Validating Local Drivers Influencing Land Use Cover Change (LUCC) in Southwestern Ghana: A Mixed-Method Approach (MMA) Analysis.

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Research Article

Keywords: Land use, contribution rate, confidence level, AHP, Southwestern Ghana

Posted Date: January 31st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-947297/v1

Abstract

Addressing undesirable changes associated with the driving forces of land use cover change are critical to sustainable land management, and the future modelling of land use systems in developing countries. The study ascertains local drivers of land-use cover change in Southwestern Ghana using a mixed-method approach. The approach aided in identifying key land-use drivers, using different research strategies for comparisons through confidence level analysis and Analytic Hierarchy Process. We used expert interviews, existing literature and geostatistical tools to ascertain the driving forces triggering such unprecedented changes. Landsat imagery 5 MSS, 4 and 5 TM, 7 ETM+ and 8 OLI/TIRS were acquired from the United States Geological Survey's website. Land use analysis revealed a decline in forests (-334.8 km^2yr^{-1}.) and areas covered by waterbodies (-4.79 km^2yr^{-1}.). A remarkable increase in built-up (+137.93 km^2yr^{-1}.) and farmlands/shrubs (+131.97 km^2yr^{-1}.) areas were also observed. The contribution rate of change analysis revealed built-up areas and increasing population contributed the most to surface temperature and land use change. A steady increase in surface temperature can be attributed to the undesirable changes associated with land-use systems over the past 50 years. Socio-economic development in Southwestern Ghana is fuelling interest in studies related to land use cover change. Biophysical, cultural and technological factors are considered key drivers despite the "medium-to-very low confidence" in results generated. They could potentially impact climate-sensitive sectors that significantly modify land-use systems from the pessimists and optimists' perspectives. Standpoints established through this study will enrich basic datasets for further studies at the continental level.

1. Introduction

Land use and forest management remain pivotal in achieving the United Nations' Sustainable Development Goals (SDGs). Studies have comprehensively reflected on the linkage between 'Sustainability' and Forest Transition Theory 'FTT' (Rudel et al. 2010; Turner et al. 2007; Mather et al. 1998). When viewed through the lens of the SDGs, making gains in FTT application may complement global efforts at achieving SDGs 1 (No Poverty), 2 (End Hunger), 13 (Climate Action), and 15 (Life on Land) in various ways. Meyfroidt and Lambin (2011), in their research on FTT, reinforced the connection between land use change dynamics and the FTT concept, as echoed by Foley et al. (2005). Arguably, both studies implicitly and explicitly provide opportunities for forest transition to 'reinstate' poorer, forest dependent populations into more favourable socio-economic positions as access to natural capital becomes possible. This must however, be supported by enabling factors, mainly a corruption free system. There is also a possibility for a non-realisation of the 'full potential' of natural resource access alone in reducing poverty, considering arguments brought forward by studies which explore the five capitals model (Gazzola and Querci, 2017; Sim et al. 2004; Angelsen and Wunder 2003; Smith and Scherr 2002; Hyden 1998). They argued that effective poverty reduction is achieved when access to all five capitals (Gazzola and Querci 2017) exist, hence, possibly undermining positive forest transition outcomes in poverty alleviation; highly possible in the tropics and less developed countries.

Systems responsible for sustainable use of forest resources are essential (Damnyag et al. 2017; FAO 2013) in themselves, and for contributing to forest transition (Waggoner and Ausubel 2001). In the same vein, forest transition can contribute to sustainable forest resource management (Lambin and Meyfroidt 2011). Land cover (LC) requires robust use of the elements of Sustainable Forest Management (SFM); "biomass; flora and fauna; forest health and vitality; productive functions of forest resources; conservative functions of forest resources; ecosystem services; legal, policy and institutional framework" (FAO 2013). Various studies support the central idea that efforts geared at the SFM elements remain critical for a fair forest resource use regime across all facets of socio-economic status, underscored by transparency in the context of forest transition (Rudel et al. 2020; Southworth et al. 2012; Lambin and Meyfroidt 2011; Meyfroidt and Lambin 2011). Concepts of "ecoconsumerism" (Meyfroidt and Lambin 2011), and "new corporate environmentalism" (Nasi and Frost 2009), re-emphasise rigorous SFM approaches through forest transition. These ensure land cover related benefits mainly ecosystem/ecological service advantages, and forest product use benefits become, and remain (if existent), reality.

The human-environment relationship varies in time and space. Land Use Cover Change (LUCC) is often caused by an interplay of multiple factors (Tolessa et al. 2019; Lambin and Meyfroidt 2011; Sim 2004). The dynamic interactions result in the formation of undesirable changes associated with LUCC. In response to the growing demands of human survival and developmental needs, the earth 's surface is continuously altered. Historically, LUCC in the current age-of-anthropocene, evolve from multiple direct and indirect factors (Mensah et al. 2019; Acheampong et al. 2018). These events accelerated substantially with the evolution of farming activities, resulting in the massive clearance of pristine environments. More recently, structural economic policies have driven industrialization, forcing people to migrate to urban centres, thereby resulting in the depopulation of rural areas. This is accompanied by the intensification of agriculture in the most productive lands, and neglect of marginal lands (Damnyag et al. 2017; Saad et. al. 2013; Kusimi 2008). When land is transformed from a primary forest to a farm, the loss of forest species within deforested areas occurs. Similarly, undisturbed environments are relatively transformed to more intensive uses, including livestock grazing, selective tree harvest, among others (Ellis and Pontius 2010). Some areas are often left bare, exposing such areas to unfavourable conditions which often leads to rending these areas unproductive.

In recent years, different scholars have applied useful techniques to study LUCC across Ghana. They primarily focused on changes in and around reserves/catchment areas (Gockowski and Sonwa, 2011; Alo and Pontius, 2008), spatial determinants of classes, dynamisms in future modelling (Addae and Oppelt, 2019; Koranteng et al.2017), along with establishing links between demographic changes and land use systems (Moller-Jensen and Knudsen, 2006). Others researchers have conducted meta-analysis or review studies on land use systems and water sedimentation (Boakye et al., 2018). Local studies conducted in various towns, districts and regions have assessed impacts of urbanization, illegal logging of trees and intensiveness of large scale mining and artisanal or small-scale mining (LSM/ASM) (Owusu-Nimo et al., 2018; Awotwi et al. 2018; Basommi et al. 2015), urban heat islands (Aduah et al. 2012), driving forces and consequences in regional capitals; notably Bolgatanga, Accra, Kumasi (McGregor, 2011), Sekondi-Takoradi (Obeng-Odoom, 2013) among other municipalities/towns like Kintampo Municipality (Bessa et al. 2019) and New Juaben, respectively. Watershed and other river basin studies around Lake Bosomtwe (Bessa et al. 2020; Amproche et al. 2019; Awotwi et al. 2015; Adjei et al. 2014; Leemhuis et al. 2009) in the Ashanti region of Ghana; Black and White Volta River Basins in the Volta/Oti regions (Tahiru, 2020) in the far east; Ankobra, Pra and Densu River Basins (Oti et al., 2020) in the west and Southernmost part of Ghana assessed the impacts of illegal mining (primarily gold and bauxite mining), deforestation among other factors that induce land cover transitions in these areas. The Southwestern region of Ghana hosts two-thirds of the country's high forest zone, and is most endowed in natural resources among the sixteen (16) administrative regions in Ghana. The agricultural and mineral sectors are critical to the growth and development of Ghana's economy. Considering Southwestern Ghana's contribution to the country's overall Gross Domestic Product (GDP), the region produces almost two-thirds of Ghana's cocoa (contributing about 30% of the country's export earnings) among other cash crops, as well as gold, bauxite, diamond and manganese (Owusu-Nimo et al., 2018; Asante-Poku, 2013). Ghana is Africa's leading gold producer (generated about 6.2 billion US dollars revenue from exports) unseating South Africa in 2019, coupled with being the second largest producer of cocoa in Africa with discovery of several oil fields for exploration (Geiger et al. 2019). These major commodities that contribute significantly to the country's GDP remain the main stay of the study area and the country at large. We sought to ascertain the main drivers of LUCC in Southwestern Ghana using the mixed-method approach (MMA) (1970-2020). Ineffective monitoring and regulation of these drivers, could further exacerbate land degradation in the region. This could hamper productivity levels that will influence the country's GDP. The MMA employs both qualitative and quantitative strategies to identify and analyse both direct and indirect factors that influence LUCC. It does not solely detect changes, but also validates information on dynamics in environmental issues that provide strategic directions for policy-makers, and inform the choices of local communities. Contextually, only few studies have attempted to quantify non-spatial/indirect drivers of LUCC (Kleemann et al. 2017; Jacobs et al. 2015; MA 2005). Long term residents and expert opinions are key in understanding why LULD in the study area is constantly changing, since the triggering effects constitute direct and indirect forces. Kleemann et al. (2017) focused on urbanization and patterns of change in two regional capitals, both in the northern and southern part of Ghana. This regional study further introduces the contribution rates of Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) to temperature variations. Additionally, it sought to adopt the Analytical Hierarchy Process (AHP) to compare and assign weights to experts' judgements in the validation of the key drivers. Hence, employing the MMA to quantify both spatial and non-spatial drivers, aimed to enhance comparisons, consistency and confidence in study findings. In the frame of this research, we attempted to address the following research questions:

i. What direct and indirect factors influence LUCC in Southwestern Ghana?
ii. What is the contribution rate of change for each class within the various indices against surface temperature?
iii. How consistent are the findings of expert interviews and literature review, against results from geospatial analysis that could drive land cover transitions and land degradation?
iv. Does consistency in the study approach enhance confidence and validity in findings that could be used to test existing theories?

Studies on land use assessments require a large amount of spatial data and other qualitative tools for effective evaluation and prioritization of alternative decisions. The novelty of this study dwells on the application value of concepts/applications, aimed at identifying and assessing local drivers influencing LUCC in Southwestern Ghana. We replicated and tested the approach, introduced by IPCC's fifth AR5 Working Group. The integrated approach is holistic, and can be tested in other areas.

2. Methodology

2.1 Study area

The study was conducted in Southwestern Ghana as part of a broad study that analysed spatiotemporal development of land use systems and climate variability in Ghana between 1970 and 2020. The study domain (Fig. 1) is located on latitude 5.3902°N and longitude 2.1450°W. It currently covers an approximate surface area of 23,921 km^2 (9,236 sq. mi) representing about 10 percent of Ghana's total land surface area. About 75 per cent of Ghana's high forest vegetation among other natural resources can be found in the region. The study area hosts two administrative regions; Western North and Western region.

2.2 Image classification

In this study, six Landsat images archived for the given period (1970-2020) (Table 1) from Landsat 5 MSS, Landsat 4 TM, Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI/TIRS were acquired from the United States Geological Survey's (USGS) website (http://earthexplorer.usgs.gov/*).* ArcGIS 10.6, ENVI 5.0 and 5.3 were used for the image pre-processing. Other image processing and enhancement procedures constituted *image mosaicking*, *calibration, layer stacking, region of interest (ROI) and supervised classification* (Table 2) were performed to rectify atmospheric effects and distortions in images. A *Maximum Likelihood Classification Algorithm (MLCA*) was employed for preliminary classifications based on the results of the supervised classification (Fig. 2).

Table 1
Description of imagery data used for LUCC study in Southwestern Ghana

Imagery type	Year Acquired	Resolution	Data Source	Path	Row
LANDSAT 5 MSS	1970s	30m	USGS	194/195/208/209	054/055/056
LANDSAT 4 TM	1980s	30m	USGS	194/195/208/209	054/055/056
LANDSAT 5 TM	1990s	30m	USGS	194/195/208/209	054/055/056
LANDSAT 7 ETM+	2000	30m	USGS	194/195/208/209	054/055/056
LANDSAT 7 ETM+	2010	30m	USGS	194/195/208/209	054/055/056
LANDSAT 8 OLI/TIRS	2020	30m	USGS	194/195/208/209	054/055/056

Table 2
Description of land cover types identified in the study area

Land Cover	Description
Forests	Areas dominated by closely knit trees and luxurious vegetative cover. It also encompasses all vegetative areas that expose no bare soil.
Built-up areas	Residential, commercial and industrial areas are classified as built-up areas. Parks, gardens, playing grounds and lorry stations within communities also fall under this class.
Bare land	These are usually patches of land or rocks which are not covered by vegetation. Bare lands are common in and near built-up areas. Lands that have been cleared in readiness for building or farming fall under this class.
Farmlands and shrubs	Describes all areas that portray sparsely located trees, shrubs, isolated thickets and areas with non-tree crops.
Water bodies	Comprise rivers, lagoons, lakes and so on.

Table 3
Combinations between agreement and evidence levels for each finding. Each level is defined for the respective method (RS= remote sensing; expert interviews; literature review).

Symbol	Level of Agreement	Details
√√√	High Agreement	Statement is confirmed within one method.
√√	Medium Agreement	-for expert interviews: >60% of respondents confirmed
√	Low Agreement	-for literature: more than two sources confirmed
x		-for RS: if study was conducted in the same area with similar scope. Otherwise, not applicable.
		Statement is confirmed but limited data within one method
		-for expert interviews: 25-60% of respondents confirmed
		-for literature: one or two sources confirmed
		-for RS: Confirmed
		Confirmation and rejection within one method
		-for expert interviews: <25% of respondents confirmed
		-for literature: confirmation and rejection balanced
		No data or evidence
	Level of evidence	**Details**
	High evidence	All three methods can provide information
	Medium evidence	Two methods can provide information
	Low evidence	One method can provide information.

2.3 Change Detection Analysis

Change detection analysis was run to ascertain the regularity of land use systems, and its drivers in southwestern Ghana (1970-2020). The present study applied image differencing, NDVI, post-classification and Geographic Information System (GIS) techniques in determining the spatiotemporal development of land use systems in the area. LUCC was computed based on the following expressions:

$$\text{ChangeinLUCC}\left(x^2\right) = \frac{\text{LUCC}_{\text{Currentyear}} - \text{LUCC}_{\text{Pastyear}}}{\text{LUCC}_{\text{Pastyear}}} \cdots \text{Eqn1}$$

$$\backslash\%\text{ChangeinLUCC}\left(x^2\right) = \frac{\text{LUCC}_{\text{Currentyear}} - \text{LUCC}_{\text{Pastyear}}}{\text{LUCC}_{\text{Pastyear}}} \text{x100}\backslash\% \cdots \text{Eqn2}$$

$$\text{RateofChangeinLUCCperyear} = \left[\left(\frac{\text{LUCC}_{\text{Currentyear}} - \text{LUCC}_{\text{Pastyear}}}{\text{LUCC}_{\text{Pastyear}}}\right)\text{x100}\backslash\%\right] \div 50\text{years} \cdots \text{Eqn3}$$

The change detection statistics for the study period (1970-2020) was obtained using pixel count, area in km^2 and percentages for the purpose of analysis. This facilitated the generation of statistical data of change occurrence over the years in relation to each class.

2.4 Temperature analysis

2.4.1 Image Calibration (Radiance)

Radiometric correction (radiance) was done *to* rectify atmospheric effects and enhance clarity. Gap-filling was performed to remove stripes in images. Distortions in images were removed during the calibration process (Coll et al., 2010). Using the mathematical expression:

$$\mathrm{L}_{\lambda} = \frac{\left(\mathrm{LMAX}_{\lambda} - \mathrm{LMIN}_{\lambda}\right)}{(\mathrm{QCALMAX} - \mathrm{QCALMIN})} \mathrm{x}(\mathrm{DN} - \mathrm{QCALMIN}) + \mathrm{LMIN}_{\lambda} \cdots \mathrm{Eqn.}\ 4$$

Where L_{λ} is cell value as radiance in $W/\left(M^2 * sr * \mu m\right)$;

$LMAX_{\lambda}$ is the sensor spectral radiance that is scaled to $(QCALMAX)$ in $W/\left(M^2 * sr * \mu m\right)$; $LMIN_{\lambda}$ is the sensor spectral radiance that is scaled to $(QCALMIN)$ in $[W/\left(M^2 * sr * \mu m\right)]$. $(QCALMAX)$ is the maximum quantized calibrated pixel value to $LMAX_{\lambda}$ [DN], $(QCALMIN)$ is the minimum quantized calibrated pixel value corresponding to $LMIN_{\lambda}$ [DN]; and QCAL is the quantized calibrated pixel value [DN]. Equation 4 can be observed from header files ETM+ and TM datasets from USGS website. The LMIN and LMAX are the spectral radiances for each band at digital numbers (DN) 1 and 255 for Landsat 7 ETM+, 1 and 65535 for Landsat 8 OLI/TIRS. λ is the wavelength.

Conversion of Spectral Radiance (L_{λ}) to Kelvin with emissivity value:

$$\mathrm{T} = \frac{\mathrm{K}_2}{\ln\left(\frac{\mathrm{K}_1 * \mathrm{E}}{\mathrm{L}_{\lambda}} + 1\right)} \cdots \mathrm{Eqn.}\ 5$$

Therefore, k_1 and k_2 become coefficients determined by effective wavelength of a satellite sensor (Avdan & Jovanovska 2016; Ghulam, 2010).

$$\mathrm{BT} = \frac{\mathrm{K}_2}{\ln\left[\left(\mathrm{K}_1 / \mathrm{L}_{\lambda}\right) + 1\right]} \cdots \mathrm{Eqn.}\ 6$$

2.4.2 Conversion of Spectral radiance (L_{λ}) to Kelvin with emissivity value from Landsat 8

Since temperature is required in Degree Celsius (**°C) (**T_c), results for various temperatures must be converted from Kelvin (K) (T_B) to degree Celsius (**°C) (**T_c):

$$\mathrm{T}_C = \mathrm{T}_B - 273.15 \cdots \mathrm{Eqn.}\ 7$$

Where T_B is value at satellite brightness temperature (K) and T_C is temperature in Degree Celsius.

2.4.3 Contribution rate of change for the various indices

Reclassification was performed for the understudied indices (NDVI and NDBI) over the given study period (1970-2020). Five classes were generated for each of the indices for each period using ArcMap. The classes were obtained based on value range results from high to low considering the output of the indices. The classes were reclassified based on their value range using the identification tool in ArcMap. This resulted in the identification and classification of forests, farmlands/shrubs, water bodies, bare land and built-up value range within the understudied indices.

After obtaining the various classes based on the value range, the zonal geometry tool in ArcMap was used to obtain the area coverage in square meters for each class. The table obtained was exported to Statistical Package for Social Sciences (SPSS Inc. Chicago, USA, version 16) for conversion of the area (sq.km), percentage contributions of the various classes for the various indices, along with existing changes in terms of area coverage for the given years. Using the expressions:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})} \cdots \mathrm{Eqn.}\ 8$$

where; NIR= Near-infrared, RED= Red visible bands (Xu, 2007). Again, Normalized Difference Built-up index (NDBI) was expressed as:

$$\mathrm{NDBI} = \left(\frac{(\mathrm{SWIR} - \mathrm{NIR})}{(\mathrm{SWIR} + \mathrm{NIR})}\right) \ldots \mathrm{Eqn.9}$$

For Landsat 7 data, NDBI = (Band 5 – Band 4) / (Band 5 + Band 4).

$$ContributionRateofChange(CRC) = \frac{LUC(sq.\ km)_{Present/\ futureyear}}{LUC(sq.\ km)_{Past/\ Previousyear}} - 1 \ldots Eqn10$$

Where: CRC=contribution rate of change for a given class, over a given study period among the understudied indices, whilst LUC=land use class. Here, the value of change for each class given the output indicates the rate of change/contribution. High positive values indicate an increment (rate of contribution) in area coverage for a particular class over the given study period. Contrarily, negative values represent a decline (rate of contribution) in area coverage for a given class. Considering the expression above (Eqn. 10), the rate of change (+/-) based on the results generated will indicate which class contributed the most towards change in the area.

2.5 Data Analysis

The MMA approach was primarily used in IPCC's fifth assessment report to validate the inconsistencies, associated with the various working groups' reports on indirect drivers of LUCC (Kleemann et al. 2017; Jacobs et al. 2015). A semi-structured questionnaire was designed and administered to some experts in the study area. "Experts" in this study is defined as individuals with extensive knowledge and experience in relation to the scope of this study, and have lived or worked in the area for more than 20 years. In-depth interviews were conducted among 30 experts to ascertain the major drivers of LUCC. Experts were chosen based on willingness and availability to contribute to the study.

Excel and Statistical Package for SPSS v.16 software were employed to capture, clean and analyse the data collected. Results from respondents' knowledge were used to validate the outcome of satellite imagery and existing literature over the given study period.

2.5.1 Confidence Level Analysis

To express the validity and reliability of findings, we adopted the confidence level approach provided by Kleemann et al. (2017), Jacobs et al. (2015), based on Mastrandrea et al. (2011) for the IPCC AR5 and the Millennium Ecosystem Assessment (MA, 2005). They established synergy between agreement and evidence levels to examine confidence in avouching study findings (Tables 4 and 5). This parameter is important in correcting the degree of inconsistencies or inaccuracies in various approaches used. The present study moves further to introduce contribution rates of various indices to changes in temperature and LUCC, coupled with AHP to assign weights to expert judgements, which were not employed in the aforementioned studies.

Table 4

Confidence level table of findings from interviews, remote sensing and existing literature

Level of confidence	Limited evidence	Medium evidence	Robust evidence
High Agreement	Medium	High	Very High
Medium Agreement	Low	Medium	High
Low Agreement	Very low	Low	Medium

Adapted from Kleemann et al. (2017) and Jacobs et al. (2015) based on Mastrandrea et al. (2011) and MA (2005).

Table 4.1

Saaty's (1980) scale for comparison of various elements.

Scale	Judgement of Preference	Description
1	Equally important	Two factors contribute to the objectives
3	Moderately important	Experience and judgement slightly favor one over the other
5	Important	Experience and judgement strongly important favor one over the other
7	Very strongly important	Experience and judgement strongly important favor one over the other
9	Extremely important	The evidence favoring one over the other is of the highest possible validity
2,4,6,8	Intermediate preference between adjacent scales	When compromised is needed
1/3, 1/5, 1/7, 1/9	Values for inverse comparison	With respect to values assigned to row and column elements

Table 4.2

Random index matrix of the same dimension

No. of Criteria	2	3	4	5	6	7	8	9	10	11
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Table 5
Biodata of respondents in Southwestern Ghana

Characteristics	Variables	Frequency (n=30)	Percentage (%)
Gender	Male	26	86.7
	Female	4	13.3
Age limit	18-25	-	-
	26-40	16	53.3
	41-65	14	46.7
	>65	-	-
Educational Status	No formal education	-	-
	Primary	-	-
	Secondary	8	26.7
	Tertiary	22	73.3
Length of stay/work period	<5 years	-	-
	5-15 years	8	26.7
	16-40 years	22	73.3
	>40 years	-	-

QN	Institution	Role/Capacity	Research Interests

The distribution above presents the institution/affiliation, role and research interests of the 30 experts who were interviewed using the semi-structured questionnaire. Location(T)=Takoradi, SW Ghana, (E)=Enchi, SW Ghana; QN=Questionnaire number; (*) =same institution

Characteristics		Variables	Frequency (n=30)	Percentage (%)
QN1	Lands Commission, T	Principal Technical Officer	-Land policy and administration, Sustainable Development.	
QN2	*		-Land tenure systems, management and administration.	
		Senior Staff		
QN3	*		-Land Use, Population & Demographic studies, and Natural Resource Management	
		Planning Officer		
QN4	Minerals Commission, T			
		Minerals Geological Officer	-Geology, Pedology, Resource Use Management & Environmental policy	
QN5	*			
			-Geology, Environmental Policy and Management.	
QN6	Environmental Protection Agency (EPA), T	Senior Staff		
			-Environmental Impact Assessment, Env. policy & Management, Land Use	
QN7		Environmental Officer		
	*		-Remote sensing and Land use change	
QN8		Senior Staff		
	Ghana Meteorological Agency, T		-Climatology, regional and local land use planning	
QN9		Climate Research Officer		
	*		-Climate change adaptation & Remote Sensing	
QN10				
	Lands Commission, E	Senior Staff	-Land administration and management, agriculture & Rural development	
QN11				
	*	Municipal Stool Lands Officer	-Land tenure, rural development & Dev. studies	
QN12				
	*		-Land use change, GIS, Policy Analysis, Soil & water engineering, Regional Planning	
QN13		Senior Staff		
	Forestry Commission, E			
QN14		Principal Technical Director	-Forestry & Wildlife, Agroforestry & Ecosystem Services.	
	*			
QN15			-Forestry and wildlife, regional and local planning, development policy & land use	
	Ghana Immigration Service, E	District Manager		
QN16			-Population studies, Migration and rural development	
	*	Zonal Co-Ordinator		
QN17			-Population studies, Environmental policy & Planning	
	Ghana Fire Service, E	Senior Officer		
QN18			-Risks & Disaster Management, Remote sensing, Regional land use planning	
	*	Senior Officer		
QN19			-Risks & Disaster Management, network systems and local land use planning	
	Feeder & Urban Roads, T	Assistant Divisional Officer		
QN20			-Regional and local land use planning, remote sensing, transportation and network services	
	*			
QN21		Senior Staff		
	NADMO, E		-Remote sensing and GIS, Planning and architecture	
QN22		Senior Transport Officer		
	*		-Risks and Disaster Management, agriculture economics and soil conservation	
QN23		Junior Staff		
	*		-Disaster management, Peri-urban Development	
QN24		Zonal Co-Ordinator		
	Physical Planning Department, T		-Land use planning & Disaster Management	
QN25		Senior Staff		
	*		-Land use planning, GIS, Demography studies & policy analysis.	
QN26		Deputy Zonal Co.		
	Town and Country Planning, T		-Landscape patterns, Urban Dev. & Logistics	
QN27		Acting Physical Officer		
QN28		Senior Staff		
QN29		Senior Staff		
	Social Welfare, E		-Planning, architecture, Physical and Human Geography	
	*		-Development studies, sociology and population studies	
	Forestry Commission, T		-Sociology and Rural livelihoods	
QN30	*	Head of Department	-Ecosystem based services, agroforestry, land use analysis & resource management	
	*	Senior Staff		
			-Natural resource management, environmental science & planning	
		Senior Staff		
			-Forestry and Wildlife, Food security, Resource Economics, Environmental policy and management.	
		Senior Staff		
		Senior Staff		

The distribution above presents the institution/affiliation, role and research interests of the 30 experts who were interviewed using the semi-structured questionnaire. Location(T)=Takoradi, SW Ghana, (E)=Enchi, SW Ghana; QN=Questionnaire number; (*) =same institution

2.6 Analytical Hierarchy Process (AHP) model

The AHP is an analytical tool used to illustrate a phenomenon, examine and advance priorities, based on the user's discretion with the aim of solving complex problems (Saaty, 1980). AHP analysis employs six steps (Saaty, 1980) enhanced by Danumah et al. (2016): Breaking a complex unstructured problem down into its component factors; formulation of hierarchical structure; paired comparison matrix determined by coercing results; allocating values to subjective judgments and measuring the relative weights of each criterion; systemize results to determine the priority variables, and look-out for consistency in assessments and judgments. The unique basic quality of AHP is the calculation of consistency ratio which reduces bias to a larger extent, and determine how logical results are. If consistency ratio is less than or equal to 0.1, then the factor is considered as acceptable consistency. However, AHP approach is built on three levels as evident in Fig. 3. Level 0 (main objective); Level 1 (criteria analysis which constitute biophysical and proximate/underlying factors) whereas Level 2 lists the elements associated with Level 1 (Danumah et al, 2016; Nejad et al. 2015; Chakraborty & Joshi, 2014). In this study, criteria weightings were assigned to judgements from experts to draw a logical conclusion on validating local drivers that influences LULD in Southwestern Ghana.

2.6.1 Principles for selecting each weight factor (AHP)

The ideal intent is to design a matrix that exhibits relative values of Level 2 elements in a hierarchy. Expert opinions or judgments are assigned a number according to Saaty's scale. A simple, but very pragmatic assumption is that if for instance, element A is very strongly crucial than element B, then A is assigned or valued as 7. B becomes less important than A, hence, B is valued at 1/7. A pair-wise comparison was done for all the listed factors. Again, relative weights were calculated (eigenvector).

2.6.2 Pairwise Comparison

The binary combination is based on Saaty's (1980) proposition to compare key and potential drivers whilst the pairwise comparison is the basic element of AHP process. For pairing in each criterion, the preferable element is weighted on a scale ranging from 1 (equally good) to 9 (absolutely better), whereas the less preferred element is assigned a weight, reciprocal to this value. Each score illustrates how better element "X" meets criterion "Y". The ratings are normalized, and their consistency are being calculated (Table 4.1).

2.6.3 Development and Prioritization Matrix

Developing and prioritizing matrix are done to ascertain the eigenvectors (Vp) of each criterion for each item as expressed in eqn.11;

$$V_p = n\sqrt{W1x\ldots}Wn\ldots eqn(11)$$

n represents the number of parameters. Wn ratings are the main parameters. The criteria weight (Cp) is measured as:

$$C_w = \frac{V_p}{V_p1 + \cdots + V_{pn}}\ldots eqn(12)$$

The sum of criteria weights (C_W) of all parameters of a matrix equals 1 and expressed as a percentage. Normalize the matrix by dividing each element by the sum of the column, and calculate the mean of each line to determine the priority vector [C]. λ is calculated by averaging the value of the consistency vector. It is generated from the summation of products between each element of Eigen vector and the normalized relative weight. λ max (eqn.13); CI (eqn.14) and CR (eqn.15) are calculated as:

$$\lambda\max = \frac{[E]}{n}\ldots eqn(13)$$

$$CI = (\lambda\max - \mathrm{n}) / (\mathrm{n} - 1)\ldots eqn(14)$$

The ratio of consistency is the probability that the croak is completed randomly. When CR ≤ 10%, the results are considered to be pragmatic. However, a CR > 0.1 indicates the need for revision.

$$CR = \frac{CI}{RI}\ldots eqn(15)$$

The random index (RI) estimations are presented in Table 4.2.

2.7 Accuracy Assessment: Ground Truthing exercise

Ground truthing sampled points were taken using a Mobile Data Collection Application (MDC). The samples were imported unto the Southwestern Ghana shapefile in ArcMap for verification. Samples taken for each class (Table 2) were divided/distributed based on area coverage. Thus, bare land (70), built-up areas (177), waterbodies (20), forests (104) and farmlands/shrubs (153) sampled points were taken from the field, making a total of five hundred and twenty-four (524) samples (Fig. 4 and Fig. 5). We designed a sampled collection form using a licensed GIS Cloud for the ground-truthing exercise. Using a confusion matrix, we assessed and improved the user and producer's accuracy assessment technique that culminates randomized, and overall sampled points. The mathematical expression (Eqn.16) adapted from Sarfo et al. 2021, was used in calculating the accuracy assessment:

$$\mathbf{AccuracyAssessment(A.\,A)} = [(\mathrm{ASP} / \mathrm{TSP}) \times 100\cdots\mathrm{Eqn.\ 16}]$$

where:ASP = Number of sample points that accurately falls on each required feature (ASP=493).TSP = Number of total sample points generated (TSP=524).A.A = Accuracy Assessment [(493/524) X 100 =94.08%].Therefore, the present study had 94% accuracy over the study period considering the samples collected.

Figures 4 and 5 depict areas where the sampled points (524) were taken using the Mobile Data Collection (MDC) Application (see Annex II), as well as areas where the questionnaires were administered. Considering the characteristics of Southwestern Ghana as presented in section 2.1 (Fig. 1), the sample size for each land class was determined based on the dominance or proportion of coverage of each land cover. Random sampling was performed to obtain information for each class.

3. Results

3.1 Sociodemographic characteristics of respondents

Majority of the respondents interviewed were males (87%) whilst the remaining quota (13%) represented females in Southwestern Ghana (Table 5). The distribution below (Table 5) shows 53% of respondents had an age range of 26-40 years while 47% ranged between 41-65 years. In terms of educational background, 27% of respondents had attained secondary education while 73% had obtained tertiary education with various degrees. Also, most (73%) of the respondents had been living or working in the study area for (±28) years. The remaining quota (27%) on the other hand, asserted they have been living or working in the area for (±10) years.

3.2 Change Detection Analysis: Drivers of Land Use Cover Change

An array of factors that influence land cover types from the local to the global level are often anthropocentric and biophysical in nature. We identified over eight (8) major factors (proximate/ underlying) that drive LUCC in Southwestern Ghana (Table 7 and Table 9, Fig. 6). Results presented in Table 6 shows an area coverage (sq.km) for each class and evidence of considerable LUCC patterns in Southwestern Ghana between 1970 and 2020 (Fig. 6). The main land use features that increased progressively over the study period were built-up and farmlands/shrubs (Fig. 7 and Fig. 10-11). Additionally, bare land, waterbodies and forest areas experienced dynamic ebb over the given period.

Table 6

Area coverage for LUCC in Southwestern Ghana (1970-2020)

Area coverage for each class (km^2) over the given period (1970-2020)						
LUCC class	**1970s**	**1980s**	**1990s**	**2000**	**2010**	**2020**
Bare land	417.63	320.91	2607.63	2134.04	1928.93	1607.11
Built-up areas	535.26	623.636	750.81	3278.45	4843.33	8212.04
Waterbodies	874.48	3120.54	2420.37	1708.19	1330.68	1192.43
Farmlands and Shrubs	1784.22	5632.85	8002.66	11093.37	10283.95	10391.86
Forests	20312.42	14226.92	10991.20	6124	4439.02	1628.13
Total	23924.01	23924.86	24772.67	24333.05	22835.91	23031.57
Contribution rate of change for NDBI						
Class/Period	**1970s-1980s**	**1980s-1990s**	**1990s-2000**	**2000-2010**	**2010-2020**	**1970s-2020**
	CRC	**CRC**	**CRC**	**CRC**	**CRC**	**CRC**
Forests	-0.04	0.06	-0.12	-0.11	-0.18	-0.34
Farmlands/shrubs	0.17	-0.14	0.17	0.11	0.03	0.33
Waterbodies	-0.36	0.14	-0.25	0.17	0.00	-0.55
Bare land	-0.43	0.25	0.33	-0.50	0.00	-0.71
Built-Up	2.00	0.33	0.25	0.40	0.43	9.00
Contribution rate of change for NDVI						
Class/Period	**1970s-1980s**	**1980s-1990s**	**1990s-2000**	**2000-2010**	**2010-2020**	**1970s-2020**
	CRC	**CRC**	**CRC**	**CRC**	**CRC**	**CRC**
Forests	-0.17	0.07	-0.06	-0.04	-0.12	-0.30
Farmlands/shrubs	0.35	0.03	-0.03	0.09	0.05	0.54
Waterbodies	-0.47	0.40	-0.14	-0.50	-0.33	-0.79
Bare land	0.13	-0.78	1.00	-0.50	0.00	-0.75
Built-Up	1.40	0.17	0.43	0.40	0.29	6.20
Population Growth (million) for Southwestern Ghana						
Region/Period	**1960**	**1970**	**1984**	**2000**	**2010**	**2020**
Southwestern Ghana	625,155	770,087	1,157,807	1,924,577	2,376,021	3,093,200
Annual population growth rate (%) statistics for the study area						
	1960-1970	**1970-1984**	**1984-2000**	**2000-2010**	**2010-2020**	**1960-2020**
Southwestern Ghana	2.1	3.0	3.2	2.0	3.0	6.5
Source: Ghana Statistical Service (GSS), 2020 Annual Population and Housing Census Report Summary						

Table 7
Summary of existing literature on policy-driven factors, major events, and LULD studies in Southwestern Ghana (1970-2020)

Periods	Driving factors	Consequences	Transitions	Source (Literature)
1970s	Agricultural expansion (proximate cause).	Increase in small-scale subsistent farming (farmlands & shrubs) resulting in marginal deterioration of natural forests (pristine environment).	Bare land and forest lands to farmlands and shrubs, small-scale farms as well as settlements.	Gockowski and Sonwa 2011; Dickson and Benneh 1988; Hall and Swaine 1976; Ahn 1958
1970s-1980s	Population growth and distribution (Underlying cause). Agricultural expansion (proximate cause).	Increase in human settlements. Increase in small-scale subsistent farming (farmlands & shrubs) resulting in marginal alteration of natural forests (pristine environment).	Bare land and forest lands to farmlands and shrubs, subsistent/medium-scale farms	Damnyag et al. 2017; Gyasi et. al 1994; Brooke 1989; Arhin 1985; Hall and Swaine 1976.
1980s-1990s	Biophysical and climatic factors (i.e., Droughts (1981-1983), Famine, bushfires and higher temperatures) (proximate cause) Economic (Macro-economic Reforms), Socio-political (Policy) and institutional factors (i.e., 1983 (GoG) Economic Recovery Program with support from IMF/World Bank, land tenure systems) (Underlying cause).	Spontaneous immigration and forced settlements from other regions and increase in population led to reduction in natural forests and significant increase in bare land, farmlands and shrubs (Table 4). Loss of biodiversity and health problems. Increasing temperatures (dry climate) and reduced rainfall. Redistribution of lands and conversion of natural forests to farmlands. The state and individuals emerged as dominant economic agents in the economy.	Forest lands converted to farmlands and shrubs, bare land and human settlements.	Tan and Rockmore 2018; Huq and Tribe 2018; Abbam et al. 2018; Nikoi 2015; Aryeetey and Kabur 2008; Gyasi et. al 1994; Kusi 1991; Brooke 1989; Dei 1988.
1990s-2000	Socio-economic development (i.e., Policies driven towards Ghana's Vision 2020, poverty reduction (i.e., Core Welfare Indicators Questionnaire (CWIQ) and the Ghana Living Standards Survey (GLSS), improvement in Human Development Indicators (HDIs), export led agricultural production and expansion in foreign investment) (Underlying causes). Population pressure (underlying cause). Biophysical and climatic factors (i.e., temperature rise) (Proximate cause).	Development of infrastructure such as transportation networks, education and health facilities. Domestic and foreign investment in farming activities. Population growth and significant increase in human settlements. High rate of deforestation. Need to meet food demands led to an increase in the rate of farming activities. Increase in surface temperatures and reduced precipitation (Table 4 and Fig. 5) due to significant increase in built-up environment. Loss of biodiversity and health problems.	Forests, bare land, farmlands and shrubs converted to settlements/infrastructure, subsistent and medium/large scale farms	Huq and Tribe 2018; Abbam et al. 2018; Damnyag et al. 2017; Koranteng and Zawila-Niedzwieki 2016; Noponen et al. 2014; Gockowski and Sonwa 2011; Kusimi 2008; Gyasi et al. 1994; Kusi 1991.

Periods	Driving factors	Consequences	Transitions	Source (Literature)
2000-2010	Adoption of new governance systems (i.e., Adoption of capitalism and free-market (liberalists) (Underlying cause). Rapid population growth (Underlying cause) Economic Reforms led to the application for enhanced Highly Indebted Poor Country (HIPC) in 2001, Ghana Poverty Reduction Strategy I (2003-2005) & II. Implementation of sectoral policies designed to promote Sustainable Economic Growth and high incidence of poverty in Ghana. Interventions like the School Feeding Program, NYEP/GYEEDA, LEAP, NHIS).	High rate of deforestation. Increasing rate of settlements and infrastructure. Increase in surface temperatures and a decline in rainfall. Decline in farming activities (Table 4).	Farmlands and shrubs, bare land, and forests converted to settlements and infrastructure.	Mensah et al. 2019; Acheampong et al. 2018; Huq and Tribe 2018; Abbam et al. 2018; Damnyag et. al 2017; Aduah and Baffoe 2013; Aduah et. al 2012; Gockowski and Sonwa 2011; Kusimi 2008; Aryeetey and Kabur 2008.
2010-2020	Population growth and distribution (Underlying cause) Tree plantation (Afforestation) (i.e., GYEEDA, Carbon Sequestration Development Project, REDD+ Hotspot Strategy, planting for food and jobs). Infrastructural Development (2010-2016) (i.e., Community Day schools, district and regional hospitals, Roads and railway networks, Storage Facilities-Warehouses, Housing units among others) (proximate cause). Economic policies driven towards Industrialization and fiscal discipline (Macro and micro economic stability) (i.e., One-district-one factory, reducing Balance of Payment deficits (BoP) and so on. Increase in the prices of some agricultural commodities (i.e., increase in cashew, timber, cocoa producer prices). Encouraging domestic and foreign investors to venture into agriculture and other natural resource or profit-oriented sectors (Underlying cause).	Expansion of settlements and infrastructure. High rate of deforestation. Increase in surface temperature and decline in rainfall. Expansion of cultivated lands done on small, medium and large scale to boost exports and provide more raw materials for industries. Efforts channeled towards profit-oriented sectors (i.e., natural resources) have resulted in a decline of other sectors.	Forests and bare land converted to human settlements and farmlands.	Mensah et al. 2019; Geiger et al. 2019; Acheampong et al. 2018; Huq and Tribe 2018; Abbam et al. 2018; Damnyag et. al 2017; Kleemann et. al 2017; Koranteng et al.2017; Noponen et. al 2014; Aduah and Baffoe 2013; Aduah et. al 2012; Logah et. al 2011.

Table 8: Description of experts' rank on most influential drivers of LULD in Southwestern Ghana

Driving Factors	Tally/Rank	Frequency (N=22) (%)	Position
a. **Expansion in settlements & social infrastructure:** Schools, health facilities, transportation networks, housing/real estates, Market and storage facilities, drainage systems and so on).	√√√√	6 (28%)	**2nd**
b. **Economic factors:** Population growth and distribution, micro/macro-economic factors, Mining, illegal logging, incentives/subsidies and so on, market forces/prices, price of commodities on domestic and international market, promoting exports/balance of payment deficit and so on.	√√√√√	8 (36%)	**1st**
c. **Political factors:** state policies that promote farming and deforestation and land degradation, weak governance systems, institutional frameworks, land tenure systems, monitoring and enforcement of regulations.	√√√	4 (18%)	**3rd**
d. **Agricultural activities & Technological factors**: agro-technical input and efficiency, mining technology, transportation networks)	√√	2 (9%)	**4th**
e. **Natural or biophysical factors**: Increase in temperature, droughts, wildfires, flooding, fluctuations in rainfall, topography, aspect, slope and so on	√	2 (9%)	**5th**

Respondents' assertion of some key driving forces influencing LULD IN SW Ghana. The rank (Table 8) among other key parameters highlights the most/least influential factors resulting in substantial LULD over the past five decades.

Table 9

Confidence level analysis using the MMA to ascertain local drivers of LULD

Scope: Drivers of LULD	Keywords	Literature Review	Interviews	Spatial Analysis	Confidence level
		SW Ghana	SW Ghana	SW Ghana	SW Ghana
Proximate Causes	Deforestation	√√√	√√√	√√√	**Very high**
	Settlements	√√√	√√√	√√√	**Very High**
	Wood extraction	√√	√√	√	**Medium**
	Setting up profit-oriented industries	√√	√	√	**Medium**
	Mining & Infrastructure	√√√	√√√	√√√	**Very High**
	Agriculture expansion	√√√	√√	√√√	**High**
	Bushfires/Wildfires	√	√	X	**Low**
	Famine	√√√	√	X	**Medium**
	High temperature	√√√	√√√	√√√	**Very High**
	Floods	√√	√√	X	**Medium**
	Soil Quality	X	√	X	**Very Low**
Underlying Causes					
	Migration	√√√	√√√	√√√	**Very High**
	Poverty	√√√	√√√	X	**High**
	Population growth and distribution	√√√	√√√	√√√	**Very High**
	Weak governance, Monitoring and Enforcement mechanisms	√√	√√	X	**Medium**
	Technology (Science, research, mining technology, agro-technical change and efficiency, transportation networks)	√√	√√	X	**Medium**
	Cultural values, behaviour and beliefs	√√	√√√	X	**Medium**
Effects on some climatic variables	Increasing temperature	√√√	√√√	√√√	**Very High**
	Unpredictable/Fluctuations in rainfall patterns	√√√	√√√	X	**High**

3.4 Interpretation of results based on AHP

The risk factors stated in this study comprised biophysical (natural) and proximate/underlying drivers that influence LUCC in Southwestern Ghana (Tables 10). The pair-wise matrices were normalized, along with their generated level of consistencies. The value of consistency ratio (CR) of the drivers on the pair-wise matrix is 0.01. This indicates the outlined drivers in the pair-wise matrix is reasonably consistent. High Temperature (**HT**) is given 30.88% weight representing the highest ranked biophysical driver and in descending order of severity; Bushfires/Wildfires (**BFW**) having 22.62% weight; Unpredicted/Fluctuations in rainfall patterns (**UFRP**) given 17.80% weighting; Floods (**FI**) and Famine (**F**) assigned 11.16% weighting respectively,whereas soil quality (**SQ**) obtained 6.37% weighting.

Table 10
Measuring consistency of biophysical and proximate/underlying drivers

	D	S	WE	SPOI	MI	AE	M	P	PGD	WGMEM	T	CVBB	CW	WSV
D	0.129	0.129	0.124	0.124	0.129	0.147	0.129	0.147	0.129	0.124	0.124	0.124	0.129	1.559
S	0.129	0.129	0.124	0.124	0.129	0.147	0.129	0.147	0.129	0.124	0.124	0.124	0.129	1.559
WE	0.043	0.043	0.041	0.041	0.043	0.037	0.043	0.037	0.043	0.041	0.041	0.041	0.041	0.495
SPOI	0.043	0.043	0.041	0.041	0.043	0.037	0.043	0.037	0.043	0.041	0.041	0.041	0.041	0.495
MI	0.129	0.129	0.124	0.124	0.129	0.147	0.129	0.147	0.129	0.124	0.124	0.124	0.129	1.559
AE	0.065	0.065	0.082	0.082	0.065	0.073	0.065	0.073	0.065	0.082	0.082	0.082	0.073	0.883
M	0.129	0.129	0.124	0.124	0.129	0.147	0.129	0.147	0.129	0.124	0.124	0.124	0.129	1.559
P	0.065	0.065	0.082	0.082	0.065	0.147	0.065	0.073	0.065	0.082	0.082	0.082	0.073	0.956
PGD	0.129	0.129	0.124	0.124	0.129	0.147	0.129	0.147	0.129	0.124	0.124	0.124	0.129	1.559
WGMEM	0.043	0.043	0.041	0.041	0.043	0.037	0.043	0.037	0.043	0.041	0.041	0.041	0.041	0.495
T	0.043	0.043	0.041	0.041	0.043	0.037	0.043	0.037	0.043	0.041	0.041	0.041	0.041	0.495
CVBB	0.043	0.043	0.041	0.041	0.043	0.037	0.043	0.037	0.043	0.041	0.041	0.041	0.041	0.495
Measuring consistency of biophysical drivers														
CW	**0.1116**	**0.3088**	**0.1116**	**0.0637**	**0.2262**	**0.178**								
	F	**HT**	**FI**	**SQ**	**BFW**	**UFRP**	**WSV**	**WSV/CW**	**λ max**	**CI**	**CR**			
F	0.1116	0.1029	0.1116	0.1910	0.0754	0.0890	0.6816	6.1063						
HT	0.3349	0.3088	0.3349	0.3184	0.2262	0.3560	1.8792	6.0850						
FI	0.1116	0.1029	0.1116	0.1910	0.0754	0.0890	0.6816	6.1063	**6.0763**	**0.0153**	**0.01**			
SQ	0.0372	0.0618	0.0372	0.0637	0.1131	0.0593	0.3723	5.8472						
BFW	0.0558	0.3088	0.3349	0.1273	0.2262	0.3560	1.4091	6.2289						
UFRP	0.2233	0.1544	0.2233	0.1910	0.1131	0.1780	1.0831	6.0841						

Again, consistency for the given parameters that drive land degradation and land cover change entailed Deforestation (**D**), Settlements (**S)** Mining/infrastructure (**MI**); Migration (**M**) and Population Growth and Distribution (**PGD**) are given 12.94% respectively; Agriculture Expansion (**AE**) and Poverty (**P**) again received 7.34% weightings; Wood Extraction (**WE**) and Setting up Profit Oriented Industries (**SPOI**) obtained 4.12% weightings while Technology (**T**); Weak Governance, Monitoring & Enforcement Mechanisms (**WGMEM**) and Cultural Values, Behaviours and Beliefs (**CVBB**) received 4.12% weightings. Findings based on CR and CI show experts' judgements are pragmatic. Hence, results generated from the expert interviews can be used to validate findings from existing literature and spatial analysis.

3.5 Temperature Analysis

Figure 9 indicates temperature range on average was between 27.78^{o} C and 20.23 ^{o} C in the 1970s. However, the average temperature range for 1980s was between 30.44^{o} C and 27.78 ^{o} C, which could be attributed to biophysical factors (i.e., bushfires and prolonged dryness that occurred in the 1980s), which caused significant increase in surface temperatures in the study area. The range for the 1990s was between 28.88^{o} C and 25.45 ^{o} C. Average temperature range for 2000, 2010 and 2020 were between 30.12^{o} C and 23.67^{o} C, 31.66^{o} C and 24.44^{o} C, as well as 33.76^{o} C and 24.54^{o} C, respectively. Dark red and yellowish areas indicate areas with high or moderately high temperatures whilst dark blue areas represent low temperature regions with transient colour zones.

4. Discussion

4.1 Land use cover change in Southwestern Ghana

Per the conversions in various land cover types observed in Fig. 6-7 and Fig. 10-11, there is evidence of expansion in farmlands/shrubs and built-up areas over the given period. Additionally, previous studies, policy-driven initiatives and experts' assertion highlighted in Tables 7-8 respectively, illustrate recurrent changes in the study area. Findings based on geo-statistical analysis illustrated drastic increase in farmlands/shrubs (+369.81%) and built-up areas (+1288.36%) at the expense of a reduction in forested areas (-82%), waterbodies (-27%) and bare land (-18.06). Conversely, 73% of experts asserted that there has a decline in forest areas in Southwestern Ghana over the past 50 years. Results agree with the standpoints of Kusimi (2008), Damnyag et al. (2017), Kleemann et al. (2017), Acheampong et al. (2018) and Mensah et al. (2019), who attributed loss of forests areas over the past few decades to several socio-economic factors namely; rapid urbanization, population growth and distribution, influx of profit-oriented industries, agriculture and infrastructure expansion.

4.1.1 Contribution rate of change for the various indices (1970-2020) in Southwestern Ghana

The estimated NDVI range for the 1970s was between -0.96 and 1. The range for 1980s was between -0.97 and 0.79. The 1990s had a range of -0.93 and 0.81; 2000s had a range of -0.85 and 0.75; 2010 ranged between -0.87 and 0.70, and 2020 depicted an NDVI range of -0.90 and 0.64. Fig. 10 illustrates a steady decline in vegetative index over the study period. Larger values of NDVI represent forest areas due to higher green biomass of trees and other vegetation. These areas as observed over the study period (1970-2020) constitute mainly forest and wildlife reserves/parks, closed (dense) and open canopies. Decrease in NDVI based on study findings could be attributed to the main drivers highlighted in Table 7. Differences in measurement of vegetation in Southwestern Ghana was visualized in image differencing using NDVI over the given study periods. Areas marked with violet (Fig. 10) represent a highly negative change, thus, major reduction in vegetation cover as observed in the 1970s and 1980s. Such areas as depicted in Fig. 10 are subdued by the sea or built-up environment. Yellowish and greenish areas indicate areas with moderate and dense vegetation cover, respectively with an increasing rate of agricultural areas (between 2000 and 2020).

Figure 11 illustrates changes in NDBI over the study period in Southwestern Ghana. It is observed that NDBI ranged between -0.80 and 0.29 for the 1970s. The 1980s had an NDBI range between -0.77 and 0.37, and -0.75 to 0.49 for the 1990s. Again, the NDBI range for the 2000s was between -0.70 and 0.62. A significant increment was observed in 2010 when NDBI ranged between -0.85 and 0.77; NDBI range for 2020 was between -0.83 and 0.79. There is clear evidence of continuous expansion of settlements over the study period in the study area. Differences in measurement of built-up areas in Southwestern Ghana was visualized in image differencing using NDBI over the given study period. Dark red and yellowish areas indicate high presence of built-up environment. Light green and green areas represent areas covered by farmlands and shrubs as well as less dense vegetation. Dark blue areas represent areas covered by forest and wildlife reserves (deciduous and semi-deciduous zones) or water bodies as shown in Figure 11.

Given the results in Fig. 10 and Fig. 11, along with the contribution rate of change for the various classes among the given indices presented in Table 6, it is evident that built-up areas contributed the most to changes among other classes in NDBI (9.00) and NDVI (6.20), followed by farmlands/shrubs (0.33 and 0.54 in relation to the respective indices) with a decline in area coverage for the other classes over the given study period. Results presented in Table 6 shows continuous increase in built-up in the distribution for CRC depicted in Table 6 & Fig. 9 (LST) revealed a positive or direct relationship between built-up and LST.

4.2 Identified drivers of LUCC based on Confidence level results

In this study, results from LUCC analysis (Table 6), early studies (Table 7) and expert interviews revealed substantial increase in built-up areas. Geospatial analysis (Fig. 7 and Fig. 11) and observations in Table 9 shows built-up class (+1288.36%) was the highest contributor of change over the last 50 years among other classes. These undesirable and unprecedented changes are associated population growth, high rate of deforestation as a result of increasing settlements, LSM/ASM activities and development of socio-economic infrastructure, could influence long term consequences linked to land/soil degradation and climate variability. The distribution (Table 6) according to GSS (2020) shows an increase in population growth rate between 1960-1984 (2.1-3.2%), followed by a decline in 2000-2010 (2%). The area has experienced an annual growth rate of 6.5% (1960-2020), thereby validating experts' judgements and results from geospatial analysis conducted. Respondents affirmed there had been a remarkable increase in human population over the past 50 years. The rapid growth in population based on GSS (2020), Moller-Jensen and Knudsen (2008) and experts interviewed were attributed to migration of people from nearby regions and border towns of neighbouring countries. 53% asserted migration was the main cause of increasing population in the region, while 13% revealed high birth rate as the cause; with 33% attributing the reason to both migration and high birth rate. Studies highlighted above revealed people migrated to Southwestern Ghana for greener pastures. Common activities in the area include LSM/ASM, fisheries/agriculture and construction. Moller-Jensen and Knudsen (2008) and Owusu-Nimo et.al (2018) revealed population growth exacerbated pressure on land, minerals and forest resources in the region. Hence, the conversion of forests, bare land and areas covered by waterbodies into built-up (Fig. 7). Competing needs among relevant stakeholders have resulted in several unintended consequences, driving land and forest degradation through farming activities to boost exports, illegal logging of trees and chain sawing of timber plantations, coupled with LSM/ASM activities without prudent post-mining reclamation plans.

Considering the outcome presented in Table 9, it is evident that there is robust evidence and high agreement between the three methods. Spatial results (Fig. 7-8 and Fig. 10-11) present the contribution rates of various classes or indices (NDBI and NDVI) towards transitions and land or forest degradation. It can clearly be stated that there is "very high confidence" in the aforementioned drivers identified in this study. Results proved these economic driving forces causing unprecedented changes in the region are influenced by some macro and micro-economic factors, primarily state policies, aimed towards poverty alleviation or improving living standards, as presented in Table 7. Intensification and extensification of agricultural activities (Table 9) (Fig. 6 and Fig. 7) in the area over the study period have been linked to the citizenry resorting to use of traditional and reserved lands/forest reserves (encroaching protected areas) among other natural resources as the last means of employment. Damnyag et al. (2017) and Noponen et al. (2014) revealed increase in producer price of some commodities like cocoa on the international and domestic markets in recent times motivated most locals to venture into farming. This has resulted in cash cropping regimes, influencing land cover change in the area as several forests are cleared and burnt. Among the major crops cultivated in the area as revealed by experts and existing literature (Damnyag et al. 2017; Noponen et al. 2014) constitute cocoa, rubber, plantain, cassava and cocoyam. However, unfavourable climatic conditions coupled with rapid increase in LSM/ASM activities commonly known in local terms as "Galamsey (connotes gather and sell)", have propelled most of the youth to venture into mining instead of agriculture today. These factors have rendered most lands and soils unproductive.

Moreover, geospatial analysis presented in Fig. 6 and Fig. 7 between 1980 and 2000 presents significant changes through a reduction in areas covered by natural forests, and a substantial increase in farmlands/shrubs and built-up areas. Ghana in the early 1980s, specifically 1983 experienced famine along with recorded incidents of wildfires which claimed several forests and farmlands, thereby influencing prevailing micro-climatic conditions, specifically temperature (Fig. 9). Post-famine period saw the formulation and effective implementation of an "Economic Recovery and Stabilization Program (ERP) in 1983" that boosted agriculture with the intention of enhancing food production and improving living standards. Provision of basic amenities and construction of quality transportation networks was intensified. These policies within the said period caused several conversions and modification of several land cover types. Despite the amplitude of several structural transformation programs to change Ghana's economy (2000-2020) from a raw to a manufacturing/industrialized economy, the country's commitment to achieve the SDGs 1, 2, 13 and 15 in recent years have significantly altered land use processes and prevailing micro-climatic conditions in the region (Table 7) (Fig. 7) (Abbam et al. 2018; Aduah and Baffoe, 2013; Aduah et al. 2012; Logah et al. 2011). It was during the 1980-2000 era that natural factors significantly influenced these modifications. From the lens of the pessimists, despite increasing temperature and recorded incidents of flood events in recent periods (Abbam et al. 2018; Damnyag et al. 2017), major events like prolonged dryness, wildfires, among others, degraded most lands and rendered most areas unproductive. Extensiveness of agricultural activities (Fig. 6) (Table 8) due to massive clearing of forest areas, coupled with slash and burn have exposed several top-soils to wild fires, thereby reducing their fertility. These have partly accounted for the decline in cocoa and other cash crops productivity in recent years. Ghana recorded 1 million tonnes of cocoa production in 2012, with two-thirds of this production evolving from Southwestern Ghana. In recent years, cocoa production in the area has been declining mainly as a result of these drivers causing modifications and land degradation. Results from the table of confidence (Table 9) exhibited "very high-to-very low confidence" in some biophysical factors like temperature, bushfires, floods and soil quality, respectively. The distribution shows there was limited evidence provided by at least one method. Hence, providing "very high-to-very low confidence" for most direct and indirect drivers identified using the three (3) methods. There was however no spatial information on other natural factors other than temperature (Fig. 9), which may partly influence confidence in results despite expert interviews and existing studies presenting evidence and agreement levels. With "very high confidence" changes in temperature based on spatial analysis, expert interviews and literature review (Table 7) (Table 9) (Abbam et al. 2018; Aduah and Baffoe 2013; Aduah et al. 2012) show temperature as a climatic variable with spatiotemporal attributes are capable of driving land cover change and land degradation. In the same vein, there was agreement in results from the expert interviews and existing literature, in relation to other contributory factors like institutional/political (governance structures, monitoring and enforcement mechanisms), technology (science and research, agroforestry, climate-smart agriculture, mining operations, transportation networks and technical efficiency) as well as cultural and behavioural (lifestyle, beliefs, traditions and perception) factors. Evidence from these two methods, coupled with the level of agreement between them proved there is "medium confidence" in the drivers identified. This eventually shows evidence provided to ascertain major influences of LULD are valid and reliable based on the qualitative and quantitative strategies used.

Damnyag et al. (2017) reported that political and technological factors could sooner or later become dominant drivers from the pessimist and optimist perspective. They attributed reasons to current trends and advocacy for intensive scientific research and innovation to enhance productivity aimed at meeting global demands. We considered technological, cultural and behavioural factors which are often overlooked or deemed irrelevant in LULD studies as drivers that could be further analysed and addressed against the unknown. Based on the aforementioned reasons, it is becoming increasingly evident that biophysical (emanating from climate disturbances/stressors), cultural and technological factors that had "medium-to-very low confidence" (Table 9) could potentially influence food security, land/water resources and livelihoods in the near future. Therefore, these parameters cannot be overlooked since in the distant future, they could be dominant in causing significant changes to land cover systems and forest resources.

Table 11 presents the strengths and limitations of individual methods that could affect the validity and reliability of study findings. Consequently, the adoption of MMA for analysing the main drivers of land cover change and land degradation provides the needed platform for comparative studies. In the present study, we demonstrated that a combination of expert interviews, literature review and spatial analysis can be used to assess and improve confidence in results. Expert interviews and AHP through the use of questionnaires, were used to bridge paucity of information in existing literature and spatial analysis. Geospatial analysis provided vivid details of changes on the ground (Rindfuss and Stern 1998). This complements the limitation of subjectivity in the other two qualitative research strategies. Again, results from most qualitative research strategies are often regarded as less reliable based on several discretionary factors (Haradhan 2018; Queirós et al. 2017). Weight of importance are given to outcomes generated by quantitative tools. Qualitative methods used in this study aim at deepening our understanding on factors that cannot be quantified with high rate of flexibility and exploratory analysis (Haradhan 2018; Queirós et al. 2017). The AHP was used to assign weights to expert judgements, thereby ensuring consistency or accuracy in findings to limit subjectivity. Contextually, satellite imagery is limited in identifying indirect/underlying factors that drive LULD. Here, we resorted to merge both strategies (Table 9), adhering to the strengths of these methods and restricting the limitations in the use of these methods to ensure "high confidence" in findings.

Table 11
Strengths and limitations of various methods used in our study

Method	Strengths	Limitations
Summary of Literature	-Entails thematic areas that cover the overall scope of this study and studies linked to land use/ climate variability. - This approach was used to describe land use studies and methodologies, carried out in the study area. Studies used either support (build) or reject existing knowledge/propositions.	-Most studies on Land use conducted in SW Ghana are limited to small areas with limited scope. -Approaches used in most of the studies differ from one another. -May have overlooked some other relevant studies which are not found in most common journals or institutional platforms and databases.
Expert Interviews	-Using semi-structured questionnaires, primarily focused on major influences in SW Ghana that drive LUCC. It was employed as an approach to validate results from the other two-methods used. -Provided information about both indirect/underlying (non-spatial) factors that influenced LUCC to bridge knowledge gaps in the other methods and deepen our understanding about the subject matter. -Scientific background and professional capacity of experts made it feasible and easy to filter irrelevant information based on inputs given. -Concept of “think globally” and “act locally” is adhered to considering land use being considered as a mesoscale element and driver of global climate/environmental change. This approach has a high rate of flexibility and exploratory in its analysis (Queirós et al. 2017) -Use of general academic and technical words which respondents were familiar with.	-Cultural and behavioural concerns mainly due to the pandemic (COVID-19). -Definition of experts as stipulated in this study may be relative/discretional. -Despite most interviewees having technical & social science backgrounds, some other drivers which may be known to some other knowledge groups might have been omitted/overlooked.
Geo-spatial analysis	-Use of statistics and change detection among the classes used to provide relevant information on spatial distribution of the drivers.	-Limited assessment of indirect (non-spatial) drivers of LUCC. -Require detailed/advanced datasets to provide more details on multiple factors influencing LUCC. Example: Identify social and economic factors which contributed most to the substantial increase in built up.

5. Conclusion

The paper primarily analyses local drivers that influence land cover change and land degradation in Southwestern Ghana using the mixed method approach. Conducting studies on microclimates related to LUCC is quite challenging. Local studies of this nature are fundamental to understanding the global earth systems and climate dynamics, along with the courses of action that need to be designed to ensure consistency with scientific explanations. Understanding direct and indirect drivers of LUCC along with its dynamics and prospect are essential in attaining United Nation’s Sustainable Development Goals. Advocacy and concerns in the wake of our changing climate and observable changes in the earth system propel the need for further research that improves existing knowledge, innovation and inform the decisions of city planners, Municipal authority, researchers and interested organizations. Findings would enrich basic datasets that would assist land use planners and strategists in future modelling of land use systems. Based on results obtained using the MMA, it can be concluded that:

- A substantial increase in built-up and farmlands/shrubs areas have contributed to forests and LUCC in the study area.
- Contribution rate of change analysis revealed built-up areas contributed the most among other classes for the given indices.
- Change in prevailing microclimatic conditions, specifically surface temperature can be attributed to the undesirable and unprecedented changes in land use systems over the past 50 years.
- Biophysical, cultural and technological factors can be considered as key drivers despite the “medium-to-very low confidence” in results obtained, as they could potentially impact climate sensitive sectors that could significantly modify land use processes.

We presented an objective and a detailed framework to enhance reliability and validity of study findings using confidence level analysis. The underlying theories for the present study are anchored in sustainable livelihood frameworks, FTT, land use/land degradation and sustainable development. Therefore, the key drivers of LUCC that poses threats to livelihoods, ecosystem services can be examined holistically using an interdisciplinary approach to solve basic problems that stem regions without incurring unintended consequences. The present study hereby proposes further analyses of LUCC drivers with “medium to very low” confidence levels for further action. Again, local or regional studies of this nature influence global studies (international scientific community) by highlighting valid and reliable contributions or actions at the local or regional levels that drives significant change.

Declarations

Data Availability

Data that support study findings are available, and would be shared upon request.

Acknowledgement

The authors wish to express their sincere gratitude to Nanjing University of Information Science and Technology (NUIST) for making available relevant materials and creating an enabling environment, needed to complete this research. Special thanks go to the Research Institute for History of Science & Technology, School of Law and Public Affairs for making available the datasets used for this study. This work was supported by the National Natural Science Foundation of China (No. 41971340 and No.41271410). The authors would like to thank the handling editor and anonymous reviewers for their careful reviews and helpful remarks.

Conflict of Interest

The authors declare that they have no competing interests.

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Annex Ii

Annex II: Ground-truthing sample points using MDC for each class in the study domain

Town Name	Land Cover Type	Latitude	Longitude
Abochia	Forest	5.7724304	-2.7417033
Abochia	Waterbodies	5.7747888	-2.7373905
Aboi Nkwanta	Farmlands/Shrubs	5.7731764	-2.4790277
Aboi Nkwanta	Farmlands/Shrubs	5.7757688	-2.4720021
Aboi Nkwanta	Bare land	5.7909471	-2.4638667
Aboi Nkwanta	Farmlands/Shrubs	5.7867807	-2.4662858
Aboi Nkwanta	Farmlands/Shrubs	5.795318	-2.459068
Aboi Nkwanta	Built-up	5.7976689	-2.4550062
Aboi Nkwanta	Bare land	5.8016515	-2.4493658
Abokyia	Built-up	5.7721831	-2.7444794
Abora	Built-up	5.6247933	-2.223478
Abora	Farmlands/Shrubs	5.6247933	-2.223478
Abora	Built-up	5.6247933	-2.223478
Abora	Farmlands/Shrubs	5.6247933	-2.223478
Achichire	Built-up	5.7116363	-2.3274181
Achichire	Farmlands/Shrubs	5.7038642	-2.3239394
Achichire	Farmlands/Shrubs	5.6752853	-2.3058358
Achichire	Farmlands/Shrubs	5.6645194	-2.2980422
Achimfo	Bare land	5.778455	-2.7310312
Achimfo	Forest	5.7794714	-2.7303202
Achimfo	Waterbodies	5.7824016	-2.7297608
Achimfo	Built-up	5.7828116	-2.726489
Achimfo	Built-up	5.7831558	-2.7276108
Achimfo	Forest	5.7833488	-2.7290849
Achimfo	Bare land	5.778695	-2.7309494
Achimfo	Waterbodies	5.77784	-2.7319652
Achimfo	Forest	5.7761414	-2.7332229
Achimfo	Forest	5.7749629	-2.7340713
Achimfo	Forest	5.7750415	-2.7378088
Adjakaa	Farmlands/Shrubs	5.7731549	-2.7626148
Adjakaa	Built-up	5.7728571	-2.7612506
Adjakaa	Built-up	5.7726524	-2.7601049
Adjakaa	Forest	5.7722928	-2.7570706
Adjakaa	Waterbodies	5.7722473	-2.7566832
Adjakaa	Built-up	5.7723433	-2.7526647
Adjakaa	Bare land	5.7726107	-2.7517878
Adjakaa	Built-up	5.7718865	-2.7482012
Adjakaa	Farmlands/Shrubs	5.7729035	-2.7412537
Adjakaa	Built-up	5.7722726	-2.7435331
Adjakaa	Farmlands/Shrubs	5.7727648	-2.75002
Adjakaa	Bare land	5.7728384	-2.7505657
Adjakaa	Farmlands/Shrubs	5.7723826	-2.7529477
Adjakaa	Farmlands/Shrubs	5.7723826	-2.7529477
Adjakaa	Farmlands/Shrubs	5.7723271	-2.7567217
Adjakaa	Built-up	5.772843	-2.7610071
Adjakaa	Farmlands/Shrubs	5.774871	-2.763657
Adjakaa	Forest	5.7762445	-2.7642983
Adjakaa	Farmlands/Shrubs	5.7789471	-2.7675303
Adjakaa	Farmlands/Shrubs	5.7801503	-2.7700112
Adjakaa	Farmlands/Shrubs	5.7806319	-2.7725103
Adjakaa	Farmlands/Shrubs	5.7809644	-2.7743215
Adjakaa	Farmlands/Shrubs	5.7812677	-2.7759535
Adjakaa	Bare land	5.7816694	-2.7781994
Adjakaa	Forest	5.7815595	-2.7810551
Agona	Bare land	4.9795824	-2.002476
Agona	Forest	4.9604026	-1.9798008
Agona	Built-up	4.948206	-1.9789434
Agona	Bare land	4.9307693	-1.9773826
Agona	Forest	4.9294022	-1.9772507
Agona nkwanta	Forest	4.9242317	-1.9775407
Agona nkwanta	Built-up	4.9042831	-1.9703604
Agona nkwanta	Built-up	4.890716	-1.959516
Agona nkwanta	Farmlands/Shrubs	4.8960616	-1.9337102
Agona nkwanta	Built-up	4.9014313	-1.9118607
Agona nkwanta	Waterbodies	4.9017983	-1.9058699
Agona nkwanta	Built-up	4.8919269	-1.8650352
Agona nkwanta	Farmlands/Shrubs	4.892803	-1.8481021
Agona nkwanta	Built-up	4.8926576	-1.8228637
Agona nkwanta	Built-up	4.9077653	-1.7985792
Amenfi central	Forest	5.6314968	-2.2367701
Amenfi central	Bare land	5.6320024	-2.2288169

Amenfi central	Built-up	5.6312013	-2.22762
Amoakrom	Farmlands/Shrubs	5.7628641	-2.4101565
Amoakrom	Farmlands/Shrubs	5.7613876	-2.4052803
Amoakrom	Forest	5.7594411	-2.3998685
Amoakrom	Built-up	5.7569353	-2.396663
Amoamang	Farmlands/Shrubs	5.7671017	-2.4998874
Amoamang	Built-up	5.7695093	-2.4898881
Amoamang	Built-up	5.7689285	-2.4917864
Amoamang	Built-up	5.7745352	-2.4753451
Asan	Forest	5.7796136	-2.7125955
Asan	Farmlands/Shrubs	5.7837252	-2.7051619
Asan	Farmlands/Shrubs	5.7876262	-2.6974838
Asan	Built-up	5.7907073	-2.6923852
Asan	Farmlands/Shrubs	5.7952261	-2.6819038
Asankagua	Forest	5.7815053	-2.7915585
Asankagua	Farmlands/Shrubs	5.7820792	-2.7894839
Asankagua	Farmlands/Shrubs	5.7815712	-2.7839699
Asankagua	Farmlands/Shrubs	5.779979	-2.7696997
Asankragua	Built-up	5.8037103	-2.4474133
Asankragua	Built-up	5.8063783	-2.4459083
Asankragua	Built-up	5.8093825	-2.438074
Asankragua	Built-up	5.8078821	-2.4352706
Asankragua	Built-up	5.8054283	-2.432525
Asankragua	Built-up	5.8069744	-2.4340065
Asankragua	Bare land	5.7935903	-2.427006
Asankragua	Farmlands/Shrubs	5.7910534	-2.4235698
Asankragua	Bare land	5.7768976	-2.4191112
Asankragua	Farmlands/Shrubs	5.7656394	-2.4141844
Asantekrom	Built-up	5.7765948	-2.6216944
Asantekrom	Farmlands/Shrubs	5.7731084	-2.6085383
Asantekrom	Farmlands/Shrubs	5.7740441	-2.6109621
Asantekrom	Farmlands/Shrubs	5.7696406	-2.601916
Asantekrom	Built-up	5.7676215	-2.6004611
Bawdie	Farmlands/Shrubs	5.6247933	-2.223478
Bawdie	Forest	5.6247933	-2.223478
Bawdie	Forest	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Farmlands/Shrubs	5.6247933	-2.223478
Bawdie	Farmlands/Shrubs	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Bare land	5.6247933	-2.223478
Bawdie	Bare land	5.6247933	-2.223478
Bawdie	Farmlands/Shrubs	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Farmlands/Shrubs	5.6247933	-2.223478
Bawdie	Bare land	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Farmlands/Shrubs	5.6247933	-2.223478
Bawdie	Waterbodies	5.6247933	-2.223478
Bawdie	Farmlands/Shrubs	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Built-up	5.6247933	-2.223478
Bawdie	Built-up	5.3210119	-1.9858939
Bawdie	Bare land	5.3170418	-1.9891407
Bawdie	Built-up	5.3137893	-1.9905549
Bawdie	Built-up	5.308967	-1.993578
Bawdie	Built-up	5.306455	-1.9949467
Bawdie	Built-up	5.306088	-1.9941129
Beposo	Built-up	5.117733421	-1.620969462
Beposo	Waterbodies	5.123176862	-1.617846847
Beposo	Built-up	5.123848452	-1.613322879
Beposo	Farmlands/Shrubs	5.123794395	-1.609115739
Beposo	Farmlands/Shrubs	5.123946226	-1.606856831
Beposo	Farmlands/Shrubs	5.121201241	-1.603611216
Beposo	Farmlands/Shrubs	5.119131043	-1.603644784
Beposo	Farmlands/Shrubs	5.110649444	-1.600790656
Bogoso	Forest	5.6247933	-2.223478

Bogoso	Farmlands/Shrubs	5.6247933	-2.223478
Bogoso	Farmlands/Shrubs	5.6247933	-2.223478
Bogoso	Built-up	5.6247933	-2.223478
Bogoso	Forest	5.6247933	-2.223478
Bogoso	Bare land	5.6315684	-2.2280839
Bogoso	Farmlands/Shrubs	5.6247933	-2.223478
Bogoso	Built-up	5.6247933	-2.223478
Bogoso	Built-up	5.6247933	-2.223478
Bogoso	Farmlands/Shrubs	5.6247933	-2.223478
Bogoso	Waterbodies	5.6247933	-2.223478
Bonsa	Waterbodies	5.1805041	-2.0429004
Bonsa	Built-up	5.1786821	-2.0449472
Bonsa	Farmlands/Shrubs	5.1775916	-2.04999
Bonsa	Forest	5.1742762	-2.0526224
Bonsa	Farmlands/Shrubs	5.1715467	-2.0547386
Bonsa	Forest	5.1702977	-2.0607458
Bonsa	Farmlands/Shrubs	5.1659001	-2.0694848
Bonsa	Built-up	5.158224	-2.0751867
Bonsa	Built-up	5.1555357	-2.0757217
Bonsa	Farmlands/Shrubs	5.1522493	-2.0792259
Bonsa	Forest	5.1513079	-2.0814549
Bonsa	Bare land	5.1479521	-2.0846719
Bonsa	Farmlands/Shrubs	5.1450881	-2.0865302
Bonsa	Bare land	5.1373192	-2.091567
Bonsa	Farmlands/Shrubs	5.1347235	-2.0950671
Bonsa	Bare land	5.1339535	-2.0951517
Bonsa	Built-up	5.1311083	-2.095586
Bonsa	Forest	5.040257	-2.0871845
Bonsa	Forest	5.00367	-2.0680619
Bonsa	Forest	5.0021238	-2.0622763
Bonsa	Forest	5.0030167	-2.0480745
Bonsa	Built-up	4.8990194	-1.9643569
Bonsa	Farmlands/Shrubs	4.8972505	-1.9621961
Bonsa	Built-up	4.8907609	-1.9554344
Bonsa	Farmlands/Shrubs	4.891974	-1.9486254
Bonsa	Built-up	4.8992058	-1.9012358
Bonsa	Built-up	4.8947931	-1.8970939
Bonsa	Built-up	4.8921061	-1.8188959
Bonsa	Bare land	4.8991231	-1.8045651
Bonsa	Forest	5.126423	-2.0990707
Bonsa	Bare land	5.1012162	-2.1123051
Bonsa	Forest	5.0983034	-2.1108655
Bonsa	Built-up	5.083397	-2.1098058
Bonsa	Forest	5.0815369	-2.1097138
Bonsa	Forest	5.0378687	-2.0870709
Bonsa	Forest	5.0059842	-2.0765298
Bonsa	Forest	4.9754866	-1.9974092
Brodzekrom	Built-up	5.749773	-2.3953311
Brodzekrom	Bare land	5.7471044	-2.3943361
Brodzekrom	Forest	5.7454052	-2.3911821
Brodzekrom	Farmlands/Shrubs	5.7449032	-2.3894228
Brodzekrom	Farmlands/Shrubs	5.7439919	-2.3870871
Daboase	Farmlands/Shrubs	5.111464612	-1.632404093
Daboase	Bare land	5.112116687	-1.630525318
Daboase	Bare land	5.11215884	-1.629173686
Daboase	Farmlands/Shrubs	5.112839892	-1.623764691
Daboase	Farmlands/Shrubs	5.114032808	-1.622196952
Daboase	Built-up	5.115987034	-1.621303913
Densam	Farmlands/Shrubs	5.6976839	-2.3175873
Densam	Built-up	5.6830614	-2.3102984
Densam	Forest	5.6708519	-2.3029933
Densam	Farmlands/Shrubs	5.6685109	-2.3012083
Densam	Forest	5.6556802	-2.2923515
Densam	Forest	5.6518927	-2.2890249
Densam	Built-up	5.6403035	-2.2641269
Densam	Built-up	5.6344357	-2.2533786
Densam	Built-up	5.633259	-2.2475251
Densam	Farmlands/Shrubs	5.6247933	-2.223478
Densam	Farmlands/Shrubs	5.6247933	-2.223478
Densam	Farmlands/Shrubs	5.6247933	-2.223478
Densam	Built-up	5.6247933	-2.223478
Elubo	Farmlands/Shrubs	5.7761464	-2.7925709

Elubo	Forest	5.7742342	-2.7355266
Elubo	Built-up	5.7830923	-2.7278872
Elubo road	Forest	5.7779138	-2.794478
Enchi	Built-up	5.8218236	-2.823244
Enchi	Bare land	5.8187036	-2.8250094
Enchi	Farmlands/Shrubs	5.81723	-2.8244014
Enchi	Built-up	5.8138331	-2.8249005
Enchi	Forest	5.7971596	-2.8128529
Enchi	Farmlands/Shrubs	5.7882961	-2.8082597
Enchi	Farmlands/Shrubs	5.782555	-2.800649
Enchi	Built-up	5.7812364	-2.795622
Enchi	Built-up	5.7818456	-2.7985412
Enchi	Farmlands/Shrubs	5.7839101	-2.8020767
Enchi	Bare land	5.7850223	-2.8049192
Enchi	Forest	5.7873294	-2.8074895
Enchi	Farmlands/Shrubs	5.7911184	-2.811428
Enchi	Farmlands/Shrubs	5.7931413	-2.8123355
Enchi	Bare land	5.7952845	-2.8126209
Enchi	Farmlands/Shrubs	5.797293	-2.8128019
Enchi	Built-up	5.7993413	-2.8146221
Enchi	Farmlands/Shrubs	5.8013314	-2.8175672
Enchi	Bare land	5.801264	-2.8197241
Enchi	Bare land	5.8019052	-2.8222639
Enchi	Built-up	5.8041878	-2.8245258
Enchi	Bare land	5.8067581	-2.8264036
Enchi	Built-up	5.8117791	-2.8239717
Enchi	Built-up	5.8165268	-2.8254751
Enchi	Built-up	5.8212664	-2.8241698
Enchi	Built-up	5.8210413	-2.8237789
Enchi	Forest	5.7903133	-2.810635
Enchi	Farmlands/Shrubs	5.7824391	-2.785523
Enchi	Bare land	5.7826888	-2.7863125
Enchi	Bare land	5.7825047	-2.7881924
Enchi	Bare land	5.7822519	-2.7891373
Enchi	Farmlands/Shrubs	5.8151338	-2.825148
Enchi	Built-up	5.8152138	-2.8249673
Enchi	Waterbodies	5.8193689	-2.8252261
Fiaseman	Built-up	5.2934604	-1.9974524
Fiaseman	Built-up	5.2892638	-1.9983913
Fiaseman	Built-up	5.2859559	-2.0004871
Fiaseman	Built-up	5.2791985	-2.0030336
Fiaseman	Built-up	5.2720263	-2.0067614
Fiaseman	Built-up	5.2668272	-2.0065923
Fiaseman	Built-up	5.2640872	-2.0059469
Fiaseman	Built-up	5.2609297	-2.0041441
Fiaseman	Built-up	5.258688	-2.0035201
Fiaseman	Bare land	5.2533505	-2.0045141
Fiaseman	Built-up	5.2455448	-2.0065081
Fiaseman	Bare land	5.2444319	-2.0069979
Fiaseman	Farmlands/Shrubs	5.2402845	-2.0094957
Fiaseman	Built-up	5.237618	-2.0111993
Fiaseman	Built-up	5.2337935	-2.0127482
Fiaseman	Farmlands/Shrubs	5.2260888	-2.0167859
Fiaseman	Forest	5.2218063	-2.0201238
Gran	Forest	5.7178788	-2.3514529
Gran	Farmlands/Shrubs	5.715202	-2.3470061
Gran	Farmlands/Shrubs	5.7175327	-2.3359171
Gran	Farmlands/Shrubs	5.6922546	-2.3115557
Hiawa	Built-up	5.6247933	-2.223478
Hiawa	Built-up	5.6247933	-2.223478
Hiawa	Built-up	5.6247933	-2.223478
Hiawa	Farmlands/Shrubs	5.6247933	-2.223478
Hiawa	Farmlands/Shrubs	5.6247933	-2.223478
Hiawa	Farmlands/Shrubs	5.6247933	-2.223478
Hiawa	Waterbodies	5.6247933	-2.223478
Hiawa	Farmlands/Shrubs	5.6247933	-2.223478
Hiawa	Built-up	5.6247933	-2.223478
Huni Ano	Farmlands/Shrubs	5.6247933	-2.223478
Huni Ano	Forest	5.6247933	-2.223478
Huni Ano	Built-up	5.6247933	-2.223478
Huni Ano	Built-up	5.6247933	-2.223478
Huni Ano	Bare land	5.6247933	-2.223478

Huni Ano	Bare land	5.6247933	-2.223478
Jomoro Enchi	Farmlands/Shrubs	5.7651643	-2.5994983
Jomoro Enchi	Built-up	5.7604142	-2.5922528
Jomoro Enchi	Farmlands/Shrubs	5.7602436	-2.5903879
Jomoro Enchi	Bare land	5.7605395	-2.5881754
Jomoro Enchi	Forest	5.7623849	-2.5777847
K Boateng	Forest	5.6628668	-2.2963313
K Boateng	Forest	5.6604762	-2.2955102
K Boateng	Built-up	5.6531527	-2.2918049
K Boateng	Forest	5.6485145	-2.2744123
K Boateng	Forest	5.6315369	-2.2410895
K Boateng	Bare land	5.6300531	-2.2269643
K Boateng	Farmlands/Shrubs	5.6247933	-2.223478
K Boateng	Farmlands/Shrubs	5.7375434	-2.3802338
K Boateng	Forest	5.7247883	-2.3644376
K Boateng	Forest	5.7269672	-2.3665777
K Boateng	Forest	5.7245246	-2.3621037
K Boateng	Farmlands/Shrubs	5.7242997	-2.3600675
K Boateng	Farmlands/Shrubs	5.7198934	-2.3546139
Mando Amenfi	Forest	5.64882	-2.276025
Mando Amenfi	Forest	5.6460341	-2.2694278
Mando Amenfi	Built-up	5.6434423	-2.268532
Mando Amenfi	Forest	5.6321434	-2.2427021
Mando Amenfi	Forest	5.6306463	-2.2390589
Mempeasem	Bare land	5.2214854	-2.0202423
Mempeasem	Bare land	5.2192204	-2.0212039
Mempeasem	Farmlands/Shrubs	5.2066628	-2.0281055
Mempeasem	Bare land	5.1958116	-2.0321357
Mempeasem	Farmlands/Shrubs	5.1888986	-2.036978
Mempeasem	Bare land	5.1869638	-2.0384229
Mempeasem	Built-up	5.182622	-2.0415238
Nsuaem	Bare land	4.8925694	-1.8928628
Nsuaem	Farmlands/Shrubs	4.8920418	-1.888316
Nsuaem	Bare land	4.8934211	-1.834469
Nsuaem	Forest	5.0568485	-2.0970696
Nsuaem	Built-up	5.030064	-2.08665
Nsuaem	Farmlands/Shrubs	5.0052443	-2.0738555
Nsuaem	Built-up	5.0027138	-2.0252646
Nsuaem	Forest	4.9921162	-2.0182028
Nsuaem	Forest	5.0043177	-2.0703931
Nsuaem	Built-up	5.004357	-2.0357449
Nsuaem	Forest	4.9975721	-2.0230747
Nsuaem	Forest	4.9957281	-2.0220048
Nsuaem	Farmlands/Shrubs	4.9840114	-2.0080939
Nya	Farmlands/Shrubs	5.7872277	-2.6717185
Nya	Built-up	5.3253847	-1.9825107
Nya	Bare land	5.7346415	-2.3773603
Nya	Forest	5.7064848	-2.3246181
Nyametiase	Farmlands/Shrubs	5.6247933	-2.223478
Nyametiase	Built-up	5.6247933	-2.223478
Nyametiase	Farmlands/Shrubs	5.6247933	-2.223478
Nyametiase	Built-up	5.6247933	-2.223478
Nyametiase	Built-up	5.6247933	-2.223478
Nyametiase	Built-up	5.6247933	-2.223478
Nyametiase	Bare land	5.6247933	-2.223478
Nyametiase	Bare land	5.7302564	-2.372268
Nyametiase	Farmlands/Shrubs	5.6584121	-2.2941531
Nyametiase	Farmlands/Shrubs	5.6522835	-2.2882657
Nyametiase	Forest	5.6247933	-2.223478
Nyametiase	Waterbodies	5.6247933	-2.223478
Nyametiase	Farmlands/Shrubs	5.6247933	-2.223478
Nyametiase	Built-up	5.6247933	-2.223478
Nyametiase	Built-up	5.6247933	-2.223478
Nyametiase	Farmlands/Shrubs	5.6247933	-2.223478
Pantoso	Waterbodies	5.7698637	-2.5709487
Pantoso	Built-up	5.7703918	-2.568473
Pantoso	Forest	5.7708073	-2.5604985
Pantoso	Farmlands/Shrubs	5.7713379	-2.5591144
Pantoso	Built-up	5.7724658	-2.5334899
Pantoso	Built-up	5.772795	-2.540285
Pantoso	Built-up	5.7743097	-2.5313814
Pantoso	Farmlands/Shrubs	5.7731143	-2.5196096

Pantoso	Farmlands/Shrubs	5.7719406	-2.5138868
Pantoso	Bare land	5.7688464	-2.5098793
Pantoso	Farmlands/Shrubs	5.7674725	-2.5011995
Petepon	Built-up	5.6247933	-2.223478
Petepon	Built-up	5.6247933	-2.223478
Petepon	Built-up	5.6247933	-2.223478
Petepon	Farmlands/Shrubs	5.6247933	-2.223478
Petepon	Forest	5.6247933	-2.223478
Petepon	Built-up	5.6247933	-2.223478
Petepon	Built-up	5.6247933	-2.223478
Petepon	Built-up	5.6247933	-2.223478
Petepon	Forest	5.6247933	-2.223478
Petepon	Waterbodies	5.6247933	-2.223478
Petepon	Bare land	5.6247933	-2.223478
Petepon	Built-up	5.6247933	-2.223478
Petepon	Farmlands/Shrubs	5.6394875	-2.2613292
Petepon	Built-up	5.6326585	-2.2356167
Petepon	Forest	5.6337014	-2.2329625
Petepon	Forest	5.6281978	-2.224905
Petepon	Farmlands/Shrubs	5.6247933	-2.223478
Petepon	Built-up	5.6247933	-2.223478
Petepon	Farmlands/Shrubs	5.6247933	-2.223478
Petepon	Farmlands/Shrubs	5.6247933	-2.223478
Samahu	Built-up	5.6247933	-2.223478
Sekondi	Bare land	4.981071746	-1.703316041
Sekondi	Built-up	4.98384578	-1.690543684
Sekondi	Built-up	4.986396853	-1.686009185
Sekondi	Forest	4.989351823	-1.684250038
Sekondi	Built-up	4.993914186	-1.681770255
Sekondi	Built-up	4.995510854	-1.680833392
Sekondi	Waterbodies	4.996225596	-1.680481145
Sekondi	Bare land	5.011633193	-1.667837511
Sekondi	Farmlands/Shrubs	5.017023195	-1.664991567
Sekondi	Farmlands/Shrubs	5.033433115	-1.662371466
Sekondi	Bare land	5.034443731	-1.661812642
Sekondi	Bare land	5.039296842	-1.659257281
Sekondi	Built-up	5.046485183	-1.659906999
Sekondi	Built-up	5.050055196	-1.65992817
Sekondi	Farmlands/Shrubs	5.053968141	-1.659103704
Sekondi	Bare land	5.056765328	-1.65834984
Sekondi	Bare land	5.059147487	-1.657683855
Sekondi	Farmlands/Shrubs	5.061423299	-1.657446956
Sekondi	Farmlands/Shrubs	5.063263997	-1.657815816
Sekondi	Built-up	5.064566773	-1.657765225
Sekondi	Farmlands/Shrubs	5.066531208	-1.657236498
Sekondi	Farmlands/Shrubs	5.072636144	-1.659077986
Sekondi	Farmlands/Shrubs	5.08231858	-1.656875289
Sekondi	Bare land	5.083264577	-1.656258935
Sekondi	Built-up	5.08836956	-1.650408756
Sekondi	Waterbodies	5.088590326	-1.649589901
Sekondi	Waterbodies	5.089008602	-1.648259838
Sekondi	Farmlands/Shrubs	5.092449905	-1.644865958
Sekondi	Bare land	5.094907875	-1.642610056
Sekondi	Bare land	5.100080991	-1.639969148
Sekondi	Forest	5.105918685	-1.636545206
Sekondi	Forest	5.10676712	-1.635252277
Simpa	Forest	4.9671108	-1.982734
Simpa	Farmlands/Shrubs	4.8961903	-1.9613612
Simpa	Forest	5.124434	-2.0996887
Simpa	Forest	5.1208471	-2.1004563
Simpa	Farmlands/Shrubs	5.1183377	-2.1031483
Simpa	Built-up	5.1116846	-2.1095497
Simpa	Forest	5.0028389	-2.065024
Simpa	Forest	5.0019133	-2.0579305
Simpa	Built-up	5.0048309	-2.0312886
Simpa	Built-up	5.0000172	-2.0241244
Simpa	Forest	4.9945834	-2.021352
Simpa	Forest	4.9880901	-2.0132058
Simpa	Forest	4.9775376	-1.9999298
Simpa	Forest	4.964483	-1.9805508
Simpa	Forest	4.9450753	-1.9787513
Simpa	Farmlands/Shrubs	4.9323343	-1.9775734

Simpa	Built-up	4.9228056	-1.9781813
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Simpa	Farmlands/Shrubs	4.8916177	-1.8751595
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Simpa	Built-up	4.9111059	-1.7905588
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Simpa	Farmlands/Shrubs	5.074902	-2.1037855
Simpa	Built-up	5.0593333	-2.0978323
Simpa	Forest	5.0351012	-2.0869449
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Sureso	Farmlands/Shrubs	5.7421022	-2.3846263
Sureso	Farmlands/Shrubs	5.7403294	-2.3823464
Sureso	Built-up	5.7324284	-2.374951
Sureso	Farmlands/Shrubs	5.7288055	-2.3696199
Sureso	Farmlands/Shrubs	5.7151425	-2.3406464
Sureso	Forest	5.7171815	-2.3309613
Takoradi	Built-up	4.902413017	-1.757937547
Takoradi	Built-up	4.900615895	-1.753039743
Takoradi	Bare land	4.901706137	-1.753217088
Takoradi	Built-up	4.902714391	-1.761149546
Takoradi	Built-up	4.917378186	-1.768600407
Takoradi	Built-up	4.931854443	-1.762745326
Takoradi	Bare land	4.936431517	-1.756667313
Takoradi	Farmlands/Shrubs	4.943385074	-1.752279565
Takoradi	Waterbodies	4.959675202	-1.736686621
Takoradi	Built-up	4.965007662	-1.733043819
Takoradi	Built-up	4.966636212	-1.728443967
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Takoradi	Built-up	4.973188531	-1.716764645
Takoradi	Bare land	4.976964337	-1.715101399
Takoradi	Built-up	5.0050532	-2.028768
Takoradi	Forest	4.9658955	-1.9816799
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Takoradi	Bare land	4.892615	-1.8518078
Takoradi	Built-up	4.8931455	-1.8266697
Takoradi	Forest	5.0862533	-2.108585
Takoradi	Forest	5.080348	-2.1092255
Takoradi	Built-up	5.0691614	-2.0982327
Takoradi	Forest	5.0679345	-2.0973289
Takoradi	Forest	5.0619644	-2.0973
Takoradi	Forest	5.0520178	-2.093893
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Takoradi	Forest	4.96908	-1.98471
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Takoradi	Built-up	4.9096871	-1.9731285
Takoradi	Built-up	4.9094282	-1.7947036
Takoradi	Forest	5.0644825	-2.0966642
Takoradi	Forest	5.0499747	-2.0925606
Takoradi	Forest	5.0021585	-2.0558429
Takoradi	Forest	5.0036057	-2.0420698
Takoradi	Farmlands/Shrubs	5.0041353	-2.0374857
Takoradi	Built-up	5.004322	-2.0265984
Takoradi	Farmlands/Shrubs	4.9359189	-1.9779885
Takoradi	Farmlands/Shrubs	4.9016832	-1.9075507
Takoradi	Built-up	4.9119349	-1.7841684
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Takoradi	Built-up	4.9082006	-1.7778442
Takoradi	Built-up	4.9033652	-1.7693175
Takoradi	Built-up	4.8985936	-1.7529065
Tarkwa	Built-up	5.6247933	-2.223478
Tarkwa	Built-up	5.6247933	-2.223478
Tarkwa	Built-up	5.3278937	-1.9816643
Tarkwa	Built-up	5.7137202	-2.3274828
Tarkwa	Forest	5.6527617	-2.2844424
Tarkwa	Bare land	5.6446488	-2.2689285

Tarkwa	Built-up	5.6399536	-2.2628259
Tarkwa	Built-up	5.6364597	-2.256053
Tarkwa	Forest	5.6486788	-2.2775177
Tarkwa	Farmlands/Shrubs	5.625145	-2.2238767
Tarkwa	Farmlands/Shrubs	5.6247933	-2.223478
Tarkwa	Forest	5.6247933	-2.223478
Tarkwa	Farmlands/Shrubs	5.6247933	-2.223478
Tarkwa	Farmlands/Shrubs	5.6247933	-2.223478
Tarkwa	Bare land	5.6247933	-2.223478
Tarkwa	Farmlands/Shrubs	5.6247933	-2.223478
Wangara Krom	Farmlands/Shrubs	5.6247933	-2.223478
Wangara Krom	Farmlands/Shrubs	5.6247933	-2.223478
Wangara Krom	Farmlands/Shrubs	5.6247933	-2.223478
Yiwabra Nkwanta	Built-up	5.7959186	-2.6766276
Yiwabra Nkwanta	Bare land	5.7905741	-2.6735574
Yiwabra Nkwanta	Farmlands/Shrubs	5.7821798	-2.6614652
Yiwabra Nkwanta	Built-up	5.7800707	-2.6585705
Yiwabra Nkwanta	Farmlands/Shrubs	5.7806367	-2.6508106
Yiwabra Nkwanta	Bare land	5.7805307	-2.6490029
Yiwabra Nkwanta	Forest	5.7778537	-2.6376516
Yiwabra Nkwanta	Farmlands/Shrubs	5.7761135	-2.6308095

Features	**Number of Total Samples**
Forest	**104**
Farmlands/Shrubs	**153**
Built-up	**177**
Bare land	**70**
Waterbodies	**20**
Total	524

Figures

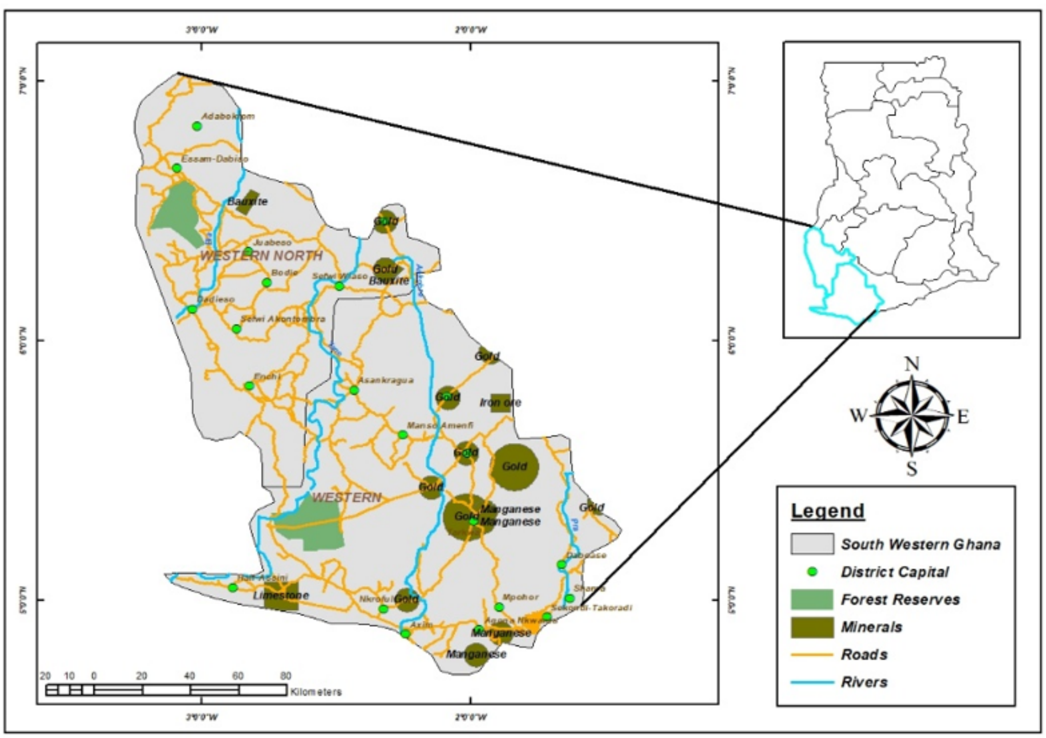


Figure 1

Location of the study area

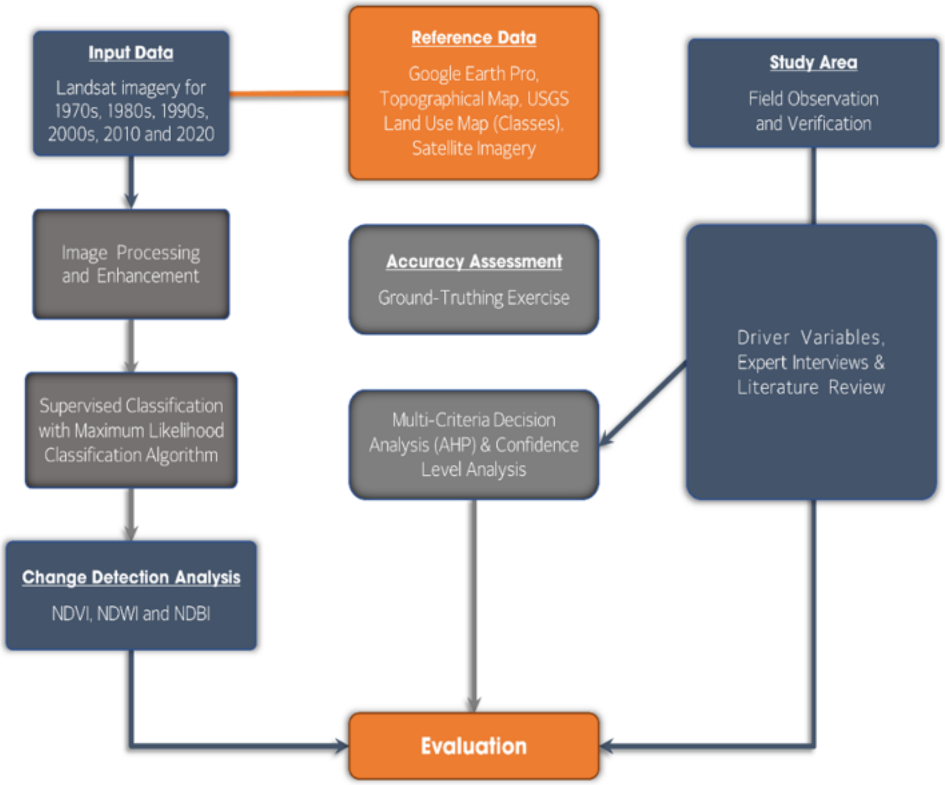


Figure 2

Flow-chat designed for this study

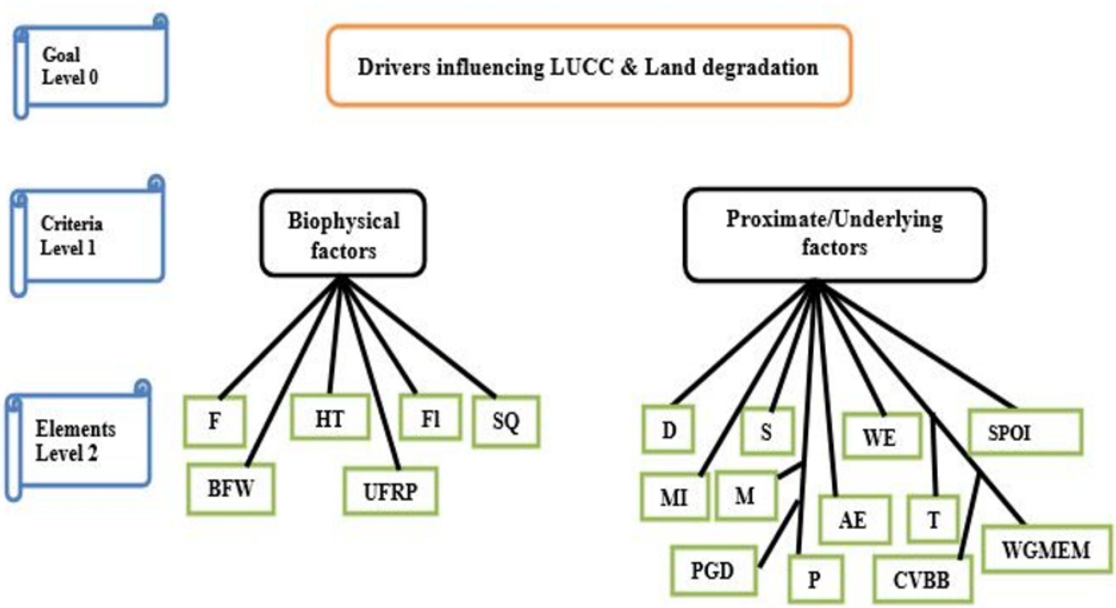


Figure 3

AHP model of factors influencing LUCC and land degradation

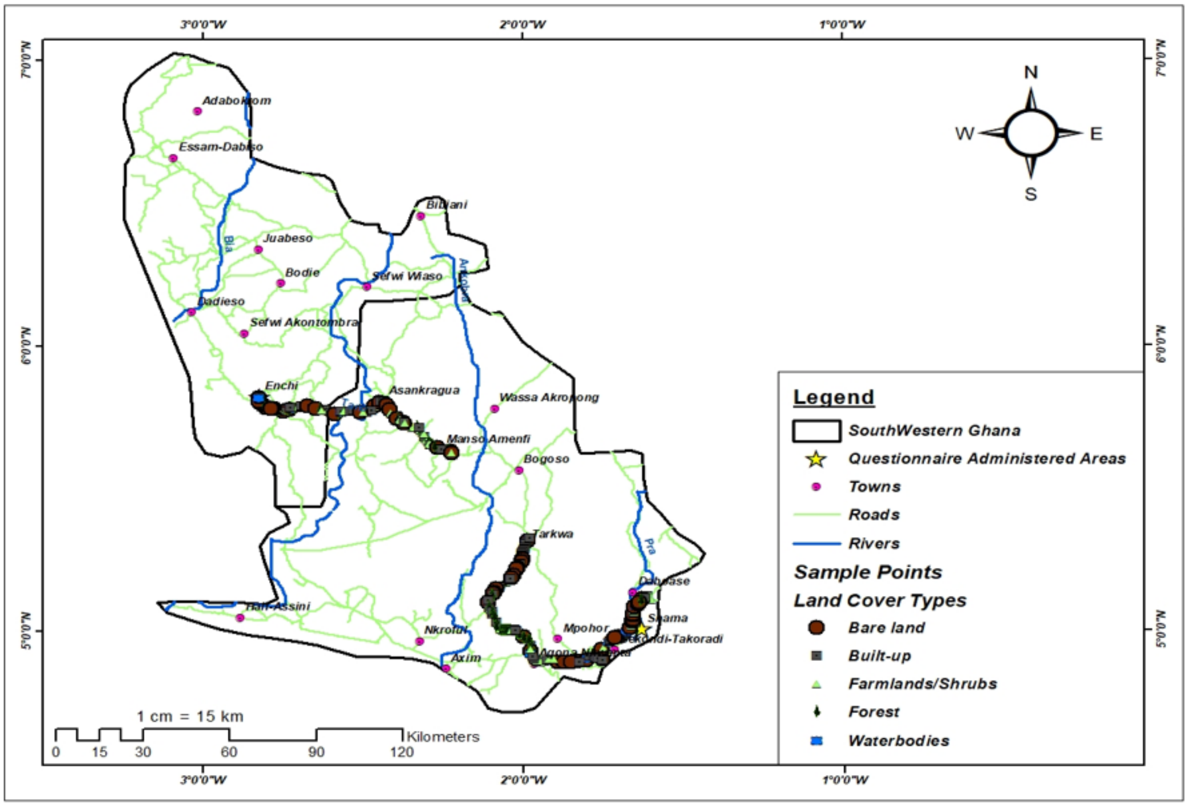


Figure 4

Geographical map depicting sample locations during the ground-truthing exercise

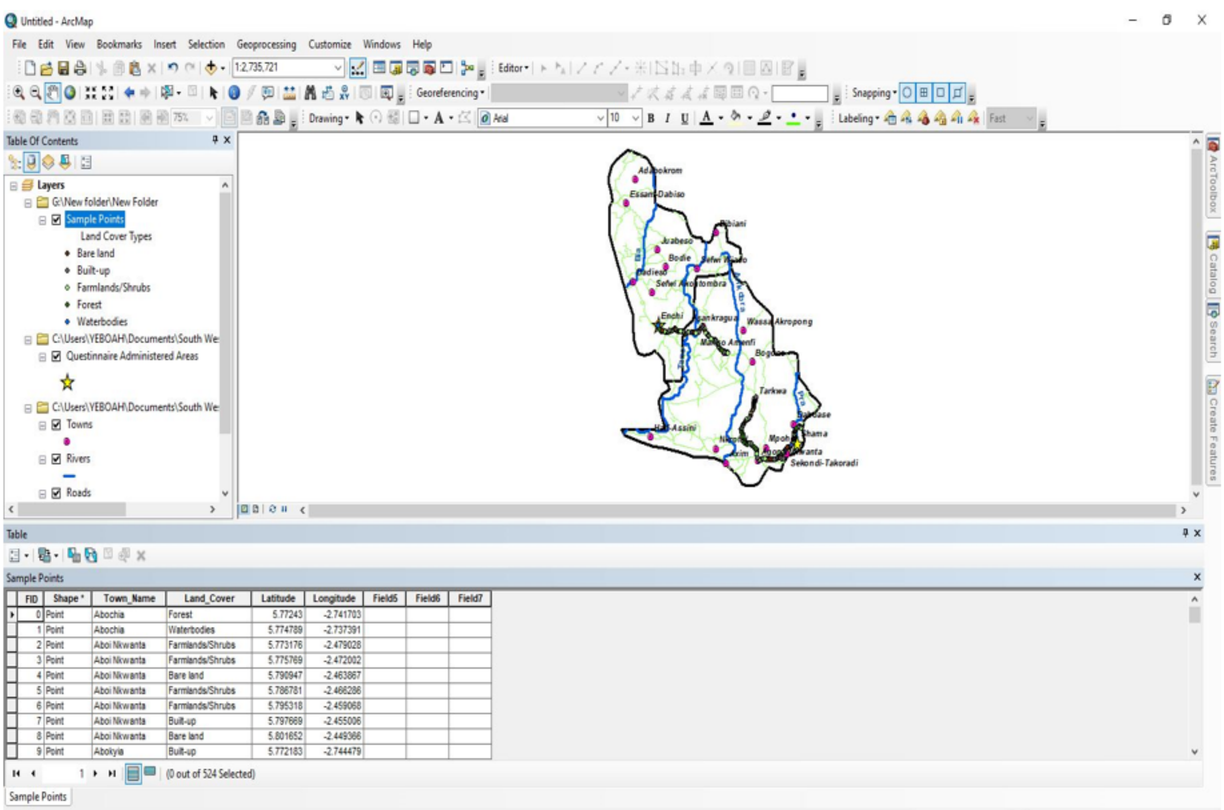


Figure 5

Sample locations/co-ordinates for land cover classes using the Mobile Data Collection Application

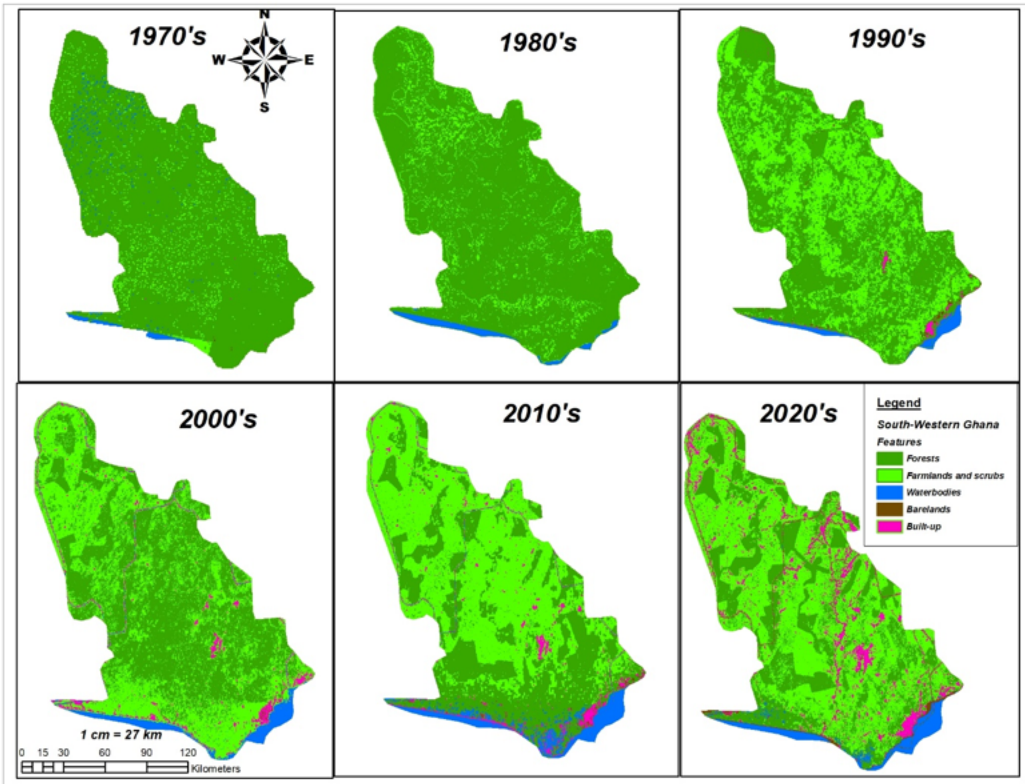
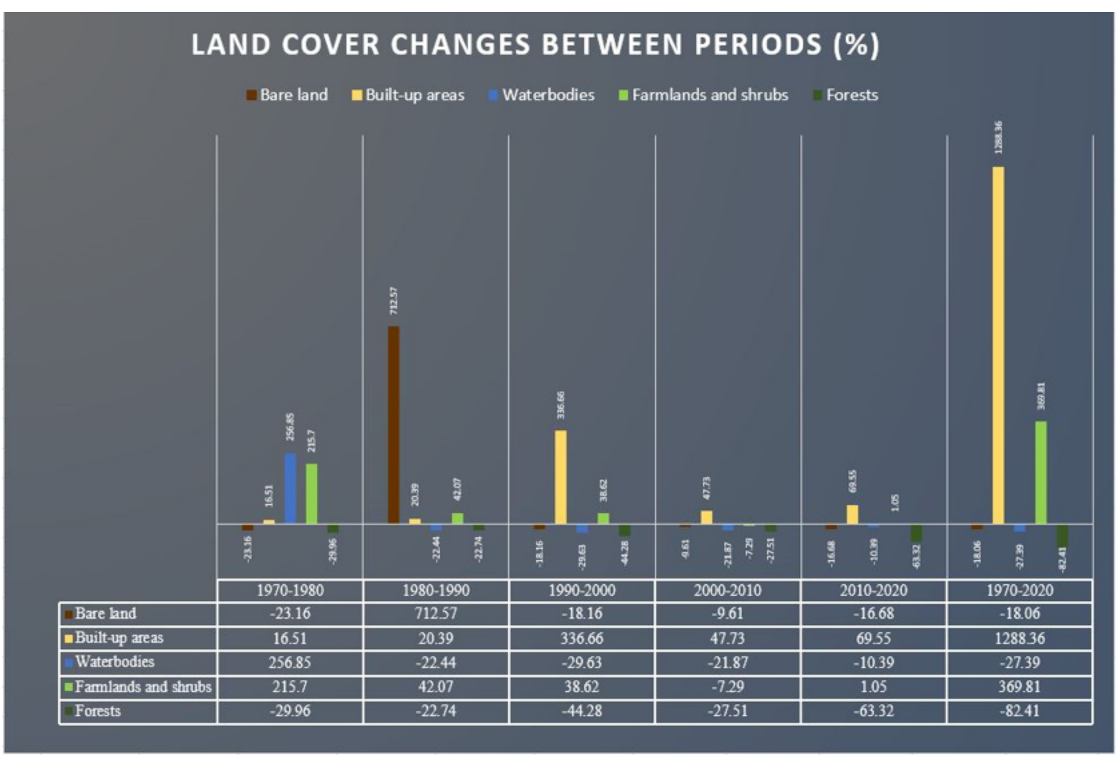


Figure 6

LUCC over the study period (1970-2020) in Southwestern Ghana.



	1970-1980	1980-1990	1990-2000	2000-2010	2010-2020	1970-2020
Bare land	-23.16	712.57	-18.16	-9.61	-16.68	-18.06
Built-up areas	16.51	20.39	336.66	47.73	69.55	1288.36
Waterbodies	256.85	-22.44	-29.63	-21.87	-10.39	-27.39
Farmlands and shrubs	215.7	42.07	38.62	-7.29	1.05	369.81
Forests	-29.96	-22.74	-44.28	-27.51	-63.32	-82.41

Figure 7

Land cover changes between periods (%)

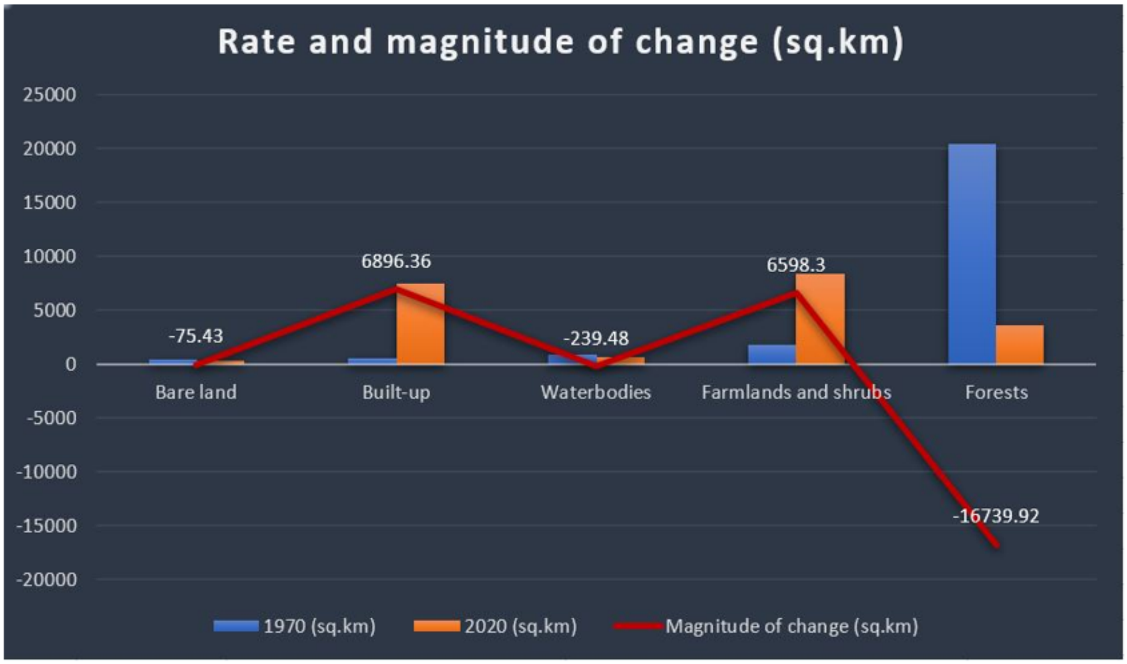


Figure 8

Rate and magnitude of change (sq.km) over the past 50 years in Southwestern Ghana.

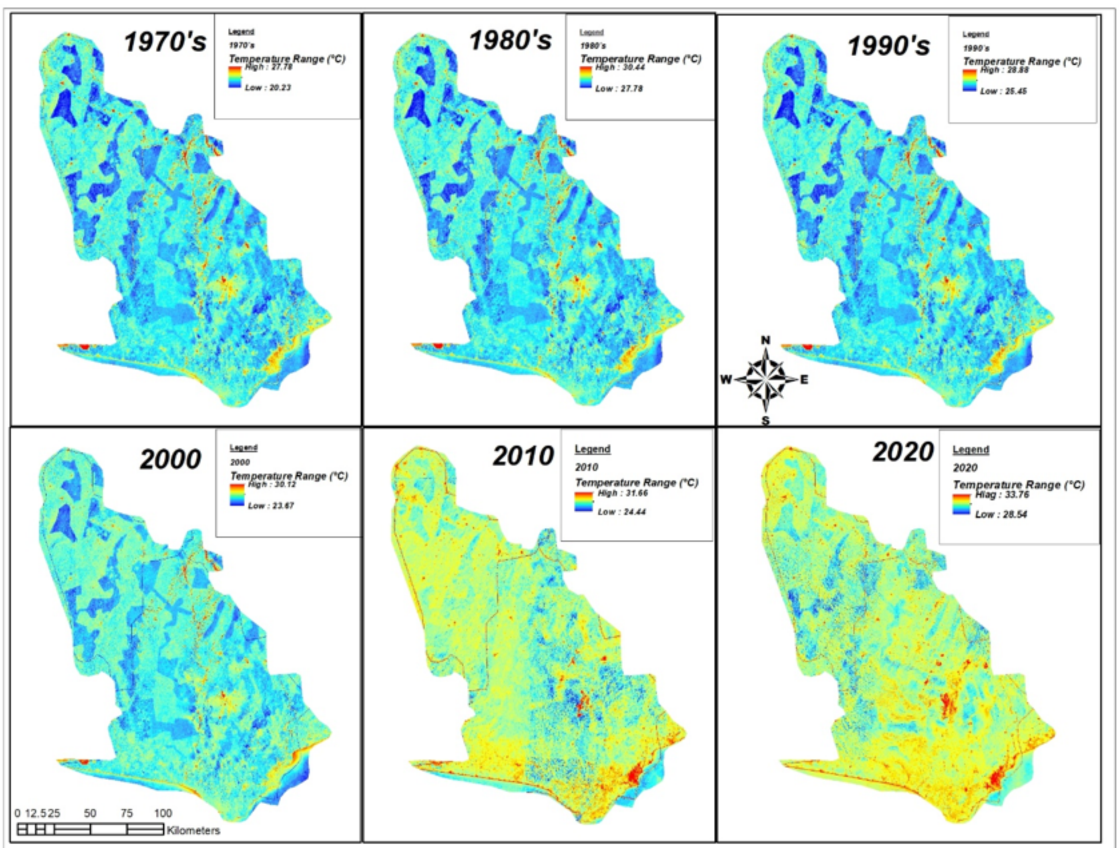


Figure 9

Temperature analysis over the study period (1970-2020) in Southwestern Ghana.

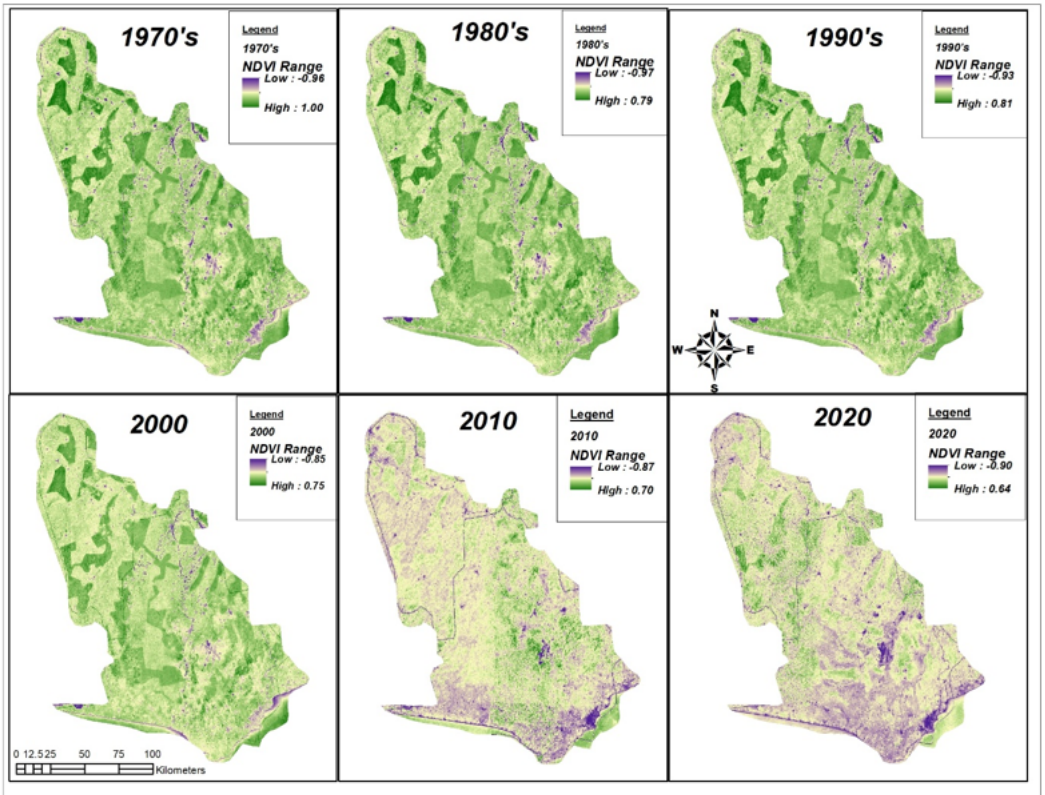


Figure 10

Changes in NDVI over the study period (1970-2020) in Southwestern Ghana.

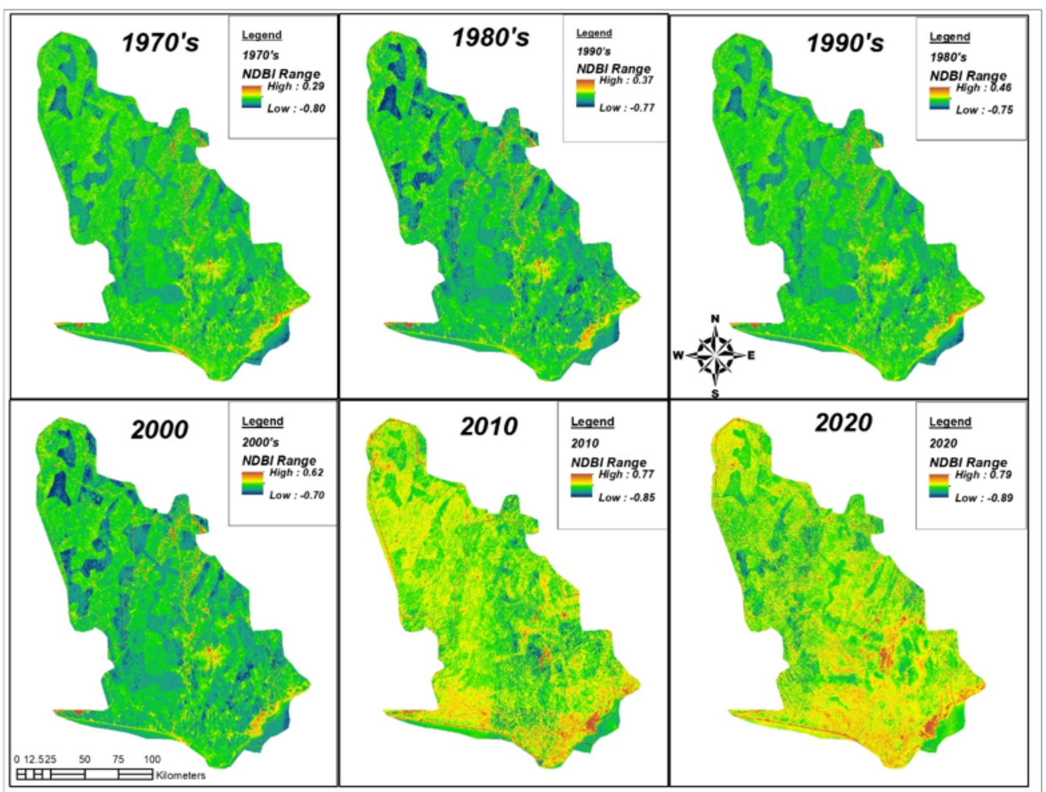


Figure 11

Changes in NDBI over the study period (1970-2020) in SW Ghana.

Supplementary Files

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- SupplementaryfileENGENOTPARTOFMANUSCRIPT.docx