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.
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 dynamics 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; Basomni 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 km² (9236 m²) 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:

\[
\text{Change in LUCC} (x^2) = \frac{\text{LUCC}_{\text{Current year}} - \text{LUCC}_{\text{Past year}}}{\text{LUCC}_{\text{Past year}}} (1)
\]

\[
\% \text{Change in LUCC} (x^2) = \frac{\text{LUCC}_{\text{Current year}} - \text{LUCC}_{\text{Past year}}}{\text{LUCC}_{\text{Past year}}} \times 100\% (2)
\]

Rate of change in LUCC per year

\[
= \left( \frac{(\text{LUCC}_{\text{Current year}} - \text{LUCC}_{\text{Past year}})}{\text{LUCC}_{\text{Past year}}} \right) \times 100\% / 50 \text{ years}. (3)
\]

The change detection statistics for the study period (1970–2020) was obtained using pixel count, with area in km² and percentages for analysis. This facilitated the generation of statistical data of change occurrence over the years, for each class.
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

\[
L_\lambda = \frac{(\text{LMAX}_j - \text{LMIN}_j)}{(\text{QCALMAX} - \text{QCALMIN})} \times (\text{DN} - \text{QCALMIN}) + \text{LMIN}_j,
\]

where \(L_\lambda\) is cell value as radiance in \(\text{W}/(\text{m}^2 \times \text{sr} \times \text{µm})\); \(\text{LMAX}_j\) is the sensor spectral radiance that is scaled to (QCALMAX) in \(\text{W}/(\text{m}^2 \times \text{sr} \times \text{µm})\); \(\text{LMIN}_j\) is the sensor spectral radiance that is scaled to (QCALMIN) in \(\text{W}/(\text{m}^2 \times \text{sr} \times \text{µm})\). (QCALMAX) is the maximum quantized calibrated pixel value to \(\text{LMAX}_j\) [DN]. (QCALMIN) is the minimum quantized calibrated pixel value corresponding to \(\text{LMIN}_j\) [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 \(\text{LMIN}\) and \(\text{LMAX}\) 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. \(\lambda\) is the wavelength.

Conversion of spectral radiance \((L_\lambda)\) to kelvin with emissivity value

\[
T = \frac{K_2}{\ln\left(\frac{K_1 \times E}{L_\lambda}\right) + 1},
\]

Therefore, \(K_1\) and \(K_2\) become coefficients determined by the effective wavelength of a satellite sensor (Avdan and Jovanovska 2016; Ghulam 2010)

\[
\text{BT} = \frac{K_2}{\ln\left((K_1/K_j) + 1\right)}.\]

Conversion of spectral radiance \((L_j)\) to kelvin with emissivity value from Landsat 8

Since temperature is required in degree Celsius \((^\circ \text{C})\) \((T_\text{C})\), results for various temperatures must be converted from kelvin \((K)\) \((T_\text{B})\) to degree Celsius \((^\circ \text{C})\) \((T_\text{C})\)

\[
T_\text{C} = T_\text{B} - 273.15,
\]

Fig. 1 Location of the study area
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                                                                                                  |
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

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}, \quad (8)$$

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

$$\text{NDBI} = \frac{(\text{SWIR} - \text{NIR})}{(\text{SWIR} + \text{NIR})}, \quad (9)$$

where $\text{CRC}$ = contribution rate of change for a given class, over a given study period among the understudied indices, while $\text{LUC}$ = 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 ($\pm$) based on the results generated will indicate which class contributed the most toward change in the area.

| 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 |
| √√     | 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 |

| 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 |

Table 3 Combinations between agreement and evidence levels for each finding

Table 4 Confidence level table of findings from interviews, remote sensing, and existing literature

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

$$V_p = n \sqrt{W_1 x \cdots W_n};$$

(11)

$n$ represents the number of parameters. $W_n$ ratings are the main parameters. The criteria weight ($C_p$) is measured as

$$C_w = \frac{V_p}{V_p 1 + \cdots + V_p n}. $$

(12)

The sum of criteria weights ($C_w$) of all parameters of a matrix equals 1 and expressed as a percentage. Normalize the matrix by dividing each element by the sum of the
column, and calculate the mean of each line to determine the priority vector \([C]\). \(\lambda\) 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.

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

\[ \text{CI} = (\lambda_{\text{max}} - n) / (n - 1). \]  \hspace{1cm} (14)

The ratio of consistency is the probability that the croak is completed randomly. When \(\text{CR} \leq 10\%\), the results are considered to be pragmatic. However, a \(\text{CR} > 0.1\) indicates the need for revision.

\[ \text{CR} = \frac{\text{CI}}{\text{RI}}. \]  \hspace{1cm} (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...
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:

\[
\text{Accuracy assessment (A.A) = } \frac{\text{ASP}}{\text{TSP}} \times 100, \tag{16}
\]

where:

\(\text{ASP} = \text{number of sample points that accurately fall on each required feature (ASP = 493)}.\)

\(\text{TSP} = \text{number of total sample points generated (TSP = 524)}.\)

\(\text{A.A} = \text{Accuracy assessment } \left(\frac{493}{524} \times 100 = 94.08\%\right).\)

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.
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, $\lambda_{\text{max}}$, 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 |
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 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                    |
|     |                                   |                       |                                                   |

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
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), Danmuyag 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.

**Table 8** Area coverage for LUCC in Southwestern Ghana (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| 623.63| 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| 8006.62| 11093.37| 10283.95| 10391.86|
| Forests           | 20312.42| 14226.92| 10991.20| 6124   | 4439.02| 1682.13|
| Total             | 23924.01| 23924.86| 24772.67| 24333.05| 22835.91| 23031.57|

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 sub-due to 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 contributing to the...
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)             | 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)                           | Increase in human settlements                                                | 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; Areyetey 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 (CWlQ) 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) |
| Periods       | Driving factors                                                                 | Consequences                                                                 | Transitions                                                                 | Source (literature)                                                                 |
|--------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| 2000–2010    | Adoption of new governance systems (i.e., Adoption of capitalism and free-market (liberals) (Underlying cause) | High rate of deforestation                                                   | 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) |
|              | Rapid population growth (Underlying cause)                                       | Increasing rate of settlements and infrastructure                            |                                                                            |                                                                                   |
|              | 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/GYEEA, LEAP, NHIS) | 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 |                                                                            |                                                                                   |
|              |                                                                                   | Forests and bare land converted to human settlements and farmlands           |                                                                            |                                                                                   |
|              |                                                                                   | Efforts channeled toward profit-oriented sectors (i.e., natural resources) have resulted in a decline of other sectors |                                                                            |                                                                                   |
| 2010–2020    | Population growth and distribution (Underlying cause)                             |                                                                             |                                                                            |                                                                                   |
|              | Tree plantation (Afforestation) (i.e., GYEEA, Carbon Sequestration Development Project, REDD + Hotspot Strategy, planting for food and jobs) | Expansion of settlements and infrastructure                                   |                                                                            |                                                                                   |
|              | 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) | High rate of deforestation                                                   |                                                                            |                                                                                   |
|              | 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) | 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 |                                                                            |                                                                                   |
|              |                                                                                   | Farmlands and shrubs, bare land, and forests converted to settlements and infrastructure |                                                                            |                                                                                   |
|              |                                                                                   | Forests and bare land converted to human settlements and farmlands           |                                                                            |                                                                                   |
|              |                                                                                   | Efforts channeled toward profit-oriented sectors (i.e., natural resources) have resulted in a decline of other sectors |                                                                            |                                                                                   |
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.
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 degradation. Confidence level analysis based on existing literature (Table 9), expert interviews and spatial analysis (Fig. 4) for SW Ghana; \( \sqrt{\sqrt{\sqrt{\sqrt{\sqrt{}}}}}= \text{High agreement}; \sqrt{\sqrt{\sqrt{}}}= \text{Medium agreement}; \sqrt{\sqrt{}}= \text{Low agreement}; \sqrt{}= \text{No data or evidence}

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

| Driving factors                                                                 | Frequency (N=22) (%) | Position |
|--------------------------------------------------------------------------------|----------------------|----------|
| Expansion in settlements and social infrastructure: Schools, health facilities,  | \( \sqrt{\sqrt{\sqrt{\sqrt{}}}} \) 6 (28) | 2nd      |
| transportation networks, housing/real estates, Market and storage facilities,    |                       |          |
| drainage systems and so on)                                                      | usable width         |          |
| 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 | \( \sqrt{\sqrt{\sqrt{\sqrt{\sqrt{}}}} \sqrt{\sqrt{\sqrt{}}}} \) 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 | \( \sqrt{\sqrt{\sqrt{}} \sqrt{\sqrt{\sqrt{}}}} \) 4 (18) | 3rd      |
| Agricultural activities and Technological factors: agro-technical input and efficiency, mining technology, transportation networks | \( \sqrt{\sqrt{\sqrt{}} \sqrt{}} \) 2 (9) | 4th      |
| Natural or biophysical factors: Increase in temperature, droughts, wildfires, flooding, fluctuations in rainfall, topography, aspect, slope and so on | \( \sqrt{\sqrt{\sqrt{}} \sqrt{}} \) 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 | Interviews | Spatial Analyses | Confidence level |
|------------------------|----------|-------------------|------------|-----------------|------------------|
| Proximate Causes       | Deforestation | \( \sqrt{\sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}} \sqrt{\sqrt{\sqrt{}}}}} \) | Very High |
|                        | Settlements | \( \sqrt{\sqrt{\sqrt{\sqrt{}} \sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Very High |
|                        | Wood extraction | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Medium |
|                        | Setting up profit-oriented industries | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Medium |
|                        | Mining & Infrastructure | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Medium |
|                        | Agriculture expansion | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | High |
|                        | Bushfire/Wildfires | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Medium |
|                        | Farming | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Medium |
|                        | High temperature | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Medium |
|                        | Floods | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Medium |
|                        | Soil Quality | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Very High |

| Underlying Causes      | Migration | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Very High |
|                        | Poverty | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | High |
|                        | Population growth and distribution | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Very High |
|                        | Weak governance, Monitoring and Enforcement mechanisms | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Medium |
|                        | Technology (Science, research, mining technology, agro-technical change and efficiency, transportation networks) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Medium |
|                        | Cultural values, behaviour and beliefs | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Medium |

| Effects on some climatic variables | Increasing temperature | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Very High |
|                                  | Unpredictable/Fluctuations in rainfall patterns | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} \) | Very High |

Confidence level analysis based on existing literature (Table 9), expert interviews and spatial analysis (Fig. 4) for SW Ghana; \( \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} \sqrt{\sqrt{\sqrt{}}}} = \text{High agreement}; \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{\sqrt{}}} = \text{Medium agreement}; \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{}} = \text{Low agreement}; \sqrt{\sqrt{\sqrt{\sqrt{}}} \sqrt{}} = \text{No data or evidence}
### 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 | 0.129 | 0.147 | 0.129 | 0.124 | 0.129 | 0.124 | 0.124 | 0.124 | 0.129 | 1.559 | 12.046 |
| S        | 0.129 | 0.129 | 0.124 | 0.129 | 0.147 | 0.129 | 0.124 | 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 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.041 | 0.041 |
| SPOI     | 0.043 | 0.043 | 0.041 | 0.041 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.041 | 0.041 |
| MI       | 0.129 | 0.129 | 0.124 | 0.129 | 0.147 | 0.129 | 0.129 | 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 | 0.073 | 0.883 | 12.026 |
| M        | 0.129 | 0.129 | 0.124 | 0.129 | 0.147 | 0.129 | 0.129 | 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 | 0.073 | 0.065 | 0.073 | 0.065 | 0.082 | 0.082 | 0.073 | 0.956 | 13.026 |
| PGD      | 0.129 | 0.129 | 0.124 | 0.129 | 0.147 | 0.129 | 0.129 | 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 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.041 | 0.041 |
| T        | 0.043 | 0.043 | 0.041 | 0.041 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.041 | 0.041 |
| CVBB     | 0.043 | 0.043 | 0.041 | 0.041 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 | 0.041 | 0.041 |

### 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 |
| 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 |

**Note:** The values in bold represent the highest or lowest consistency measures.
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
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; Damnayag 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. 10  Changes in NDVI over the study period (1970–2020) in Southwestern 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

Fig. 11 Changes in NDBI over the study period (1970–2020) in SW Ghana
### 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/positions. | 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    | Farmlands/Shrubs| 5.7909471 | -2.4638667 |
| Aboi Nkwanta    | Farmlands/Shrubs| 5.7868767 | -2.4662858 |
| Aboi Nkwanta    | Farmlands/Shrubs| 5.7953138 | -2.4590688 |
| Aboi Nkwanta    | Built-up        | 5.7976689 | -2.4550062 |
| Aboi Nkwanta    | Built-up        | 5.8016515 | -2.4493658 |
| Abockia         | Built-up        | 5.7721831 | -2.7447494 |
| Abockia         | Built-up        | 5.6247933 | -2.223478 |
| Abockia         | Built-up        | 5.6247933 | -2.223478 |
| Abockia         | Built-up        | 5.6247933 | -2.223478 |
| Abockia         | Built-up        | 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       | 5.779455  | -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     | 5.777884  | -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         | Built-up        | 5.7722928 | -2.7570706 |
| Adjakaa         | Waterbodies     | 5.7722473 | -2.7568632 |
| Adjakaa         | Built-up        | 5.7723433 | -2.7526647 |
| Adjakaa         | Built-up        | 5.7726107 | -2.7517878 |
| Adjakaa         | Built-up        | 5.7718865 | -2.7482012 |
| Adjakaa         | Farmlands/Shrubs| 5.7729035 | -2.7412537 |
| Adjakaa         | Built-up        | 5.7722726 | -2.7433313 |
| Adjakaa         | Farmlands/Shrubs| 5.7727648 | -2.75002 |
| Adjakaa         | Built-up        | 5.7728384 | -2.7505657 |
| Adjakaa         | Farmlands/Shrubs| 5.7723826 | -2.7529477 |
| Adjakaa         | Farmlands/Shrubs| 5.7723826 | -2.7529477 |
| Adjakaa         | Built-up        | 5.7722726 | -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 |
| Location       | Land Use                  | Original Value | Change Value |
|---------------|---------------------------|----------------|--------------|
| Asankragua    | Built-up                  | 5.8054283      | -2.432525    |
| Asankragua    | Bare land                 | 5.7935903      | -2.427006    |
| Asankragua    | Farmlands/Shrubs          | 5.7910534      | -2.4235608   |
| 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    |
| Bawdie        | Farmlands/Shrubs          | 5.6247933      | -2.223478    |
| Bawdie        | Forest                    | 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        | Bare land                 | 5.6247933      | -2.223478    |
| Bawdie        | Built-up                  | 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        | 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        | Built-up                  | 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                  | 5.6247933      | -2.223478    |
| Bawdie        | Bare land                 | 5.3170418      | -1.998939    |
| Bawdie        | Built-up                  | 5.3173893      | -1.9905549   |
| Bawdie        | Built-up                  | 5.308967       | -1.993578    |
| Bawdie        | Built-up                  | 5.306455       | -1.994467    |
| Bawdie        | Built-up                  | 5.306088       | -1.994112    |
| Beposo        | Built-up                  | 5.11773421     | -1.62096462  |
| Beposo        | Waterbodies               | 5.123176862    | -1.617846847 |
| Beposo        | Built-up                  | 5.123848452    | -1.613322879 |
| Beposo        | Farmlands/Shrubs          | 5.123794395    | -1.609115739 |
| Beposo        | Farmlands/Shrubs          | 5.123946226    | -1.606856831 |
| Beposo        | Farmlands/Shrubs          | 5.121201241    | -1.603611216 |
| Beposo        | Farmlands/Shrubs          | 5.11931043     | -1.603644784 |
| Beposo        | Farmlands/Shrubs          | 5.110649444    | -1.600790656 |
| Beposo        | Forest                    | 5.6247933      | -2.223478    |
| Beposo        | Farmlands/Shrubs          | 5.6247933      | -2.223478    |
| Beposo        | Farmlands/Shrubs          | 5.6247933      | -2.223478    |
| Beposo        | Built-up                  | 5.6247933      | -2.223478    |
| Beposo        | Forest                    | 5.6247933      | -2.223478    |
| Beposo        | Bare land                 | 5.6315684      | -2.2280839   |
| Beposo        | Farmlands/Shrubs          | 5.6247933      | -2.223478    |
| Beposo        | Built-up                  | 5.6247933      | -2.223478    |
| Beposo        | Built-up                  | 5.6247933      | -2.223478    |
| Beposo        | Waterbodies               | 5.6247933      | -2.223478    |
| Beposo        | 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          | 5.1699001      | -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      | -1.9643656   |
| Bonsa         | Farmlands/Shrubs          | 4.8972505      | -1.9621961   |
| Bonsa         | Built-up                  | 4.8907609      | -1.9554344   |
| Bonsa         | Built-up                  | 4.8976185      | -1.9486254   |
| Bonsa         | Built-up                  | 4.8947931      | -1.8970939   |
| Bonsa         | Built-up                  | 4.8921061      | -1.8188959   |
Table 14 (continued)

| Location          | Type          | Value       |
|-------------------|---------------|-------------|
| Enchi              | Built up      | 5.7812364   |
| Enchi              | Built-up      | 5.7818456   |
| Enchi              | Farmlands/Shrubs | 5.7839101   |
| Enchi              | Bare land     | 5.7850223   |
| Enchi              | Forest        | 5.7873294   |
| Enchi              | Farmlands/Shrubs | 5.7911184   |
| Enchi              | Farmlands/Shrubs | 5.7931413   |
| Enchi              | Bare land     | 5.7952845   |
| Enchi              | Farmlands/Shrubs | 5.797293    |
| Enchi              | Built-up      | 5.7993413   |
| Enchi              | Farmlands/Shrubs | 5.8013314   |
| Enchi              | Bare land     | 5.801264    |
| Enchi              | Bare land     | 5.8019052   |
| Enchi              | Built-up      | 5.8041878   |
| Enchi              | Bare land     | 5.8067581   |
| Enchi              | Built-up      | 5.8117791   |
| Enchi              | Built-up      | 5.8165268   |
| Enchi              | Built-up      | 5.8212664   |
| Enchi              | Built-up      | 5.8210413   |
| Enchi              | Forest        | 5.7903133   |
| Enchi              | Farmlands/Shrubs | 5.7824391   |
| Enchi              | Bare land     | 5.7826888   |
| Enchi              | Bare land     | 5.7825047   |
| Enchi              | Bare land     | 5.7825219   |
| Enchi              | Bare land     | 5.8151338   |
| Enchi              | Built-up      | 5.8152128   |
| Enchi              | Waterbodies   | 5.8193689   |
| Fiaseman           | Built-up      | 5.2934604   |
| Fiaseman           | Built-up      | 5.2892638   |
| Fiaseman           | Built-up      | 5.2895559   |
| Fiaseman           | Built-up      | 5.2791985   |
| Fiaseman           | Built-up      | 5.2720263   |
| Fiaseman           | Built-up      | 5.2668272   |
| Fiaseman           | Built-up      | 5.2640872   |
| Fiaseman           | Built-up      | 5.2609297   |
| Fiaseman           | Built-up      | 5.258688    |
| Fiaseman           | Bare land     | 5.2533505   |
| Fiaseman           | Built-up      | 5.2455448   |
| Fiaseman           | Bare land     | 5.2444319   |
| Fiaseman           | Farmlands/Shrubs | 5.2402845   |
| Fiaseman           | Built-up      | 5.237618    |
| Fiaseman           | Built-up      | 5.237935    |
| Fiaseman           | Farmlands/Shrubs | 5.2260888   |
| Fiaseman           | Forest        | 5.2218063   |

Table 14 (continued)

| Location          | Type          | Value       |
|-------------------|---------------|-------------|
| Bonsa             | Bare land     | 4.8991231   |
| Bonsa             | Forest        | 5.126423    |
| Bonsa             | Bare land     | 5.1012162   |
| Bonsa             | Forest        | 5.0983034   |
| Bonsa             | Built-up      | 5.0833997   |
| Bonsa             | Forest        | 5.0815369   |
| Bonsa             | Forest        | 5.0378867   |
| Bonsa             | Forest        | 5.0059842   |
| Bonsa             | Forest        | 4.9758466   |
| Brodziak          | Bare land     | 5.7471044   |
| Brodziak          | Forest        | 5.7454052   |
| Brodziak          | Forest        | 5.7449032   |
| Brodziak          | Farmlands/Shrubs | 5.7439919   |
| Daboase           | Farmlands/Shrubs | 5.111464612 |
| Daboase           | Bare land     | 5.112116687 |
| Daboase           | Bare land     | 5.11215884  |
| Daboase           | Farmlands/Shrubs | 5.112838992 |
| Daboase           | Built-up      | 5.115987034 |
| Densam            | Farmlands/Shrubs | 5.6976839   |
| Densam            | Built-up      | 5.6830614   |
| Densam            | Forest        | 5.6708519   |
| Densam            | Farmlands/Shrubs | 5.6685109   |
| Densam            | Forest        | 5.6556802   |
| Densam            | Forest        | 5.6518927   |
| Densam            | Built-up      | 5.6403035   |
| Densam            | Built-up      | 5.6344357   |
| Densam            | Built-up      | 5.633259    |
| Densam            | Farmlands/Shrubs | 5.6247933   |
| Densam            | Farmlands/Shrubs | 5.6247933   |
| Densam            | Farmlands/Shrubs | 5.6247933   |
| Densam            | Built-up      | 5.6247933   |
| Elubo             | Farmlands/Shrubs | 5.7761464   |
| Elubo             | Forest        | 5.7742342   |
| Elubo             | Built-up      | 5.7830923   |
| Elubo road        | Forest        | 5.7779138   |
| Enchi             | Bare land     | 5.8218236   |
| Enchi             | Forest        | 5.8178036   |
| Enchi             | Farmlands/Shrubs | 5.81723     |
| Enchi             | Built-up      | 5.8138331   |
| Enchi             | Forest        | 5.7971596   |
| Enchi             | Farmlands/Shrubs | 5.7882961   |
| Enchi             | Farmlands/Shrubs | 5.782555    |
| Gran   | Forest  | 5.7178788 | -2.3514529 |
|--------|---------|-----------|-------------|
| Gran   | Farmlands/Shrubs | 5.715202 | -2.3470061 |
| Gran   | Farmlands/Shrubs | 5.7195327 | -2.3359171 |
| Gran   | Farmlands/Shrubs | 5.6922546 | -2.3115557 |
| Hiawa  | Built-up | 5.6247933 | -2.2234782 |
| Hiawa  | Built-up | 5.6247933 | -2.2234782 |
| Hiawa  | Built-up | 5.6247933 | -2.2234782 |
| Hiawa  | Farmlands/Shrubs | 5.6247933 | -2.2234782 |
| Hiawa  | Farmlands/Shrubs | 5.6247933 | -2.2234782 |
| Hiawa  | Farmlands/Shrubs | 5.6247933 | -2.2234782 |
| Hiawa  | Farmlands/Shrubs | 5.6247933 | -2.2234782 |
| Hiawa  | Waterbodies | 5.6247933 | -2.2234782 |
| Hiawa  | Farmlands/Shrubs | 5.6247933 | -2.2234782 |
| Hiawa  | Built-up | 5.6247933 | -2.2234782 |
| Huni Ano | Farmlands/Shrubs | 5.6247933 | -2.2234782 |
| Huni Ano | Forest | 5.6247933 | -2.2234782 |
| Huni Ano | Built-up | 5.6247933 | -2.2234782 |
| Huni Ano | Built-up | 5.6247933 | -2.2234782 |
| Huni Ano | Bare land | 5.6247933 | -2.2234782 |
| Huni Ano | Bare land | 5.6247933 | -2.2234782 |
| Jomoro Enchi | Farmlands/Shrubs | 5.7651643 | -2.5994983 |
| Jomoro Enchi | Built-up | 5.7604142 | -2.5922528 |
| Jomoro Enchi | Farmlands/Shrubs | 5.7602436 | -2.5930879 |
| Jomoro Enchi | Bare land | 5.7605395 | -2.5881754 |
| Jomoro Enchi | Forest | 5.7623849 | -2.5778447 |
| K Boateng | Forest | 5.6626668 | -2.2963313 |
| K Boateng | Forest | 5.6604762 | -2.295102 |
| 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 | -2.2234782 |
| 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 | -2.3545139 |
| Mando Amenfi | Forest | 5.64882 | -2.276025 |
| Mando Amenfi | Forest | 5.6460341 | -2.2694278 |
| Mando Amenfi | Built-up | 5.6434423 | -2.268532 |
| Mando Amenfi | Forest | 5.6321434 | -2.2427021 |
| Mando Amenfi | Forest | 5.6306463 | -2.2390589 |
| Mempeasem | Bare land | 5.2214854 | -2.0202423 |
| Mempeasem | Bare land | 5.2192204 | -2.0212039 |
| Mempeasem | Farmlands/Shrubs | 5.2066628 | -2.0281055 |
| Mempeasem | Bare land | 5.1958116 | -2.0321357 |
| Mempeasem | Farmlands/Shrubs | 5.1888986 | -2.036978 |
| Mempeasem | Bare land | 5.1869638 | -2.0384229 |
| Mempeasem | Built-up | 5.182622 | -2.0415238 |
| Nsuaem | Bare land | 4.8925694 | -1.8928628 |
| Nsuaem | Farmlands/Shrubs | 4.8920418 | -1.888316 |
| Nsuaem | Bare land | 4.8934211 | -1.834469 |
| Nsuaem | Forest | 5.0568485 | -2.0970969 |
| Nsuaem | Built-up | 5.030064 | -2.08665 |
| Nsuaem | Farmlands/Shrubs | 5.0052443 | -2.0738555 |
| Nsuaem | Built-up | 5.0027138 | -2.0252846 |
| Nsuaem | Forest | 4.9921162 | -2.0182078 |
| 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 | 5.7364645 | -2.3773603 |
| Nya | Forest | 5.7064848 | -2.3246181 |
| Nyamitase | Farmlands/Shrubs | 5.6247933 | -2.223478 |
| Nyamitase | Built-up | 5.6247933 | -2.223478 |
| Nyamitase | Farmlands/Shrubs | 5.6247933 | -2.223478 |
| Nyamitase | Built-up | 5.6247933 | -2.223478 |
| Nyamitase | Built-up | 5.6247933 | -2.223478 |
| Nyamitase | Built-up | 5.6247933 | -2.223478 |
| Nyamitase | Built-up | 5.6247933 | -2.223478 |
| Nyamitase | Built-up | 5.6247933 | -2.223478 |
| Nyamitase | Bare land | 5.6247933 | -2.223478 |
| Nyamitase | Bare land | 5.7302564 | -2.372268 |
| Nyamitase | Farmlands/Shrubs | 5.6584121 | -2.2941531 |
| Nyamitase | Farmlands/Shrubs | 5.6522835 | -2.2882657 |
| Nyamitase | Forest | 5.6247933 | -2.223478 |
| Nyamitase | Waterbodies | 5.6247933 | -2.223478 |
| Nyamitase | Farmlands/Shrubs | 5.6247933 | -2.223478 |
| Nyamitase | Built-up | 5.6247933 | -2.223478 |
| Nyamitase | Built-up | 5.6247933 | -2.223478 |
| Nyamitase | Built-up | 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 | 5.7729795 | -2.540285 |
### Table 14 (continued)

| Region          | Land Use               | FDR       | PDR       |
|-----------------|------------------------|-----------|-----------|
| Pantoso         | Built-up               | 5.7743097 | -2.5313814 |
| Pantoso         | Farmlands/Shrubs       | 5.7731143  | -2.5196059 |
| Pantoso         | Farmlands/Shrubs       | 5.7719406  | -2.5138686 |
| Pantoso         | Bare land              | 5.7688464  | -2.5098793 |
| Pantoso         | Farmlands/Shrubs       | 5.7674725  | -2.5011995 |
| Petopeon        | Built-up               | 5.6247933  | -2.223478  |
| Petopeon        | Built-up               | 5.6247933  | -2.223478  |
| Petopeon        | Built-up               | 5.6247933  | -2.223478  |
| Petopeon        | Farmlands/Shrubs       | 5.6247933  | -2.223478  |
| Petopeon        | Forest                 | 5.6247933  | -2.223478  |
| Petopeon        | Waterbodies            | 5.6247933  | -2.223478  |
| Petopeon        | Bare land              | 5.6247933  | -2.223478  |
| Petopeon        | Farmlands/Shrubs       | 5.6394875  | -2.2613292 |
| Petopeon        | Built-up               | 5.6326585  | -2.2356167 |
| Petopeon        | Forest                 | 5.6337014  | -2.2329625 |
| Petopeon        | Forest                 | 5.6281978  | -2.224905  |
| Petopeon        | Farmlands/Shrubs       | 5.6247933  | -2.223478  |
| Petopeon        | Built-up               | 5.6247933  | -2.223478  |
| Petopeon        | Farmlands/Shrubs       | 5.6247933  | -2.223478  |
| Simpah          | Built-up               | 5.6247933  | -2.223478  |
| Simpah          | Bare land              | 4.98107174  | -1.70331604 |
| Simpah          | Farmlands/Shrubs       | 4.98384578  | -1.69054368 |
| Simpah          | Built-up               | 4.986396853 | -1.686000918 |
| Sekondi         | Built-up               | 4.989351823 | -1.684250038 |
| Sekondi         | Built-up               | 4.993914186 | -1.681770255 |
| Sekondi         | Built-up               | 4.995510854 | -1.68083392 |
| 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              | 5.034447371 | -1.661812642 |
| Sekondi         | Bare land              | 5.039296842 | -1.659257281 |
| Sekondi         | Built-up               | 5.046485183 | -1.659069999 |
| 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)

| Location       | Coverage Type | Number of Total Samples | Number of Total Samples |
|----------------|---------------|-------------------------|-------------------------|
| Takoradi       | Built-up      | 5.00432                 | -2.0265984              |
| Takoradi       | Farmlands/Shrubs | 4.935919                | -1.979885               |
| Takoradi       | Built-up      | 4.911934                | -1.784684               |
| Takoradi       | Built-up      | 4.910024                | -1.780805               |
| Takoradi       | Built-up      | 4.908200                | -1.777843               |
| Takoradi       | Built-up      | 4.903365                | -1.769317               |
| Takoradi       | Built-up      | 4.898594                | -1.752906               |
| Takoradi       | Built-up      | 5.624793                | -2.223478               |
| Tarkwa         | Built-up      | 5.327893                | -1.981664               |
| Tarkwa         | Built-up      | 5.713720                | -2.327482               |
| Tarkwa         | Forest        | 5.652761                | -2.284442               |
| Tarkwa         | Bare land     | 5.644648                | -2.268928               |
| Tarkwa         | Built-up      | 5.639954                | -2.262859               |
| Tarkwa         | Built-up      | 5.636459                | -2.256053               |
| Tarkwa         | Forest        | 5.648678                | -2.277517               |
| Tarkwa         | Farmlands/Shrubs | 5.625145                | -2.223876               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Forest        | 5.624793                | -2.223478               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Farmlands/Shrubs | 5.624793                | -2.223478               |
| Tarkwa         | Bare land     | 5.795916                | -2.676276               |
| Tarkwa         | Bare land     | 5.796574                | -2.676574               |
| Tarkwa         | Bare land     | 5.782179                | -2.601456               |
| Tarkwa         | Bare land     | 5.780070                | -2.658570               |
| Tarkwa         | Bare land     | 5.780637                | -2.650816               |
| Tarkwa         | Bare land     | 5.780537                | -2.649002               |
| Tarkwa         | Bare land     | 5.777853                | -2.6376516              |
| Tarkwa         | Farmlands/Shrubs | 5.776135                | -2.630895               |

### Table 14 (continued)

| Location       | Coverage Type | Number of Total Samples | Number of Total Samples |
|----------------|---------------|-------------------------|-------------------------|
| Simreso        | Forest        | 5.0141916               | -2.0857276              |
| 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         | 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             | -1.762745376            |
| 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     | 4.976604337             | -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      | 4.8931655               | -1.8266697              |
| Takoradi       | Forest        | 5.0852533               | -2.108588               |
| Takoradi       | Forest        | 5.080348                | -2.1092255              |
| Takoradi       | Built-up      | 5.0691614               | -2.0982327              |
| Takoradi       | Forest        | 5.0679345               | -2.0973289              |
| Takoradi       | Forest        | 5.0619644               | -2.0973289              |
| 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      | 4.9094822               | -1.7947036              |
| Takoradi       | Forest        | 5.0644825               | -2.0966442              |
| 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              |
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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.

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