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Abstract- An assessment of landuse and landcover (LULC) patterns and changes at catchment level is crucial to planning and management of dam reservoirs. LULC changes over a 30-year period for 9 reservoir catchments in northern Ghana were assessed using a mixed-method approach involving GIS/remote sensing technique and key informant interviews. Four major LULC namely; cropland, water bodies, built-up land and open savannah woodlands were identified and classified from 1986, 1996, 2006 and 2016 LandSat TM images of the reservoir catchments. Substantial changes in LULC were observed in the reservoir catchments from 1986 to 2016, mainly through the conversion of large areas of closed and open savannah woodlands to cropland and built-up areas. Across all the catchments, cropland and built-up land increased significantly whilst water bodies, open savannah woodland and closed savannah woodland experienced a declined over the past 30-years. Between the years 1986 and 2016, cropland and built-up areas increased by 13.80 to 58.88% and 3.17 to 18.82% respectively, whereas water bodies and open savannah woodland decreased by 14.28 to 46.03% and 0.17 to 5.29% respectively. The driving factors of these changes have been noted as human population, farmland expansion, deforestation, lack of community involvement in the management of the catchments and lack of proper education on catchment management. The changes in LULC in the catchments could lead to dramatic changes in the catchment peak flows, increase in soil erosion, high sediment loads and sedimentation of the reservoirs. Good agricultural practices are necessary in the catchment management.

Keywords: landuse and landcover changes, reservoir catchments, croplands, waterbodies, built-up areas, closed and open savannah woodlands.

I. Introduction

Landuse and landcover (LULC) changes in reservoir catchments around the globe have significant environmental implications and consequences, which may include distresses in hydrological cycles, loss of biodiversity, increase in soil erosion, sediment loads and reservoir sedimentation (Lambin and Geist, 2006). Changes in LULC in a reservoir catchment can be categorized by the complex interaction of structural and behavioral factors associated with technological capacity, demand and social relations that affect both environmental capacity and the demand, along with the nature of the environment of interest (Verburg et al., 2004). Changes in LULC are primarily associated with anthropogenic activities such as deforestation, bush burning, urbanization, construction of dams and agriculture (Yigzaw and Hossain, 2016). Anthropogenic activities have been identified as the main cause of landuse/landcover changes and sedimentation in the Shiyang Reservoir in China with 43% of woodland areas converted into agricultural land (Zhou, 2002). Mzuza *et al.* (2017) reported that the Nkula Dam in the Middle Shire River Catchment in Malawi had been threatened with massive sedimentation and this was attributed to increased human population and agricultural activities in the reservoir catchment. In Ghana, a similar study conducted by Boakye et al. (2008) to assess the impact of landuse changes in the Barekese catchment on its associated reservoir revealed a loss in reservoir storage capacity of 45% due to sedimentation over a period of six years. The causes for the rapid rate of sedimentation of the reservoir were attributed to deforestation, population growth and lack of proper education of the communities in catchment management.

Increased demands on available resources mainly due to expanding population globally have led to the clearing of marginal lands for agricultural production and for settlement purposes. This has resulted in increased erosion, more rapid rates of sediment loading in reservoirs and reduced socio-economic benefits which they were constructed for (Mavima et al., 2011). In northern Ghana, the estimated mean annual soil loss in reservoir catchments ranged from 3.71 – 8.17 t/ha/yr and this could potentially contribute to sedimentation of their associated reservoirs (Adongo et al., 2019a). Spatial and temporal data on landuse and landcover changes is required to arrive at informed decisions in integrated water management (Mavima et al., 2011). LULC Change detection involves applying multi-temporal remote sensing information to analyze the historical effects of an occurrence quantitatively and thus helps in determining the changes associated with land cover and landuse properties with reference to the multi-temporal datasets (Ahmad, 2012; Seif and Mokarram, 2012).

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In recent years, a variety of LULC change detection techniques and algorithms have been developed that make use of remotely sensed images. The most commonly used techniques include; Unsupervised classification, Supervised classification, Principal Component Analysis, Hybrid classification, Fuzzy classification, image overlay, classification comparisons of land cover statistics, change vector analysis, image rationing and the differencing of Normalized Difference Vegetation Index (NDVI) (Duadze, 2004). With proper understanding of the spatial and temporal variations occurring in a reservoir catchment over time and the interaction of the hydrological components of a reservoir catchment with each other, better water conservation strategies can be formulated (Ashraf, 2013). The question regarding information on landuse and landcover changes over time, and their driving forces in the reservoir catchments in northern Ghana are not known. Such knowledge is critical to the development of policies and action plans necessary for controlling sediment accumulation in reservoirs. Therefore, this study was carried out using GIS and Remote Sensing applications to analyze the extent of changes in nine (9) reservoir catchments over a period of 30 years in northern Ghana.

II. Materials and Methods

a) *Study Area*

The study was carried out in nine (9) reservoir catchments in northern Ghana as presented in Table 1 which also contains their principal characteristics and with Fig. 1 being the maps of the study sites.

Table 1: Study Reservoirs and Their Principal Characteristics

Region		Northern			Upper East			Upper West		
Reservoir		Bontanga	Golinga	Libga	Gambibgo	Tono	Vea	Daffiama	Karni	Sankana
District/ Municipality		Kumbungu	Tolon	Savelugu	Bolgatanga	Kassena - Nankana	Bongo	Daffiama-Bussie-Issa	Lambussie-Karni	Nadowli-Kaleo
Location Coordinates		9° 57'N 1° 02'W	9° 22'N 0° 57'W	9°59'N 0° 85'W	10° 45'N 0° 50'W	10° 52'N 1° 08'W	10°52'N 0° 51'W	10° 27'N 02° 34'W	10° 40'N 02° 38'W	10° 11'N 02° 36'W
Catchment Area (km^2)		165	53	31	1.70	650	136	21	35	141
Rainfall System	Type	Uni-modal			Uni-modal			Uni-modal		
	Annual Mean (mm)	1,000 – 1,300			700 – 1,010			800 – 1,100		
	Duration (months)	5 – 6			5 – 6			5 – 6		
Temperature (°C)	Day	33 – 39			20 – 22			29.0		
	Night	35 – 45			23 – 28			32.2		
	Mean	33 – 45			36 – 55			35 - 50		
Relative Humidity (%)	Dry Season	50			10			20		
	Wet Season	80			65			70		
Agro-ecological Zone		Guinea Savannah			Guinea/Sudan Savannah			Guinea Savannah		
Geology		Precambrian basement rocks and Paleozoic rocks from the voltaian sedimentary basin			Metamorphic and igneous rocks with gneisss, granodiorite and sandstone			Precambrian, granite and metamorphic rocks		
Soil Classes		Acrisols, plinthosols, planosols, luvisols, gleysols and fluvisols			Plinthosols, luvisols, vertisols, leptosols, lixisols, and fluvisols			Lixisols, fluvisols, leptosols, vertisols, acrisols and plinthosols		

Adapted from Adongo et al. (2019a)

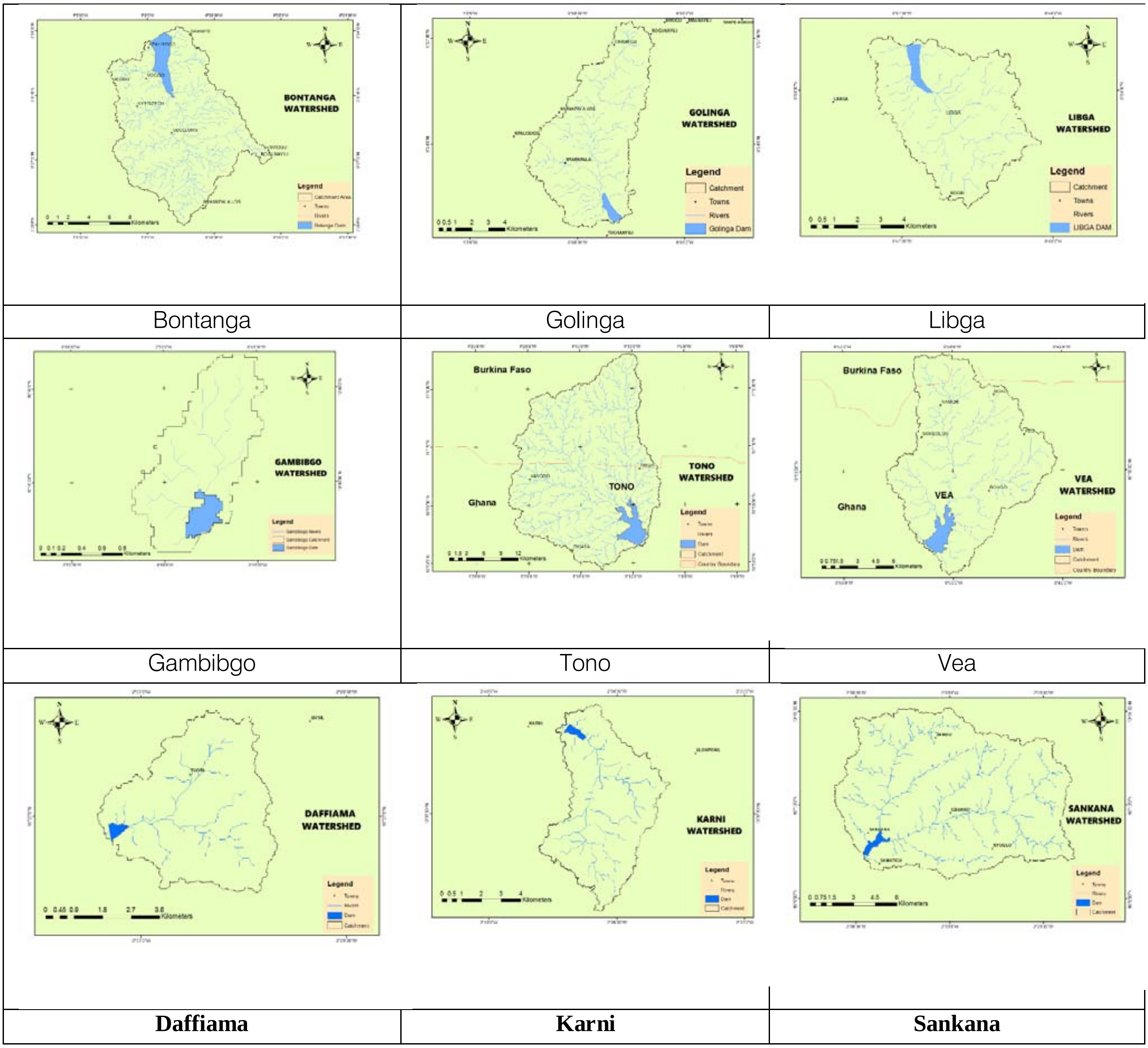
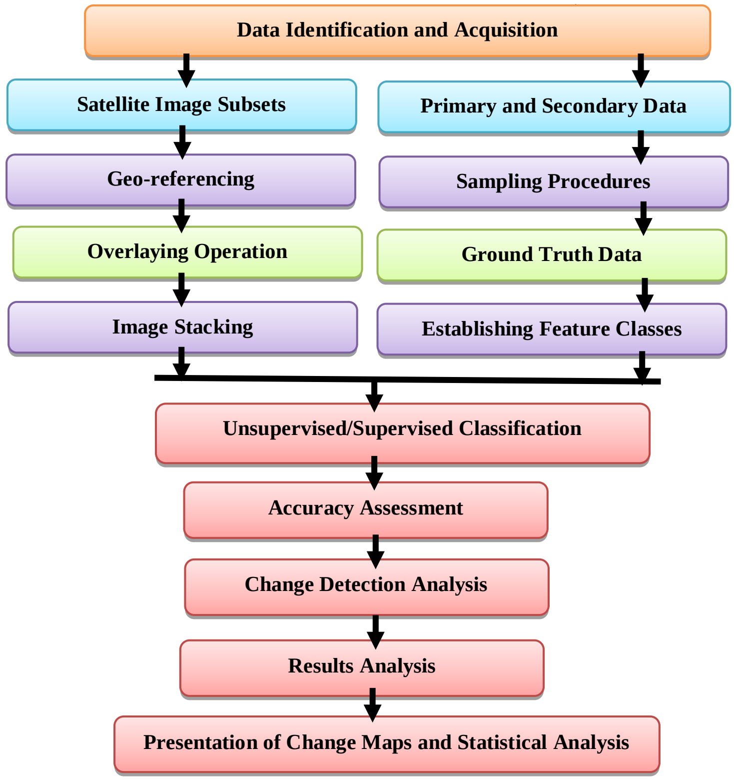


Fig. 1: Maps of the Study Reservoir Catchments

b) Methodology

The study used multi-temporal and multi-sensor Landsat satellite imageries to establish the landuse and landcover (LULC) changes in the study reservoir catchments for the years of 1986, 1996, 2006 and 2016. A summary of the flow chart of the methodology of LULC change detection analysis of the reservoir catchments is presented in Fig. 2.



Adapted from Luca (2013)

Fig. 2: Methodology flow chart for LULC Change Analysis

The satellite images were derived from an open source Satellite Imagery Database from the United States Geological Survey (USGS) website. Detailed characteristics of the Landsat images of the various catchments is presented in Table 2.

Table 2: Characteristics of Landsat Images of the Reservoir Catchments

Catchment	Sensors	Date of Acquisition	Spatial Resolution (m)	Spectral Bands	Path/ Row	Source
Gambibgo, Tono	Landsat TM	05/10/1986	30 x 30	4,3,2	195/52	USGS GloVis
	Landsat TM	05/10/1996	30 x 30	4,3,2	195/52	
	Landsat TM	05/10/2006	30 x 30	4,3,2	195/52	
	Landsat 8 OLI	05/10/2016	30 x 30	5,4,3	195/52	
Vea	Landsat TM	05/10/1986	30 x 30	4,3,2	194/52	USGS GloVis
	Landsat TM	05/10/1996	30 x 30	4,3,2	194/53	
	Landsat TM	05/10/2006	30 x 30	4,3,2	194/53	
	Landsat 8 OLI	05/10/2016	30 x 30	5,4,3	194/52	
Bontanga, Golinga, Libga	Landsat TM	05/10/1986	30 x 30	4,3,2	194/53	USGS GloVis
	Landsat TM	05/10/1996	30 x 30	4,3,2	194/53	
	Landsat TM	05/10/2006	30 x 30	4,3,2	194/53	
	Landsat 8 OLI	05/10/ 2016	30 x 30	5,4,3	195/53	
Daffiama, Karni, Sankana	Landsat TM	05/10/1986	30 x 30	4,3,2	195/53	USGS GloVis
	Landsat TM	05/10/1996	30 x 30	4,3,2	195/53	
	Landsat TM	05/10/2006	30 x 30	4,3,2	195/53	
	Landsat 8 OLI	05/10/ 2016	30 x 30	5,4,3	195/53	

TM – Thematic Mapper; OLI – Operational Land Image; USGS GloVis – United States Global Visualization Viewer

Two software; ERDAS Imagine version 10.4 and ArcGIS version 10.4 were used to process the satellite images for layer stacking, mosaicking, geo-referencing, subsetting and training of the images according to the Area of Interest (AOI). In ERDAS Imagine, image band combinations were manipulated from the default natural colour band combination in the image drape viewer to effectively identify different land use types in the study area, and the findings were later verified by ground truthing (gathered information/image material related to real features on the ground) to generate an appropriate training sample dataset for supervised classification. To improve the visual interpretability of the satellite data for a particular application, image enhancement was performed on all the acquired scenes. A classification scheme was then developed of which the following five (5) landuse and landcover classes were distinguished; cropland, water body, built-up land/bare land/rocky ground, closed savannah woodland and open savannah woodland. Description of the various LULC classification schemes used in this study is presented in Table 3.

Table 3: Description of Delineated Landuse and Landcover Classes of the Catchments

Serial Number	Landuse/Landcover Class	Description
1	Cropland	Lands used for the cultivation of crops, i.e, crop fields.
2	Waterbodies	Waterbodies in the catchment area that empty into the reservoirs. These include; streams, lakes, ponds and rivers.
3	Built-up land/rocky ground/ bare land	Areas with intense infrastructural developments and exposed surfaces due to human activities or natural factors. These include; residential areas, industrial areas, commercial areas, recreational grounds, farmsteads, schools, lorry parks, roads and rocks. Bare land is land covered with sand or gravel. It has limited ability to support life and therefore uncultivated.
4	Closed savannah woodland	Thick forest lands, groves, thick plantations.
5	Open savannah woodland	Shrublands, grasslands and fallow lands.

Enhancement techniques were used together with classification techniques to extract features for the study reservoir catchments, locating areas and objects on the ground and deriving useful information from the images. Furthermore, use of enhancement techniques to visually interpret the images helped optimise the complementary capabilities of the processing. Classification was done for 1986, 1996, 2006 and 2016 images to identify the various LULC types and changes occurring over the years. Accuracy assessment of the classified imagery was performed to establish the level of accuracy of the classification. A non-parametric Cohen's Kappa test was performed to measure the extent of classification accuracy. Cohen's Kappa tries to measure the agreement between predefined producer-ratings and user assigned-ratings (Butt et al., 2015). It is computed using Equation 1 developed by Viera and Garrett (2005):

$$K = \frac{P(A) - P(E)}{1 - P(E)} \quad \text{.........................} \quad (1)$$

Where: P (A) – Number of times the k raters agree and P (E) – Number of times the k raters are expected to agree only by chance. The P(A) and P(E) were generated in ArcGIS using the ground coordinates of the ground truth samples.

The classification comparison of LULC statistics method was used for the change detection analysis. This method was adapted because the study sought to determine quantitative changes in the areas of the various LULC categories. Using the post-classification procedure, the area statistics for each of the LULC classes was derived from the classifications of the images for each date (1986, 1996, 2006 and 2016) separately, using functions in the ERDAS-Imagine-Software 10.4. The areas covered by each LULC type for the various time intervals were compared. The percentage landuse and landcover change (% LULCC) at the catchments was computed using the formula developed by Lambin(2001) and presented in Equation 2.

$$\% \, LULCC = \frac{Observed \;\; Area \;\; Change}{Total \;\; Area \;\; of \;\; Catchment} \times 100 \quad \text{................} \quad (2)$$

ArcGIS 10.4 was used for map composition as it increases the level of accuracy of the LULC change determined from the image.

c) Key-Informant Interviews

Key-informant interviews were conducted with key stakeholders such as local traditional leaders in the communities of the catchments and the management of the irrigation dams from January to March, 2018. The key-informant interviews were conducted so as to augment the data that was obtained from Landsat images and field measurements. A total of 81 respondents (9 from each catchment) were interviewed. To ensure the acquisition of comprehensive information, the respondents were people of age 45 to 60 years, who are longtime residents (i.e > 25 years) of the selected communities. They were selected based on their experience and knowledge on landuse and landcover changes in the catchments.

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III. Results and Discussion

a) Areal Extent of Landuse and Landcover Classes in the Reservoir Catchments

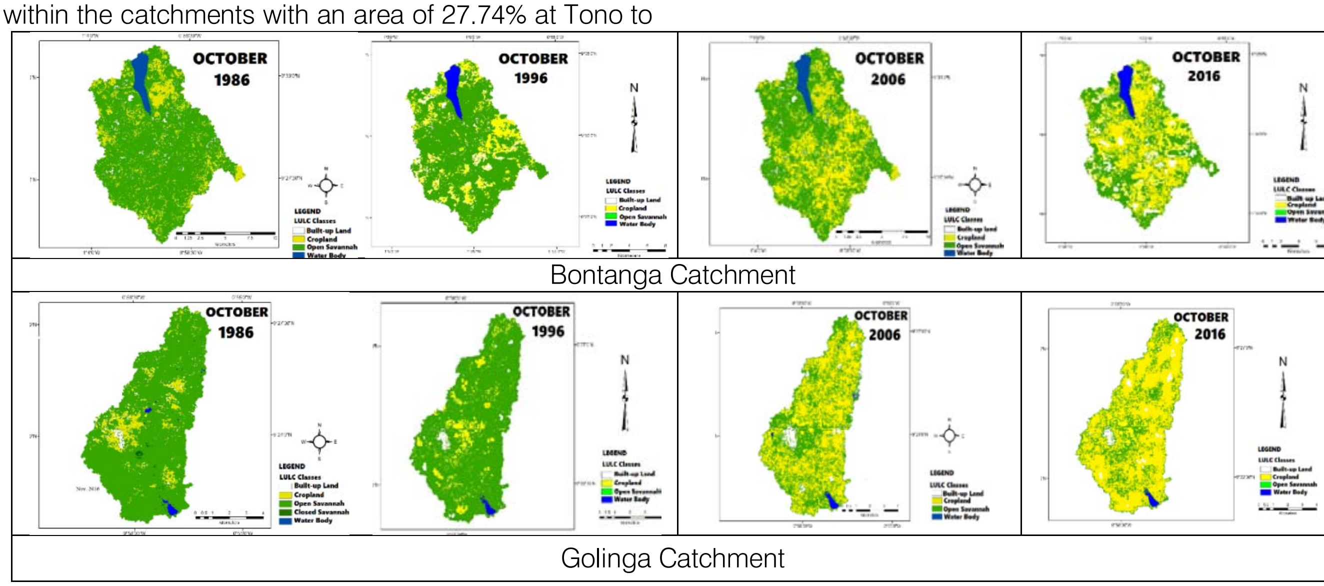
Four (4) major landuse/landcover (LULC) categories namely; cropland, waterbodies, built-up land and open savannah woodland were identified and classified in the reservoir catchments, except Tono catchment where closed savannah woodland was identified as the fifth (5th) major LULC class (Figure 3 and Table 4). The LULC maps of the catchments clearly showed that there were variations in the LULC types in the last 30 years (1986-2016).

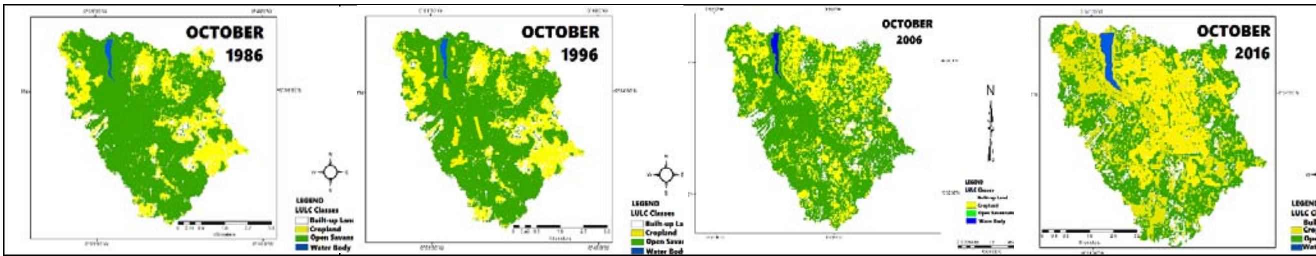
In 1986, except the Tono catchment, open savannah woodland was the predominant LULC class, occupying an area of 45.99% at Bontanga to 80.72 %at Golinga. At Tono catchment, the predominant LULC was closed savannah woodland with a coverage area of 233.89 ha (35.98%), followed by open savannah woodland with area occupancy of 30.56%. Except Tono catchment, the second most predominant class was cropland with coverage area of 15.57% at Golinga to 45.57% at Bontanga, followed by built-up area with a coverage of 1.7% at Bontanga to 8.24% at Gambibgo. Across all the catchments, water body occupied the least area with values ranging from 0.44% at Sankana to 6.75% at Vea (Table 4).

The 1996 Landsat images of the catchments showed a reduction of LULC change compared with 1986 for the different LULC classes, except cropland and built-up areas. Open savannah woodland occupied a significant portion of the catchments with an area coverage of 32.94% at Gambibgo to 66.55% at Golinga, followed by cropland which was randomly distributed within the catchments with an area of 27.74% at Tono to 52.78% at Bontanga. Built-up area occupied a minor area of 2.39% at Bontanga to 15.29% at Gambibgo. Water bodies occupied the least area of 0.40% at Sankana to 5.85% at Vea (Table 4).

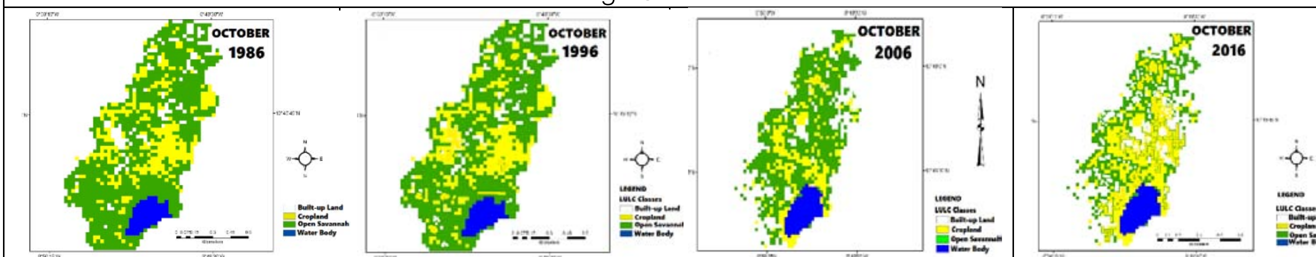
From the 2006 image classification it was noted that both water bodies and open savannah woodland were reduced from their coverage in 1996 (Table 4). Water bodies were reduced by 0.05% at Sankana to 2.35% at Gambibgo whilst open savannah woodland reduced by 5.75% at Vea to 18.94% at Golinga. Closed savannah woodland also reduced by 8.37% at Tono. On the other hand, cropland coverage increased by 3.11% at Tono to 18.72% at Golinga, and built-up areas coverage also increased by 0.36% at Golinga to 9.41% at Gambibgo catchment.

The 2016 Landsat map showed substantial changes relative to the previous 20-year period with croplands occupying the greatest area of the catchments with values ranging from 37.82% at Tono to 74.45% at Golinga, followed by open savannah woodland with 17.68% at Golinga to 33.63% at Tono catchment. However, at the Libga and Gambibgo catchments, built-up areas were noted to be the second largest LULC class occupying 22.87% and 37.06% of their areas respectively. Patches of closed savannah woodland with a total area coverage of 13.84% were found in the northern zone of the Tono catchment. Except Libga and Gambibgo catchments, built-up areas occupied an area of 4.99% at Bontanga to 18.62% at Daffiama catchment. The remaining parts of the catchments were composed of water bodies with the least area of 0.27% at Sankana to 4.49% at Bontanga (Table 4).

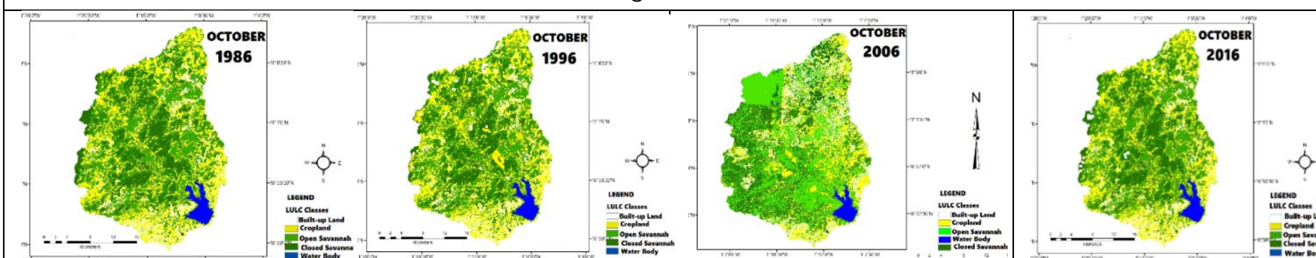




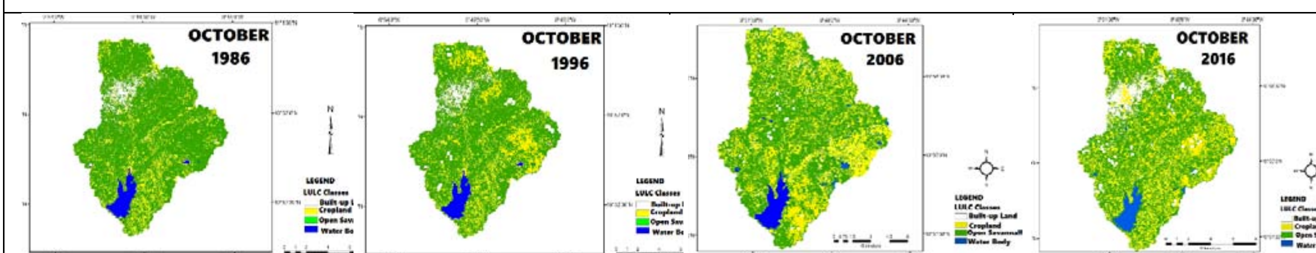
Libga Catchment



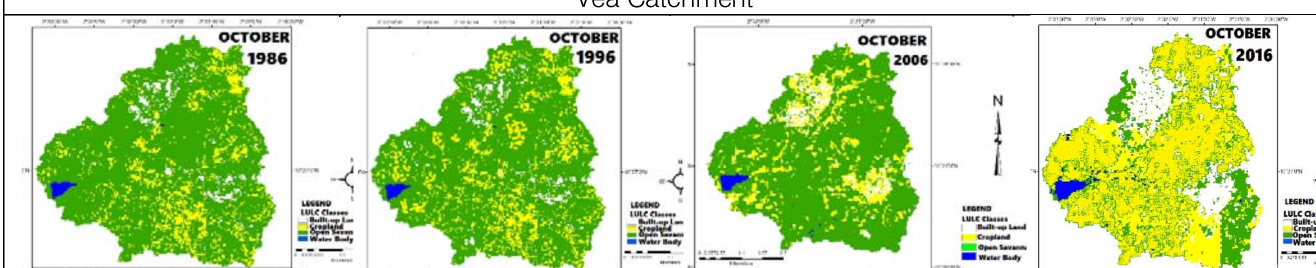
Gambibgo Catchment



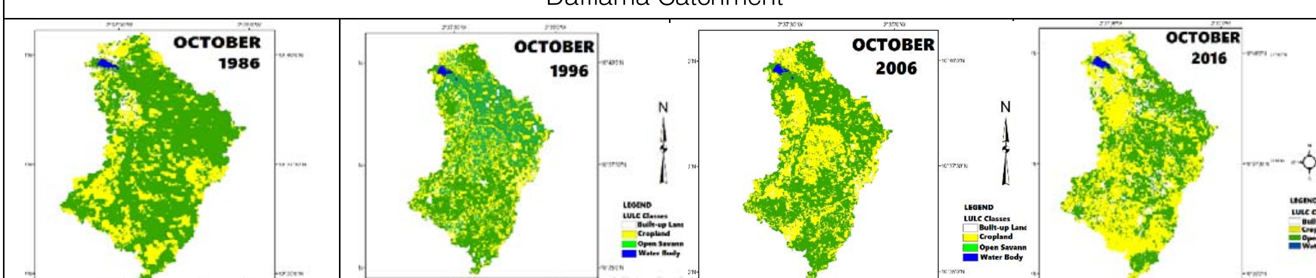
Tono Catchment



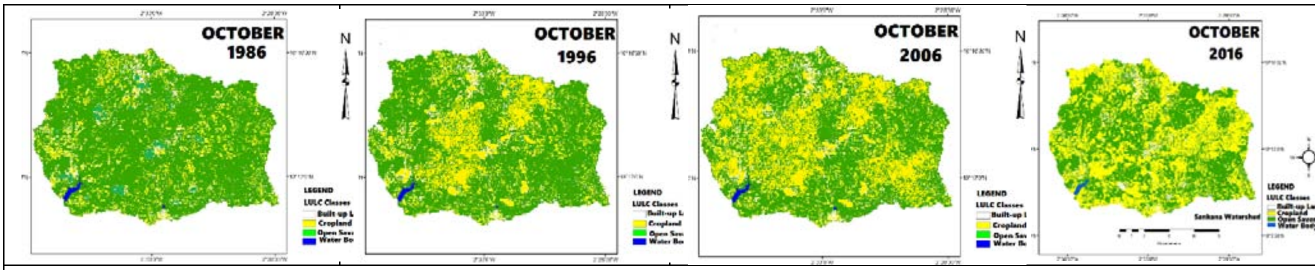
Vea Catchment



Daffiama Catchment



Karni Catchment



Sankana Catchment

Fig. 3: Landuse/Landcover Landsat Images of Study Reservoir Catchments for 1986, 1996, 2006 and 2016

Table 4: Areal Extent of Different Landuse/Landcover Classes in the Study Reservoir Catchments from the Year 1986 to 2016

Bontanga Catchment								
Landuse/ Landcover Class	1986		1996		2006		2016	
	km^2	%	km^2	%	km^2	%	km^2	%
Cropland	75.19	45.57	87.09	52.78	97.67	59.19	111	67.27
Built-up land	2.80	1.70	3.94	2.39	5.86	3.55	8.23	4.99
Water body	11.13	6.75	9.67	5.86	8.76	5.31	7.41	4.49
Open SW	75.88	45.99	64.30	38.97	52.71	31.95	38.36	23.25
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	165	100	165	100	165	100	165	100
Golinga Catchment								
Landuse/ Landcover	1986		1996		2006		2016	
	km^2	%	km^2	%	km^2	%	km^2	%
Cropland	8.25	15.57	15.45	29.15	25.37	47.87	39.46	74.45
Built-up land	1.12	2.11	1.77	3.34	1.96	3.70	3.77	7.11
Water body	0.59	1.11	0.51	0.96	0.44	0.83	0.40	0.75
Open SW	42.78	80.72	35.27	66.55	25.23	47.60	9.37	17.68
Closed SW	0.26	0.49	0.0	0.0	0.0	0.0	0.0	0.0
Total	53	100	53	100	53	100	53	100
Libga Catchment								
Landuse/ Landcover	1986		1996		2006		2016	
	km^2	%	km^2	%	km^2	%	km^2	%
Cropland	10.37	33.45	14.53	46.87	16.15	52.10	16.95	54.68
Built-up land	1.96	6.32	3.08	9.94	4.92	15.87	7.04	22.71
Water body	0.52	1.68	0.35	1.13	0.28	0.90	0.23	0.74
Open SW	18.15	58.55	13.04	42.06	9.65	31.13	6.78	21.87
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	31	100	31	100	31	100	31	100
Gambibgo Catchment								
Landuse/ Landcover	1986		1996		2006		2016	
	km^2	%	km^2	%	km^2	%	km^2	%
Cropland	0.35	20.59	0.66	38.82	0.8	47.06	0.70	41.18
Built-up land	0.14	8.24	0.26	15.29	0.42	24.71	0.63	37.06
Water body	0.37	21.76	0.22	2.94	0.18	1.59	0.11	0.47
Open SW	0.84	49.41	0.56	32.94	0.30	17.65	0.26	15.29
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.7	100	1.7	100	1.7	100	1.7	100
Tono Catchment								
Landuse/ Landcover	1986		1996		2006		2016	
	km^2	%	km^2	%	km^2	%	km^2	%
Cropland	156.17	24.03	180.32	27.74	200.55	30.85	245.86	37.82
Built-up land	41.54	6.39	50.75	7.81	65.86	10.13	79.43	12.22
Water body	19.78	3.04	18.82	2.90	17.81	2.74	16.19	2.49
Open SW	198.62	30.56	234.94	36.14	255.02	39.23	218.60	33.63

Closed SW	233.89	35.98	165.17	25.41	110.76	17.05	89.92	13.84
Total	**650**	**100**	**650**	**100**	**650**	**100**	**650**	**100**
Vea Catchment								
Landuse/ Landcover	1986		1996		2006		2016	
	km^2	%	km^2	%	km^2	%	km^2	%
Cropland	53.46	39.31	59.33	43.63	65.74	48.34	74.86	55.04
Built-up land	4.17	3.07	5.71	4.20	7.92	5.82	10.38	7.63
Water body	8.71	6.40	7.95	5.85	7.15	5.26	5.59	4.11
Open SW	69.66	51.22	63.01	46.33	55.19	40.58	45.17	33.21
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**136**	**100**	**136**	**100**	**136**	**100**	**136**	**100**
Daffiama Catchment								
Landuse/ Landcover	1986		1996		2006		2016	
	km^2	%	km^2	%	km^2	%	km^2	%
Cropland	4.08	19.43	6.95	33.10	8.51	39.10	10.58	50.38
Built-up land	0.68	3.24	1.16	5.52	2.74	13.05	3.91	18.62
Water body	0.43	2.05	0.35	1.67	0.26	1.24	0.11	0.52
Open SW	15.81	75.29	12.54	59.71	9.79	46.62	6.40	30.48
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**21**	**100**	**21**	**100**	**21**	**100**	**21**	**100**
Karni Catchment								
Landuse/ Landcover	1986		1996		2006		2016	
	km^2	%	km^2	%		km^2	%	km^2
Cropland	10.99	31.40	14.26	40.74	17.84	50.97	23.25	66.43
Built-up land	1.46	4.17	1.75	5.0	2.22	6.34	3.01	8.60
Water body	0.46	1.31	0.42	1.20	0.33	0.94	0.20	0.57
Open SW	22.09	63.11	18.57	53.06	14.61	41.74	8.54	24.40
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**35**	**100**	**35**	**100**	**35**	**100**	**35**	**100**
Sankana Catchment								
Landuse/ Landcover	1986		1996		2006		2016	
	km^2	%	km^2	%		km^2	%	km^2
Cropland	41.18	29.21	57.63	40.87	76.64	54.35	96.52	68.45
Built-up land	4.34	3.08	5.11	3.62	6.43	4.56	8.80	6.24
Water body	0.62	0.44	0.56	0.40	0.49	0.35	0.38	0.27
Open SW	94.86	67.28	77.70	55.11	57.44	40.74	35.30	25.04
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**141**	**100**	**141**	**100**	**141**	**100**	**141**	**100**

SW = Savannah woodland

b) Landuse and Landcover Classification Accuracy Assessment for 2016

According to Owojori and Xie (2005), it is crucial to perform accuracy assessment for LULC classification if the classification data are to be used for change detection analysis. Accuracy assessment establishes the level of accuracy of the classfication . Coppin and Bauer (1996) reported that a classification accuracy of 0 - 69% indicates low accuracy whereas 70 – 100% indicates high accuracy, and a kappa coefficient < 0.5 and > 0.5 indicates low and high accuracies respectively. As presented in Table 5, an accuracy assessment elaborated for the 2016 image classification revealed an overall classification accuracy of 80% and overall Kappa coefficient (statistic) of 0.75. The highest user accuracy of all the LULC classes was obtained for water bodies of 92.5% whilst cropland recorded the lowest user accuracy of 72.2%. Also, for producer accuracies, water bodies and cropland recorded the highest and lowest values of 100% and 64.4% respectively. Based on the assertion of Coppin and Bauer (1996), the classification accuracy for the study was high. In a similar study in Ghana, Antwi-Agyei et al. (2019) obtained high overall classification accuracy of 77.56% and overall Kappa statistic of 0.77 in Owabi reservoir catchment.

Table 5: Classification Accuracy Assessment for the Year 2016

LULC Class	Reference Totals	Classified Totals	Correct Number	Producer's Accuracy (%)	User's Accuracy (%)	Kappa Coefficient
Cropland	45	40	29	64.4	72.2	0.68
Built-up land	34	40	30	88.2	75.0	0.71
Water body	37	40	37	100.0	92.5	0.87
Open SW	43	40	35	81.4	87.5	0.82
Closed SW	41	40	29	70.7	72.5	0.68
Total	**200**	**200**	**160**	-	-	-
Overall classification accuracy = 80.0 % and overall kappa coefficient (statistic) = 0.75						

LULC = Landuse and Landcover; SW = Savannah woodland

c) Landuse and Landcover Changes Detection Analysis with the Reservoir Catchments from 1986 to 2016

Substantial changes in LULC categories were observed to have taken place in the reservoir catchments from 1986 to 2016, mainly through the conversion of large areas of closed and open savannah woodlands to cropland and built-up areas. Across all the catchments, cropland and built-up land saw a consistent and significant increased whilst water bodies, open savannah woodland and closed savannah woodland experienced a declined over the past 30-years (Table 6). Between 1986 and 1996, cropland increased by 3.58% at Karni to 18.24% at Gambibgo. Also, built-up land increased by 0.47% at Karni to 7.06% at Gambibgo. Water bodies decreased by 0.04% at Sankana to 8.82% at Gambibgo whilst open savannah woodland declined by 5.75% at Vea to 16.48% at Libga. At Tono catchment, however, open savannah woodland increased by 5.59% and closed savannah woodland saw a decrease of 10.57% to other LULC classes.

The study also found that between 1996 and 2006, cropland increased by 3.11% at Tono catchment to 18.72% at Golinga catchment, whilst built-up land increased by 0.36% at Golinga to 9.41% at Gambibgo catchment. However, water bodies recorded a marginal declined by 0.05% at Sankana catchment to 2.35% at Gambibgo catchment. Open savannah woodland experienced a declined by 5.75% at Vea catchment to 18.94% at Golinga catchment as presented in Table 6.

Between 2006 and 2016, cropland significantly increased by 2.58% at Libga catchment to 26.59% at Golinga catchment, whilst at Gambibgo catchment, it decreased by 5.88% probably to settlement built-up areas. Also, built-up land increased by 1.44% at Sankana catchment to 12.35% at Gambibgo catchment. However, water bodies decreased marginally by 0.08% at Golinga and Sankana catchments to very high of 4.12% at Gambibgo catchment. Open savannah woodland also saw a decline of 2.21% at Tono catchment to 29.92% at Golinga catchment (Table 6). It was also noted that the closed savannah woodland at Tono catchment decreased by 5.60% to probably other LULC categories such as cropland and built-up land.

Table 6: Landuse and Landcover Changes of the Study Reservoir Catchments

Catchment	Bontanga						Golinga					
Landuse/ Landcover Change	1986-1996		1996-2006		2006-2016		1986-1996		1996-2006		2006-2016	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Cropland	11.21	6.79	10.58	6.41	13.33	8.08	7.20	13.58	9.92	18.72	14.09	26.59
Built-up land	1.14	0.69	1.92	1.16	2.37	1.68	0.65	1.23	0.19	0.36	1.81	3.42
Water body	-1.46	-0.88	-0.91	-0.55	-1.35	-0.82	-0.08	-0.15	-0.07	-0.13	-0.04	-0.08
Open SW	-10.89	-6.60	-11.59	-7.02	-14.35	-8.70	-7.51	-14.17	-10.04	-18.94	-15.86	-29.92
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0	-0.26	-0.49	0.0	0.0	0.0	0.0
Catchment	Libga						Gambibgo					
Cropland	4.16	13.42	1.62	5.23	0.8	2.58	0.31	18.24	0.14	8.24	-0.1	-5.88
Built-up land	1.12	3.61	1.84	5.94	2.12	6.84	0.12	7.06	0.16	9.41	0.21	12.35
Water body	-0.17	-0.55	-0.07	-0.23	-0.05	-0.16	-0.15	-8.82	-0.04	-2.35	-0.07	-4.12
Open SW	-5.11	-16.48	-3.39	-10.94	-2.87	-9.26	-0.28	-16.41	-0.26	-15.29	-0.04	-3.35
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catchment	Tono						Vea					
Cropland	24.15	3.72	20.23	3.11	45.31	6.97	5.87	4.32	6.41	4.71	9.12	6.71

Built-up land	9.21	1.42	15.11	2.32	13.57	2.09	1.54	1.13	2.21	1.63	2.46	1.81
Water body	-0.96	-0.15	-1.01	-0.16	-1.62	-0.25	-0.76	-0.56	-0.80	-0.59	-1.56	-1.15
Open SW	36.32	5.59	20.08	3.09	-36.42	-2.21	-6.65	-4.89	-7.82	-5.75	-10.02	-7.37
Closed SW	-68.72	-10.57	-54.41	-8.37	-20.84	-5.60	0.0	0.0	0.0	0.0	0.0	0.0
Catchment	Daffiama						Karni					
Cropland	2.87	13.67	1.56	7.43	2.07	9.86	3.27	9.34	3.58	10.23	5.41	15.46
Built-up land	0.48	2.29	1.58	7.52	.01.17	5.57	0.29	0.83	0.47	1.34	0.79	2.26
Water body	-0.08	-0.38	-0.09	-0.43	-0.15	-0.71	-0.04	-0.11	-0.09	-0.26	-0.13	-0.37
Open SW	-3.27	-15.57	-2.75	- 13.10	-3.39	- 16.14	-3.52	-10.06	-3.96	-11.31	-6.07	-17.34
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catchment	Sankana											
Cropland	16.45	11.67	19.01	13.48	19.88	14.10						
Built-up land	0.77	0.55	1.32	0.94	2.37	1.44						
Water body	-0.06	-0.04	-0.07	-0.05	-0.11	-0.08						
Open SW	-17.16	-12.17	-20.26	- 14.37	-22.14	- 15.70						
Closed SW	0.0	0.0	0.0	0.0	0.0	0.0						

SW = Savannah woodland;
+ indicates increase; and
- indicates decrease

d) *Causes of the Landuse and Landcover Changes in Reservoir Catchments*

The driving forces for LULC changes in the study reservoir catchments resulted from direct and indirect causes. The direct causes constituted human activities that originated from intended landuse and directly affect LULC. The results from key informant interviews in communities located in the catchments during the study indicated that there is a significant evidence of LULC change resulting from farmland expansion (37%); clearing trees for fuelwood and charcoal for domestic consumption and for sale (24%); clearing of forest for human settlement development (20%); wildfires (15%) and illegal harvesting of forests for timber production (4%) (Fig. 4). The most significant indirect drivers behind the LULC changes noticed on the catchments were related to human population increase (demographic factors) (43%); economic, technological and cultural factors among the land ownership (27%); climate variability in the catchment (19%) and institutional factors (11%) (Fig. 5).

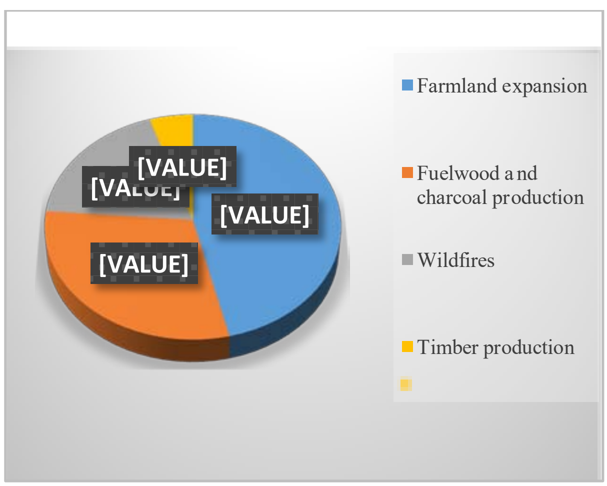


Fig. 4: Direct Causes of LULC Changes in Reservoir Catchments

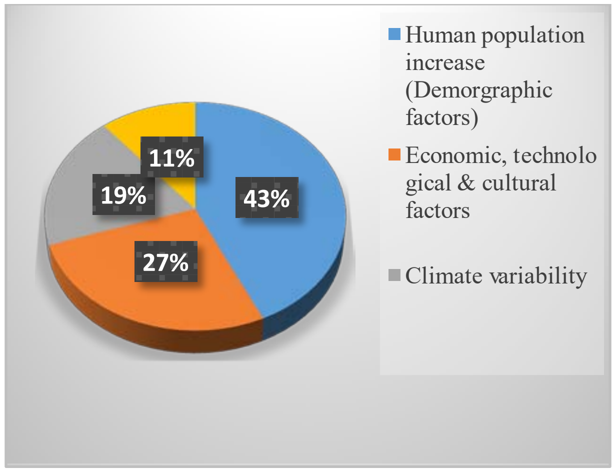


Fig. 5: Indirect Causes of LULC Changes in the Reservoir Catchments

The increased in human population in the catchments over the years has accelerated the demand for agricultural land and settlement development which had led to deforestation and thus reduced the forest cover. The results of the study showed a massive reduction in forested areas in the Tono catchment which was noted to correspond to the results of other studies suggesting that forest areas in Ghana have undergone massive reduction (Adade and Oppelt, 2019). Census data showed that between 1986 and 2016, human population in the five (5) regions of northern Ghana increased with an average growth rate of 2.1% per annum (GSS, 2014), implying an expansion of agricultural land and built-up areas to meet demand. According to Attua and Fisher (2011) and Antwi et al. (2014), human population growth is widely recognized as a main driver of environmental and LULC change, especially in developing countries. The changes observed in the study reservoir catchments are consistent with those observed in many studies conducted at national and regional levels in Ghana such as Antwi et al. (2014), Kleeman et al. (2017) Asubonteng et al. (2018), Shoyama et al. (2018), Adade and Oppelt (2019) and Antwi-Agyei et al. (2019). For example, using a mixed-method approach, Kleeman et al. (2017) identified population growth as a major driver of LULC changes in Ghana's Upper East Region. Various anthropogenic activities, including agriculture, have led to encroachment of human settlements on forest lands, with devastating consequences for biodiversity (Antwi et al., 2014). In Namibia and Kenya, studies have identified agricultural expansion, human population growth increase and illegal logging as the key drivers of landuse and landcover changes in catchments, with serious debilitating effects on their associated reservoirs and peoples' livelihood activities (Ogechi and Waithaka, 2017). Overall, a large population entails a higher demand for fuelwood and conversion of more agricultural land to human settlements to meet the growing feeding needs (Kassa et al., 2017). With the projected steady increase of the global human population at a rate of 1.1% per annum (UN-DESA, 2017), the fragile reservoir catchments of northern Ghana will without doubt continue to suffer from anthropogenic pressures.

e) Potential Consequences of the Landuse and Landcover Changes in the Study Catchments

The trend of landuse and landcover changes detected in the study has shown general conversion of the closed and open savannah woodland to cropland and built-up and open areas. These conversions have potential consequences on the catchments' characteristics and hydrology. According to Weiss and Milich (1997), landcover is a function of rainfall regime, soil conditions and geomorphology. This indicates that the conversion of the closed and open savannah woodlands to croplands, grasslands and settlements would definitely lead to changes in the soil conditions and the geomorphology of the catchments.

Similarly, Costa et al. (2003) reported that the conversion of forest to grassland disrupts the hydrological cycle of the catchment by altering the balance between rainfall and evaporation and, consequently, the runoff response of the area. With less litter due to wildfires and clear/burn practices in the catchments, the capacity of surface detention is decreased, and a greater proportion of the rainfall runs off as overland flow. The shift from sub-surface flow to overland storm flows accompanying deforestation, expansion of croplands and built-up areas may produce dramatic changes in the catchment peak flows as well and make the land more vulnerable to erosion leading to sedimentation of the reservoirs. Adongo et al. (2019b) reported that the estimated mean annual soil loss in the reservoir catchments ranged from 3.71 to 8.17 t/ha/yr. Lack of enforcement of environmental by-laws by the local rural district council regarding deforestation has led to uncontrolled cutting down of trees within the catchment and much of the woodland has now become grassland area.

Also, Boakye et al. (2008) noted that practices relating to farming and urbanization such as construction and soil compaction during logging can reduce the infiltration capacity of the soil and in turn the flow of water through the soil profile in Barekese catchment in Ghana. Moreover, the increase in farming activities in the catchments coupled with increasing runoff could also increase erosion and sedimentation of the reservoirs thus, transporting more sediment into the river leading to the gradual sedimentation of the reservoirs. Therefore, these LULC changes detected could be the cause of the sedimentation in the reservoirs at a rate of 0.26 to 0.91%/yr, as reported by Adongo et al. (2019b). A similar study conducted in Ghana noted a similar trend whereby sedimentation of reservoirs was mainly attributed to deforestation and lack of proper education of the communities in catchment management (Boakye et al., 2008).

IV. Conclusions

The study identified and classified cropland, water bodies, built-up land, open savannah woodland and closed savannah woodland as the five major landuse and landcover categories in the various sites. Over the 30 year period, substantial areas of closed and open savannah woodlands were noted to have been converted into croplands and built-up areas with water bodies declining mainly due to anthropogenic activities. Closed savannah woodland was only identified in the Tono reservoir catchment although its area decreased overtime.

Farmland expansion, domestic and commercial fuelwood and charcoal production, construction activities, wildfires/bushfires, and illegal harvesting of forests for timber production were observed as casual factors for these changes. These factors were influenced by human population increase, economic, climate variability in the catchment, etc. These changes observed in the various catchments have an effect on catchment hydrological characteristics thus affecting water flows and increasing the level of vulnerability to erosion and its attendant effect on reservoir sedimentation. Strategies such as afforestation, ban on illegal harvesting of forest products, etc and involving local communities for effective and sustainable management of the catchments to reduce the effect of landuse and landcover change on catchment characteristics are recommended.

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