Environment, Development and Sustainability (2022) 24:9851–9883
https://doi.org/10.1007/s10668-021-01848-5

Spatiotemporal development of land use systems, influences and climate variability in Southwestern Ghana (1970–2020)

Isaac Sarfo[1] · Bi Shuoben[2] · Li Beibei[1,3] · Solomon Obiri Yeboah Amankwah[2] · Emmanuel Yeboah[4] · John Ernest Koku[5] · Edward Kweku Nunoo[6] · Clement Kwang[4]

Received: 7 April 2021 / Accepted: 25 August 2021 / Published online: 9 October 2021

Abstract
This study assesses the spatiotemporal development of land use systems and climate variability in Southwestern Ghana over the past five decades using integrated remote sensing techniques and existing literature. We demonstrated the relationship between Normalized Difference Vegetative Index, Normalized Difference Water Index, Normalized Difference Built-up Index, surface temperature and precipitation using geoinformatics and Pearson's correlation coefficient (*r*). We found change in land use systems in Southwestern Ghana to be immensely driven by economic and socio-political factors. Interestingly, some biophysical factors have somewhat contributed to this change. Findings revealed a drastic decline in forested areas (-334.8 km^2 yr^{-1}) and waterbodies (-4.79 km^2 yr^{-1}), along with a dramatic increase in built-up ($+137.93$ km^2 yr^{-1}) and farmlands/shrubs ($+131.97$ km^2 yr^{-1}). Change in prevailing microclimatic conditions can be associated with land cover change, considering the impact of major drivers observed over the given period. Results showed a very weak positive correlation between vegetation and temperature ($r=0.214$). Similarly, built-up correlated positively with vegetation ($r=0.165$), water-index ($r=0.818$; *strong correlation or evidence of association*) and temperature ($r=0.266$). In contrast, other used variables correlated negatively with precipitation. The study serves a seminal guide to land use developers and institutors for effective and sustainable use of natural resources.

Keywords Land use · Driving forces · Surface temperature · Forest transition theory · Sustainable development · Ghana

1 Introduction

Historical development of land use systems and climate variability is anchored in underlying theories such as Millennium Sustainable Development Goals (SDGs), Forest Transition Theory (FTT), Climate Vulnerability and Adaptation, as well as, the concept of sustainability. Obtaining accurate and up-to-date information on the spatial dimensions of land use systems and climate variability is essential in gaining a comprehensive insight into a

✉ Bi Shuoben
bishuoben@163.com

Extended author information available on the last page of the article

country's overall political, socio-economic, technological and environmental status. Few currently deny that extreme weather and climatic conditions are among the most pressing problems of our times. There is general agreement among some schools of thought that humans are intrinsically part of the problem and the solution (Jia et al., 2019; IPCC, 2000). Land use cover change (LUCC) and climate variability first emerged as earth and atmospheric concerns rather than a societal problem; it soon became clear that understanding and addressing its global and local scope would require more than a narrowed approach. Historically, the link between climate change, land use and land cover (LULC) systems, ecosystem services and livelihoods in developing countries has been well established (Wang, 2016; Boon & Ahenkan, 2011; Guo, 2002; Wang et al., 2001). Global satellite launch and data capture commenced in the late 1950s (Sodango et al., 2017). However, data capture by countries varied across the globe post-satellite launch. Ghana's spatiotemporal data capture for some key natural resources and climate variables commenced in the 1970s. Global lands and other natural resources have undergone severe pressure, mainly due to a host of factors and competitive interests. These pressures are driven by natural and anthropogenic factors. For instance, conversion of forests into other land cover types and climate variability have impacted several ecological processes and functions. Whether separately or combined, these two phenomena pose devastating threats to all localities, especially those in least developed countries (Obeng & Aguilar, 2015; Yiran et al., 2012; Käyhkö et al., 2011; Yue et al., 2007; MEA, 2005; Mitchell & Csillag, 2001).

Climate variability and LUCC have been observed to be interlinked with evidence at various scales according to IPCC's special report on land and climate (Jia et al., 2019). On-going global warming is associated wit2011h a mesoscale element like LUCC (Gichangi et al., 2015; Manatsa et al., 2014). They constitute those that affect individual households through the regional and continental scales (Mattah et al., 2018; Peters et al., 2008). Negative implications comprising induced single large climate events (Lambin & Meyfroidt, 2011; Fenger, 1999) increase in air pollution (Cheng et al., 2014; Lü et al., 2006), deterioration and impediment of water resources (Cai et al., 2016; Mensah et al., 2018; Schumann et al., 1991), alteration of natural habitats, physiological processes and behaviour of some ecosystems (Gorgani et al., 2013; Kalnay & Cai, 2003; Liu et al., 2011, 2014; Peters et al., 2008; Yue et al., 2007) have been noted. Among the effects experienced by poor individual households are the multiplicity of health-related issues as well as poor living conditions. Vegetation co-exists with climatic conditions (Chase et al., 1999; Yiran et al., 2012). Land use system analysis is an essential component of LULC. Its development and uses are tied to several needs. First and foremost, fundamental research into spatiotemporal development of LUCC inspires understanding on land use systems and processes. Secondly, vegetation, built-up and water indices have a relationship with LST and precipitation (Ullah et al., 2020). Hence, there is the need to establish the link between various indices and climate variability in the study domain. The quest of achieving Millennium Sustainable Development Goals (SDGs) 1, 2, 13 and 15 have increased the growing concerns for further commitments, investments, needed political will, capacity building programs, change in lifestyles and behaviours to avert the known and unknown (UN, 2016).

The past 50 years have seen unprecedented LUCC due to significant transformations in the spatial development of land use systems in Ghana. This change is closely related to the development of agriculture. The agricultural sector remains the main stay of Ghana's economy. The sector houses 50% of labour force and contributes 20% to the country's GDP (Doe et al., 2018; MESTI, 2015; GSS, 2014; NDPC, 2010). Livelihood dependence on the sector results in the use of several tracts of land, increasing concerns to curtail risks associated with global food security, micro/macro-economic stability, foreign revenue through exports, employment rates and so on. Policies embedded in these parameters have fuelled interests among interested parties to invest in large- and medium-scale (commercial) agricultural activities. Several researches have attributed the root cause of LUCC in the country to expansion of croplands. Economic growth, on the other hand, was mentioned as an important driver with accompanying rapid urbanization and industrialization processes (Acheampong et al., 2018; Damnyag et al., 2017; Hengazy & Kaloop, 2015; Gougha & Yankson, 2012; Kusimi, 2008). However, wildfire, pests, disease infestation and other natural disasters are not major drivers since their impacts are insignificant towards land cover change in a country for several years (FAO, 2011; Attua, 2010; Chuvieco & Congalton, 1988). Consequently, this unceasing and unprecedented LUCC in Ghana has resulted in habitat, productivity and biodiversity loss, pollution risks, alteration in prevailing microclimatic conditions, desertification, waste accumulation and other associated problems. Several studies have confirmed a great deal of efforts to mitigate the negative impacts of LUCC by the government of Ghana. The rate of forest cover decline was estimated to be 2.24% per annum between 2005 and 2010 (Forestry Commission, 2015; MESTI, 2015; NDPC, 2010). Presently, Ghana's Forestry Commission projects a 2% (1154 km^2) annual rate of deforestation (Forestry Commission, 2015; Oduro et al., 2015). Recent trends show the most obvious LUCC in Ghana is the remarkable increase in agricultural lands across the length and breadth of the country. Surprisingly, these unprecedented changes can be observed in the northeast, east-central and southwestern regions of Ghana (Forestry Commission, 2015). The increasing rate of farming activities and human settlements is unheard of in the country's history, foraying other land cover types which comprise Ghana's savannas, forests and woodlands. Between 1975 and 2000, agricultural lands amplified from 13 to 28% per the total land area of Ghana. This continuous dilation persisted from 2000 to 2013 where agricultural activities skyrocketed, reaching 32% of the country's total area size. This expansion has significance beyond the simple area numbers.

Studies have noticed a positive correlation between the extensiveness of agriculture or economic growth, and environmental changes across the globe. According to Abbam et al. (2018), Lwasa (2014) and Silitshena (1996), such changes constitute LUCC, biophysical and biogeochemical changes as well as fluctuations in hydrological cycles. Apparently, most of these studies were carried out using GIS and remote sensing imagery. In spite of the complex nature of climate variability and LUCC, the essence of remote sensing/GIS tools, existing literature, expert knowledge and experience on LUCC, driving forces, stakeholder involvement, effectiveness of institutional and policy frameworks, among others, cannot be overlooked (Sarfo et al., 2019; Yiran et al., 2012). Importantly, using satellite imagery and existing literature have proven to be vital instruments in assessing historic changes associated with spatiotemporal development of land use systems and microclimatic conditions (Barakat et al., 2019; Bora & Goswami, 2016; Changkakati, 2019).

Southwestern Ghana hosts the country's rich natural resources which constitutes gold, timber, bauxite, coffee, crude oil, cocoa, ecological reserves, national parks/wildlife (eco-tourist sites) among others. Southwestern Ghana (wettest part of the country with an average rainfall of 1600 mm per annum) receives the highest amount of rainfall among the other zones in Ghana. Again, the study area is noted to produce more than half of Ghana's cocoa productivity (Tsekpo, 2018) as well as timber. The competitive interests in the use of these natural resources for various reasons among relevant stakeholders have placed pristine environment under enormous pressure. These reasons have partly driven the need to carry out this study, aimed at assessing the spatiotemporal development of land use systems and climate variability in Southwestern Ghana between 1970 and 2020. The study would propel practical capacity building at various regional and district levels through the development and strengthening of local institutions in aspects related to sustainable land and natural resource use, adaptation practices and climate-smart agriculture.

1.1 Forest transition theory (FTT) analysis: in the context of selected SDGs (1, 2, 13 and 15)

The Forest Transition Theory (FTT) as propounded by Alexander Mather during the 1990s seeks to primarily assess forest recovery dynamics under numerous circumstances across differing geographies (Rudel et al., 2005). It closely monitors changes in forest cover from a state of deforestation to that of reforestation. Thus, it offers opportunities to analyse the push and pull conditions which play key roles in shifting non-forested areas to forested areas (and vice versa), despite the theory's focus on deforestation (Singh et al., 2017). Arguably, some common causal factors responsible for loss of forested land area include population increase, land right issues, agricultural modernization and forest reliant practices among others. Conversely, sustainability policy implementation regimes, climate change mitigation and adaptation, coupled with reforestation initiatives among others, contribute to gains in forested land area (Grimm et al., 2008; Singh et al., 2017), and promote forest transition efforts.

It is critical to mention that some popular studies have looked at the FTT concept from differing standpoints. For instance, earlier in 2007, Perz argued that the quest for a modern economy by nations defines their journey towards forest transition, thereby focusing on the modernization theory's linkage to forest transition (Perz, 2007). Later, Barbier et al., (2010), in their research viewed FTT as a 'natural' trend of 'forest loss followed by forest gain' affected positively or negatively by policy favourability or non-favourability, respectively. This review however, is not aimed at delving into differing views on FTT.

A close observation of some underlying factors for shifting land areas from degraded to reforested status as indicated above, explicitly underscores key elements of 'sustainability'. In this regard, the objective of this brief analytical study is to review the relationship between FTT and the Sustainable Development Goals (SDGs); specifically, SDGs 1 (No Poverty), 2 (End Hunger), 13 (Climate Action), and 15 (Life on Land). This shall encompass the assessment of socio-economic dynamics of land use, climate change impacts and forest resource management. Studies have directly and indirectly reflected on the linkage between 'Sustainability' and 'FTT' (Rudel et al., 2005; 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 the SDGs 1 (No Poverty), 2 (End Hunger), 13 (Climate Action) and 15 (Life on Land) in various ways (Fig. 1).

2 Methodology

2.1 Description of the study area

The study area (Figs. 2 and 3) lies within latitude 5.3902°N and longitude 2.1450°W. Southwestern Ghana is approximately 23,921 km^2 (9236 sq. mi) representing about 10 percent of Ghana's total land surface with a long stretching coastline of about 202 km from Ghana's border with Cote D'Ivoire to the area's boundary with the central region. About

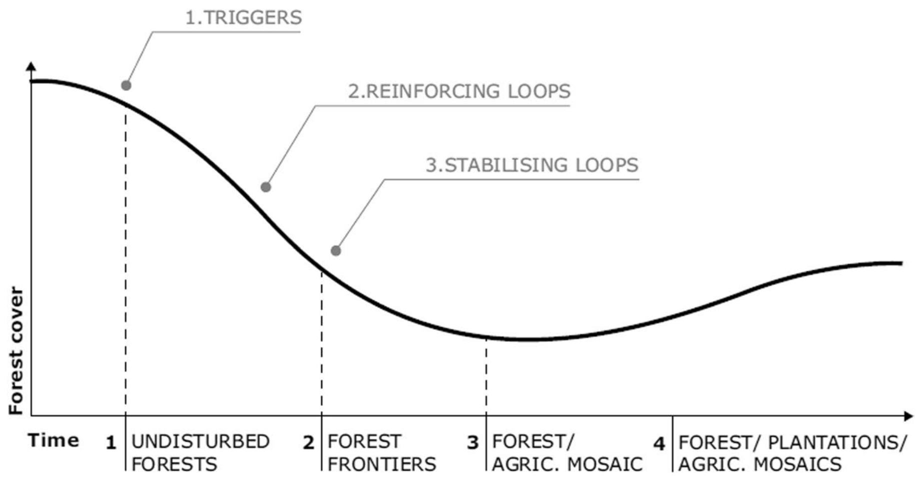


Fig. 1 The forest transition theory (FTT). *Source* Adopted from Mather (1998)

75% of the nation's high forest vegetation can be found in Southwestern Ghana. The population of the region according to 2010 Population and Housing Census stood at 2,376,021 with 1,187,774 males and 1,188,247 females.

2.2 Satellite imagery and classification of land use systems

In this study, six Landsat images archived for the given period (1970–2020) from Landsat 5 MSS, Landsat 4 TM, Landsat 5 TM, Landsat 7 ETM+and Landsat 8 OLI/TIRS were acquired from the United States Geological Survey's (USGS) website (http://earthexplorer.usgs.gov/). Images obtained from USGS website had visible and clear weather conditions which cover the entire study area. ArcGIS 10.6, ENVI 5.0 and 5.3 were used for the image pre-processing. Other image pre-processing procedures which were performed include image calibration, layer stacking and supervised classification (Fig. 4).

The flow-diagram above illustrates a system process on where and how data were acquired for this study, processed and analysed. LUCC type was determined using ENVI (Maximum Likelihood Classification Algorithm (MLCA). Topographic maps of the study area were designed using GIS tools. All data sets used in the study were geometrically calibrated using UTM Zone 30 North projection (Tables 1 and 2).

2.3 Change detection analysis

Change detection analysis was run to ascertain the regularity of land use systems and its drivers in southwestern part of Ghana (1970–2020). The present study applied image differencing, NDVI, post-classification and GIS techniques in determining the spatiotemporal development of land use systems in Southwestern Ghana. These are common standard change detection analysis techniques, used in several environmental monitoring and modelling related studies. ArcGIS 10.6 was used to produce absolute pixels and the percentage of pixels in each LUCC type.

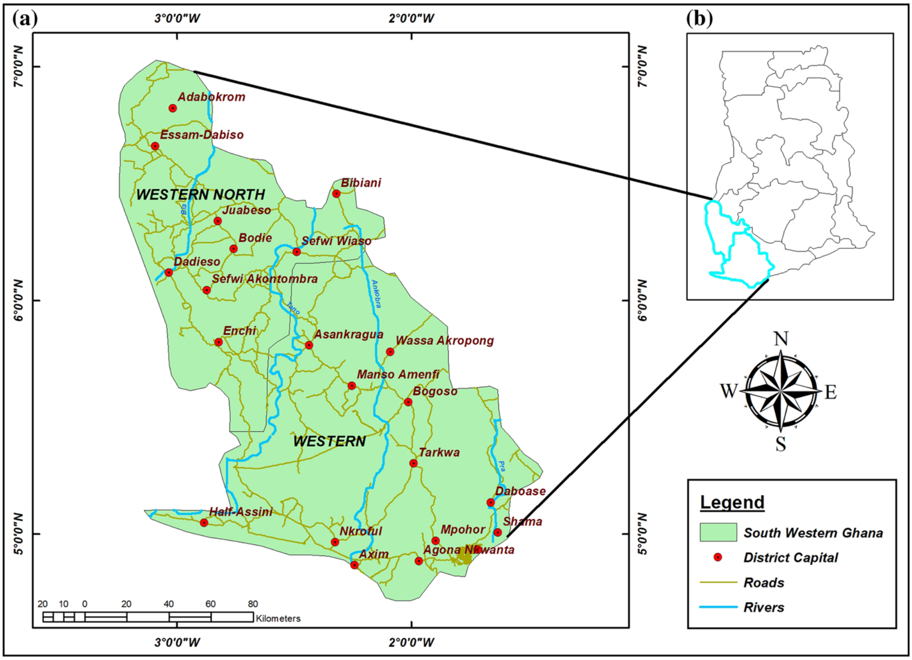


Fig. 2 Location of the study area: **a** Map of Ghana **b** Southwestern Ghana

2.4 Temperature analysis

2.4.1 Image calibration (radiance)

Radiometric correction (radiance) was done to rectify atmospheric effects and enhance clarity. Gap-filling was done for images that may have had stripes. Distortions in images were removed in the calibration process. It was done in order to enhance the image quality before other processes were carried out.

2.4.2 Digital number (DN) to radiance

The ETM+DN values range between 0 and 255. A conversion of DN to spectral Radiance was done according to Coll et al. (2010) as retrieved from USGS Landsat User handbook. The mathematical expression below was used to determine the radiance for the study area.

$$\mathrm{L}_{\lambda} = \frac{\left(\mathrm{LMAX}_{\lambda} - \mathrm{LMIN}_{\lambda}\right)}{(\mathrm{QCALMAX} - \mathrm{QCALMIN})} \mathrm{x}\ (\mathrm{DN} - \mathrm{QCALMIN}) + \mathrm{LMIN}_{\lambda} \quad (1)$$

where L_{λ} is cell value as radiance in $W/\left(M^2 * sr * \mu m\right)$, $LMAX_{\lambda}$ is the sensor spectral radiance that is scaled to $(QCALMAX)$ in $W/\left(M^2 * sr * \mu m\right)$, $LMIN_{\lambda}$ is the sensor spectral radiance that is scaled to $(QCALMIN)$ in $[W/\left(M^2 * sr * \mu m\right)]$. $(QCALMAX)$ is the maximum quantized calibrated pixel value to $LMAX_{\lambda}$ [DN], $(QCALMIN)$ is the minimum quantized calibrated pixel value corresponding to $LMIN_{\lambda}$ [DN] and QCAL is the quantized calibrated pixel value [DN]. The equation above can be observed from header files ETM+and

TM datasets from USGS website. The LMIN and LMAX are the spectral radiances for each band at digital numbers (DN) 1 and 255 for Landsat 7 ETM+, 1 and 65,535 for Landsat 8 OLI/TIRS. λ is the wavelength. This was done using ArcGIS 10.6.

Conversion of Spectral Radiance (L_λ) to Kelvin with emissivity value:

$$T = \frac{K_2}{\ln\left(\frac{K_1 * E}{L_\lambda} + 1\right)} \tag{2}$$

Therefore, k_1 and k_2 become a coefficient determined by effective wavelength of a satellite sensor (Table 3).

$$BT = \frac{K_2}{\ln\left[\left(K_1/L_\lambda\right) + 1\right]} \tag{3}$$

2.4.3 Conversion of spectral radiance (L_λ) to kelvin with emissivity value from Landsat 8

ENVI 5.0 software was used for the correction of thermal band 10 in order to remove atmospheric distortions from the thermal infrared data (Table 4).

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

$$T_C = T_B - 273.15 \tag{4}$$

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

2.5 Accuracy assessment

Accuracy assessment of land use classes was carried out for each period (1970–2020) using different ground truthing sampled points from random locations using ENVI and ArcGIS. These samples were overlaid on google earth pro for verification. Hundred (100) samples were generated from each class (Table 2) in the classified images for the accuracy assessment, making a total of five hundred (500) samples. The user and producer's accuracy assessment were employed along with a confusion matrix that culminates randomized and overall sampled points. The expression below was used to calculate the accuracy assessment:

$$\mathbf{AccuracyAssessment}(\mathbf{A.A}) = \left[(\mathrm{ASP}/\mathrm{TSP}) \times 100\right] \tag{5}$$

where ASP = Number of sample points that accurately falls on each required feature (ASP = 460). TSP = Number of total sample points generated (TSP = 500). A.A = Accuracy Assessment [(460/500) X 100 = 92%].

Therefore, the present study had 92% accuracy for the given years (1970–2020). A higher value gives vivid accuracy to the raster map and features depicted on the map.

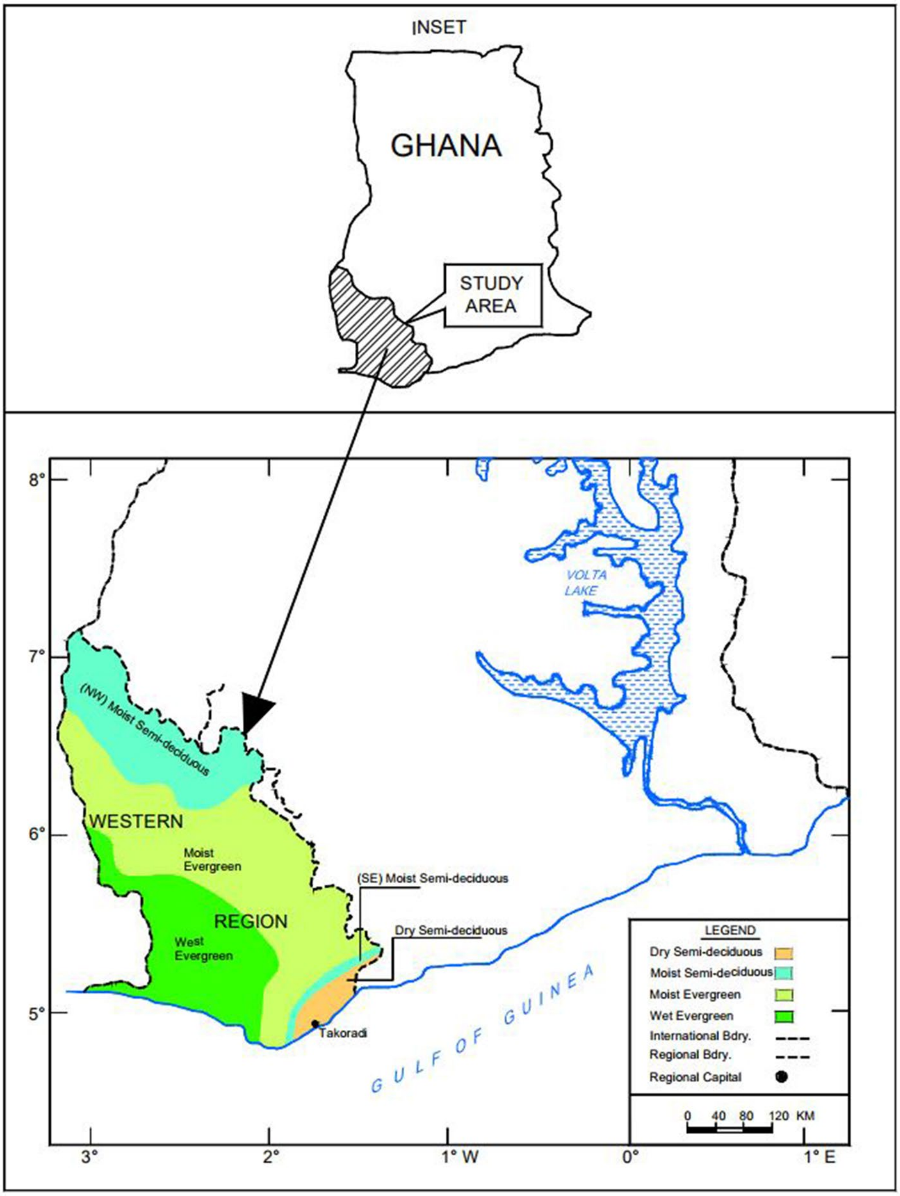


Fig. 3 Forest vegetation in the study area. *Source* Adapted and modified from deGraft-Johnson et al. (2010)

2.6 Data analysis

The present study used GIS tools coupled with existing literature on LUCC and climate variability in the study area for its analysis. Using satellite imagery and existing literature have proven to be vital instruments in assessing historic changes associated with spatiotemporal development of land use systems and microclimatic conditions. Using satellite

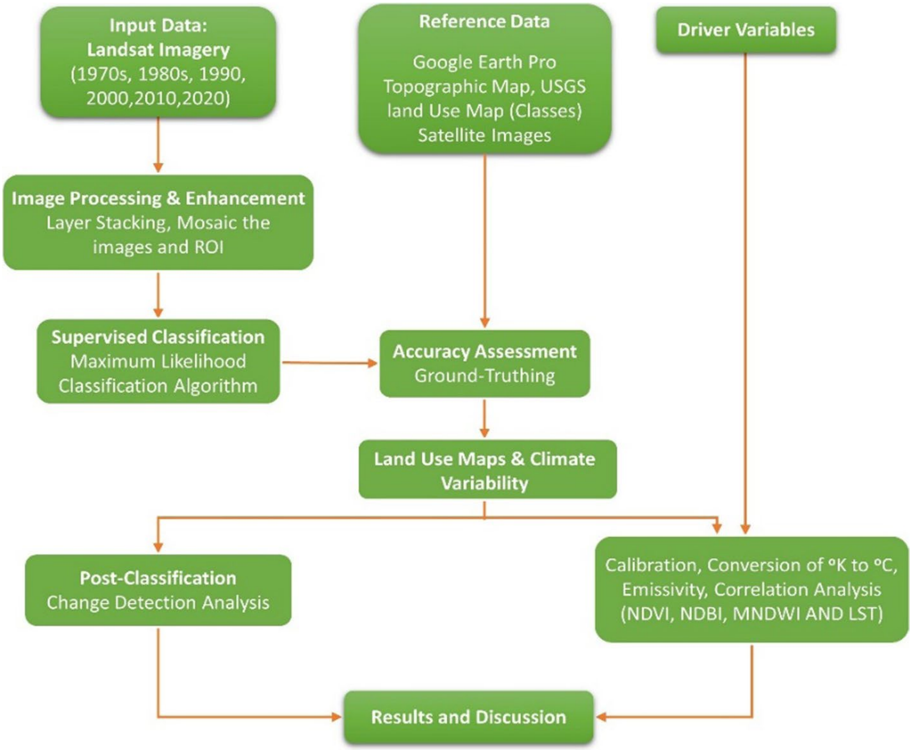


Fig. 4 Flowchart illustrating data and image processing procedure

Table 1 Description of imagery data used for land cover change study in Southwestern Ghana

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

imagery and existing literature to detect and establish historical changes does not only validate information on environmental changes observed in the study area but provide some strategic directions to inform policies and choices for communities.

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

2.6.1 Establishing a relationship between various input variables

The average maps of the input variables were stacked, and a random pixel sampling (10%) (n = 2,722,431) was performed to obtain information for each variable. The total number of pixels for the study area are 28, 725, 130. The resulting dataframe (*df*) was cleaned, normalized and used to calculate the Pearson's correlation between the variables using the Pandas (a python data analysis library). Correlation coefficients are statistics that measure the relation between variables or features of datasets.

2.6.2 Pearson correlation: pandas implementation

Pearson's correlation coefficient factors a dataset with two features: x and y. Given the premise, the first value x_1 from x corresponds to the first value y_1 from y, the second value x_2 from x to the second value y_2 from y, and so on. Again, there are n pairs of corresponding values*:* (x_1, y_1), (x_2, y_2), and so on. Each of these x–y pairs represents a single observation. In addition, it measures the linear relationship between two features and connotes the ratio of the covariance of x and y to the product of their standard deviations. The coefficient is denoted using the letter "*r*". It can be expressed using the mathematical function:

$$r = \Sigma_i\left(\left(x_i - \text{mean}(x)\right)\left(y_i - \text{mean}(y)\right)\right)\left(\sqrt{\Sigma_i\left(x_i - \text{mean}(x)\right)^2\sqrt{\Sigma_i\left(y_i - \text{mean}(y)\right)^2}}\right)^{-1} \tag{6}$$

From the expression above, i takes on the values 1, 2,…, n. The mean values of x and y are expressed with mean(x) and mean(y). Interpretation of "r" values:

- "*r*" can assume any real value in the range $-1 \leq r \leq 1$.
- *"r = 1"* connotes a strong positive linear relationship between x and y.
- *"r > 0"* indicates positive correlation between x and y.
- *"r = 0"* means x and y are independent.
- *"r < 0"* indicates negative correlation between x and y.
- "*r = −1*" shows a strong negative linear relationship between x and y.

Table 3 ETM + and TM thermal band calibration constants. *Source* Ghulam (2010)

	$K_1\left(Wm^{-2}sr^{-1}\mu m^{-1}\right)$	k_2(Kelvin)
Landsat 7–ETM +	666.09	1282.71
Landsat 5–TM	607.76	1260.56

Table 4 Thermal constant, Band 10. *Source* Avdan & Jovanovska (2016)

K_1	1321.08
K_2	777.89

In summary, a larger absolute value of r indicates stronger correlation, closer to a linear function. A smaller absolute value of r indicates weaker correlation.

3 Results

3.1 Change detection analysis between 1970 and 2020

Land cover classification from the five classes identified over the past five decades indicate an overall conversion of each land cover type (Tables 5 and 6) based on class total and image differencing results. Results generated for this study present evidence in alteration and declension in LUCC over the past 50 years. The arch land use that increased progressively over the study period was built-up and farmlands/shrubs. In all, between 1970 and 2020 (see Annex I), bare land obtained an area of 342.20 Km^2 (39.65%) and lost 75.43 Km^2 (−60.35%) to other classes. Built-up obtained an area of 7431.62 Km^2 (217.48%) following a 6896.36 Km^2 (117.48%) increment gained from other classes. Water bodies obtained an area of 635 Km^2 (51.84%) following a 239.48 Km^2 (−48.16%) loss to other classes. Farmlands and shrubs obtained an area of 8382.52 Km^2 (137.55%) following a 6598.30 Km^2 (37.55%) increment whilst forests covered an area of 3572.50 Km^2 (40.48%) and lost 16,739.92 Km^2 (−59.52%) to other classes (Table 6; Fig. 5).

Considering the overall conversions of LUCC systems (land cover changes between periods) as depicted in Tables 5 and 7, bare land have decreased at a rate of 18.06% (with 0.36% decline per year), built-up increased at a rate of 1288.36% (with 25.77% increase per year), waterbodies declined by 27.39% (with 0.55% decline per year), farmlands and shrubs increased by 369.81% (at a rate of 7.4% increase each year) whilst forests over the study period declined by 82.41% (at a rate of 1.65% each year).

3.2 Drivers of land use cover change

From a range of socio-cultural, economic, land reforms and institutional/state policies, demographic, technological and biophysical factors, over eight (8) key drivers (proximate and underlying causes) have been highlighted in existing literature as major influences of LUCC in the study area (Fig. 8) (Table 8). Major historical events (i.e. underlying causes of change) and the linkages between the main divers and the most important LUCC transitions are the implications of the changes drawn from findings of previous studies and spatial results generated for this study over the past five decades (Table 8).

3.3 Temperature analysis

Figure 6 shows the temperature range on average was between 27.78 °C and 20.23 °C in the 1970s. However, the average temperature range for 1980s was between 30.44 °C and 27.78 °C, which could be attributed to biophysical factors (i.e. bushfires/wildfires and prolonged dryness that occurred in the 1980s), which caused significant rise in surface temperatures in the study area. The average temperature range for the 1990s was between 28.88 °C and 25.45 °C. Average temperature range for 2000, 2010 and 2020 were between 30.12 °C and 23.67 °C, 31.66 °C and 24.44 °C, as well as 33.76 °C and 24.54 °C, respectively. Dark red and yellowish areas indicate areas with high or moderately high temperatures (these areas are heavily characterised by built-up) whilst dark blue areas represent areas with low temperature (mostly characterised by forest reserves or deciduous forests) with transient light blue zones.

3.4 Precipitation analysis

Rainfall data (in mm) archived for the study period were acquired from Trading Economics' website (https://tradingeconomics.com/ghana/precipitation). The precipitation analysis was performed using the Inverse Distance Weighted (IDW) interpolation to depict areas within the study area with high and low average rainfall (Fig. 7).

The precipitation range was between 50.27 mm and 100.54 mm for the 1970s; that of the 1980s ranged between 38.25 mm and 50.11 mm. However, the precipitation range for the 1990s ranged between 25.85 mm and 70.77 mm. A range of 39.17 mm and 45.21 mm can be observed for the 2000s; 10.70 mm to 39.85 mm is recorded for 2010, and 0.70 mm to 20.88 mm observed in early 2020.

The distribution above presents correlation analysis between various indices and climatic variables. Considering the results generated in relation to "*r*" shows the impact or degree of evidence identified by the present study as negligible; very weak or weak; least moderate or moderate, and robust or strong correlation. Here,

$0.5 \geq r \leq 1$ connotes *robust or strong correlation* (evidence of association) between both variables

$0.5 \geq \mathrm{r} \leq 0.6$ means least moderate or moderate correlation (evidence of association) exist.

$0.2 \geq r \leq 0.49$ means very *weak or weak* correlation (evidence of association) exist.

Below 0.2 ($r < 0.2$) means limited or no evidence of association (*negligible).*

4 Discussion

4.1 Major influences of LUCC and its implications

The comparison of each class over the study period showed there has been a remarkable change in LUCC of Southwestern Ghana during the last 50 years. Much of the changes is directly correlated to human-induced factors especially the conversion of forest areas to built-up areas and farmlands/shrubs. This therefore affirms the claim (Acheampong et al., 2018; Damnyag et al., 2017; Kusimi, 2008; Mensah et al., 2019) that economic forces are

Table 5 Area coverage for LUCC in Southwestern Ghana (1970–2020)

Area coverage for each class (km^2) over the given period (1970–2020)						
LUCC class	1970s	1980s	1990s	2000	2010	2020
Bare land	417.63	320.91	2607.63	2134.04	1928.93	1607.11
Built-up areas	535.26	623.636	750.81	3278.45	4843.33	8212.04
Waterbodies	874.48	3120.54	2420.37	1708.19	1330.68	1192.43
Farmlands and shrubs	1784.22	5632.85	8002.66	11,093.37	10,283.95	10,391.86
Forests	20,312.42	14,226.92	10,991.20	6124	4439.02	1628.13
Total	23,924.01	23,924.86	24,772.67	24,333.05	22,835.91	23,031.57

Table 6 Land cover changes between periods (%)

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

direct stimuli to the dramatic change in land cover or pristine environments. Table 6 illustrates specifically how built-up lands and farmlands/shrubs have increased at the expense of natural vegetation, waterbodies and bare land.

Overall, the natural vegetation (forests) and waterbodies in Southwestern Ghana over the given period reduced by 82% whereas areas covered by waterbodies reduced by 27%. The changes as illustrated in (Fig. 5) can be spatially observed across the length and breadth of the study area. We observed that the changes experienced in land use systems during the last 50 years, as depicted in Table 8 is primarily driven by economic factors which constitute rapid increase in population growth and distribution, agricultural activities, mining and illegal logging, state policies driven towards social interventions and industrialization, boosting exports through foreign exchange, bridging housing deficit gaps and poverty alleviation. The significant change, observed between 1980 and beyond, was mainly as a result of biophysical factors (i.e. prolonged dryness and wildfires) that were experienced in 1983. Various reforms and economic policies-initiated post-famine period till date are driven towards micro- and macro-economic stability as well as enhancing social infrastructure. Technological improvement and the development of new transportation networks which comprise railway networks to link major towns and cities, as well as, new roads for cocoa growing areas, mining and crude oil exploration towns have triggered changes contributing to the dramatic increase in built-up environment during the last 50 years. Presently, most farmers among other indigenes are trained in the use of several technologies, used to enhance productivity of cash crops and other perennial crops grown in the region. Improving soil fertility and adapting to climate-smart agricultural techniques among a host of technological equipment for farming and mining by multinational and small-scale operators have degraded forests and land resources in Southwestern Ghana (Fig. 8).

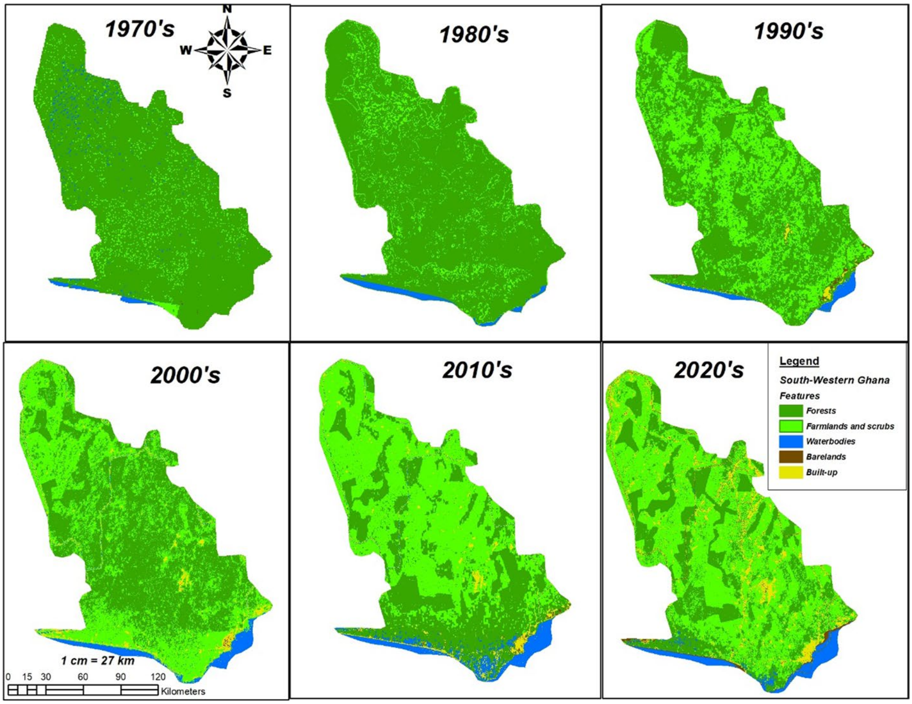


Fig. 5 LUCC changes over the past five decades (1970–2020) in Southwestern Ghana

Table 7 Rate and magnitude of change (sq.km) of LUCC in Southwestern Ghana (1970–2020)

Classes	1970s (sq.km)	2020 (sq.km)	Magnitude of change (sq.km)	Magnitude of change (sq.km)/year	Rate of change (%)/year
Bare land	417.63	342.20	−75.43	−1.51	−0.36
Built-up	535.26	7431.62	6896.36	+137.93	+25.77
Waterbodies	874.48	635	−239.48	−4.79	−0.55
Farmlands and shrubs	1784.22	8382.52	6598.3	+131.97	+7.4
Forests	20,312.42	3572.50	−16,739.92	−334.8	−1.65

Again, evidence of human-induced factors driving this dramatic change is exacerbated by some natural or biophysical factors emanating from climate change as depicted in Table 8 and (Figs. 6 and 7). In effect, these drivers demonstrate a "*causal chain*" where one cause (underlying cause) could lead to the other (direct cause). Perhaps, "an effect" could drive "a cause". For instance, reduction in forest areas through various socio-economic activities could influence prevailing microclimatic conditions (Figs. 6 and 7). Changes in prevailing microclimatic conditions could eventually cause droughts and flooding which could affect farmlands, shrubs, waterbodies and so on. Findings of this study are congruent with the stand points of Acheampong et al. (2018) and Damnyag et al. (2017), who posited those economic and socio-political factors like urban sprawl, mining, state/institutional policies, population growth and distribution as well as expansion in agricultural activities, are major factors driving LUCC in the study area. It is worthy to mention that efforts by the Government of Ghana through the Forestry Commission, International organizations and some Community Based Organizations (CBOs)/NGOs have over the past two to three decades, initiated various schemes to avert the acceleration of deforestation and land degradation. Among such interventions are re-afforestation projects outlined in sustainable forest and land resource management policies like: GYEEDA, planting for food and jobs, REDD + Hotspot initiatives or policies, as well as sensitizing farmers and indigenes on climate-smart agriculture and alternative livelihood sources that do not degrade land and forest. Some green projects or alternative livelihood source initiatives in the study area constitute the Community Resource Management Area (CREMA) and the Additional Livelihood Support Scheme of the Enhancing Natural Forests and Agro-forest Landscapes (ENFAL) projects. These initiatives provide a practical avenue for local communities to economically benefit from managing their resources sustainably. Creating green alternative livelihood sources for local folks in various rural communities across the entire study area could reduce the rate of urbanization and cater for future requisition of processed timber among other factors that cause forest and land degradation. In the quest of achieving SDGs 1, 2, 13 and 15, several livelihood options like tree nurseries, mushroom farming, bee keeping, grass cutter rearing, soap making, rabbit and snail rearing among other sustainable and cost-effective green projects could manage competing interests among relevant stakeholders in the region. LUCC in the study area is tied to several needs of various stakeholders. Hence, it is needful to adhere to policies or initiatives that will meet the needs of interested stakeholders while simultaneously protecting natural resources.

4.2 Various indices (NDVI, NDBI and NDWI), climatic variables and change detection from 1970–2020

4.2.1 NDVI change detection of SW Ghana from 1970–2020

The estimated NDVI range for the 1970s was between −0.96 and 1. The range for 1980s was between −0.97 and 0.79. The 1990s had a range of -0.93 and 0.81; 2000s had a range of −0.85 and 0.75; 2010 ranged between −0.87 and 0.70, and 2020 depicted an NDVI range of −0.90 and 0.64. Figure 9 illustrates a steady decline in vegetative index over the study period. Larger values of NDVI represent forest areas due to higher green biomass of trees and other vegetation. These areas as observed over the study period (1970–2020) constitute mainly forest and wildlife reserves/parks, closed (dense) and open canopies. Decrease in NDVI based on study findings could be attributed to the main drivers highlighted in Table 8, which are primarily, economic, socio-political and biophysical factors. This aligns with the assertions of Acheampong et al., (2018), Damnyag et al. (2017), Kleemann et al. (2017) and Kusimi (2008) that the major factors causing deforestation in the study area are economic and socio-political which constitute population and economic growth, weak governance.

Quantification of differences in vegetation in Southwestern Ghana was visualized in image differencing using NDVI for the study periods (1970s, 1980s, 1990s, 2000, 2010 and 2020). Areas marked with violet (Fig. 9) represent a highly negative change, thus,

Table 8 Major events, key drivers, consequences and transitions of LUCC in Southwestern Ghana (1970–2020)

Periods	Driving factors	Consequences	Transitions	Source (Literature)
1970s	Agricultural expansion (proximate cause)	Increase in small-scale subsistent farming (farmlands & shrubs) resulting in marginal deterioration of natural forests (pristine environment)	Bare land and forests to farmlands and shrubs, as well as settlements	Gockowski and Sonwa (2011); Dickson and Benneh (1988); Hall and Swaine (1976); Ahn (1958)
1970s–1980s	Population growth and distribution (Underlying cause) Agricultural expansion (proximate cause)	Increase in human settlements Increase in small-scale subsistent farming (farmlands & shrubs) resulting in marginal alteration of natural forests (pristine environment)	Bare land and forests to farmlands/shrubs, and 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 high 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 5) Loss of biodiversity and health problems. Increasing temperatures (dry climate) and reduced rainfall Redistribution of lands and conversion of natural forests to farmlands. The state and individuals emerged as dominant economic agents in the economy	Forest lands converted to farmlands and shrubs, bare land and human settlements	Tan and Rockmore (2018); Huq and Tribe (2018); Abbam et al. (2018); Nikoi (2015); Aryeetey and Kabur (2007); Gyasi et al. (1994); Kusi (1991); Brooke (1989); Dei (1988)

Table 8 (continued)

Periods	Driving factors	Consequences	Transitions	Source (Literature)
1990s–2000	Socio-economic development (i.e. Policies driven towards Ghana's Vision 2020, poverty reduction (i.e. Core Welfare Indicators Questionnaire (CWIQ) and the Ghana Living Standards Survey (GLSS), improvement in Human Development Indicators (HDIs), export led agricultural production and expansion in foreign investment) (Underlying causes) Population pressure (underlying cause) Biophysical and climatic factors (i.e. temperature rise) (Proximate cause)	Development of infrastructure such as transportation networks, education and health facilities Domestic and foreign investment in farming activities Population growth and significant increase in human settlements. High rate of deforestation. Need to meet food demands led to an increase in the rate of farming activities Increase in surface temperatures and reduced precipitation (Table 5 and Fig. 7) due to significant increase in built-up environment Loss of biodiversity and health problems	Forests, bare land, farmlands and shrubs converted to settlements/infrastructure, subsistent and medium/large-scale farms	Huq and Tribe (2018); Abbam et al. (2018); Damnyag et al. (2017); Koranteng and Zawila-Niedzwieki (2016); Noponen et al. (2014); Gockowski and Sonwa (2011); Kusimi (2008); Gyasi et al. (1994); Kusi (1991)

Table 8 (continued)

Periods	Driving factors	Consequences	Transitions	Source (Literature)
2000–2010	Adoption of new governance systems (i.e. Adoption of capitalism and free-market (liberalists) (Underlying cause) Rapid population growth (Underlying cause) Economic Reforms led to the application for enhanced Highly Indebted Poor Country (HIPC) in 2001, Ghana Poverty Reduction Strategy I (2003–2005) & II. Implementation of sectoral policies designed to promote Sustainable Economic Growth and high incidence of poverty in Ghana. Interventions like the School Feeding Program, NYEP/GYEEDA, LEAP, NHIS)	High rate of deforestation Increasing rate of settlements and infrastructure Increase in surface temperatures and a decline in rainfall Decline in farming activities (Table 5)	Farmlands and shrubs, bare land, and forests converted to settlements and infrastructure	Mensah et al. (2019); Acheampong et al. (2018); Huq and Tribe (2018); Abbam et al. (2018); Damnyag et al. (2017); Aduah and Baffoe (2013); Aduah et al. (2012); Gockowski and Sonwa (2011); Kusimi (2008); Aryeetey and Kabur (2007)

Table 8 (continued)

Periods	Driving factors	Consequences	Transitions	Source (Literature)
2010–2020	Population growth and distribution (Underlying cause) Tree plantation (Afforestation) (i.e. GYEEDA, Carbon Sequestration Development Project, REDD + Hotspot Strategy, planting for food and jobs) Infrastructural Development (2010–2016) (i.e. Community Day schools, district and regional hospitals, Roads and railway networks, Storage Facilities-Warehouses, Housing units among others) (proximate cause) Economic policies driven towards Industrialization and fiscal discipline (Macro and micro economic stability) (i.e. One-district-one factory, reducing Balance of Payment deficits (BoP) and so on. Increase in the prices of some agricultural commodities (i.e. increase in cashew, timber, cocoa producer prices). Encouraging domestic and foreign investors to venture into agriculture and other natural resource or profit-oriented sectors (Underlying cause)	Expansion of settlements and infrastructure High rate of deforestation Increase in surface temperature and decline in rainfall Expansion of cultivated lands done on small, medium and large scale to boost exports and provide more raw materials for industries Efforts channeled towards profit-oriented sectors (i.e. natural resources) have resulted in a decline of other sectors	Forests and bare land converted to human settlements and farmlands	Mensah et al. (2019); Geiger et al. (2019); Acheampong et al. (2018); Huq and Tribe (2018); Abbam et al. (2018); Damnyag et al. (2017); Kleemann et al. (2017); Koranteng and Zawila-Niedzwieki (2016); Noponen et al. (2014); Aduah and Baffoe (2013); Aduah et al. (2012); Logah et al. (2013)

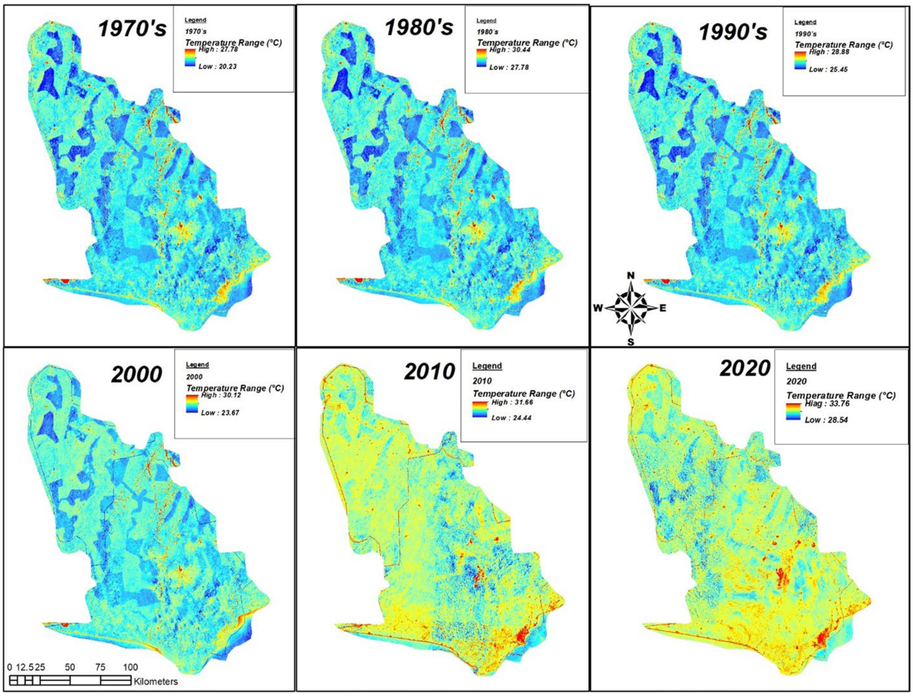


Fig. 6 Temperature variations over the study period (1970–2020) in the study area

major reduction in vegetation cover as observed in the 1970s and 1980s. Such areas as depicted in Fig. 9 are subdued by the sea or built-up environment. Yellowish and greenish areas indicate areas with moderate and dense vegetation cover, respectively, with an increasing rate of agricultural areas (between 2000 and 2020).

4.2.2 NDBI change detection of SW Ghana from 1970–2020

Figure 10 illustrates changes in NDBI over the study period in Southwestern Ghana. It is observed that NDBI ranged between −0.80 and 0.29 for the 1970s. The 1980s had an NDBI range between −0.77 and 0.37, and −0.75 to 0.49 for the 1990s. Again, the NDBI range for the 2000s was between −0.70 and 0.62. A significant increment was observed in 2010 when NDBI ranged between −0.85 and 0.77; NDBI range for 2020 was between −0.83 and 0.79. There is clear evidence of continuous expansion of settlements over the study period in the study area. Dark red and yellowish areas indicate high presence of built-up environment. Light green and green areas represent areas covered by farmlands and shrubs as well as less dense vegetation. Dark blue areas represent areas covered by forest and wildlife reserves (deciduous and semi-deciduous zones) or water bodies as shown in Fig. 10.

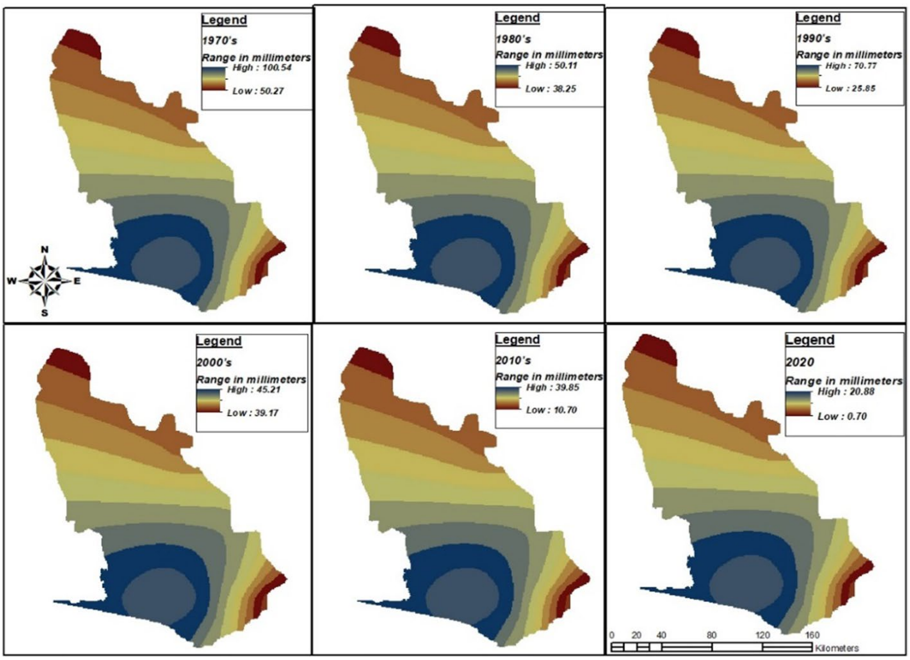


Fig. 7 Changes in rainfall amounts (in mm) received in specific zones over the study period (1970–2020) in the study area

4.2.3 NDWI change detection of SW Ghana from 1970–2020

From the illustrations below, the NDWI range for the 1970s was between −0.85 and 1 whilst that of the 1980s was between −0.90 and 0.95. However, the range for the 1990s was between −0.87 and 0.97. A significant change of −0.94 and 0.99 is observed for the 2000s whilst 2010 had a range between −0.96 and 0.99. Finally, 2020 NDWI ranged between −0.98 and 0.99. Figure 11 illustrates changes in water index over the study period. Dark blue areas represent areas covered by the sea while light blue areas are covered by rivers and other waterbodies. Greenish areas are areas covered by natural vegetation, forest reserves/parks whilst light green and yellowish areas are covered by farmlands/shrubs and built-up environment (settlements) as observed during the past 50 years (Fig. 11). No drastic change was observed for NDWI. Decline in waterbodies over the study period as presented in Table 5 could be attributed to the dramatic increase in built-up areas and farmlands. In addition, biophysical factors like increase in surface temperatures (Fig. 6) through evapotranspiration and other processes in Southwestern Ghana, coupled with fluctuations in rainfall patterns (Fig. 7) could partly contribute to the decline in water areas in the study region.

4.3 Relationship between various variable inputs

Monitoring ecosystems that are sensitive to climate change ensures a comprehensive understanding of the link between some climatic variables and ecosystems. This insight

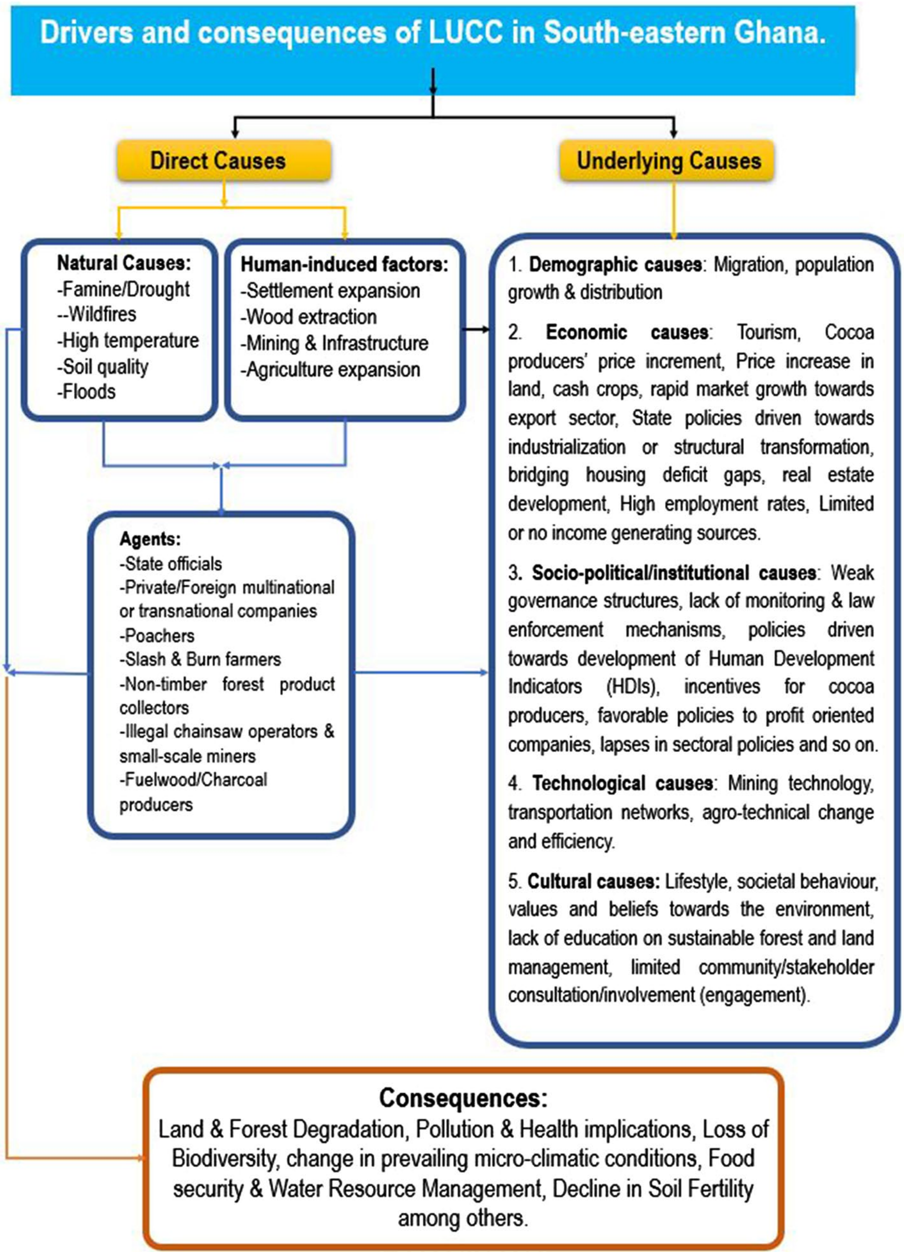


Fig. 8 Drivers and consequences of LUCC in Southwestern Ghana

is critical for future land use planning and management. One of the key objectives of this study was to examine the relationships between NDVI, NDBI, NDWI and some climatic variables (temperature and precipitation). Surprisingly, results indicated NDVI and temperature were positively correlated ($r = 0.214$) (Table 9). This means both NDVI and LST are increasing steadily which partly agrees with the findings of most studies considering the period (December-harmattan season) the data was captured among other reasons (Guo, 2002; Sun & Kafatos, 2007; Wang, 2016; Wang et al., 2001). Several studies have depicted a negative correlation (Gorgani et al., 2013; Liu et al., 2011; Yue et al., 2007) between NDVI and LST. The reasons for this result in the case of Southwestern Ghana could be attributed to the increase in farmlands/shrubs and grasslands, which does not significantly influence surface temperature. Thus, the impact of grasslands and farmlands/shrubs is marginal unlike forests or natural vegetation. Hence, as farmlands/shrubs (Table 6) (Fig. 5) increased during the study period, LST also increased steadily. More so, the presence of waterbodies in randomly sampled zones, used for the present study could somewhat cause NDVI and LST to be positively correlated as revealed by (Guo, 2002; Wang et al., 2001). However, the study area does not have major or more waterbodies that could affect the results generated since the random points generated were evenly distributed in the study area. Again, further analysis was conducted to remove sampling points that fell within zones of waterbodies to validate findings. Results generated indicated a very weak positive correlation ($r = 0.214$) was detected by the present study which somewhat validates the presence and increase in farmlands/shrubs and grasslands. Contextually, a very weak positive correlation generated for NDVI and LST eventually indicates very weak evidence of association exists for the two given variables in the study area.

On the other hand, NDVI and precipitation had a negative correlation ($r = -0.11$). Here, the decreasing trends in vegetation coverage (forest areas) and increasing trends in farmlands/shrubs and grasslands (Fig. LULCC), had resulted in the changes in rainfall patterns (Table 9) (Figs. 7 and 9). This result corroborates with the initial findings of Changkakati (2019) and the results of Bora and Goswami (2016). They attributed the negative correlation to growing monsoons among a host of other factors. Mitchell and Csillag (2001) in their study concluded that precipitation was a critical variable for vegetation in the mixed prairie ecosystem. Only the general correlation and regression between vegetation index and some climate elements were compared in their study. A thorough study should be conducted to reveal how precipitation is critical, which period of the season is worth noting for precipitation, coupled with which vegetation type is more delicate to precipitation. A negative correlation of ($r = -0.11$) is however negligible; since there is insufficient evidence of association to support the relationship between NDVI and precipitation per the results generated for this study.

We observed temperature and NDWI were positively correlated ($r = 0.342$) (Table 9) (Fig. 12a). The findings in the study agreed with the standpoints in previous studies (Abbam et al., 2018; Aduah & Baffoe, 2013; Logah et al. 2013). They revealed increasing temperatures in the study area could influence NDWI through high evaporation as well as expansion of waterbodies due to high temperatures. This somewhat explains why LST (Fig. 6) is positively correlated to NDWI during the past 50 years. NDWI and precipitation had a negative correlation ($r = -0.305$). It could also be observed that NDVI and NDWI have a positive correlation ($r = 0.540$). Both indices per results in (Figs. 9 and 11) show a decreasing trend. Results ($r = -0.305$) proved a weak correlation exist between temperature and NDWI variables in the study domain. Hence, weak evidence of association exists for the given variables.

Results revealed NDBI is positively correlated to LST ($r = 0.265$*; very weak correlation/evidence of association*), NDWI ($r = 0.818$*; the study detected a strong correlation or evidence of association between NDBI and NDWI*), NDVI ($r = 0.165$) and negatively correlated to precipitation ($r = -0.189$). Positive correlation between NDBI and LST shows

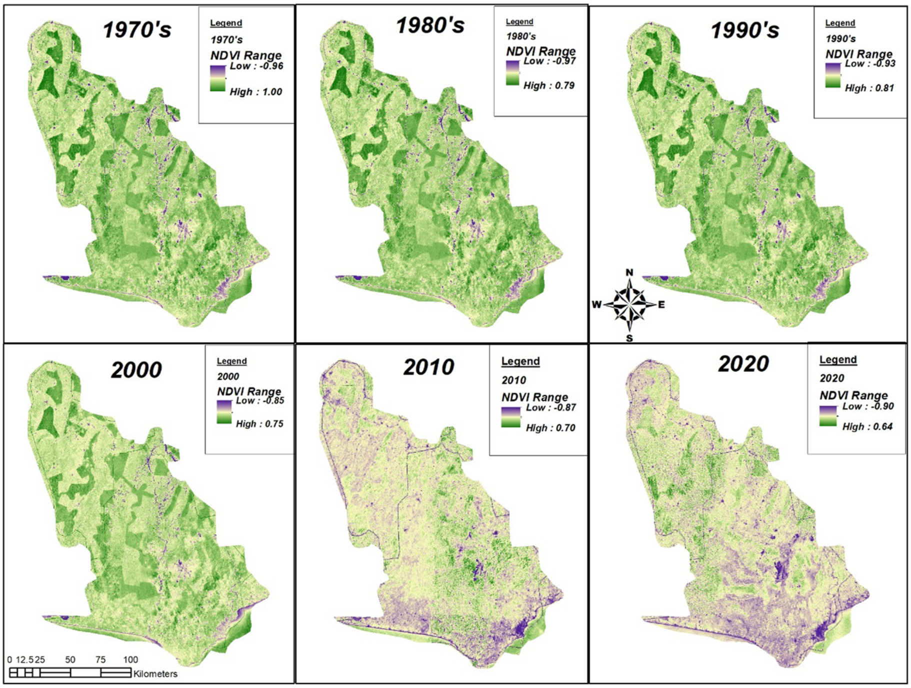


Fig. 9 Changes in NDVI over the study period (1970–2020) in Southwestern Ghana

that, drastic increment in built-up (Fig. 10) has resulted to an increase in surface temperatures (Fig. 6). Also, the positive correlation between NDBI and NDVI shows an increase in built-up (settlements) (Fig. 10) and farmlands/shrubs and grasslands (Fig. 5) (Table 5). The negative correlation (Table 9) between NDBI (Fig. 10) and precipitation shows a significant increase in built-up environment has resulted to a decline in rainfall amounts received (changes in rainfall patterns) (Fig. 7). Our findings corroborate with the assertions of (Abbam et al., 2018; Aduah & Baffoe, 2013; Aduah et al., 2012; Mensah et al., 2019) on built-up's influence on LST and precipitation. Precipitation and LST per the distribution above (Table 9) (Fig. 12b) show an inverse correlation ($r = -0.155$). In effect, an increase in LST (Fig. 6) has resulted in the fluctuations in rainfall patterns (Fig. 7) in the study area.

LUCC associated with biophysical variables such as vegetation index and climatic data provides the type of information required for categorization and etching of habitats. Ghana has experienced severe loss and fragmentation of natural vegetation over the last 50 years (Forestry Commission, 2015). Findings based on major influences have accounted for the dramatic loss in vegetation, and a significant increase in built-up and farmlands/shrubs. Among the two factors stated above, human-induced factors mainly driven by economic and socio-political factors as presented in Table 8 (Fig. 8) have influenced these unprecedented changes during the last 50 years in Southwestern Ghana. The potential human drivers in the study area have been explored in several local studies in different scopes. Some studies (Abbam et al., 2018; Acheampong et al., 2018; Aduah & Baffoe, 2013; Aduah et al., 2012; Damnyag et al., 2017; Kusimi, 2008; Mensah et al., 2019) confirmed that decreasing trends in vegetative coverage and land degradation in the study area were attributed to

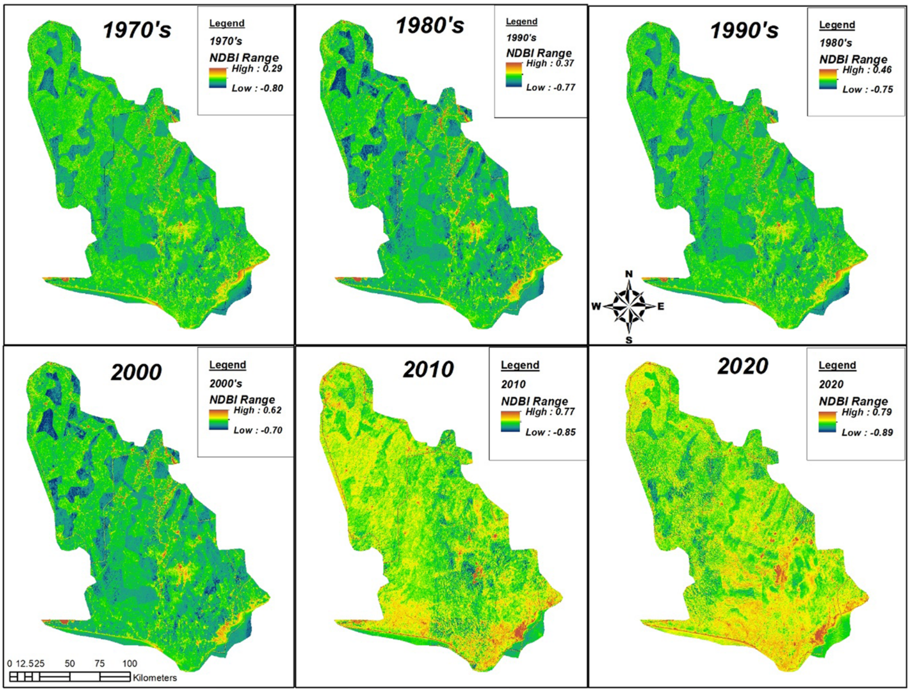


Fig. 10 Changes in NDBI over the study period (1970–2020) in Southwestern Ghana

urban sprawl, industrialization, expansion in farmlands, mining and illegal logging of timber, population growth and distribution, as well as weak governance. Findings presented in this study indicated built-up (i.e. increase in human settlements, population growth and distribution, and infrastructure among other factors) and farmlands/shrubs (i.e. expansion in agricultural activities and so on) are the two major LUCC classes, driving major changes in the region. Importantly, the need to regulate various needs, tied to the use of natural resources in the region must be prioritized in our quest to achieve the Millennium Sustainable Development Goals. The study area is vital to the growth and development of Ghana's economy, hence, competing interests among relevant stakeholders in the use of natural resources must be major area of concern. Advancement in technology, observed in transportation networks and other infrastructure, as well as agricultural activities, mainly to boost exports and productivity, has amplified the conversion of natural vegetation zones into farmlands and built-up environments.

The present study therefore recommends the need for remote sensing in contemporary forest and sustainable land management. The study showed more land cover will be targeted for conversion as farmers expand their farmlands and adapt to new technological approaches to improve productivity, considering the increasing rate of producer price index for cocoa and other cash crops on the international market. LUCC known as a mesoscale element and a contributing factor to climate change, makes it a topical issue for effective management, planning and inventory mapping. Land conversion scenarios highlighted in the study are very useful for stakeholders to better understand the environment. Using remote sensing and GIS techniques to monitor environmental change gives a

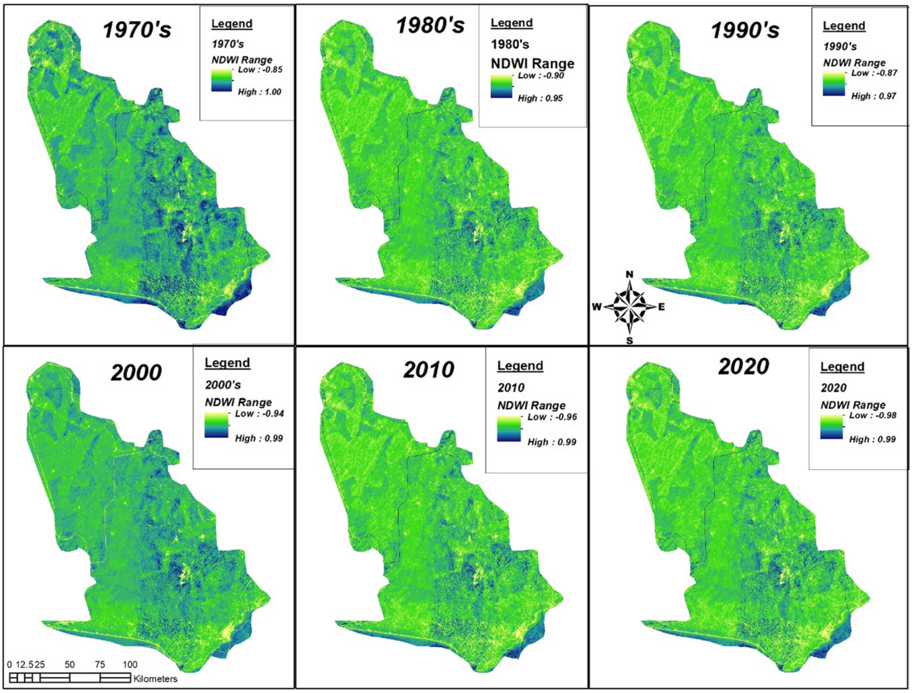


Fig. 11 Changes in NDWI over the study period (1970–2020) in Southwestern Ghana

Table 9 Pearson's correlation coefficient (r) between various indices and climatic variables

Variables	Temperature	NDWI	NDVI	NDBI	Precipitation
Temperature	1	0.343	0.214	0.266	−0.155
NDWI	0.342	1	0.540	0.818	−0.305
NDVI	0.214	0.540	1	0.165	−0.110
NDBI	0.266	0.817	0.165	1	−0.189
Precipitation	−0.155	−0.305	−0.110	−0.189	1

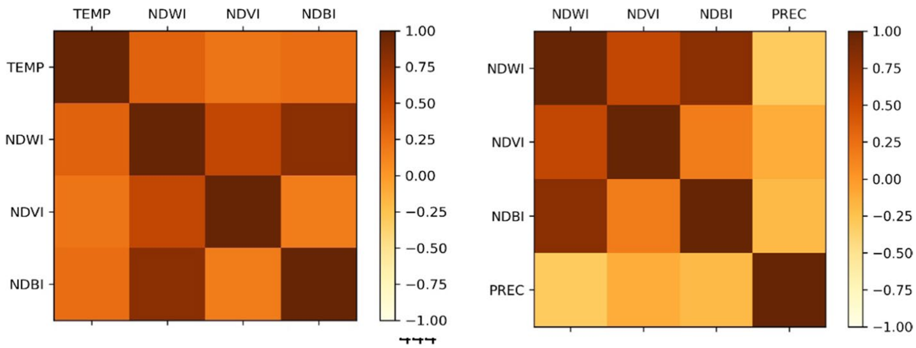
comprehensive view into the general ambience of Southwestern Ghana. The maps and statistics generated can be applied to assess the impacts of the land use changes on the local hydrology and provide a better basis for future land use planning.

5 Conclusion

The study utilised remote sensing data to assess the spatiotemporal development of land use systems, drivers and climate variability in Southwestern Ghana over the last 50 years. An attempt was made to determine the historical changes in NDVI, NDWI, NDBI, LST and precipitation. Through this study, we found that Southwestern Ghana had experienced substantial LUCC, with a decline in forested areas, waterbodies and bare land. This research further revealed a significant increase in built-up areas and farmlands/shrubs. Key variables that influenced prevailing microclimatic conditions can be associated with LUCC, considering the nature of proximate and underlying drivers, observed in the study area during the last five decades.

Here, the study established a relationship between the variable inputs mentioned above using Pearson's correlation coefficient. Monitoring ecosystems that are sensitive to climate change ensures a comprehensive understanding of the link between some climatic variables and ecosystems. Findings revealed surface temperatures had increased steadily over the study period coupled with fluctuations in rainfall. The study depicted a positive correlation between NDVI and LST. NDBI, on the other hand, correlated positively with NDVI, NDWI and LST. In contrast, NDVI, NDBI, NDWI and LST correlated negatively with precipitation. Findings based on image differencing and spatial analysis over the past 50 years were validated using previous studies related to LUCC studies in Ghana and other parts of the world. Therefore, it can be concluded that the substantial change in LUCC in the study domain are immensely driven by human-induced factors which constitute economic and socio-political factors.

We demonstrated that the synergies of satellite imagery and GIS technologies serve as powerful tools for mapping and detecting changes in LULC. This research conducted in Southwestern Ghana using these modern technologies in conjunction with existing literature showed a remarkable change in land cover. We advocate the need for strict execution of appropriate land use policies to sustain food production, coupled with other competing interests in the utilization of natural resources in the study area within this era of changing climate, population increase and economic growth. The study serves a seminal guide to land use developers and institutors for effective and sustainable use of natural resources. We therefore propose an integrative rural–urban growth management strategy that culminates spatial planning and environmental resource governance to avert the negative consequences on the natural environment of unfettered socio-economic development. The spatiotemporal analysis and characterization of LULC transformation, presented in this study



(a) Correlation between NDWI, NDVI, NDBI and Temperature.

(b) Correlation between NDWI, NDBI, NDVI and Precipitation

Fig. 12 Pearson's correlation coefficient (r) between various indices and climatic variables. **a** Correlation between NDWI, NDVI, NDBI and temperature. **b** Correlation between NDWI, NDBI, NDVI and precipitation have implications for both theory and policy. The present study's approach and underlying theories in determining the spatiotemporal development of land use systems, influences and climate variability could be extended to other areas to bridge the knowledge gap in LUCC related studies. Again, the main drivers of LUCC as presented in this study could be further analysed using multi-criteria decision-making (MCDA) tools and determining the contribution rates of various indices towards the changes in surface temperature and precipitation to substantiate the assertions or hypothesis given in this and other related studies conducted in the study area.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10668-021-01848-5.

Acknowledgements The authors wish to express their sincere gratitude to God Almighty for the knowledge bestowed on us, and secondly, the Nanjing University of Information Science and Technology (NUIST) for making available relevant materials and creating an enabling environment, needed to complete this research. Special thanks go to the Research Institute for History of Science & Technology, School of Law and Public Affairs for making available the datasets used for this study. This work was supported by the National Natural Science Foundation of China (No. 41971340, No.2017YFC1502401, No.41271410 and No.41972193). The authors would like to thank the handling editor and anonymous reviewers for their careful reviews and helpful remarks.

Authors' contributions The main author conceptualized, conducted literature search, designed, critically analysed data and wrote the final piece. The second (corresponding author) and third authors critically revised the work and provided the needed resources for this academic research, supervised and approved the final draft for submission. The remaining authors assisted in the acquisition of data, analysis, review, editing and interpretation of results.

Data availability The data that support findings of this study are available and would be shared upon request.

Declarations

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

References

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

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

Aduah, M. S., & Baffoe, P. E. (2013). Remote sensing for mapping land-use/cover changes and urban sprawl in Sekondi-Takoradi, Western Region of Ghana. *Int. J. of Eng. and Sci., 2*(10), 66–73.

Aduah, S. M., Mantey, S., & Tagoe, D. N. (2012). Mapping land surface temperature and land cover to detect urban heat island effect: A case study of Tarkwa, South West Ghana. *Research Journal of Environmental and Earth Science, 4*(1), 68–75.

Ahn, P. M. (1958). Regrowth and swamp vegetation in the western forest areas of Ghana. *Journal West African Science Association, 4*, 163–173.

Arhin, K. (1985). *The expansion of cocoa production: The working conditions of migrant cocoa farmers in central and Western Regions*. Legon: Institute of African Studies.

Aryeetey, E., & Kanbur, R. (2007). *Economy of Ghana: Analytical perspectives on stability, growth and poverty*. Boydell & Brewer. https://doi.org/10.7722/j.ctt81fmh

Attua, M. E. (2010). Historical and future land-cover change in a municipality of Ghana. *Earth Interactions, 15*(2011), 9. https://doi.org/10.1175/2010EI304.1

Avdan, U., & Jovanovska, G. (2016). Algorithm for automated mapping of land surface temperature using LANDSAT 8 satellite data. *Journal of Sensors, 2016*, 1–8. https://doi.org/10.1155/2016/1480307

Barakat, A., Ouargaf, Z., Khellouk, R., et al. (2019). Land use/land cover change and environmental impact assessment in Béni-Mellal District (Morocco) using remote sensing and GIS. *Earth Systems and Environment, 3*, 113–125. https://doi.org/10.1007/s41748-019-00088-y

Barbier, E. B., Burgess, J. C., & Grainger, A. (2010). The forest transition: Towards a more comprehensive framework. *Land Use Policy, 27*, 98–107. https://doi.org/10.1016/J.LANDUSEPOL.2009.02.001

Boon, E. & Ahenkan, A. (2011). Assessing climate change impacts on ecosystem services & livelihoods in Ghana: Case study of communities around Sui Forest Reserve. *Journal of Ecosystem and Ecography, S3*, 001. https://doi.org/10.4172/2157-7625.S3-001

Bora, M., & Goswami, D. C. (2016). A study on relationship between NDVI and precipitation over Kolong river basin, Assam, India. *Journal of Agriculture and Veterinary Science, 9*(6), 36–41.

Brooke, J. (1989). Ghana, once ‘Hopeless,’ Gets at least the look of success. The New York times archives. Retrieved from: https://www.nytimes.com/1989/01/03/world/ghana-once-hopeless-gets-at-least-the-look-of-success.html.

Cai, J., Yin, H., & Varis, O. (2016). Impacts of industrial transition on water use intensity and energy-related carbon intensity in China: A spatio-temporal analysis during 2003–2012. *Applied Energy, 183*, 1112–1122. https://doi.org/10.1016/j.apenergy.2016.09.069

Changkakati, T. (2019). Temporal response of NDVI to climatic attributes in North East India. *International Journal of Engineering Research and Technology, 8*(08), 102–108.

Chase, T. N., Pielke, R. A., Kittel, T. G. F., Nemani, R. R., & Running, S. W. (1999). Simulated impacts of historical land cover changes on global climate in northern winter. *Climate Dynamics, 16*, 93–105. https://doi.org/10.1007/s003820050007

Cheng, H., Zhou, T., Li, Q., Lu, L., & Lin, C. (2014). Anthropogenic chromium emissions in China from 1990 to 2009. *PLoS ONE, 9*(2), e87753. https://doi.org/10.1371/journal.pone.0087753

Chuvieco, E., & Congalton, R. G. (1988). Mapping and inventory of forest fires from digital processing of TM data. *Geocarto International, 3*(4), 41–53. https://doi.org/10.1080/10106048809354180

Coll, C., Galve, J. M., Sanchez, J. M., & Caselles, V. (2010). Validation of landsat-7/ETM+ thermal-band calibration and atmospheric correction with ground-based measurements. *IEEE Transactions on Geoscience and Remote Sensing, 48*(1), 547–555. https://doi.org/10.1109/TGRS.2009.2024934

Forestry Commission. (2015). Ghana national REDD+ strategy. Retrieved from http://www.fcghana.org/userfiles/files//REDD+/Ghana’s_National_REDD_Strategy_final_draft_210616.pdf.

Damnyag, L., Oduro, A. K., Obiri, D. B., Mohammed, Y., Bampoh, A. A. (2017). Assessment of drivers of deforestation and forest degradation in Bia-West-Juabeso landscape, Ghana. *Ministry of Food & Agriculture (MOFA)*, 2017. Unpublished report.

deGraft-Johnson, K. A. A., Blay, J., Nunoo, F.K.E., Amankwah, C.C. (2010). “Biodiversity threats assessment of the Western Region of Ghana”. The integrated coastal and fisheries governance (ICFG) initiative Ghana. Retrieved from www.crc.uri.edu.

Dei, G. (1988). Coping with the effects of the 1982–83 drought in Ghana the view from the village. *Africa Development/Afrique Et Développement, 13*(1), 107–122. Retrieved November 28, 2020, from http://www.jstor.org/stable/24486648.

Dickson, K. B., & Benneh, G. (1988). *A new geography of Ghana*. Longman.

Doe, E. K., Aikins, B. E., Njomaba, E., & Owusu, A. B. (2018). Land use land cover change within Kakum conservation area in the Assin South District of Ghana, 1991–2015. *West African Journal of Applied Ecology, 27*(SI), 85–97.

FAO. (2011). FAO. Achievements in Libya. FAO, Roma. http://www.fao.org/3/aba0018e.pdf. Accessed 7 Apr 2020.

Fenger, J. (1999). Urban air quality. *Atmospheric Environment, 33*(29), 4877–4900. https://doi.org/10.1016/S1352-2310(99)00290-3

Geiger, M.T., Kwakye, K.G., Vicente, C.L., Wiafe, B.M., Boakye Adjei, N.Y. (2019). Fourth Ghana Economic Update: Enhancing Financial Inclusion - Africa Region (English). Ghana Economic Update; No. 4 Washington, D.C: World Bank Group. Retrieved from http://documents.worldbank.org/curated/en/395721560318628665/Fourth-Ghana-Economic-Update-Enhancing-Financial-Inclusion-Africa-Region.

Ghana Statistical Service (GSS). (2014). 2010 population and housing census district analytical report. *Ghana Statistical Service*. https://doi.org/10.1371/journal.pone.0104053

Ghulam, A. (2010). Calculating surface temperature using Landsat thermal imagery. Department of Earth & Atmospheric Sciences, and Center for Environmental Sciences, St. Louis University, (pp 1–9). Retrieved from https://serc.carleton.edu/NAGTWorkshops/gis/activities2/48433.html

Gichangi, E. M., Gatheru, M., Njiru, E. N., Mungube, E. O., Wambua, J. M., & Wamuongo, J. W. (2015). Assessment of climate variability and change in semi-arid Eastern Kenya. *Climatic Change, 130*, 287–297. https://doi.org/10.1007/s10584-015-1341-2

Gockowski, J., & Sonwa, D. (2011). Cocoa intensification scenarios and their predicted impact on CO_2 emissions, biodiversity conservation, and rural livelihoods in the Guinea rain forest of West Africa. *Environmental Management, 48*, 307–321. https://doi.org/10.1007/s00267-010-9602-3

Gorgani, S. A., Panahi, M., Rezaie, F. (2013). The relationship between NDVI and LST in the urban area of Mashhad, Iran. International Conference on Civil Engineering, Architecture & Urban Sustainable Development, Tabriz (pp. 27–28), Iran. Retrieved from https://civilica.com/doc/274889

Gougha, K. V., & Yankson, P. W. K. (2012). Exploring the connections: Mining and urbanization in Ghana. *Journal of Contemporary African Studies, 30*, 651–668. https://doi.org/10.1080/02589001.2012.724867

Grimm, N., Faeth, S., Golubiewski, N., Redman, C., Wu, J., Bai, X., & Briggs, J. (2008). Global change and the ecology of cities. *Science, 319*, 756–760.

Guo, X. (2002). Discrimination of saskatchewan prairie ecoregions using multitemporal 10-day composite NDVI data. *Prairie Perspectives, 5*, 174–186.

Gyasi, E. A., Agyepong, G. T., Ardayfio-Schandorf, E., Enu-Kwesi, L., Nabila, J. S. and Owusu Bennoah, E. (1994). Environmental endangerment in the forest-savanna zone of Southern Ghana: A research study report. Tokyo: UNU.

Hall, J. B., & Swaine, M. D. (1976). Classification and ecology of closed-canopy forest in Ghana. *Journal of Ecology, 64*, 913–951. https://doi.org/10.2307/2258816

Hegazy, I. R., & Kaloop, M. R. (2015). Monitoring urban growth and land use change detection with GIS and remote sensing techniques in Daqahlia governorate Egypt. *International Journal of Sustainable Built Environment, 4*(1), 117–124. https://doi.org/10.1016/j.ijsbe.2015.02.005

Huq, M., & Tribe, M. (2018). *The economy of Ghana: 50 years of economic development*. Palgrave Macmillan, London: Springer. https://doi.org/10.1057/978-1-137-60243-5

Intergovernmental Panel on Climate Change (IPCC). (2000). *Land use, land-use change, and forestry*. Special Report. Cambridge Univ. Press.

Jia, G., Shevliakova, E., Artaxo, P., De Noblet-Ducoudré, N., Houghton, R., House, J., Kitajima, K., Lennard, C., Popp, A., Sirin, A., Sukumar, R., Verchot. L. (2019). Land–climate interactions. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M, Belkacemi, J. Malley, (eds.)]. In press.

Kalnay, E., & Cai, M. (2003). Impact of urbanization and land-use change on climate. *Nature, 423*(6939), 528–531. https://doi.org/10.1038/nature01675

Käyhkö, N., Fagerholm, N., Asseid, B. S., & Mzee, A. J. (2011). Dynamic land use and land cover changes and their effect on forest resources in a coastal village of Matemwe, Zanzibar Tanzania. *Land Use Policy*. https://doi.org/10.1016/j.landusepol.2010.04.006

Kleemann, J., Inkoom, N. J., Thiel, M., Shankar, S., Lautenbach, S., & Fürst, C. (2017). Peri-urban land use pattern and its relation to land use planning in Ghana West Africa. *Landscape and Urban Planning, 165*(2017), 280–294. https://doi.org/10.1016/j.landurbplan.2017.02.004

Koranteng, A., & Zawila-Niedzwiecki, T. (2016). Forest loss and other dynamic use changes in Western Region of Ghana. *Journal of Environment Protection and Sustainable Development, 2*(2), 7–16.

Kusi, N. (1991). Ghana: Can the adjustment reforms be sustained? *Africa Development/Afrique Et Développement, 16*(3/4), 181–206. Retrieved November 28, 2020, from http://www.jstor.org/stable/43657861.

Kusimi, J. M. (2008). Assessing land use and land cover change in the Wassa West District of Ghana using remote sensing. *GeoJournal, 71*, 249–259. https://doi.org/10.1007/s10708-008-9172-6

Lambin, E. F. & Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences*, *108*(9), 3465–3472. https://doi.org/10.1073/pnas.1100480108

Liu, S., Deng, L., Zhao, Q., DeGloria, S. D., & Dong, S. (2011). Effects of road network on vegetation pattern in Xishuangbanna, Yunnan Province, Southwest China. *Transportation Research Part D Transport and Environment, 16*, 591–594. https://doi.org/10.1016/j.trd.2011.08.004

Liu, J., et al. (2014). Spatiotemporal characteristics, patterns, and causes of land-use changes in China since the late 1980s. *Journal of Geographical Sciences, 24*(2), 195–210.

Logah, F.Y., Obuobie, E., Ofori, D. and Kankam-Yeboah, K. (2013). "Analysis of Rainfall Variability in Ghana". International Journal of Latest Research in Engineering and Computing, 1(1).

Lü, A., Tian, H., Liu, M., Liu, J. & Melillo, J. M. (2006). Spatial and temporal patterns of carbon emissions from forest fires in China from 1950 to 2000. *Journal of Geographical Research Atmospheres, 111*(5). https://doi.org/10.1029/2005JD006198

Lwasa, S. (2014). Managing African urbanization in the context of environmental change. *Interdisciplinary, 2*(2), 2014. https://doi.org/10.22201/CEIICH.24485705E.2014.2.46528

Manatsa, D., Yushi, M., Swadhin, K. B., Caxston, H. M., & Yamagata, T. (2014). Impact of mascarene high variability on the East African 'short rains.' *Climate Dynamics., 42*(2014), 1259–1274. https://doi.org/10.1007/s00382-013-1848-z

Mather, A., Needle, C., & Coull, J. (1998). From resource crisis to sustainability: The forest transition in Denmark. *International Journal of Sustainable Development and World Ecology, 5*, 183–192. https://doi.org/10.1080/13504509809469982

Mattah, P. A. D., Futagabi, G., & Mattah, M. M. (2018). Awareness of environmental change, climate variability, and their role in prevalence of mosquitoes among Urban Dwellers in Southern Ghana. *Journal of Environmental and Public Health*. https://doi.org/10.1155/2018/5342624

Mensah, C. A., Eshun, J. K., Asamoah, Y., & Ofori, E. (2019). Changing land use/cover of Ghana's oil city (Sekondi-Takoradi Metropolis): Implications for sustainable urban development. *International Journal of Urban Sustainable Development, 11*(2), 223–233. https://doi.org/10.1080/19463138.2019.1615492

Mensah, A. A., Sarfo, A. D., & Partey, S. T. (2018). Assessment of vegetation dynamics using remote sensing and GIS: A case of Bosomtwe range forest reserve, Ghana. *The Egyptian Journal of Remote Sensing and Space Sciences*. https://doi.org/10.1016/j.ejrs.2018.04.004

MESTI. (2015). CBD fifth national report- Ghana: Ministry of environment, science, technology and innovation. Retrieved from https://www.cbd.int/doc/world/gh/gh-nr-05-en.pdf

Millennium Ecosystem Assessment (MEA). (2005). *Ecosystem & human well-being: A framework for Assessment*. Washington (DC), USA: Island Press.

Mitchell, S. W., & Csillag, F. (2001). Assessing the stability and uncertainty of predicted vegetation growth under climatic variability: Northern mixed grass prairie. *Ecological Modelling, 139*, 101–121. https://doi.org/10.1016/S0304-3800(01)00229-0

National Development Planning Commission (NDPC). (2010). Medium-term National development policy framework: Ghana shared growth and development agenda (GSGDA), 2010–2013, volume I: Policy framework, final draft. *Government of Ghana, National Development Planning Commission, I*, 1–278.

Nikoi, E. (2015). Ghana's economic recovery programme and the globalisation of Ashanti goldfields company Ltd. *Journal of International Development, 28*(4), 588–605. https://doi.org/10.1002/jid.3199

Noponen, R. A. M., Mensah, D. B. C., Schroth G., Hayward, J. (2014). A landscape approach to climate-smart agriculture in Ghana. *ETFRN News 56*, (pp. 58–65). Retrieved from https://www.rainforest-alliance.org/sites/default/files/2016-08/A-landscape-approach-to-climate-smart-agriculture-in-Ghana.pdf

Obeng, E. A., & Aguilar, F. X. (2015). Marginal effects on biodiversity, carbon sequestration and nutrient cycling of transitions from tropical forests to cacao farming systems. *Agroforestry Systems*. https://doi.org/10.1007/s10457-014-9739-9

Oduro, K. A., Mohren, G. M. J., Pena-Claros, M., & Kyereh, B. (2015). Tracing forest resource development in Ghana through forest transition pathways. *Land Use Policy, 48*(2015), 63–72. https://doi.org/10.1016/j.landusepol.2015.05

Perz, S. G. (2007). Grand theory and context-specificity in the study of forest dynamics: Forest transition theory and other directions. *The Professional Geographer, 59*, 105–114. https://doi.org/10.1111/j.1467-9272.2007.00594.x.

Peters, D. P. C., Groffman, P. M., Nadelhoffer, K. J., et al. (2008). Living in an increasingly connected world: A framework for continental-scale environmental science. *Frontiers in Ecology and the Environment, 6*(5), 229–237. https://doi.org/10.1890/070098

Rudel, T. K., Coomes, O. T., Moran, E., Achard, F., Angelsen, A., Xu, J., & Lambin, E. (2005). Forest transitions: Towards a global understanding of land use change. *Global Environmental Change, 15*(1), 23–31. https://doi.org/10.1016/j.gloenvcha.2004.11.001

Sarfo, I., Bortey, O., & Terney Kumara, T. (2019). Effectiveness of adaptation strategies among coastal communities in Ghana: The case of Dansoman in the Greater Accra region. *Current Journal of Applied Science and Technology, 35*(6), 1–12. https://doi.org/10.9734/cjast/2019/v35i630211

Schumann, A. H., Koncsos, L. and Schultz, G. A. (1991). "Estimation of dissolved pollutant transport to rivers from urban areas: A modelling approach." In *Proceedings of a symposium on: Sediment and*

StreamWater Quality in a Changing Environment: Trends and Explanation held in Vienna, IAHS Publ. 203.

Silitshena, R. M. K. (1996). Sustaining the future: Economic, Social and Environmental Change in Sub-Saharan Africa, G. Benneh, W. B. Morgan, and J. I. Uitto, Eds., New York United Nations University Press.

Singh, M. P., Bhojvaid, P. P., de Jong, Wil, Ashraf, J., & Reddy, S. R. (2017). Forest transition and socio-economic development in India and their implications for forest transition theory. *Forest Policy and Economics, Elsevier, 76*(C), 65–71. https://doi.org/10.1016/j.forpol.2015.10.013

Sodango, T. H., Sha, J., & Xiaomei, L. (2017). Land use/land cover change (LULCC) in China, review of studies. *International Journal of Scientific and Engineering Research, 8*(8), 943.

Sun, D., & Kafatos, M. (2007). NDVI-LST relationship and the use of temperature related drought indices over North America. *Geophysical Research Letters*. https://doi.org/10.1029/2007GL031485

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

Tsekpo, E. M. (2018). Youth participation and productivity in cocoa farming in the Western North cocoa region of Ghana. Master thesis. University of Ghana http://ugspace.ug.edu.gh.

Turner, B. L., Lambin, E., & Reenberg, A. (2007). Land change science special feature: The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences of the United States of America, 104*, 20666–20671. https://doi.org/10.1073/pnas.0704119104

Ullah, M., Li, J., & Wadood, B. (2020). Analysis of urban expansion and its impacts on Land surface temperature and vegetation using RS and GIS, A case study in Xi'an City, China. *Earth Systems and Environment, 4*, 583–597. https://doi.org/10.1007/s41748-020-00166-6

UN (2016). Transforming our world: The 2030 agenda for sustainable development. Retrieved from https://sustainabledevelopment.un.org/post2015/transformingourworld.

Wang, T. (2016). Vegetation NDVI change and its relationship with climate change and human activities in Yulin, Shaanxi province of China. *Journal of Geoscience and Environment Protection, 4*, 28–40. https://doi.org/10.4236/gep.2016.410002

Wang, J., Price, K. P., & Rich, P. (2010). Spatial patterns of NDVI in response to precipitation and temperature in the central great plains. *International Journal of Remote Sensing, 22*, 3827–3844. https://doi.org/10.1080/01431160010007033

Yiran, G. A. B., Kusimi, J. M., & Kufogbe, S. K. (2012). A synthesis of remote sensing and local knowledge approaches in land degradation assessment in the Bawku East District, Ghana. *International Journal of Applied Earth Observation and Geoinformation, 14*(1), 204–213. https://doi.org/10.1016/j.jag.2011.09.016

Yue, W., Xu, J., Tan, W., & Xu, L. (2007). The relationship between land surface temperature and NDVI with remote sensing: Application to Shanghai Landsat 7 ETM + data. *International Journal of Remote Sensing, 28*(15), 3205–3226. https://doi.org/10.1080/01431160500306906

Authors and Affiliations

Isaac Sarfo[1] · Bi Shuoben[2] · Li Beibei[1,3] · Solomon Obiri Yeboah Amankwah[2] · Emmanuel Yeboah[4] · John Ernest Koku[5] · Edward Kweku Nunoo[6] · Clement Kwang[4]

Isaac Sarfo
20195129001@nuist.edu.cn

Li Beibei
libeibei-sd@163.com

Solomon Obiri Yeboah Amankwah
20195111003@nuist.edu.cn

Emmanuel Yeboah
eyeboah037@st.ug.edu.gh

John Ernest Koku
jkoku@central.edu.gh

Edward Kweku Nunoo
edward.nunoo@ucc.edu.gh

Clement Kwang
ckwang@ug.edu.gh

1 Research Institute for History of Science and Technology, Nanjing University of Information Science and Technology, Nanjing 210044, Jiangsu, China

2 School of Geographical Sciences, Nanjing University of Information Science and Technology, Nanjing 210044, Jiangsu, China

3 School of Law and Public Affairs, Nanjing University of Information Science and Technology, Nanjing 210044, Jiangsu, China

4 Department of Geography and Resource Development, University of Ghana, Legon, Accra, Ghana

5 Department of Social Sciences, Central University, Accra, Ghana

6 Institute of Oil and Gas Studies, University of Cape Coast and Department of Environment & Development Studies, Central University, Accra, Ghana