Assessing local drivers influencing Land Use Cover Change (LUCC) in Southwestern Ghana: A Mixed-Method Approach (MMA) Analyses.

Annex I: List of figures

Figure 1: The Five-capital Model
Source: Gazzola and Querci 2017

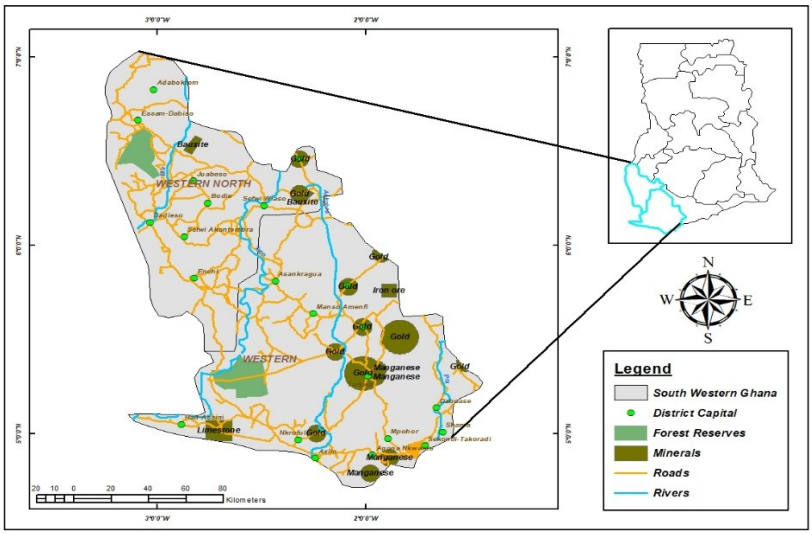


Figure 2: Location of the study area

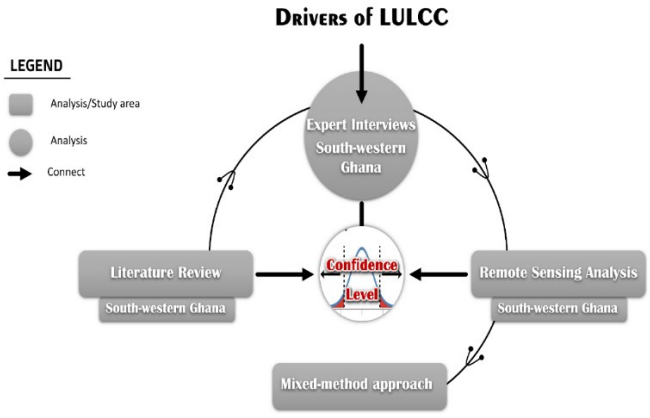


Figure 3: Mixed Method Approach (MMA) designed for this study

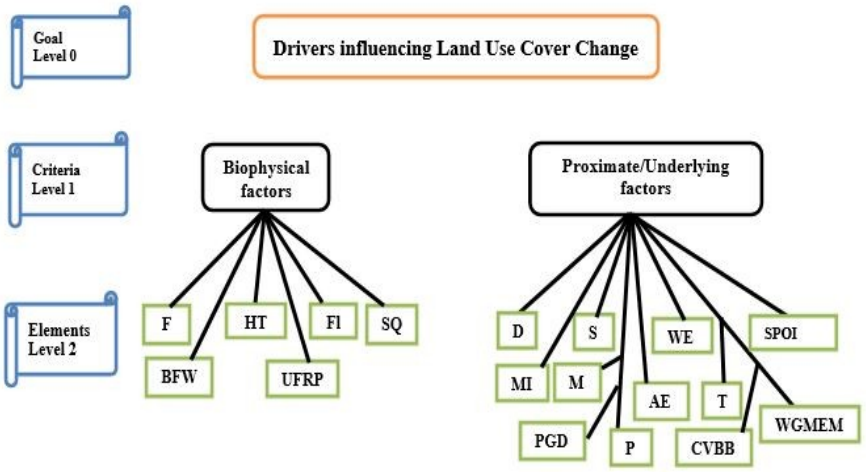


Figure 3.1: AHP model of factors influencing LUCC

D – Deforestation **S -** Settlements **WE** – Wood Extraction **SPOI** – Setting up Profit oriented industries **MI** – Mining & Infrastructure **AE** – Agriculture Expansion **BFW** – Bushfires/Wildfires **F** – Famine **HT -** High Temperature **Fl-** Flood **SQ** – Soil Quality **M** – Migration **P -** Poverty **PGD** – Population growth and distribution **WGMEM** – Weak Governance, Monitoring & Enforcement Mechanisms **T** – Technology **(**Science, Research, Mining Technology, Agro-Technical Change & Efficiency, Transportation Networks**) CVBB** – Cultural Values, Behaviours & Beliefs **IT** – Increasing Temperature **UFRP** – Unpredicted Fluctuations in Rainfall Patterns

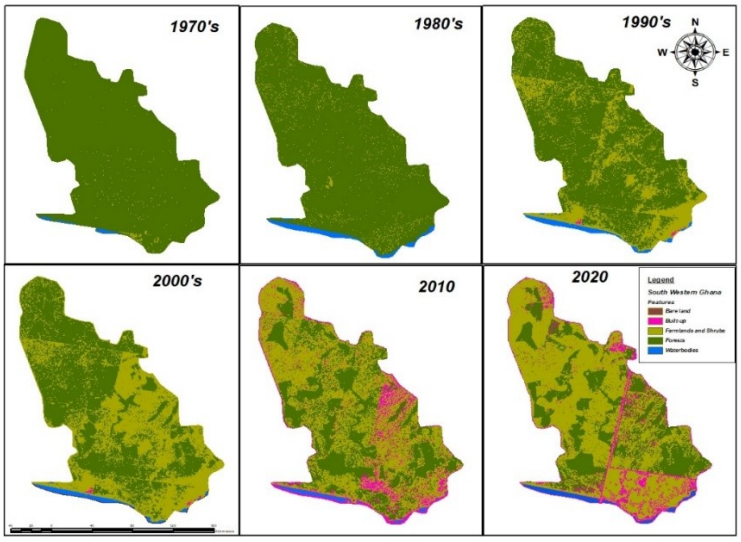


Figure 4: LUCC over the study period (1970-2020) in Southwestern Ghana.

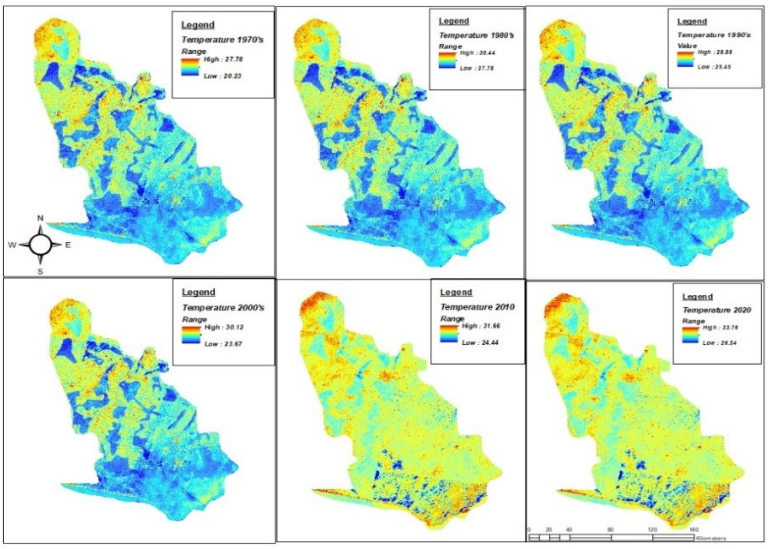
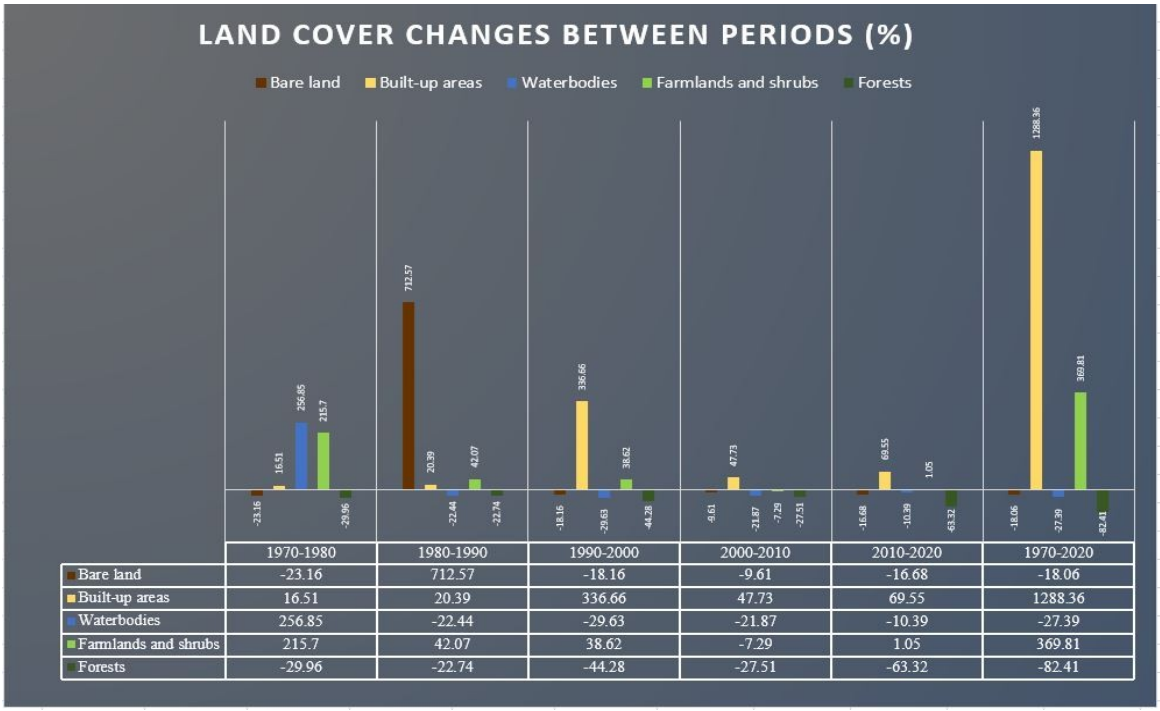


Figure 5: Temperature variations over the study period (1970-2020) in Southwestern Ghana.



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

Figure 6: Land cover changes between periods (%)

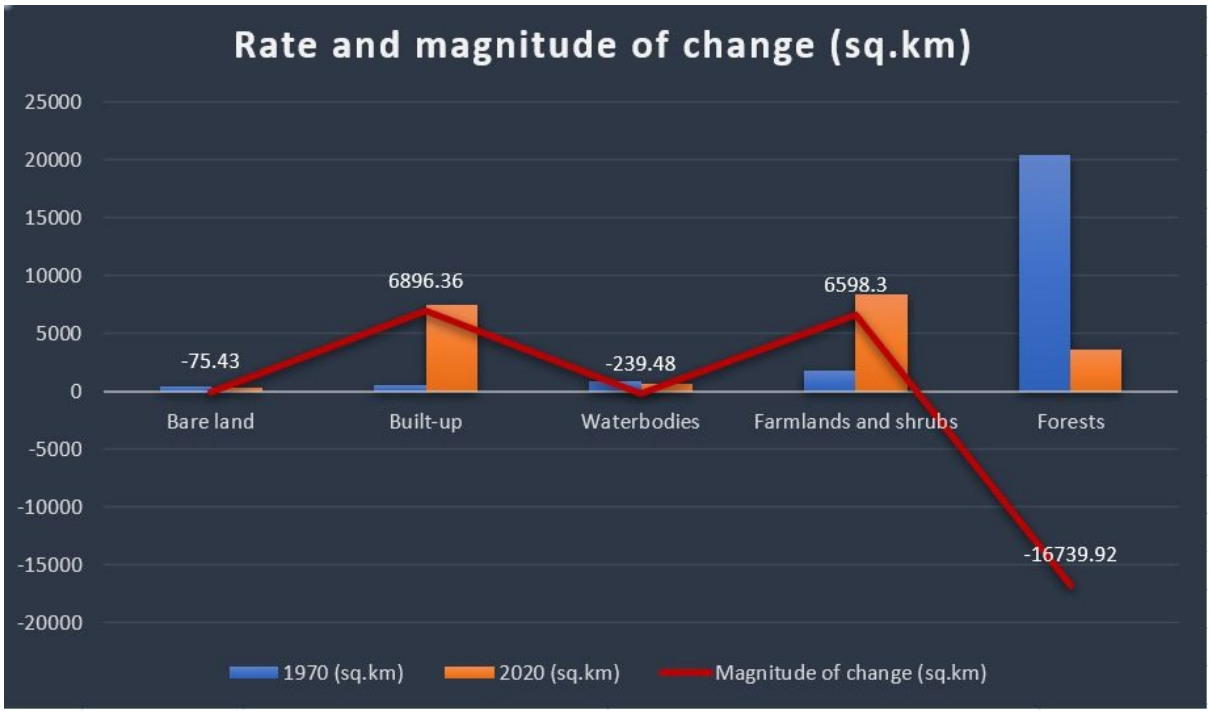


Figure 7: Rate and magnitude of change (sq.km) over the past 50 years in Southwestern Ghana.

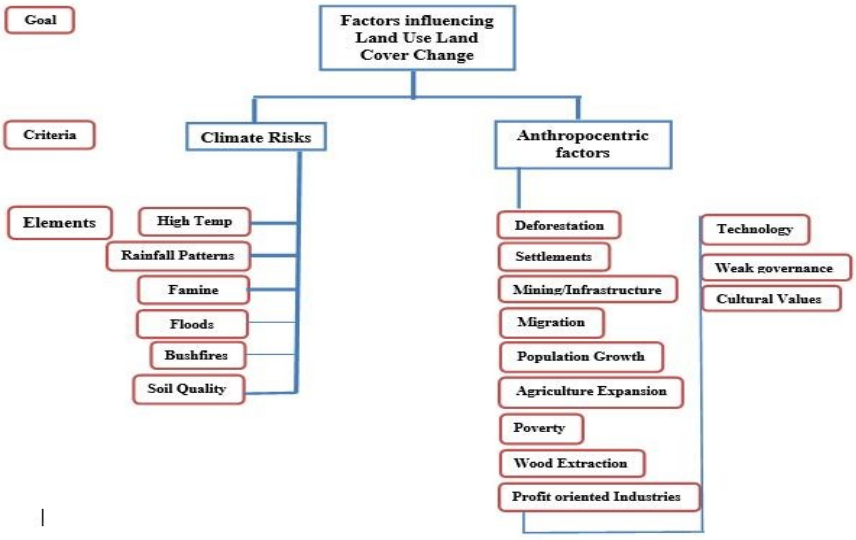


Figure 8: Hierarchy of the drivers influencing land use land cover change

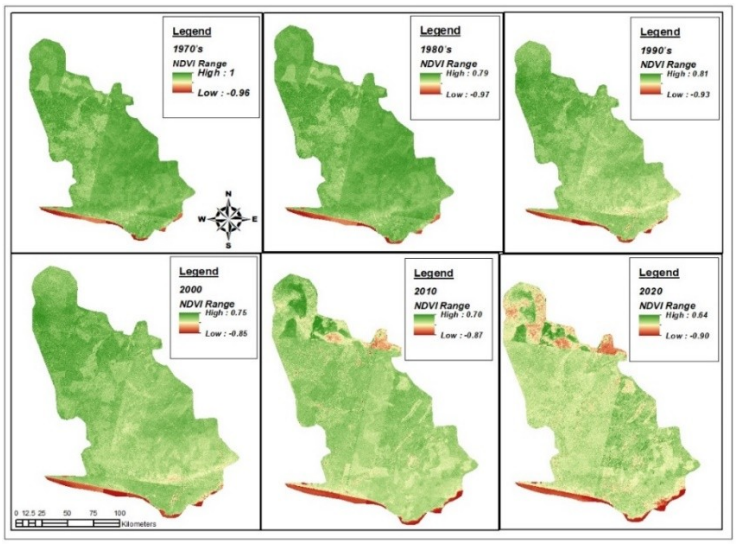


Figure 9: Changes in NDVI over the study period (1970-2020) in Southwestern Ghana.

The estimated NDVI range for the 1970s was between -0.96 and 1. The range for 1980s was between -0.97 and 0.79. The 1990s had a range of -0.93 and 0.81; 2000s had a range of -0.85 and 0.75; 2010 ranged between -0.87 and 0.70, and 2020 depicted an NDVI range of -0.90 and 0.64. Fig.8 illustrates a steady decline in vegetative index over the study period. Larger values of NDVI represent forest areas due to higher green biomass of trees and other vegetation. These areas as observed over the study period (1970-2020) constitute mainly forest and wildlife reserves/parks, closed (dense) and open canopies. Decrease in NDVI based on study findings could be attributed to the main drivers highlighted in Table 7. Differences in measurement of vegetation in Southwestern Ghana was visualized in image differencing using NDVI for the study periods (1970s, 1980s, 1990s, 2000, 2010 and 2020). Dark brown areas (Fig. 9) represent a high negative change, thus, major reduction in vegetation cover as observed in the 1970s and 1980s. Such areas as depicted in Fig.8 are subdued by the sea or built-up environment. Yellowish areas indicated zones with moderate vegetation cover and an increasing rate of agricultural areas and built-up environment (between 2000 and 2020).

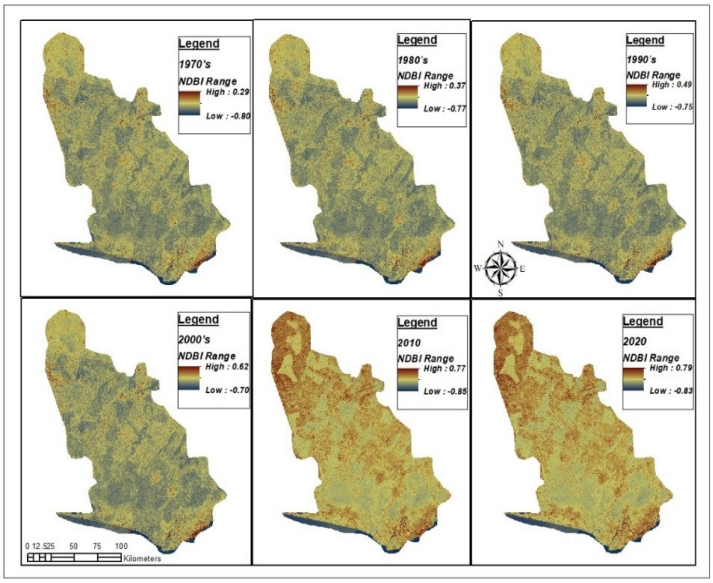


Figure 10: Changes in NDBI over the study period (1970-2020) in SW Ghana.

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. The significant increment influenced microclimatic conditions like surface temperature (Fig.5). Differences in measurement of built-up areas in Southwestern Ghana was visualized in image differencing using NDBI for the study periods (1970s, 1980s, 1990s, 2000, 2010 and 2020). Dark brown areas indicate a high positive change (presence) of built-up environment. Yellowish regions represent areas covered by farmlands and shrubs as well as less dense vegetation. Dark blue areas represent areas covered by water bodies as shown in Fig.10.

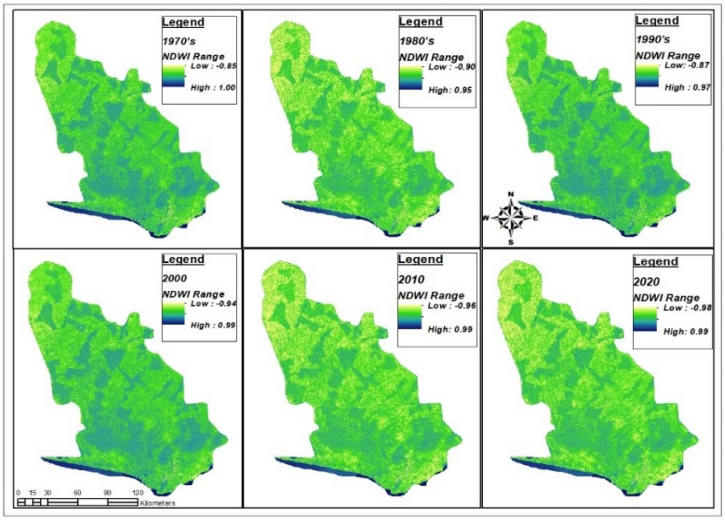


Figure 11: Changes in NDWI over the study period (1970-2020) in SW Ghana.

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. Measuring differences in waterbodies in Southwestern Ghana was visualized in image differencing using NDWI for the study periods (1970s, 1980s, 1990s, 2000, 2010 and 2020). 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 over the past 50 years. No drastic change was observed for NDWI.

Annex II: List of Tables

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

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

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

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

Table 2.1: ETM+ and TM Thermal Band Calibration Constants

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

Source: Ghulam 2010

Table 2.2: Thermal constant, Band 10

K_1	1321.08
K_2	777.89

Source: Avdan & Jovanovska 2016.

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

Symbol	Level of Agreement	Details
√√√	High Agreement	Statement is confirmed within one method. -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	Statement is confirmed but limited data within one method -for expert interviews: 25-60% of respondents confirmed -for literature: one or two sources confirmed -for RS: Confirmed
√	Low Agreement	Confirmation and rejection within one method -for expert interviews: <25% of respondents confirmed -for literature: confirmation and rejection balanced
x		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 4: Confidence level table of findings from interviews, remote sensing and existing literature

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

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

Table 4.1: Saaty's scale for comparison of various elements.

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

Source: Adapted from Saaty (1980)

Table 4.2: Random index matrix of the same dimension

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

Table 5: Biodata of respondents in Southwestern Ghana

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

QN	**Institution**	**Role/Capacity**	**Research Interests**
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 & Demographic studies, and Natural Resource Management
QN4	Minerals Commission, T	Minerals Geological Officer	-Geology, Pedology, Resource Use Management & Environmental policy
QN5	*	Senior Staff	-Geology, Environmental Policy and Management.
QN6	Environmental Protection Agency (EPA), T	Environmental Officer	-Environmental Impact Assessment, Env. policy & 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 & Remote Sensing
QN10	Lands Commission, E	Municipal Stool Lands Officer	-Land administration and management, agriculture & Rural development
QN11	*	Senior Staff	-Land tenure, rural development & Dev. studies
QN12	*	Principal Technical Director	-Land use change, GIS, Policy Analysis, Soil & water engineering, Regional Planning
QN13	Forestry Commission, E	District Manager	-Forestry & Wildlife, Agroforestry & Ecosystem Services.
QN14	*	Zonal Co-Ordinator	-Forestry and wildlife, regional and local planning,

			development policy & land use
QN15	Ghana Immigration Service, E	Senior Officer	-Population studies, Migration and rural development
QN16	*	Senior Officer	-Population studies, Environmental policy & Planning
QN17	Ghana Fire Service, E	Assistant Divisional Officer	-Risks & Disaster Management, Remote sensing, Regional land use planning
QN18	*	Senior Staff	-Risks & Disaster Management, network systems and local land use planning
QN19	Feeder & 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 & Disaster Management
QN24	Physical Planning Department, T	Acting Physical Officer	-Land use planning, GIS, Demography studies & policy analysis.
QN25	*	Senior Staff	-Landscape patterns, Urban Dev. & 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 & resource management
QN30	*	Senior Staff	-Natural resource management, environmental science & planning
			-Forestry and Wildlife, Food security, Resource Economics, Environmental policy and management.

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

Table 6: Area coverage for LUCC in Southwestern Ghana (1970-2020)

	Area coverage for each class (km^2) over the given period (1970-2020)					
LUCC class	**1970**	**1980**	**1990**	**2000**	**2010**	**2020**
Bare land	417.63	320.91	2607.63	2134.04	1928.93	1607.11
Built-up areas	535.26	623.636	750.81	3278.45	4843.33	8212.04
Waterbodies	874.48	3120.54	2420.37	1708.19	1330.68	1192.43
Farmlands and Shrubs	1784.22	5632.85	8002.66	11093.37	10283.95	10391.86
Forests	20312.42	14226.92	10991.20	6124	4439.02	1628.13
Total	23924.01	23924.86	24772.67	24333.05	22835.91	23031.57

Table 7: Summary of existing literature on major events and land use studies in Southwestern Ghana (1970-2020)

Periods	**Driving factors**	**Consequences**	**Transitions**	**Source (Literature)**
1970	Agricultural expansion (proximate cause).	Increase in small-scale subsistent farming (farmlands & shrubs) resulting in marginal deterioration of natural forests (pristine environment).	Bare land and forest lands to farmlands and shrubs, small-scale farms as well as settlements.	Gockowski and Sonwa 2011; Dickson and Benneh 1988; Hall and Swaine 1976; Ahn 1958
1970-1980	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.
	Agricultural expansion (proximate cause).	Increase in small-scale subsistent farming		

		(farmlands & shrubs) resulting in marginal alteration of natural forests (pristine environment).		
1980-1990	Biophysical and climatic factors (i.e., Droughts (1981-1983), Famine, bushfires and higher temperatures) (proximate cause) Economic (Macro-economic Reforms), Socio-political (Policy) and institutional factors (i.e., 1983 (GoG) Economic Recovery Program with support from IMF/World Bank, land tenure systems) (underlying cause).	Spontaneous immigration and forced settlements from other regions and increase in population led to reduction in natural forests and significant increase in bare land, farmlands and shrubs (Table 4). Loss of biodiversity and health problems. Increasing temperatures (dry climate) and reduced rainfall. Redistribution of lands and conversion of natural forests to farmlands. The state and individuals emerged as dominant economic agents in the economy.	Forest lands converted to farmlands and shrubs, bare land and human settlements.	Tan and Rockmore 2018; Huq and Tribe 2018; Abbam et al. 2018; Nikoi 2015; Aryeetey and Kabur 2007; Gyasi et. al 1994; Kusi 1991; Brooke 1989; Dei 1988.
1990-2000	Socio-economic development (i.e., Policies driven towards Ghana's Vision 2020, poverty reduction (i.e., Core Welfare Indicators Questionnaire (CWIQ) and the Ghana Living Standards Survey (GLSS), improvement in Human Development Indicators (HDIs), export led agricultural production and expansion in Foreign investment) (Underlying causes). Population pressure (underlying cause). Biophysical and climatic factors (i.e., temperature rise) (proximate cause).	Development of infrastructure such as transportation networks, education and health facilities. Domestic and foreign investment in farming activities. Population growth and significant increase in human settlements. High rate of deforestation. Need to meet food demands led to an increase in the rate of farming activities. Increase in surface temperatures and reduced precipitation (Table 4 and Fig.5) due to significant increase in built-up environment. Loss of biodiversity and health problems.	Forests, bare land, farmlands and shrubs converted to settlements/infrastructure, subsistent and medium/large scale farms	Huq and Tribe 2018; Abbam et al. 2018; Damnyag et al. 2017; Koranteng and Zawila-Niedzwieki 2016; Noponen et al. 2014; Gockowski and Sonwa 2011; Kusimi 2008; Gyasi et al. 1994; Kusi 1991.
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	High rate of deforestation. Increasing rate of settlements and infrastructure. Increase in surface temperatures and a decline in rainfall.	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.

	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).	Decline in farming activities (Table 4).		
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; World Bank Group and Ministry of Finance 2019; Acheampong et al. 2018; Huq and Tribe 2018; Abbam et al. 2018; Damnyag et. al 2017; Kleemann et. al 2017; Koranteng et al.2017; Noponen et. al 2014; Aduah and Baffoe 2013; Aduah et. al 2012; Logah et. al 2011.

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

	Driving Factors	Tally/Rank	Frequency (N=22) (%)	Position
a.	**Expansion in settlements & social**	√√√√	6 (28%)	**2nd**

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

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

Table 9: Confidence level analysis using the MMA to ascertain local drivers of LUCC

Scope: Drivers of LU systems	**Keywords**	**Literature Review**	**Interviews**	**Spatial Analysis**	**Confidence level**
		SW Ghana	**SW Ghana**	**SW Ghana**	**SW Ghana**
Proximate Causes	Deforestation	√√√	√√√	√√√	**Very high**
	Settlements	√√√	√√√	√√√	**Very High**
	Wood extraction	√√	√√	√	**Medium**
	Setting up profit-oriented industries	√√	√	√	**Medium**
	Mining & Infrastructure	√√√	√√√	√√√	**Very High**
	Agriculture expansion	√√√	√√	√√√	**High**
	Bushfires/Wildfires	√	√	X	**Low**
	Famine	√√√	√	X	**Medium**
	High temperature	√√√	√√√	√√√	**Very High**
	Floods	√√	√√	X	**Medium**
	Soil Quality	X	√	X	**Very Low**
Underlying Causes					
	Migration	√√√	√√√	√√√	**Very High**
	Poverty	√√√	√√√	X	**High**
	Population growth and	√√√	√√√	√√√	**Very High**

	distribution				
	Weak governance, Monitoring and Enforcement mechanisms	√√	√√	X	**Medium**
	Technology (Science, research, mining technology, agro-technical change and efficiency, transportation networks)	√√	√√	X	**Medium**
	Cultural values, behaviour and beliefs	√√	√√√	X	**Medium**
Effects on some climatic variables	Increasing temperature	√√√	√√√	√√√	**Very High**
	Unpredictable/Fluctuations in rainfall patterns	√√√	√√√	X	**High**

Confidence level analysis based on existing literature (Table 7), expert interviews (see Annex I) and spatial analysis (Fig.4) for SW Ghana; √√√=High agreement; √√=Medium Agreement; √=Low Agreement; **X**=No data or evidence.

Table 10: Pairwise Comparison matrix of Biophysical Drivers

	F	**HT**	**Fl**	**SQ**	**BFW**	**UFRP**
F	1	1/3	1	3	1/3	1/2
HT	3	1	3	5	1	2
Fl	1	1/3	1	3	1/3	1/2
SQ	1/3	1/5	1/3	1	1/2	1/3
BFW	1/2	1	3	2	1	2
UFRP	2	1/2	2	3	1/2	1
Sum	7.8333333	3.366667	10.33333	17	3.666667	6.333333

D – Deforestation **S** – Settlements **WE –** Wood Extraction **SPOI –** Setting up Profit Oriented Industries **MI –** Mining & Infrastructure **AE –** Agriculture Expansion **BFW –** Bushfires/Wildfires **F –** Famine **HT –** High Temperature **Fl –** Floods **SQ –** Soil Quality **M –** Migration **P –** Poverty **PGD –** Population Growth & Distribution **WGMEM –** Weak Governance, Monitoring & Enforcement Mechanisms **T –** Technology **CVBB –** Cultural Values, Behaviors & Beliefs **IT –** Increasing Temperature **UFRP –** Unpredictable Fluctuations in Rainfall Patterns

Table 10.1: Measuring consistency of biophysical drivers

CW	0.1116	0.3088	0.1116	0.0637	0.2262	0.178					
	F	**HT**	**Fl**	**SQ**	**BFW**	**UFRP**	**WSV**	**WSV/ CW**	**λ max**	**CI**	**CR**
F	0.1116	0.1029	0.1116	0.1910	0.0754	0.0890	0.6816	6.1063			
HT	0.3349	0.3088	0.3349	0.3184	0.2262	0.3560	1.8792	6.0850			
Fl	0.1116	0.1029	0.1116	0.1910	0.0754	0.0890	0.6816	6.1063	**6.0763**	**0.01513**	**0.01**
SQ	0.0372	0.0618	0.0372	0.0637	0.1131	0.0593	0.3723	5.8472			
BFW	0.0558	0.3088	0.3349	0.1273	0.2262	0.3560	1.4091	6.2289			
UFRP	0.2233	0.1544	0.2233	0.1910	0.1131	0.1780	1.0831	6.0841			

Table 10.2: Pairwise comparison matrix of proximate or underlining factors

	D	**S**	**WE**	**SPOI**	**MI**	**AE**	**M**	**P**	**PGD**	**WGMEM**	**T**	**CVBB**
D	1	1	3	3	1	2	1	2	1	3	3	3
S	1	1	3	3	1	2	1	2	1	3	3	3
WE	1/3	1/3	1	1	1/3	1/2	1/3	1/2	1/3	1	1	1
SPOI	1/3	1/3	1	1	1/3	1/2	1/3	1/2	1/3	1	1	1
MI	1	1	3	3	1	2	1	2	1	3	3	3
AE	½	1/2	2	2	1/2	1	1/2	1	1/2	2	2	2
M	1	1	3	3	1	2	1	2	1	3	3	3
P	½	1/2	2	2	1/2	1	1/2	1	1/2	2	2	2
PGD	1	1	3	3	1	2	1	2	1	3	3	3
WGMEM	1/3	1/3	1	1	1/3	1/2	1/3	1/2	1/3	1	1	1
T	1/3	1/3	1	1	1/3	1/2	1/3	1/2	1/3	1	1	1
CVBB	1/3	1/3	1	1	1/3	1/2	1/3	1/2	1/3	1	1	1
TOTAL	**7.6667**	**7.6667**	**24.0000**	**24.0000**	**7.6667**	**14.5000**	**7.6667**	**14.5000**	**7.6667**	**24.0000**	**24.0000**	**24.0000**

Table 10.3: Measuring consistency of Proximate/Underlying Drivers

	D	**S**	**WE**	**SPOI**	**MI**	**AE**	**M**	**P**	**PGD**	**WGMEM**	**T**	**CVBB**	**CW**	**WSV**	**WSV/CW**	**λ max**	**CI**	**CR**
D	0.129	0.129	0.124	0.124	0.129	0.147	0.129	0.147	0.129	0.124	0.124	0.124	0.129	1.559	12.046			
S	0.129	0.129	0.124	0.124	0.129	0.147	0.129	0.147	0.129	0.124	0.124	0.124	0.129	1.559	12.046			
WE	0.043	0.043	0.041	0.041	0.043	0.037	0.043	0.037	0.043	0.041	0.041	0.041	0.041	0.495	12.013			
SPOI	0.043	0.043	0.041	0.041	0.043	0.037	0.043	0.037	0.043	0.041	0.041	0.041	0.041	0.495	12.013			
MI	0.129	0.129	0.124	0.124	0.129	0.147	0.129	0.147	0.129	0.124	0.124	0.124	0.129	1.559	12.046			
AE	0.065	0.065	0.082	0.082	0.065	0.073	0.065	0.073	0.065	0.082	0.082	0.082	0.073	0.883	12.026	**12.112**	**0.010**	**0.007**
M	0.129	0.129	0.124	0.124	0.129	0.147	0.129	0.147	0.129	0.124	0.124	0.124	0.129	1.559	12.046			
P	0.065	0.065	0.082	0.082	0.065	0.147	0.065	0.073	0.065	0.082	0.082	0.082	0.073	0.956	13.026			
PGD	0.129	0.129	0.124	0.124	0.129	0.147	0.129	0.147	0.129	0.124	0.124	0.124	0.129	1.559	12.046			
WGMEM	0.043	0.043	0.041	0.041	0.043	0.037	0.043	0.037	0.043	0.041	0.041	0.041	0.041	0.495	12.013			
T	0.043	0.043	0.041	0.041	0.043	0.037	0.043	0.037	0.043	0.041	0.041	0.041	0.041	0.495	12.013			
CVBB	0.043	0.043	0.041	0.041	0.043	0.037	0.043	0.037	0.043	0.041	0.041	0.041	0.041	0.495	12.013			

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

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

Annex III: Expert: Interview Guide

Assessment of local drivers influencing Land Use Cover Change (LUCC) in Southwestern Ghana (1970-2020)

This interview guide is designed to elicit information on land use cover change, its drivers and implications on Southwestern Ghana. The guide is aimed at generating and providing useful information that would inform policy and theory on the development of land use systems and climate variability over the last 50 years. Developing a comprehensive study on spatiotemporal development of land use systems, influences and climate variability in Southwestern Ghana would give policy-makers and development practitioners a clear view of the socio-political, economic and environmental status of the study area. Therefore, your

input as an expert in completion of this questionnaire would be high appreciated. Information provided would strictly be kept confidential and used, solely for academic purposes. The researcher is a graduate student of Nanjing University of Information Science and Technology (NUIST), China and does not represent the government or any interest/profitable group.

Part I: Background Information

Questionnaire No:

Date of Interview:

Start time ……. End Time …… Time Elapsed (Duration):

Name of Institution: …… Position Held: ……. Research Interest(s): ……..

District/Municipality:

1. Sex of respondent

Gender
Male
Female

2. Age limit of respondents

Age group	**Male**	**Female**
18-25		
26-40		
41-65		
>65		

3. What is the highest level of your education?

No formal education	Primary	Secondary	Tertiary	Other (specify)

4. How long have you lived/worked in this area?

< 5 years	5-15 years	16-40 years	>40 years

Part II: Population vs. Land-Use Cover Changes

5a. Do you think the population of your community has increased over the past 50 years?

Yes ☐ No ☐

5b. If **YES**, what do you think caused an increase in population?

High fertility		Immigration		Both high fertility and immigration		Other (specify)	

6a. Do you think more land will be needed as family size or population increases?

Yes ☐ No ☐

6b. If **YES,** what class of land cover would likely be converted to meet this demand?

Forest		Farmlands/ Shrubs		Built-up		Waterbodies		Bare land	

Part III: Agriculture vs. Land-Use Cover Changes

7a. Has Farming activities contributed to land cover change in the area?

Yes ☐ No ☐

7b. If **YES**, kindly state some of the farming activities which has contributed to land cover changes in the area.

i. ……..
ii. ……..
iii. ……..
iv. ……..
v. ……..

8. List the major crops grown in this area (**Start with the most important crops**)

(i) …… (ii) …….

(iii) …….. (iv) …….

9a. Has farming activities declined or increased over the past 30-50 years in this area?

Declined		Increased		Remained same		No idea	

9b. If you indicated that farming activities have **declined/increased**, which of the following factors are the main reasons for the decline/increase? (**Tick the ones which apply**)

Declining factors				**Increasing factors**			
Inadequate labour		Unfavourable climatic conditions		Provision of incentives/subsidies from the state/NGO		Favourable climatic conditions	
Limited land		Unfavourable government policies for agriculture		Increase in producer/market prices of crops/commodities		Increase in population/Family sizes	
Soil Infertility		Lack of incentives		Limited or no other livelihood source		Unemployment	
Conflicts/competing interests in the use of land		Increase in built-up areas		Favourable policies for agriculture		Other (Specify)	

Part IV: Forest vs Land-Use Cover Changes

10a. Do you think there has been a decline in forest areas over the past 30-50 years?

Yes ☐ No ☐

10b. If **YES**, what factors have contributed to forest or land degradation in the area. [Rank on a scale of **1 to 5**; **1= least important and 5= most important**]

Driving forces	Rank
Expansion in settlements & social infrastructure: Schools, health facilities, transportation networks, housing/real estates, Market and storage facilities, drainage systems and so on.	
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.	
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.	
Agricultural activities & Technological factors (agro-technical input and efficiency, mining technology, transportation networks)	
Natural or biophysical factors: Increase in temperature, droughts, wildfires, flooding, fluctuations in rainfall, topography, aspect, slope and so on	

11a. In your opinion, do you think change in land use systems have influenced microclimatic conditions like surface temperature and rainfall in the area?

Yes ☐ No ☐

11b. If yes, kindly specify how change in land use systems have influenced temperature and rainfall variables.

Increasing Temperatures over the past 30-50 years		Fluctuations in rainfall patterns over the past 30-50 years	
Low temperatures over the past 30-50 years		Unpredictable rainfall patterns	

12a. How did these forests come into existence?

Natural ☐ Man-made ☐ Both ☐

13. What has happened to forest cover in the area over the past few decades?

Increased ☐ Declined ☐ No change ☐

Part V: Access to infrastructure and services

Access to nearest	Increased	Decreased	Unchanged
Educational facilities			
Portable Drinking Water			
Health facilities			
Water resources (E.g., River/stream)			
Main Roads			
Bus stops			

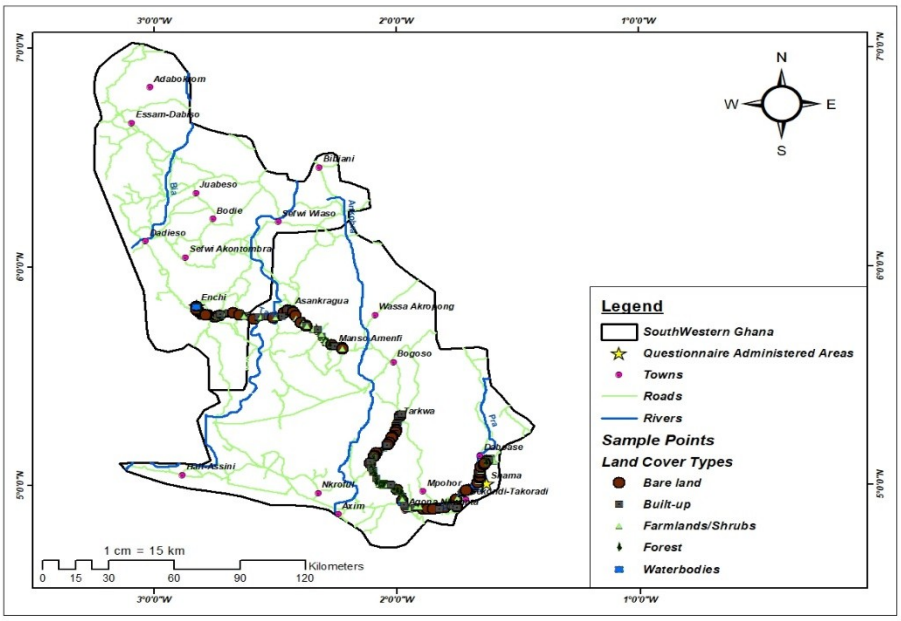
Market or shopping centres			
Town/City			

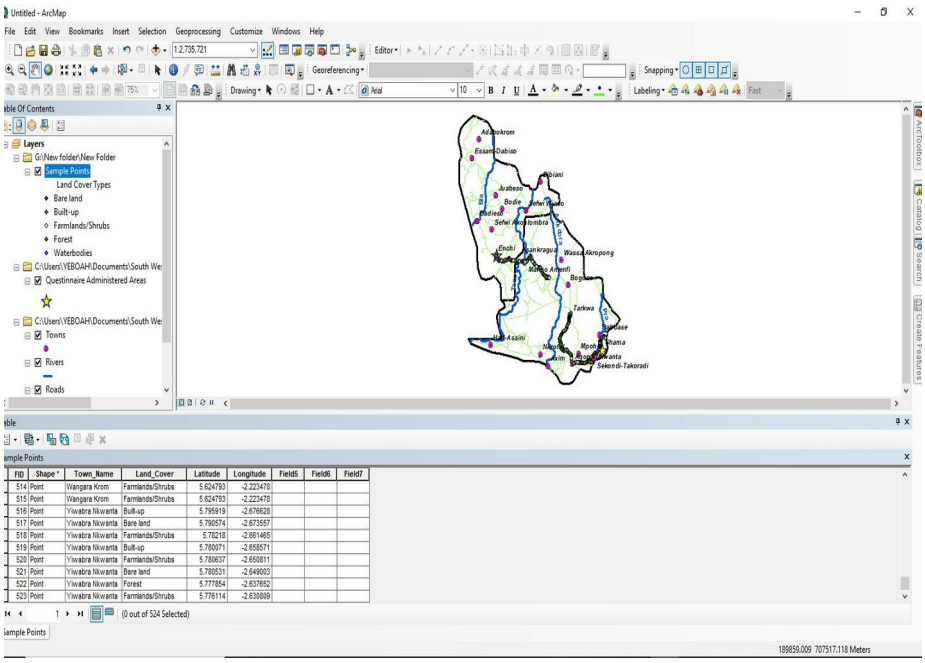
Part VI: Proximate and Underlying Causes (Drivers) of Land Use Cover Changes

What do you think are the causes of land-use cover changes in the area (Rank on a scale of 1 to 5; 1=least important and 5=most important).

Proximate cause	**Rank**				
	1	**2**	**3**	**4**	**5**
Deforestation					
Settlements					
Wood extraction					
Setting up profit-oriented industries					
Mining and Infrastructure					
Agriculture expansion					
Bushfires/ Wildfires					
Famine					
High temperature					
Floods					
Others (**Specify**)					
	Rank				
	1	**2**	**3**	**4**	**5**
Underlying causes					
Migration					
Poverty					
Population growth and distribution					
Weak governance, Monitoring and Enforcement mechanisms					
Technology (science, research, mining technology, agro-technical change and efficiency, transportation networks)					
Cultural values, behaviour and beliefs					

Annex IV: Maps depicting areas where the sampled points (524) were taken using the Mobile Data Collection (MDC) Application as well as areas were the questionnaires were administered.





FID	Shape *	Town_Name	Land_Cover	Latitude	Longitude	Field5	Field6	Field7
514	Point	Wangara Krom	Farmlands/Shrubs	5.624793	-2.223478			
515	Point	Wangara Krom	Farmlands/Shrubs	5.624793	-2.223478			
516	Point	Yiwabra Nkwanta	Built-up	5.795919	-2.676628			
517	Point	Yiwabra Nkwanta	Bare land	5.790574	-2.673557			
518	Point	Yiwabra Nkwanta	Farmlands/Shrubs	5.78218	-2.661465			
519	Point	Yiwabra Nkwanta	Built-up	5.780071	-2.658571			
520	Point	Yiwabra Nkwanta	Farmlands/Shrubs	5.780637	-2.650811			
521	Point	Yiwabra Nkwanta	Bare land	5.780531	-2.649003			
522	Point	Yiwabra Nkwanta	Forest	5.777854	-2.637652			
523	Point	Yiwabra Nkwanta	Farmlands/Shrubs	5.776114	-2.630809			