributed to the reduction of vegetation in the mountains. Based on the Kruskal-Wallis result, the impact of the roads correlated to the indiscriminate logging in the study area. According to Kleinschroth et al. (2019), in the Congo Basin unpaved roads can be linked to increased logging activities in the forests. The perceived driving forces of transformation and fragmentation in the Ado-Awaye Mountains are consistent with Beniston (2003), who concluded that mountainous landscapes are fragile environments prone to damage when exposed to agricultural activities on marginal soils, deforestation and overgrazing by livestock.

There is a dearth of information on the sociodemographic factors that influenced the local community's perception of drivers of MTF, although it has been established that age and gender shaped local people's perception of ecosystem services in African mountains, such as the Atacora Chain in the Benin Republic (Moutouama et al. 2019). However, our study has revealed that sociodemographic factors could vary according to the different perceived drivers of MTF. Islam and farming are the dominant religion and occupation in the local community of the study area. Many of the Muslims socialize during their daily prayer sessions and along the routes to their farmlands. This could be responsible for their high perception of roads as a driver of MTF. Age (more than 60) played an important role in local inhabitants' high perception of indiscriminate logging. The degree of indiscriminate logging had decreased over the years thanks to increased awareness by community leaders of its environmental danger.

Conclusion

This study aimed at providing information on the type, pattern and rate of LULC changes, and their perceived drivers, in the Ado-Awaye Mountains, between 2000 and 2019. The results revealed that the rocky outcrops / built-up areas / bare ground and savannah with scattered shrubs are the predominant LULC and vegetation. Despite the slight increase in open secondary forest over the years, its low coverage detracts from the potential serenity of the mountainous landscape. Changes in the dominant vegetation (savannah with scattered shrubs) were attributed to a few underlying factors, including overgrazing, indiscriminate logging, bush burning, climate change, human trampling, and tourism infrastructural development. The religion, occupation, monthly income and age of the local communities' inhabitants with 20+ years' experience in the Ado-Awaye Mountains influenced their perception of roads and indiscriminate logging as drivers of transformation and fragmentation in the study area.

Effective management strategies such as forest restoration programmes are recommended for improving the destination's serenity and mitigating the negative impacts of climate change. Overgrazing should be prohibited in order to reduce pressure on the savannah with scattered shrubs. Eco-friendly approaches (e.g. waste management, solar or wind-powered light cable rail system, a smart eco-lodge using solar energy and smart control technologies, green building principles, etc.) should be encouraged to reduce the environmental impact of any tourist infrastructure and activities.

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