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ORIGINAL ARTICLE

Validating local drivers influencing land use cover change in Southwestern Ghana: a mixed-method approach

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Abstract
Addressing undesirable changes associated with the driving forces of land use cover change are critical to sustainable land management, and the future modeling of land use systems in developing countries. The study accentuates 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 (−82.41%) and areas covered by waterbodies (−27.39%). A fundamental drift in built-up (+1288.36%) and farmlands/shrubs (+369.81%) areas were also observed. The contribution rate of change analysis revealed built-environment 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.

Keywords Land use · Contribution rate · Confidence level · AHP · Driving forces · Ghana

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 favorable 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-realization 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) exists, hence, possibly undermining positive forest transition outcomes in poverty alleviation; highly possible in the tropics and less-developed countries.

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Systems responsible for the 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” (Nunoo et al. 2016). 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-emphasize 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 evolves 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 centers, 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, and selective tree harvest, among others (Ellis and Pontius 2010). Some areas are often left bare, exposing such areas to unfavorable conditions which often render 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, and dynamisms in future modeling (Addae and Oppelt 2019; Koranteng et al. 2017a, b), along with establishing links between demographic changes and land-use systems (Moller-Jensen and Knudsen 2008). Other 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 the 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 et al. 2011), Sekondi-Takoradi (Obeng-Odoom 2013) among other municipalities/towns like Kintampo Municipality (Bessah et al. 2019) and New Juaben, respectively. Watershed and other river basin studies around Lake Bosomtwe (Bessah 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 et al. 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 and Angelucci 2013). Ghana is Africa’s leading gold producer (generating a revenue of about 6.2 billion US dollars 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 mainstay 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 analyze 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 a 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 parts of Ghana. This regional study further introduces the contribution rates of change for each class in 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 a 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.

Methodology

Study area

The study was conducted in Southwestern Ghana as part of a broad study that analyzed the spatiotemporal development of land-use systems and climate variability in Ghana between 1970 and 2020. The study domain (Fig. 1) is located at latitude 5.3902° N and longitude 2.1450° W. It currently covers an approximate surface area of 23,921 km^2 (9236 m^2) representing about 10% of Ghana's total land surface area. About 75% of Ghana's high forest vegetation among other natural resources can be found in the region. The study area hosts two administrative regions: the Western North and Western region.

Image classification

In this study, six Landsat images: Landsat 5 MSS, Landsat 4 and 5 TM, Landsat 7 ETM + and Landsat 8 OLI/TIRS, archived for the given period (1970–2020) (Table 1) 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.

Change detection analysis

Change detection analysis was run to ascertain the regularity of land-use systems, and their drivers in southwestern Ghana (1970–2020). We 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:

$$\text{ChangeinLUCC}\left(x^2\right) = \frac{\text{LUCC}_{\text{Currentyear}} - \text{LUCC}_{\text{Pastyear}}}{\text{LUCC}_{\text{Pastyear}}} \tag{1}$$

$$\%\text{ChangeinLUCC}\left(x^2\right) = \frac{\text{LUCC}_{\text{Currentyear}} - \text{LUCC}_{\text{Pastyear}}}{\text{LUCC}_{\text{Pastyear}}} \times 100\% \tag{2}$$

$$\text{Rate of change in LUCC per year} = \left[\left(\frac{\text{LUCC}_{\text{Current year}} - \text{LUCC}_{\text{Past year}}}{\text{LUCC}_{\text{Past year}}}\right) \times 100\%\right] / 50\ \text{years}. \tag{3}$$

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

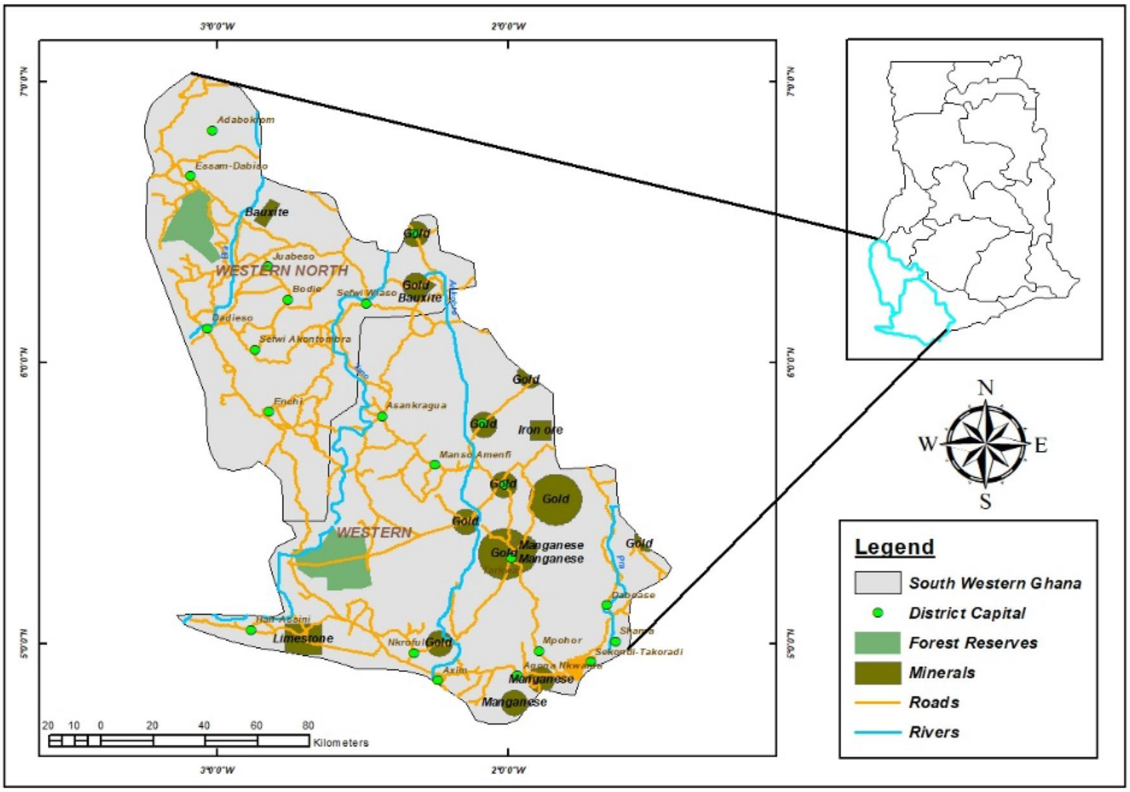


Fig. 1 Location of the study area

Temperature analysis

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

$$L_\lambda = \frac{\left(\mathrm{LMAX}_\lambda - \mathrm{LMIN}_\lambda\right)}{(\mathrm{QCALMAX} - \mathrm{QCALMIN})} \times (\mathrm{DN} - \mathrm{QCALMIN}) + \mathrm{LMIN}_\lambda, \tag{4}$$

where L_λ is cell value as radiance in $\mathrm{W}/\left(\mathrm{M}^2 \times \mathrm{sr} \times \mu\mathrm{m}\right)$; LMAX_λ is the sensor spectral radiance that is scaled to (QCALMAX) in $\mathrm{W}/\left(\mathrm{M}^2 \times \mathrm{sr} \times \mu\mathrm{m}\right)$; LMIN_λ is the sensor spectral radiance that is scaled to (*QCALMIN*) in $[\mathrm{W}/\left(\mathrm{M}^2 \times \mathrm{sr} \times \mu\mathrm{m}\right)]$. (QCALMAX) is the maximum quantized calibrated pixel value to LMAX_λ [DN], (QCALMIN) is the minimum quantized calibrated pixel value corresponding to LMIN_λ [DN]; and QCAL is the quantized calibrated pixel value [DN]. Equation 4 can be observed from header files ETM+ and TM datasets from the 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 65,535 for Landsat 8 OLI/TIRS. λ is the wavelength.

Conversion of spectral radiance (L_λ) to kelvin with emissivity value

$$T = \frac{K_2}{\ln\left(\frac{K_1 \times E}{L_\lambda} + 1\right)}. \tag{5}$$

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

$$\mathrm{BT} = \frac{K_2}{\ln[(K_1/K_\lambda) + 1]}. \tag{6}$$

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})

$$T_{\mathrm{C}} = T_{\mathrm{B}} - 273.15, \tag{7}$$

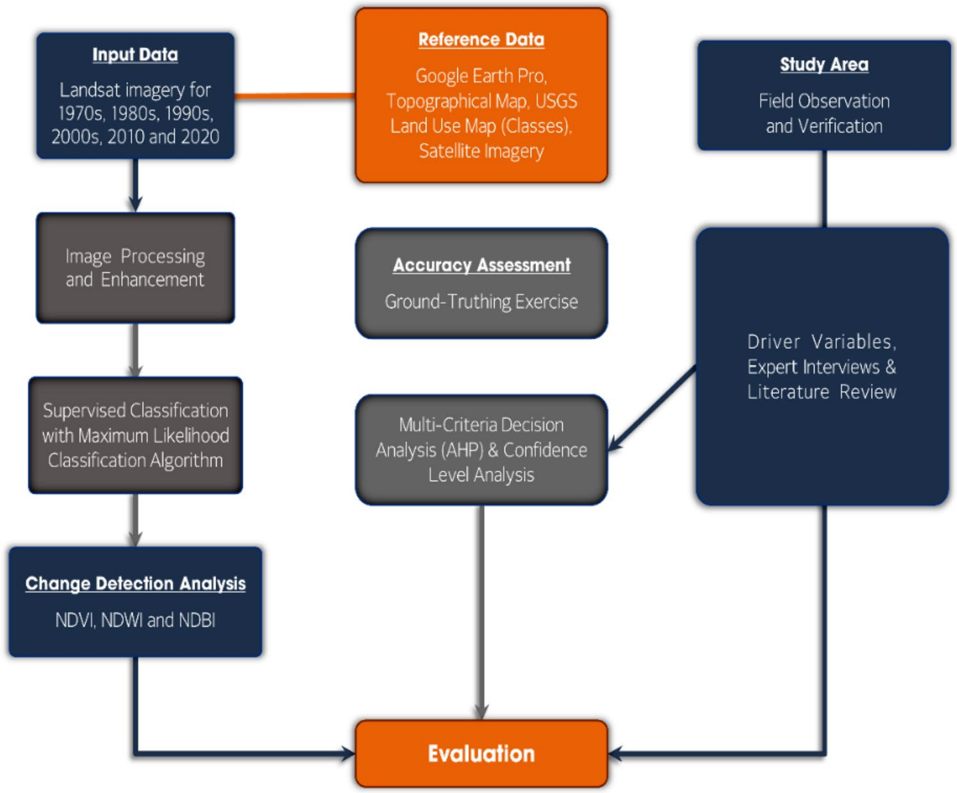


Fig. 2 Flowchart designed for this study

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

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

MSS multispectral scanner system, *TM* thematic mapper, *ETM+* enhanced thematic mapper plus, *OLI/TIRS* operational land imager/thermal infrared sensor

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

Symbol	Level of agreement	Details
√√√	High agreement	Statement is confirmed within one method For expert interviews: > 60% of respondents confirmed For literature: more than two sources confirmed 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
√√	Medium Agreement	Confirmation and rejection within one method For expert interviews: < 25% of respondents confirmed For literature: confirmation and rejection balanced
√	Low agreement	No data or evidence
x		

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

Each level is defined for the respective method (*RS* remote sensing; expert interviews; literature review)

where T_B is the value at satellite brightness temperature (K) and T_C is temperature in degree Celsius.

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 the Social Sciences (SPSS Inc. Chicago, USA, version 16) for conversion of the area (sq.km), percentage contributions of the various classes, along with existing changes in terms of area coverage for the given years. Using the expressions

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}, \tag{8}$$

where NIR = near-infrared and RED = red-visible bands (Xu 2007). Again, normalized difference built-up index (NDBI) was expressed as

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)

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

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

$$\mathrm{Contributionrateofchange(CRC)} = \frac{\mathrm{LUC(km^2)}_{\mathrm{Present/futureyear}}}{\mathrm{LUC((km^2)}_{\mathrm{Past/Previousyear}}} - 1, \tag{10}$$

where CRC = contribution rate of change for a given class, over a given study period among the understudied indices, while 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 (Eq. 10), the rate of change (±) based on the results generated will indicate which class contributed the most toward change in the area.

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 are defined as individuals with extensive knowledge and experience about the scope of this study, and had 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 Social Sciences (SPSS v.16) software were employed to capture, clean and analyze the data collected. Results from respondents' knowledge were used to validate the outcome of satellite imagery and existing literature over the given study period (Fig. 2).

Confidence level analysis

To express the validity and reliability of findings, we adopted the confidence level approach provided by Kleemann et al. (2017), and 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 3 and 4). 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 change for each class in the various indices against temperature and LUCC, coupled with AHP to assign weights to expert judgements, which were not employed in the aforementioned studies.

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 to solve complex problems (Saaty 1980). AHP analysis employs six steps formulated by Saaty (1980), and enhanced by Danumah et al. (2016): (i) breaking a complex unstructured problem down into its component factors; (ii) formulation of hierarchical structure; (iii) paired comparison matrix determined by coercing results; (iv) allocating values to subjective judgments and measuring the relative weights of each criterion; (v) systemize results to determine the priority variables, and (vi) 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 determines how logical results are. If the consistency ratio is less than or equal to 0.1, then the factor is considered acceptable consistency. However, the AHP approach is built on three levels as evident in Fig. 3. Level 0 (main objective); Level 1 (criteria analysis which constitutes biophysical and proximate/underlying factors), whereas Level 2 lists the elements associated with Level 1 (Danumah et al. 2016; Nejad et al. 2015; Chakraborty and Joshi 2014). In this study, criteria weightings were assigned to judgements from experts to draw a logical conclusion on validating local drivers that influence LULD in Southwestern Ghana.

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).

Pairwise comparison

The binary combination is based on Saaty's (1980) proposition to compare key and potential drivers, while the pair-wise comparison is the basic element of the 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 is being calculated (Table 5).

Development and prioritization matrix

Developing and prioritizing matrix are done to ascertain the eigenvectors (V_{p}) of each criterion for each item as expressed in Eq. 11

$$V_{\mathrm{p}} = n\sqrt{W1x \ldots Wn}; \tag{11}$$

n represents the number of parameters. W_{n} ratings are the main parameters. The criteria weight (C_{p}) is measured as

$$C_w = \frac{V_{\mathrm{p}}}{V_p 1 + \cdots + V_{\mathrm{p}n}}. \tag{12}$$

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

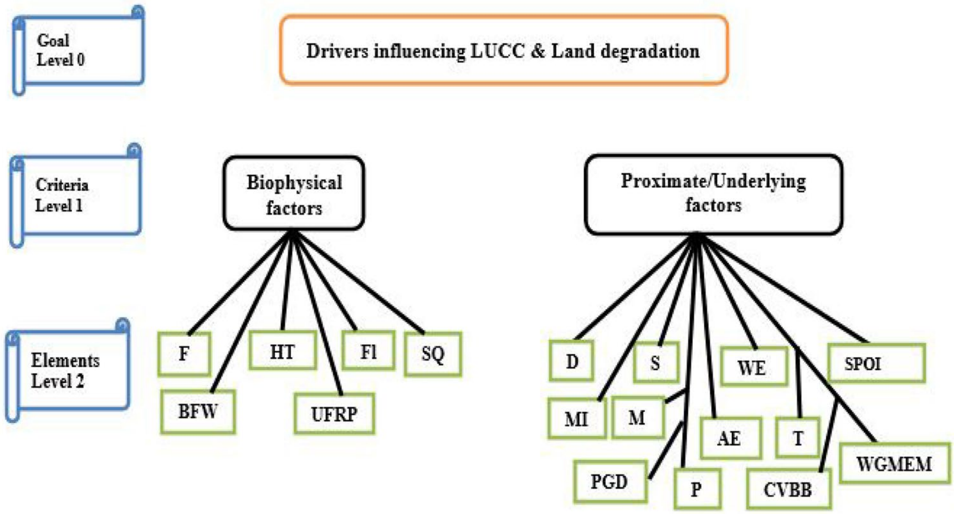


Fig. 3 AHP model of factors influencing LUCC and land degradation. *D* deforestation, *S* settlements, *WE* wood extraction, *SPOI* setting up profit-oriented industries, *MI* mining and infrastructure, *AE* agriculture expansion, *BFW* bushfires/wildfires, *F* famine, *HT* high temperature, *Fl* flood, *SQ* soil quality, *M* migration *P* poverty *PGD* population growth and distribution, *WGMEM* weak governance, monitoring and enforcement mechanisms, *T* technology (science, research, mining technology, agro-technical change and efficiency, transportation networks), CVBB cultural values, behaviors and beliefs, *IT* increasing temperature, *UFRP* unpredicted fluctuations in rainfall patterns

Table 5 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

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 the Eigenvector and the normalized relative weight. λ max (Eq. 13); CI (Eq. 14) and CR (Eq. 15) are calculated as

$$\lambda_{\max} = \frac{[E]}{n}$$

$$\mathrm{CI} = \left(\lambda_{\max} - n\right)/(n - 1). \tag{14}$$

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

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}. \tag{15}$$

The random index (RI) estimations are presented in Table 6.

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

Table 6 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

(524) samples (Figs. 4 and 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 (Eq. 16) adapted from Sarfo et al. (2021) was used in calculating the accuracy assessment

$$\text{Accuracy assessment (A.A)} = [(\text{ASP}/\text{TSP}) \times 100], \quad (16)$$

where:

ASP = number of sample points that accurately fall on each required feature (ASP = 493). TSP = number of total sample points generated (TSP = 524). A.A = Accuracy assessment [(493/524) × 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 1), as well as areas where the questionnaires were administered. Considering the characteristics of Southwestern Ghana as presented in Sect. "Study area" (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.

Results

Sociodemographic characteristics of respondents

The majority of the respondents interviewed were males (87%), while the remaining quota (13%) represented females in Southwestern Ghana (Table 7). Table 7 shows that 53% of respondents had an age range of 26–40 years, while 47% ranged between 41 and 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.

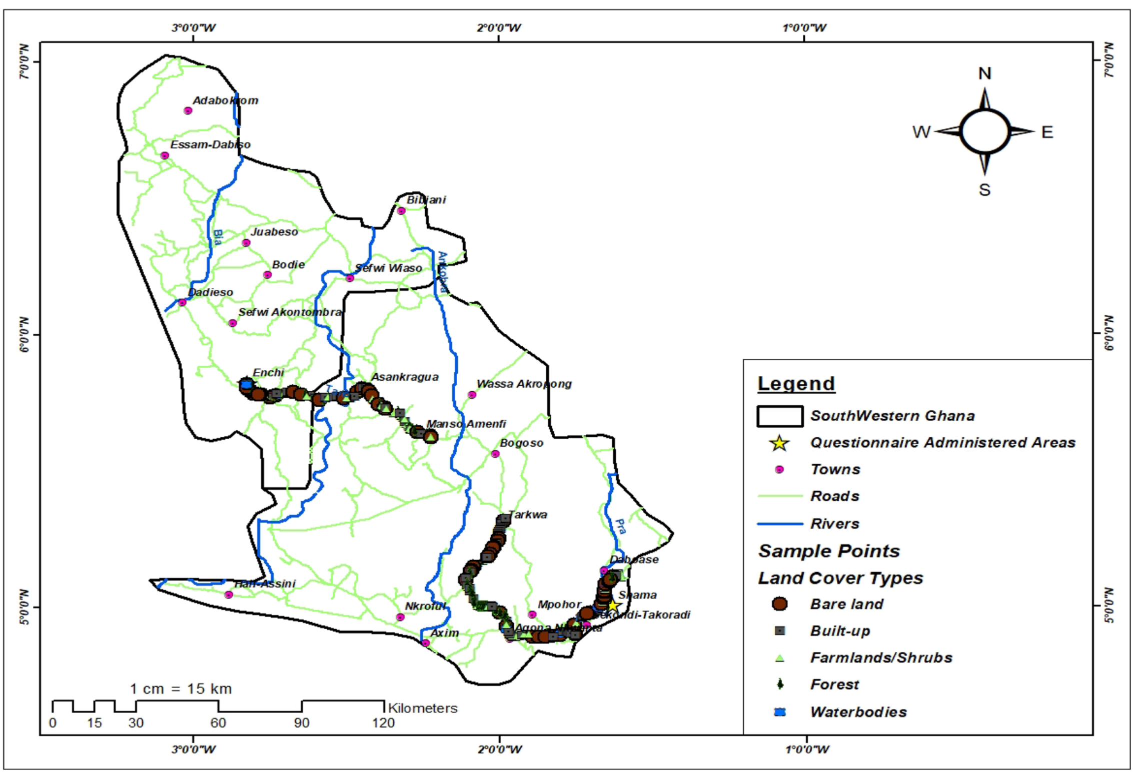


Fig. 4 Geographical map depicting sample locations during the ground-truthing exercise

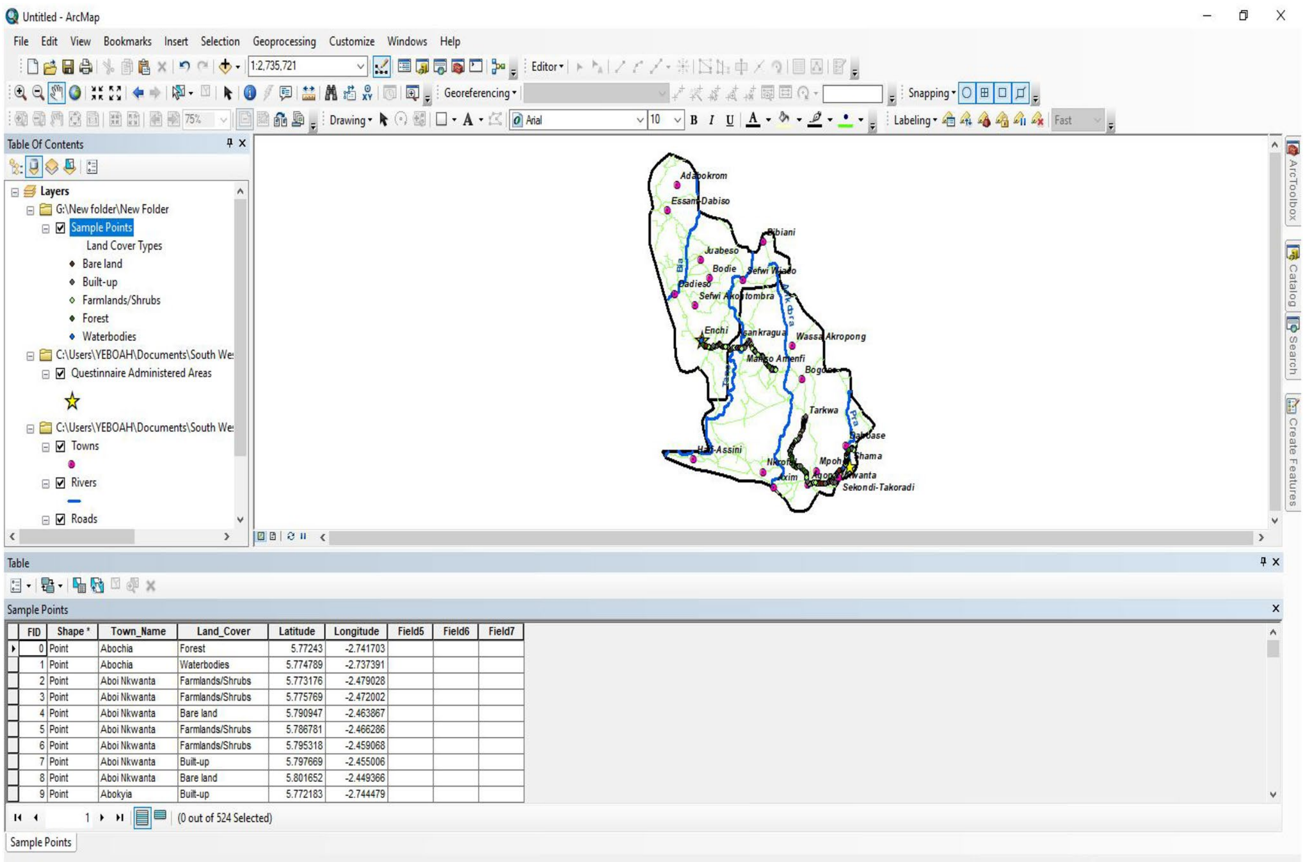


Fig. 5 Sample locations/co-ordinates for land-cover classes using the Mobile Data Collection Application (the figure generated to depict the sample locations/co-ordinates (ArcMap) using the ArcGIS software which is fully registered through the University of Ghana's Remote Sensing and GIS (RSGIS) Lab License key: ESU869965370)

The remaining quota (27%), on the other hand, asserted that they have been living or working in the area for (± 10) years.

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 (Tables 8 and 11, Fig. 6). Results presented in Table 9 show 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 (Figs. 7, 10 and 11). Additionally, bare land, waterbodies, and forest areas experienced dynamic ebb over the given period (Fig. 8; Tables 10 and 11).

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 (Table 12). 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 that the outlined drivers in the pair-wise matrix are 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. The boldened values for the given parameters in Table 12; thus, $\lambda_{\max}$, CI, and CR indicate the weight and consistency levels of the driving forces, based on experts' judgments. Resultant values indicate pragmatism in responses given, based on a standardized threshold or scale for AHP analysis.

Table 7 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
QN1	Lands Commission, T	Principal Technical Officer	Land policy and administration, Sustainable Development
QN2	*	Senior Staff	Land tenure systems, management and administration
QN3	*	Planning Officer	Land Use, Population and Demographic studies, and Natural Resource Management
QN4	Minerals Commission, T	Minerals Geological Officer	Geology, Pedology, Resource Use Management and Environmental policy
QN5	*	Senior Staff	Geology, Environmental Policy and Management
QN6	Environmental Protection Agency (EPA), T	Environmental Officer	Environmental Impact Assessment, Env. policy and Management, Land Use
QN7	*	Senior Staff	Remote sensing and land-use change
QN8	Ghana Meteorological Agency, T	Climate Research Officer	Climatology, regional and local land-use planning
QN9	*	Senior Staff	Climate change adaptation and Remote Sensing
QN10	Lands Commission, E	Municipal Stool Lands Officer	Land administration and management, agriculture and Rural development
QN11	*	Senior Staff	Land tenure, rural development and Dev. studies
QN12	*	Principal Technical Director	Land-use change, GIS, Policy Analysis, Soil and water engineering, Regional Planning
QN13	Forestry Commission, E	District Manager	Forestry and Wildlife, Agroforestry and Ecosystem Services
QN14	*	Zonal Co-Ordinator	Forestry and wildlife, regional and local planning, development policy and land use
QN15	Ghana Immigration Service, E	Senior Officer	Population studies, Migration and rural development
QN16	*	Senior Officer	Population studies, Environmental policy and Planning
QN17	Ghana Fire Service, E	Assistant Divisional Officer	Risks and Disaster Management, Remote sensing, Regional land-use planning
QN18	*	Senior Staff	Risks and Disaster Management, network systems and local land-use planning

Table 7 (continued)

QN	Institution	Role/capacity	Research interests
QN19	Feeder and Urban Roads, T	Senior Transport Officer	Regional and local land-use planning, remote sensing, transportation and network services
QN20	*	Junior Staff	Remote sensing and GIS, Planning and architecture
QN21	NADMO, E	Zonal Co-Ordinator	Risks and Disaster Management, agriculture economics and soil conservation
QN22	*	Senior Staff	Disaster management, Peri-urban Development
QN23	*	Deputy Zonal Co	Land-use planning and Disaster Management
QN24	Physical Planning Department, T	Acting Physical Officer	Land-use planning, GIS, Demography studies and policy analysis
QN25	*	Senior Staff	Landscape patterns, Urban Dev. and Logistics
QN26	Town and Country Planning, T	Senior Staff	Planning, architecture, Physical and Human Geography
QN27	Social Welfare, E	Head of Department	Development studies, sociology and population studies
QN28	*	Senior Staff	Sociology and Rural livelihoods
QN29	Forestry Commission, T	Senior Staff	Ecosystem based services, agroforestry, land-use analysis and resource management
QN30	*	Senior Staff	Natural resource management, environmental science and planning
	*	Senior Staff	Forestry and Wildlife, Food security, Resource Economics, Environmental policy and management

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

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 and 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 the existing literature and spatial analysis.

Temperature analysis

Figure 9 indicates the temperature range on average was between 27.78 and 20.23 °C in the 1970s. However, the average temperature range for the 1980s was between 30.44 and 27.78 °C, which could be attributed to biophysical factors (i.e., bushfires and prolonged dryness that occurred in the 1980s), which caused a significant increase in surface temperatures in the study area. The range for the 1990s was between 28.88 and 25.4 °C. Average temperature ranges for 2000, 2010, and 2020 were between 30.12 and 23.67 °C, 31.66 and 24.44 °C, as well as 33.76 and 24.54 °C, respectively. Dark red and yellowish areas indicate areas with high or moderately high temperatures, while dark blue areas represent low-temperature regions with transient color zones.

Discussion

Land use cover change in Southwestern Ghana

Per the conversions in various land-cover types observed in Figs. 6, 7, 10 and 11, there is evidence of expansion in farmlands/shrubs and built-up areas over the given period.

Table 8 Area coverage for LUCC in Southwestern Ghana (1970–2020)

Area coverage for each class (km²) 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 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						

Additionally, previous studies, policy-driven initiatives, and experts' assertions highlighted in Tables 7 and 8, respectively, illustrate recurrent changes in the study area. Findings based on geostatistical analysis illustrated a 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 been 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 the loss of forests areas over the past few decades to several socio-economic factors, namely, rapid urbanization, population growth and distribution, the influx of profit-oriented industries, agriculture, and infrastructure expansion.

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 the 1980s was between −0.97 and 0.79. The 1990s had a range of −0.93 and 0.81; the 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. Figure 10 illustrates a steady decline in the vegetative index over the study period. Larger values of NDVI represent forest areas due to the 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. The decrease in NDVI based on study findings could be attributed to the main drivers highlighted in Table 9. Differences in measurement of vegetation in Southwestern Ghana were 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 is as observed in the 1970s and 1980s. Such areas are subdued by the sea or built-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

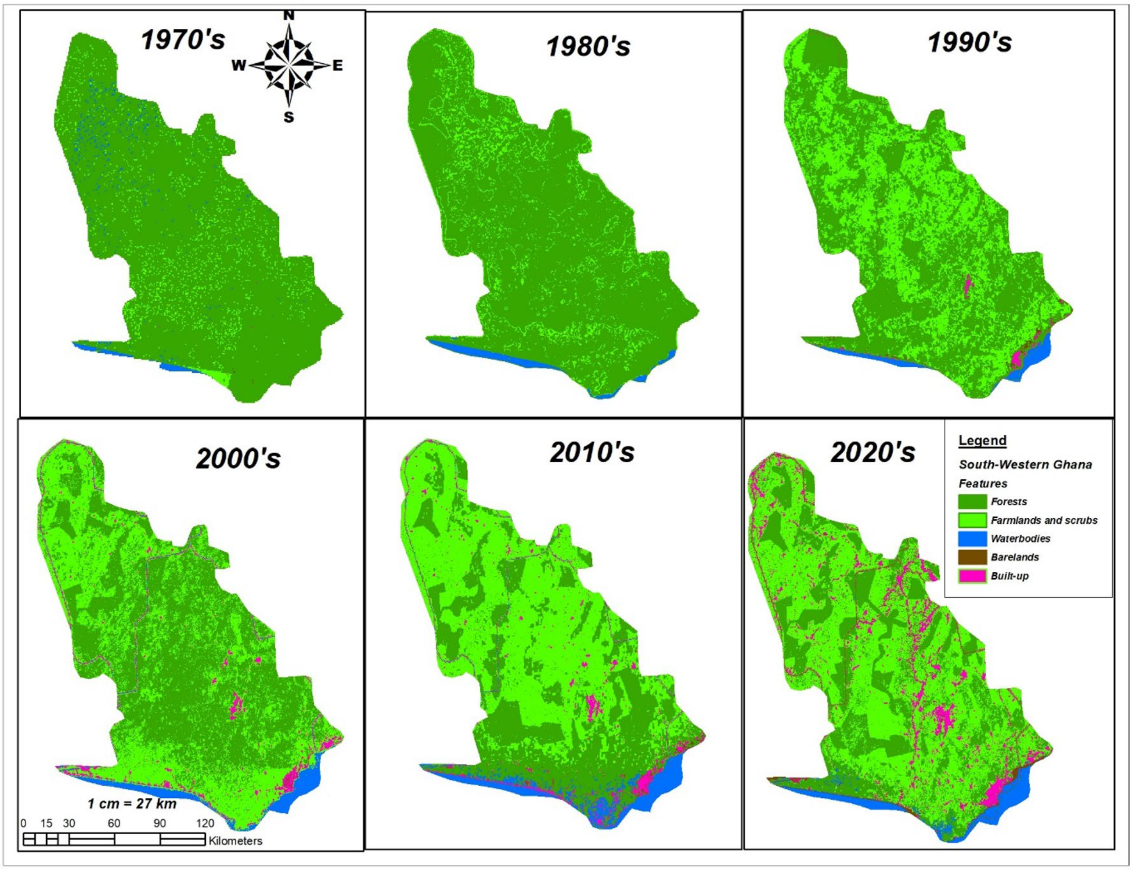


Fig. 6 LUCC over the study period (1970–2020) in Southwestern Ghana

ranged between −0.80 and 0.29 in the 1970s. The 1980s had an NDBI range between −0.77 and 0.37, and −0.75 and 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; the NDBI range for 2020 was between −0.83 and 0.79. There is clear evidence of the continuous expansion of settlements over the study period in the study area. Differences in measurement of built-up areas in Southwestern Ghana were visualized in image differencing using NDBI over the given study period. Dark red and yellowish areas indicate a high presence of a built-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 Fig. 11.

Given the results in Figs. 10 and 11, along with the contribution rate of change for the various classes among the given indices presented in Table 8, 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, about the respective indices) with a decline in area coverage for the other classes over the given study period. Results presented in Table 8 show continuous increase in built-up. Observation in Table 6 and Fig. 9 (LST) elucidates a positive or direct relationship between built-up and LST.

Identified drivers of LUCC based on confidence level results

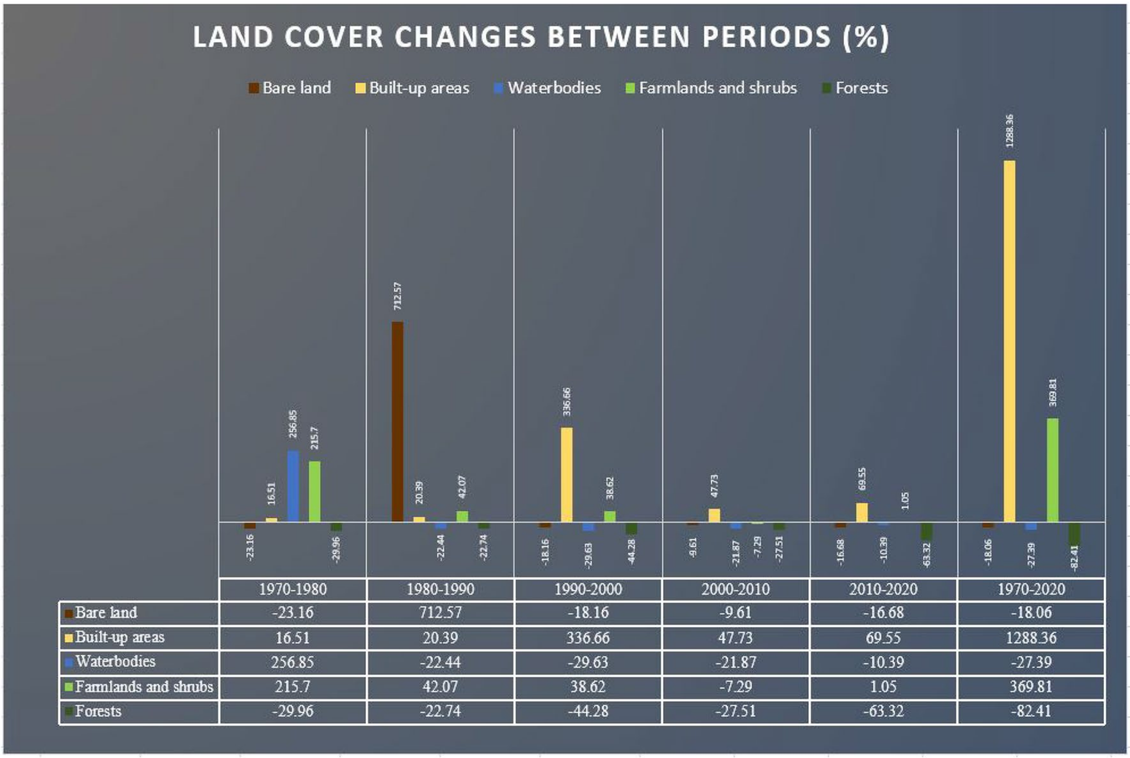
In this study, results from LUCC analysis (Table 8), early studies (Table 9), and expert interviews revealed a substantial increase in built-up areas. Geo-spatial analysis (Figs. 7 and 11) and observations in Table 11 show that built-up class (+1288.36%) was the highest contributor of change over the last 50 years among other classes. These undesirable and unprecedented changes are associated with population growth, high rate of deforestation as a result of increasing settlements, LSM/ASM activities, and the development of socio-economic infrastructure, which 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 and 1984 (2.1–3.2%), followed by a decline in 2000–2010 (2%). The area has experienced an annual

Table 9 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 and 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 and 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 8) 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 Kanbur (2008); Gyasi et al. (1994); Kusi (1991); Brooke (1989); Dei (1988)
1990s-2000	Socio-economic development (i.e., Policies driven toward 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 (Fig. 9) and reduced precipitation due to significant increase in built-up environment (Fig. 8) 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)

Table 9 (continued)

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) and 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 8)	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 Kanbur (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 toward 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 toward 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. (2017a, b); Noponen et al. (2014); Aduah and Baffoe (2013); Aduah et al. (2012); Logah et al. (2013)



	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

Fig. 7 Land-cover changes between periods (%)

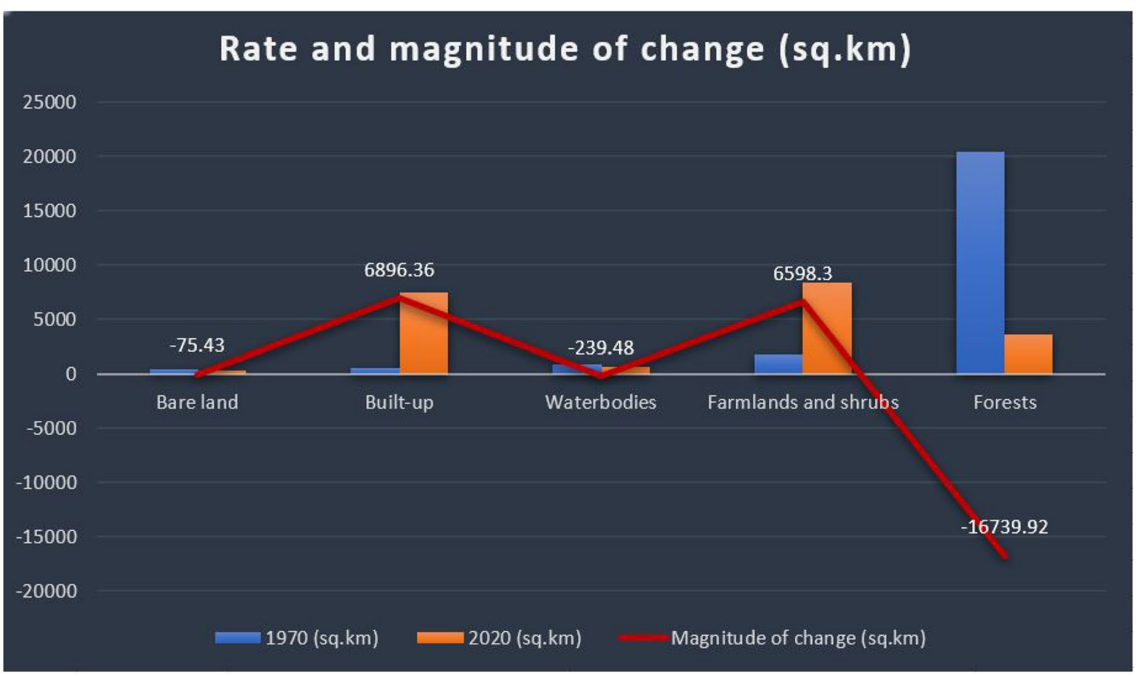


Fig. 8 Rate and magnitude of change (sq.km) over the past 50 years in Southwestern Ghana

growth rate of 6.5% (1960–2020), thereby validating experts' judgements and results from geospatial analysis conducted. Respondents affirmed that there had been a remarkable increase in the human population over the past 50 years. The

Table 10 Description of experts' rank on most influential drivers of LULD in Southwestern Ghana

Driving factors	Tally/rank	Frequency ($N=22$) (%)	Position
Expansion in settlements and social infrastructure: Schools, health facilities, transportation networks, housing/real estates, Market and storage facilities, drainage systems and so on)	√√√√	6 (28)	2nd
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
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
Agricultural activities and Technological factors: agro-technical input and efficiency, mining technology, transportation networks)	√√	2 (9)	4th
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 10) among other key parameters highlights the most/least influential factors resulting in substantial LULD over the past 5 decades

Table 11 Confidence level analysis using the MMA to ascertain local drivers of LULD

Scope: Drivers of LULD	Keywords	Literature Review SW Ghana	Interviews SW Ghana	Spatial Analysis SW Ghana	Confidence level 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**

Confidence level analysis based on existing literature (Table 9), expert interviews and spatial analysis (Fig. 4) for SW Ghana; √√√ = High agreement; √√ = Medium agreement; √ = Low agreement; **X** = No data or evidence

rapid growth in population based on GSS (2020), Moller-Jensen and Knudsen (2008), and experts interviewed were attributed to the migration of people from nearby regions and border towns of neighboring countries. 53% asserted that migration was the main cause of the 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 11, it is evident that there is robust evidence and high agreement between the three methods. Spatial results (Figs. 7, 8, 10 and 11) present the contribution rates of various classes or indices (NDBI and NDVI) toward transitions and land or forest

Table 12 Measuring consistency of biophysical and proximate/underlying drivers

	D	S	WE	SPOI	MI	AE	M	P	PGD	WGMEM	T	CVBB	CW	WSV	WSV/CW	λ_{max}	CI	CR
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	12.046			
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	12.046			
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	12.013			
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	12.013			
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	12.046			
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	12.026	**12.112**	**0.010**	**0.007**
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	12.046			
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	13.026			
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	12.046			
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	12.013			
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	12.013			
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	12.013			

Measuring consistency of biophysical drivers

CW	0.1116	0.3088	0.1116	0.0637	0.2262	0.178					
	F	HT	Fl	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			
Fl	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			

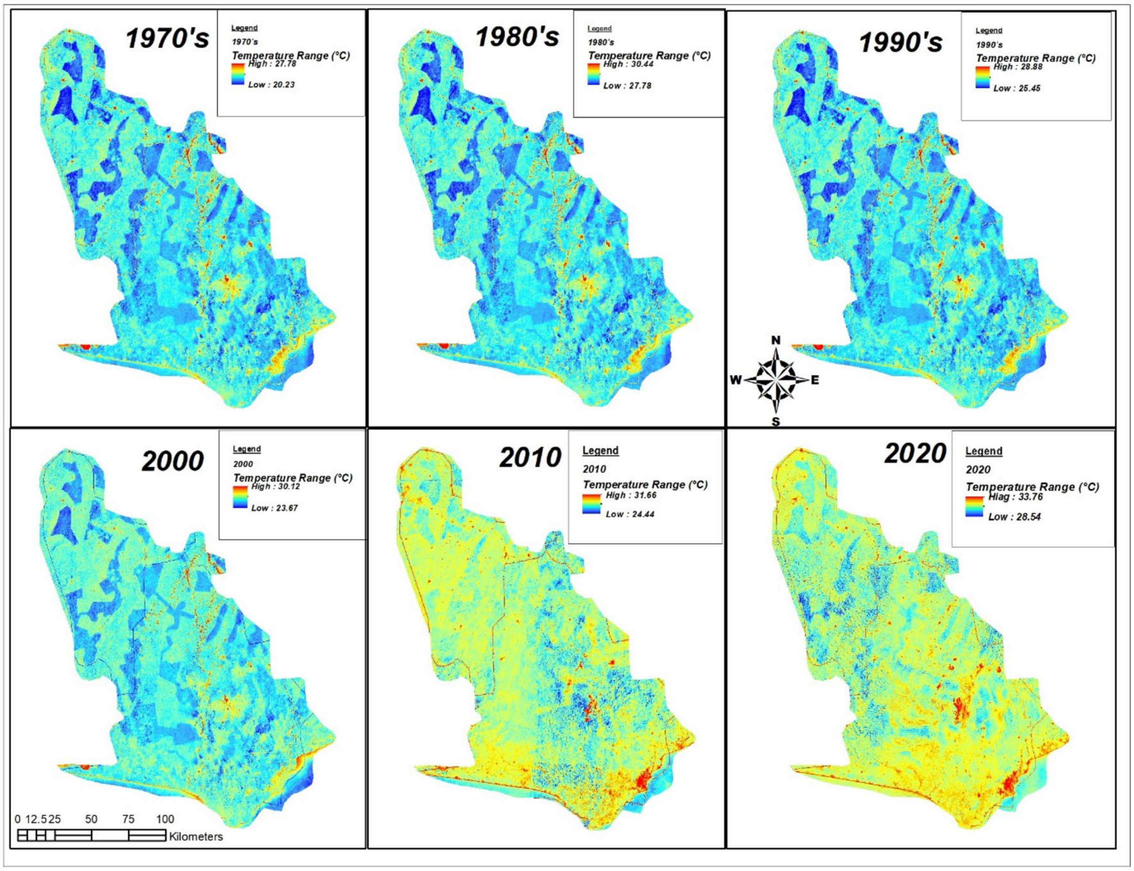


Fig. 9 Temperature analysis over the study period (1970–2020) in Southwestern Ghana

degradation. Findings suggest that there is "very high confidence" in the aforementioned drivers identified in this study. Results proved that these economic driving forces causing unprecedented changes in the region are influenced by some macro- and micro-economic factors, primarily state policies, aimed toward poverty alleviation or improving living standards, as presented in Table 9. Intensification and extensification of agricultural activities (Table 11) (Figs. 6 and 7) in the area over the study period have been linked to the citizenry resorting to the 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 an 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, unfavorable climatic conditions coupled with the 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, the geospatial analysis presented in Figs. 6 and 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-environment. Ghana in the early 1980s, specifically 1983, experienced famine along with recorded incidents of wildfires which claimed several forests and farmlands, thereby causing massive shifts in micro-climatic conditions, specifically temperature (Fig. 9). The post-famine period saw the formulation and effective implementation of an "Economic Recovery and Stabilization Program (ERP) in 1983" that boosted agriculture to enhance food production and improve living standards. The provision of basic amenities and the construction of quality transportation networks was intensified. These policies within the said period caused several conversions and modifications 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

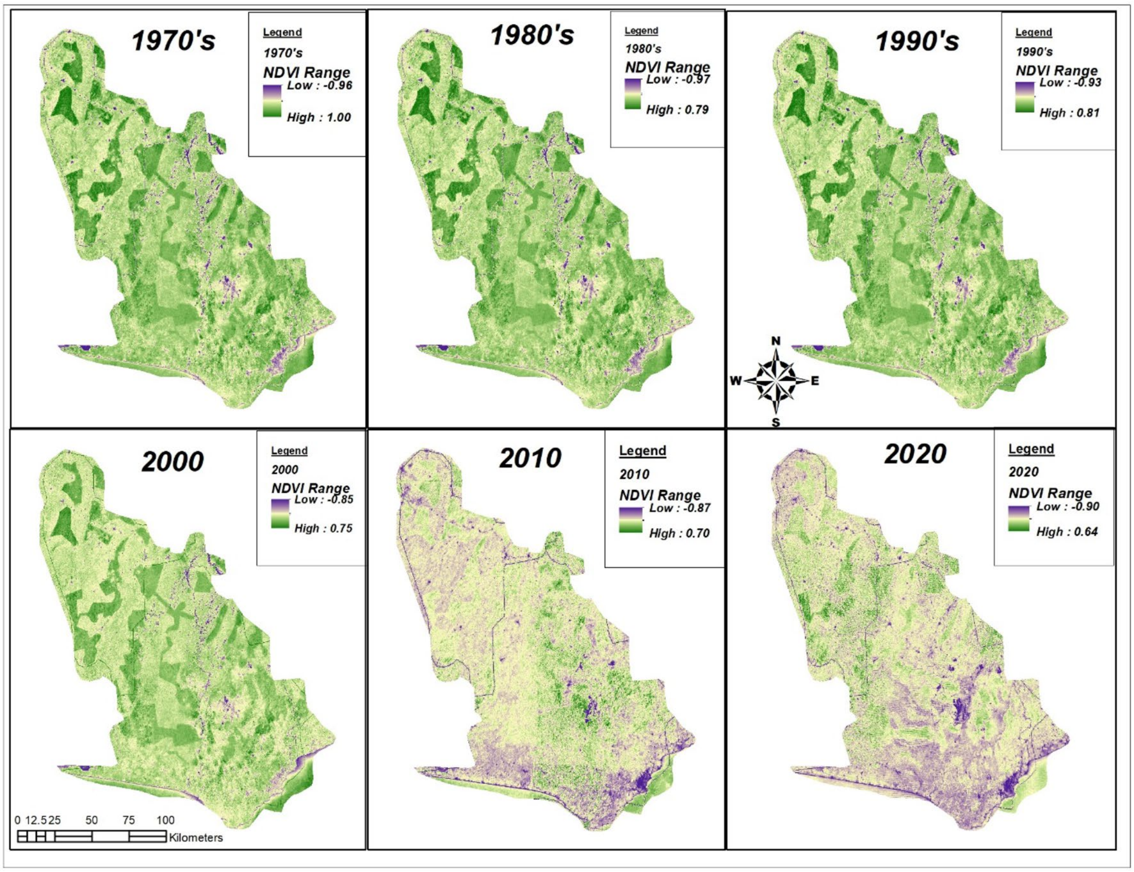


Fig. 10 Changes in NDVI over the study period (1970–2020) in Southwestern Ghana

country's commitment to achieving the Millennium Sustainable Development Goals in recent years has significantly altered land-use processes and micro-climatic conditions in the region (Table 9) (Fig. 7) (Abbam et al. 2018; Aduah and Baffoe 2013; Aduah et al. 2012; Logah et al. 2013). 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, such as prolonged dryness and wildfires, degraded most lands and rendered most areas unproductive. The extensiveness of agricultural activities (Fig. 6) (Table 10) due to massive clearing of forest areas through slash and burn have exposed several top soils to wildfires, thereby reducing their fertility rates. These have partly accounted for the decline in cocoa and other cash crops productivity in recent years. Ghana recorded 1 million tons 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 confidence level analysis (Table 11) exhibited "very high-to-very low confidence" in some biophysical factors like temperature, bushfires, floods and soil quality, respectively. The distribution shows that 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 empirical literature (Tables 9 and 11) (Abbam et al. 2018; Aduah and Baffoe 2013; Aduah et al. 2012) show temperature as a climatic variable with spatiotemporal attributes which is capable of driving land-cover change and land degradation. In the same vein, there was agreement in results from the expert interviews and early studies, about 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 behavioral (lifestyle, beliefs, traditions and perception) factors. Evidence

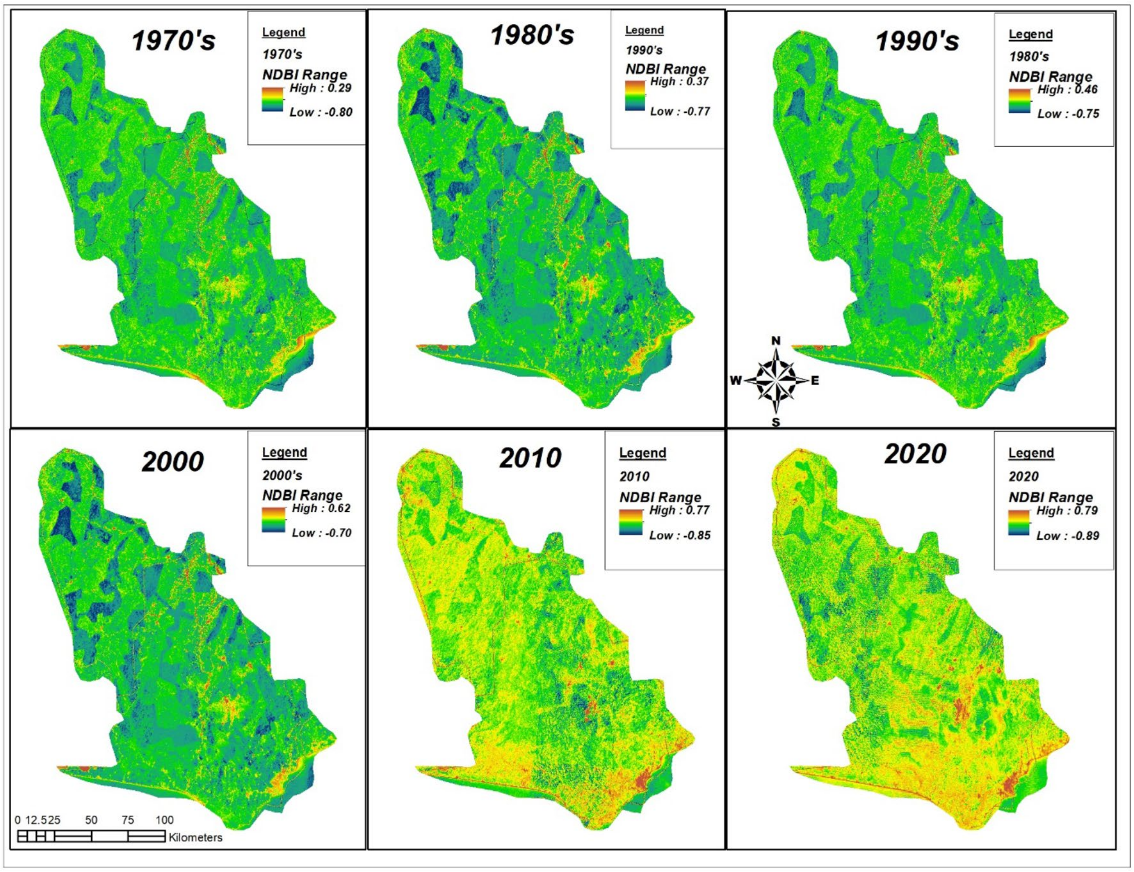


Fig. 11 Changes in NDBI over the study period (1970–2020) in SW Ghana

from these two methods, coupled with the level of agreement between them, proved that there is "medium confidence" in the drivers identified. This eventually shows that evidence provided to accentuate major influences of LULD is 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 perspectives. 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 behavioral factors which are often overlooked or deemed irrelevant in LULD studies as drivers that could be further analyzed 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 11) could potentially influence food security, land/water resources and livelihoods in the near future. Therefore, these parameters cannot be overlooked, since they could be dominant in causing significant changes to land-cover systems and forest resources in the distant future.

Table 13 presents the strengths and limitations of individual methods that could affect the validity and reliability of study findings. Consequently, the adoption of MMA for analyzing 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, empirical literature, 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 the paucity of information in existing body of knowledge and spatial analysis. The 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). Weights of importance are given to outcomes generated by quantitative tools. Qualitative methods used in this study aim at deepening our understanding of factors that cannot be quantified with a high rate of flexibility and exploratory

Table 13 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 behavioral 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 and 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

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 merging both strategies (Table 13), adhering to the strengths of these methods and restricting the limitations in the use of these methods to ensure "high confidence" and "validity" of findings related to LULD drivers at the local or regional level.

Conclusion

The paper primarily analyzes 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 the direct and indirect drivers of LUCC along with its dynamics and prospects is essential in attaining United Nations' 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 studies that improve existing knowledge, bring innovation and inform the decisions of city planners, municipal authorities, researchers and interested organizations. Findings would enrich basic datasets that would assist land-use planners and strategists in future modeling of land-use systems. Based on the confidence level analysis, the following deductions could be made:

- A substantial increase in built-up and farmlands/shrubs areas has contributed to the fundamental shift in forest resources.
- The contribution rate of change analysis revealed built-up areas contributed the most among the given classes for the understudied indices.
- Change in prevailing micro-climatic 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 their "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 the 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 pose threats to livelihoods and ecosystem services can be examined holistically using an interdisciplinary approach to solve basic problems that stem from 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 that drive significant change.

Annex 1

See Table 14.

Table 14 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

Table 14 (continued)

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

Table 14 (continued)

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

Table 14 (continued)

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

Table 14 (continued)

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

Table 14 (continued)

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

Table 14 (continued)

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

Table 14 (continued)

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

Table 14 (continued)

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
Simpa	Waterbodies	4.9195849	-1.9782022
Simpa	Built-up	4.8998317	-1.969145
Simpa	Built-up	4.8996714	-1.9285046
Simpa	Farmlands/Shrubs	4.8916177	-1.8751595
Simpa	Bare land	4.8916025	-1.873962
Simpa	Built-up	4.8933575	-1.8359136
Simpa	Bare land	4.8970706	-1.8054882
Simpa	Waterbodies	4.9044748	-1.8024535
Simpa	Built-up	4.9111059	-1.7905588
Simpa	Built-up	5.1067582	-2.1111054
Simpa	Farmlands/Shrubs	5.074902	-2.1037855
Simpa	Built-up	5.0593333	-2.0978323
Simpa	Forest	5.0351012	-2.0869449

Table 14 (continued)

Simpa	Forest	5.0141916	-2.0857272
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
Takoradi	Built-up	4.966824295	-1.724046787
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
Takoradi	Farmlands/Shrubs	4.9011742	-1.9221394
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
Takoradi	Forest	5.0018325	-2.0598543
Takoradi	Forest	5.0027671	-2.0503787
Takoradi	Forest	5.0034252	-2.0442872
Takoradi	Forest	4.96908	-1.98471
Takoradi	Forest	4.9403308	-1.978419
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

Table 14 (continued)

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
Takoradi	Built-up	4.9100242	-1.7808045
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

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

Declarations

Conflict of interest The authors declare that they have no competing interests.

References

Abbam T, Johnson FA, Dash J, Padmadas SS (2018) Spatiotemporal variations in rainfall and temperature in Ghana over the twentieth century, 1900–2014. Earth and Space Science 5:120–132. https://doi.org/10.1002/2017EA000327

Acheampong M, Yu Q, Enomah DL, Anchang J, Eduful M (2018) Land use/cover change in Ghana's oil city: Assessing the impact of neoliberal economic policies and implications for sustainable development goal number one—a remote sensing and GIS approach. Land Use Policy 73:373–384. https://doi.org/10.1016/j.landusepol.2018.02.019

Addae B, Oppelt N (2019) Land-use/land-cover change analysis and urban growth modelling in the Greater Accra Metropolitan Area (GAMA). Ghana Urban Sci 3:26. https://doi.org/10.3390/urbansci3010026

Adjei PO-W, Buor D, Addrah P (2014) Geo-spatial analysis of land use and land cover changes in the Lake Bosomtwe Basin of Ghana. Ghana J Geogr 2014(6):1–23. https://doi.org/10.4314/GJG.V6I1

Aduah MS, Baffoe PE (2013) Remote sensing for mapping land-use/cover changes and urban sprawl in Sekondi-Takoradi, Western Region of Ghana. Int J Eng Sci 66–73

Aduah MS, Mantey S, Tagoe ND (2012) Mapping land surface temperature and land cover to detect urban heat island effect: a case study of Tarkwa, South West Ghana. Res J Environ Earth Sci 68–75.

Ahn PM (1958) Regrowth and swamp vegetation in the western forest areas of Ghana. J West Afr Sci Assoc 4:163–173

Alo CA, Pontius RG Jr (2008) Identifying systematic land-cover transitions using remote sensing and GIS: the fate of forests inside and outside protected areas of Southwestern Ghana. Environ Plan B Plan Des 35:280–295. https://doi.org/10.1068/b32091

Amproche AA, Antwi M, Kabo-Bah AT (2020) Geospatial assessment of land use and land cover patterns in the Black Volta Basin. J Remote Sens GIS 9:269. https://doi.org/10.35248/2469-4134.20.9.269

Angelsen A, Wunder S (2003) Exploring the forest-poverty link: key concepts, issues and research implications. CIFOR Occasional Paper No. 40. Center for International Forestry Research, Bogor, Indonesia. https://doi.org/10.17528/cifor/001211

Arhin K (1985) The expansion of cocoa production: the working conditions of migrant cocoa farmers in central and western regions. Institute of African Studies, University of Ghana, Legon

Aryeetey E, Kanbur R (2008) The economy of Ghana: analytical perspectives on stability, growth and poverty. University of Ghana, Legon, p 15-33. https://doi.org/10.7722/j.ctt81fmh

Asante-Poku, A. & Angelucci, F. (2013). Analysis of Incentives and Disincentives for Cocoa in Ghana; MAFAP, FAO: Rome, Italy. Doi: https://doi.org/10.21955/gatesopenres.1115955.1

Avdan U, Jovanovska G (2016) Algorithm for automated mapping of land surface temperature using LANDSAT 8 satellite data. J Sens 2016:1480307. https://doi.org/10.1155/2016/1480307

Awotwi A, Kumi M, Jansson PE, Yeboah F, Nti IK (2015) Predicting hydrological responses to climate change in the White Volta catchment, *West Africa*. J Earth Sci Clim Change 6:249

Awotwi A, Anornu GK, Quaye-Ballard JA, Annor T (2018) Monitoring land use and land cover changes due to extensive gold mining, urban expansion, and agriculture in the Pra River Basin of Ghana, 1986–2025. Land Degrad Dev 29:3331–3343. https://doi.org/10.1002/ldr.3093

Basommi PL, Guan Q, Cheng D (2015) Exploring land use and land cover change in the mining areas of Wa East District, Ghana using satellite imagery. Open Geosci 1:618–626. https://doi.org/10.1515/GEO-2015-0058

Bessah E, Bala A, Agodzo SK, Okhimamhe AA, Boakye EA, Ibrahim SU (2019) The impact of crop farmers' decisions on future land use, land cover changes in Kintampo North Municipality of Ghana. Int J Clim Change Strateg Manag 11:72–87. https://doi.org/10.1108/IJCCSM-05-2017-0114

Bessah E, Raji AO, Taiwo OJ, Agodzo SK, Ololade OO, Strapasson A (2020) Hydrological responses to climate and land use changes: the paradox of regional and local climate effect in the Pra River Basin of Ghana. J Hydrol Reg Stud 27:100654. https://doi.org/10.1016/j.ejrh.2019.100654

Boakye E, Anornu GK, Quaye-Ballard JA, Donkor EA (2018) Land use change and sediment yield studies in Ghana. J Geogr Reg Plan 11:122–133. https://doi.org/10.5897/JGRP2018.0707

Brooke J (1989) Ghana, once 'hopeless,' gets at least the look of success. The New York Times Archives. https://www.nytimes.com/1989/01/03/world/ghana-once-hopeless-gets-at-least-the-look-of-success.html

Chakraborty A, Joshi PK (2014) Mapping disaster vulnerability in India using analytical hierarchy process. Geomat Nat Hazards Risk. https://doi.org/10.1080/19475705.2014.897656

Coll C, Galve JM, Sanchez JM, Caselles V (2010) Validation of Landsat-7/ETM+ thermal-band calibration and atmospheric correction with ground-based measurements. IEEE Trans Geosci Rem Sens 48:547–555. https://doi.org/10.1109/TGRS.2009.2024934

Damnyag L, Oduro AK, Obiri DB, Mohammed Y, Bampoh AA (2017) Assessment of drivers of deforestation and forest degradation in bia-West-Juabeso landscape, Ghana. Unpublished report, Ministry of Food & Agriculture (MOFA)

Danumah JH, Odai SN, Saley BM et al (2016) Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques, (cote d'ivoire). Geoenviron Disast 3:10. https://doi.org/10.1186/s40677-016-0044-y

Dei G (1988) Coping with the effects of the 1982–83 drought in Ghana: the view from the village. *Africa Dev Afrique et Développement* 107–122. http://www.jstor.org/stable/24486648

Dickson KB, Benneh G (1988) A new geography of Ghana. Longman Group, London
Ellis E, Pontius R (2010) Land-use and land-cover change. In: Cleveland CJ (eds) Encyclopaedia of earth (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. http://www.eoearth.org/article/Land-use_and_land-cover_change. Accessed 16 Dec 2020
FAO (2013) Climate change guidelines for forest managers. FAO Forestry Paper No. 172, Rome, Food and Agriculture Organization of the United Nations. www.fao.org/3/i3383e/i3383e00.htm
Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter S, Chapin FS, Coe M, Daily G, Gibbs H, Helkowski J, Holloway T, Howard E, Kucharik C, Monfreda C, Patz J, Prentice I, Ramankutty N, Snyder P (2005) Global consequences of land use. Science 309:570–574. https://doi.org/10.1126/science.1111772
Gazzola P, Querci E (2017) The connection between the quality of life and sustainable ecological development. Eur Sci J. https://doi.org/10.19044/esj.2017.v13n12p%25p
Geiger MT, Kwakye KG, Vicente CL, Wiafe BM, Boakye Adjei NY (2019) Fourth Ghana economic update: enhancing financial inclusion—Africa Region (English). Ghana Economic Update; no. 4 Washington, DC: World Bank Group. http://documents.worldbank.org/curated/en/395721560318628665/Fourth-Ghana-Economic-Update-Enhancing-Financial-Inclusion-Africa-Region
Ghana Statistical Service (GSS) (2020) 2020 Population of regions and Districts Report. Retrieved from: https://statsghana.gov.gh/gssmain/fileUpload/pressrelease/2021%20PHC%20General%20Report%20Vol%203A_Population%20of%20Regions%20and%20Districts_181121.pdf
Ghulam A (2010) Calculating surface temperature using Landsat thermal imagery. Department of Earth & Atmospheric Sciences, and Center for Environmental Sciences, St. Louis University, MO 63103. https://serc.carleton.edu/NAGTWorkshops/gis/activities2/48433.html
Gockowski J, Sonwa D (2011) Cocoa intensification scenarios and their predicted impact on CO_2 emissions, biodiversity conservation, and rural livelihoods in the Guinea rain forest of West Africa. Environ Manag 48:307–321. https://doi.org/10.1007/s00267-010-9602-3
Gyasi EA, Agyepong GT, Ardayfio-Schandorf E, Enu-Kwesi L, Nabila JS, Owusu Bennoah E (1994) Environmental endangerment in the forest-Savanna Zone of Southern Ghana: a research study report. Tokyo: UNU. https://archive.unu.edu/env/plec/country/ghana/Ghana.doc
Hall JB, Swaine MD (1976) Classification and ecology of closed-canopy forest in Ghana. J Ecol 64:913–951. https://doi.org/10.2307/2258816
Haradhan M (2018) Qualitative research methodology in social sciences and related subjects. J Econ Dev Environ People. https://doi.org/10.26458/jedep.v7i1.571
Huq M, Tribe M (2018) The economy of Ghana: 50 years of economic development. Palgrave Macmillan, London. https://doi.org/10.1057/978-1-137-60243-5
Hyden G (1998) Governance for sustainable livelihoods: operational issues. UNDP, New York
Jacobs S, Burkhard B, Van Daele T, Staes J, Schneiders A (2015) 'The Matrix Reloaded': A review of expert knowledge use for mapping ecosystem services. Ecol Model 295:21–30. https://doi.org/10.1016/j.ecolmodel.2014.08.024
Kleemann J, Inkoom NJ, Thiel M, Shankar S, Lautenbach S, Fürst C (2017) Peri-urban land use pattern and its relation to land use planning in Ghana, West Africa. Landsc Urban Plann 165(2017):280–294. https://doi.org/10.1016/j.landurbplan.2017.02.004
Koranteng A, Zawila-Niedzwiecki T (2016) Forest loss and other dynamic use changes in western region of Ghana. J Environ Prot Sus Dev 2:7–16
Koranteng A, Donkor E, Zawila-Niedzwiecki T, Kombat D (2017a) Synergies of satellite images for forest loss and other land use study in Ghana. In: International conference on applied sciences and technology (ICAST), Kumasi Technical University, vol 4, p 211–228
Koranteng A, Adu-Poku I, Zawila-Niedzwiecki T (2017b) Drivers of land use change and carbon mapping in the savannah area of Ghana. Folia for Pol 59:287–311. https://doi.org/10.3390/su13094951
Kusi N (1991) Ghana: can the adjustment reforms be sustained? Afr Dev Afrique et Développement 16(3/4):181–206
Kusimi JM (2008) Assessing land use and land cover change in the Wassa West District of Ghana using remote sensing. GeoJournal 71:249–259. https://doi.org/10.1007/s10708-008-9172-6
Lambin EF, Meyfroidt P (2011) Global land use change, economic globalization, and the looming land scarcity. Proc Natl Acad Sci 108:3465–3472. https://doi.org/10.1073/pnas.1100480108
Leemhuis C, Jung G, Kasei R, Liebe J (2009) The Volta Basin water allocation system: assessing the impact of small-scale reservoir development on the water resources of the Volta Basin, West Africa. Adv Geosci 21(57–62):2009. https://doi.org/10.5194/adgeo-21-57-2009
Logah FY, Obuobie E, Ofori D, Kankam-Yeboah K (2013) Analysis of rainfall variability in Ghana. Int J Latest Res Eng Comput (IJLREC) 1(1):1–8
Mastrandrea MD, Mach KJ, Plattner G-K, Edenhofer O, Stocker TF et al (2011) The IPCC AR5 guidance note on consistent treatment of uncertainties: a common approach across the working groups. Clim Change. https://doi.org/10.1007/s10584-011-0178-6
Mather A, Needle C, Coull J (1998) From resource crisis to sustainability: the forest transition in Denmark. Int J Sust Dev World 5:183–192. https://doi.org/10.1080/13504509809469982
McGregor DFM, Adam-Bradford A, Thompson DA, Simon D (2011) Resource management and agriculture in the peri-urban interface of Kumasi, Ghana: problems and prospects. Singap J Trop Geogr 32:382–398. https://doi.org/10.1111/J.1467-9493.2011.00438.X
Mensah CA, Eshun JK, Asamoah Y, Ofori E (2019) Changing land use/cover of Ghana's oil city (Sekondi-Takoradi Metropolis): implications for sustainable urban development. Int J Urban Sustain Dev 11(2):223–233. https://doi.org/10.1080/19463138.2019.1615492
Meyfroidt P, Lambin EF (2011) Global forest transition: prospects for an end to deforestation. Annu Rev Environ Resour 36:343–371. https://doi.org/10.1146/annurev-environ-090710-143732
Millennium Ecosystem Assessment (MA) (2005) Ecosystems and human well-being: Synthesis. Island Press, Washington, DC
Moller-Jensen L, Knudsen MH (2008) Patterns of population change in Ghana (1984–2000): urbanization and frontier development. GeoJournal 73:307–320. https://doi.org/10.1007/s10708-008-9209-x
Nasi R, Frost PG (2009) Sustainable forest management in the tropics: is everything in order but the patient still dying? Ecol Soc 14. https://hdl.handle.net/10568/20266
Nejad ARV, Esmaeili S, Aghamohammadi H (2015) Earthquake risk modeling using GIS for urban buildings, case study: Tehran municipality, district 3. Adv Nat Appl Sci 9:33–43
Nikoi E (2015) Ghana's Economic Recovery Programme and the Globalisation of Ashanti Goldfields Company Ltd. J Int Dev 28(4):588–605. https://doi.org/10.1002/jid.3199
Noponen RAM, Mensah DBC, Schroth G, Hayward J (2014) A landscape approach to climate-smart agriculture in Ghana. *ETFRN News* 56. https://www.rainforest-alliance.org/sites/default/files/2016-08/A-landscape-approach-to-climate-smart-agriculture-in-Ghana.pdf
Nunoo EK, Twum E, Panin A (2016) A criteria and indicator prognosis for sustainable forest management assessments: Concepts and optional policy baskets for the high forest zone in Ghana. J Sustain for 35:149–171. https://doi.org/10.1080/10549811.2015.1135066

Obeng-Odoom F (2013) Resource curse or blessing in Africa's oil cities? Empirical evidence from Sekondi-Takoradi, West Africa. City Cult Soc 4:229–240. https://doi.org/10.1016/j.ccs.2013.07.001

Oti JO, Kabo-Bah AT, Ofosu E (2020) Hydrologic response to climate change in the Densu River Basin in Ghana. Heliyon 6:e04722. https://doi.org/10.1016/j.heliyon.2020.e04722

Owusu-Nimo F, Mantey J, Nyarko KB, Appiah-Effah E, Aubynn A (2018) Spatial distribution patterns of illegal artisanal small scale gold mining (Galamsey) operations in Ghana: a focus on the Western Region. Heliyon. https://doi.org/10.1016/j.heliyon.2018.e00534

Queirós A, Faria D, Almeida F (2017) Strengths and limitations of qualitative and quantitative research methods. Eur J Educ Stud 3(9):369–387. https://doi.org/10.5281/zenodo.887089

Rindfuss RR, Stern PC (1998) Linking remote sensing and social science: the need and the challenges. The National Academy Press, Washington, D.C.

Rudel T, Schneider L, Uriarte M (2010) Forest transitions: an introduction. Land Use Policy 27:95–97. https://doi.org/10.1016/j.landusepol.2009.09.021

Rudel TK, Meyfroidt P, Chazdon R, Bongers F, Sloan S, Grau HR, Schneider L (2020) Whither the forest transition? Climate change, policy responses, and redistributed forests in the twenty-first century. Ambio 49:74–84. https://doi.org/10.1007/s13280-018-01143-0

Saad A, Shariff N, Gairola S (2013) Nature and causes of land degradation and desertification in Libya: need for sustainable land management. Afr J Biotechnol 10:13680–13687. https://doi.org/10.5897/AJB11.1235

Saaty TL (1980) The analytic hierarchy process: planning, priority setting, resource allocation. McGraw-Hill International Book Co., New York. https://doi.org/10.1016/0377-2217(82)90022-4

Sarfo I, Shuoben B, Beibei L et al (2021) Spatiotemporal development of land use systems, influences and climate variability in Southwestern Ghana (1970–2020). Environ Dev Sustain 2021:1–34. https://doi.org/10.1007/s10668-021-01848-5

Sim HC, Appanah S, Youn YC (2004) Forests for poverty reduction: opportunities with clean development mechanism, environmental services and biodiversity. In: Proceedings of the workshop, 27–29 August 2003, Seoul National University, Korea. http://www.fao.org/3/ae537e/ae537e00.htm

Smith J, Scherr SJ (2002) Forest carbon and local livelihoods: assessment of opportunities and policy recommendations. Occasional Paper No. 37. Bogor. CIFOR. http://www.cifor.cgiar.org/publications/pdf_files/OccPapers/OP-037.pdf

Southworth J, Nagendra H, Cassidy L (2012) Forest transition pathways in Asia—studies from Nepal, India, Thailand, and Cambodia. J Land Use Sci 7:51–65. https://doi.org/10.1080/1747423X.2010.520342

Tahiru AA, Doke DA, Baatuuwie BN (2020) Effect of land use and land cover changes on water quality in the Nawuni Catchment of the White Volta Basin, Northern Region, Ghana. Appl Water Sci 10:1–14. https://doi.org/10.1007/s13201-020-01272-6

Tan CM, Rockmore M (2018) Famine in Ghana and its impact. In: Preedy V, Patel V (eds) Handbook of famine, starvation, and nutrient deprivation. Springer, Cham. https://doi.org/10.1007/978-3-319-40007-5_95-1

Tolessa T, Dechassa C, Simane B, Alamerew B, Kidane M (2019) Land use/land cover dynamics in response to various driving forces in Didessa sub-basin, Ethiopia. GeoJournal 85:747–760. https://doi.org/10.1007/s10708-019-09990-4

Turner BL, Lambin E, Reenberg A (2007) Land change science special feature: the emergence of land change science for global environmental change and sustainability. Proc Natl Acad Sci USA 104:20666–20671. https://doi.org/10.1073/pnas.0704119104

Waggoner PE, Ausubel JH (2001) How much will feeding more and wealthier people encroach on forests? Popul Dev Rev 27:239–257

Xu H (2007) Extraction of urban built-up land features from Landsat imagery using a thematic-oriented index combination technique. Photogram Eng Remote Sens 73:1381–1391. https://doi.org/10.14358/PERS.73.12.1381

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