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Impacts of Climate Change, Land Use and Land Cover Changes on Watersheds in the Upper East Region of Ghana

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Issues of global warming and climate change as a result of the aggravation of greenhouse gases and other anthropogenic activities have remained a global discourse since time immemorial. Climate change has increased temperatures and reduced the amount and distribution of rainfall. This has become a major concern to scholars and researchers alike. This study, therefore, investigates the impacts of climate change in the North Eastern part of Ghana between 1985 and 2016. The study looks at land use and land cover changes in the watersheds of the Tono Reservoir using satellite images. Satellite images were extracted and imported into ERDAS 2010 for processing. Layer stacking was performed to put all the bands together as one file. Sub-setting was done to extract the Tono Reservoir and its environs. Climate variables such as rainfall, temperature were analysed to find their relationships with water levels of the Tono reservoir. It was found that rainfall and water levels of the Tono reservoir were decreasing at 4.4% per decade and 8% per annum, respectively, while closed forests and grasslands had reduced by 5.51% and 7.44%,

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respectively, between 1985 and 2016. There were increases in open forests (2.8%), shrublands and bushes (0.97%) and water bodies (1.2%). The study recommends that collaborative efforts between the Ministry of Environment, Science, Technology and Innovation, Ministry of Water Resources, Ministry of Lands and Natural Resources and the Ministry of Food and Agriculture were necessary to safeguard natural resources in the country.

Keywords: Tono reservoir; climate change; land use; water level; landsat image.

1. INTRODUCTION

Issues of global warming and climate change due to increasing greenhouse gases emissions and other anthropogenic activities have been a major subject of contention [1,2]. Climate change has resulted in the amplification of global and local temperatures and a reduction in the amount and distribution of rainfall [3]. The amount of water vapour available for rainfall is greater for higher base temperatures or warmer temperatures due to enhanced greenhouse conditions [4]. Climate change has been considered as the most threatening challenge in recent times since the adoption of the United Nations Framework on Climate Change in 1992 [5].

It is reported that the build-up of greenhouse gasses, particularly carbon has the potential to affect global, regional and local climates. This is worsened by changes in land use and land cover changes due to population growth and urbanization [6]. Carbon dioxide which is the principal greenhouse gas in the atmosphere creates a greenhouse effect ultimately leading to global warming [7]. Vegetation cover such as forests is a sink to carbon and absorbs carbon dioxide for photosynthesis thereby contributing significantly to reducing global warming [8]. Vegetation cover also binds the soil together in watersheds and regulates the hydrological process [9]. Impacts of climate change are found in terms of increasing temperature, decreasing the number of rainy days, rainfall variations, frequent droughts, severe heat waves, and evidence of periodic floods. Such trends threaten crop yields and risk the food security of poorer countries where agriculture is rain-fed [10].

Through land use and land cover changes, forestlands have been converted to farmlands to meet growing food demands and development [11]. According to [12], over reliance on land for various uses to satisfy human needs are now changing the land use and land cover (LULC) patterns in various parts of the world. For example, the conversion of closed forest areas to open forests or bare lands may either be natural or human-induced [13]. Many forested lands in Ghana including the scarce vegetation resource of the Upper East Region are gradually being lost as a result of increasing agriculture and urbanization [14]. Land use and land cover changes affect the environment and may reduce water availability [15] and decrease the welfare and adaptability of farmers [16].

The reduction in the population of trees in forest lands decreases their potential for the provision of ecosystem services by altering hydrological processes such as infiltration, groundwater recharge, base flow and runoff [17]. Agriculture which is the main livelihood activity in many developing countries is the main driver of forest conversion into farmlands [18]. Commercialization of agriculture requires the expansion of farmlands and that stimulates the conversion of forestlands leading to hydrological changes [3]. However, efforts made by the government of Ghana to protect forestlands have been thwarted by a reduced number of forest guards [19].

Issahaku et al. [20] in their study of the climatic variability of the Upper East Region observed that while the temperature was increasing, rainfall was decreasing. The decreasing inflow of water from overland flow into dugouts and reservoirs and increased evapotranspiration is adversely affecting the hydrology and causing these systems to dry up [21]. Research on the Weija shows that land use and land cover changes affected the hydrology of the Densu Reservoir [22]. In India, satellite imagery was used to study land use and land cover changes [23]. Their study also provides for a more holistic environmental resource management in developing countries with a diverse patchwork of different uses of natural resources that can be harnessed [24]. While these hydro-climatic changes have been proven by earlier research [25], little work has been made on the relationship between climate variables and water sources on the ecological systems of watersheds in the Upper East Region of Ghana.

The Tono Reservoir is the largest reservoir in the northern sector of Ghana [26] and was constructed to boost dry season agriculture in the Upper East Region. It is for this reason that, the study sought to investigate the relationship between climate variables and water levels in the Tono Reservoir in the Upper East Region of Ghana. The study is therefore relevant for the management of the Irrigation Company of Upper Region (ICOUR) and the Irrigation Development Authority (IDA) whose duty is to manage the Tono Reservoir to understand the dynamics of climate variables and water levels of the Tono dam and to replicate the findings of the research in other areas to preserve water bodies.

2. STUDY AREA AND METHODOLOGY

2.1 Description of the Study Area

The Tono Reservoir is located in the Kassena Nankana Municipality of the Upper East Region bounded by latitude 10.8423^{o}N and longitude 1.3276^{o}W and latitude 10.88472^{o}N and longitude1.09028^{o}W (Fig. 1). The effect of the North-East Trade Winds which are characterized by dry and dusty winds and originate from the Sahara Desert is severe in the study area in December and January. The annual temperatures in the municipality (a minimum of 15° C and a maximum of 42° C) are associated with very low mean annual rainfall, which ranged between 700 - 1300 mm [27]. The rainy season in the area is unimodal and comes between June and September [28]. The vegetation is classified as Guinea Savannah Woodland but human activities lately make it difficult to distinguish it from the Sudan Savannah [29]. Agriculture is the major economic and land-use activity of the area. Due to the very high variability in rainfall, the Tono reservoir was constructed in 1975 to provide irrigation water for a-year round agriculture to ensure food security. It has a volume of 9.26 ×107m^3 covering a surface area of 18.6km^2 with a catchment area of 650km^2 and a gross project area of 3,860 hectares.

2.2 Data Collection

Secondary data of rainfall and temperature from 1960 to 2015 were obtained from the Ghana Meteorological Agency. Similarly, records of water levels of the Reservoir from 1987 to 2015 were obtained from the Irrigation Company of Upper East Region. Two Landsat satellite images on path 195 and row 053 of resolution 30 m of the catchment area of the Tono reservoir in 1985 and 2016 were obtained from the United States Geological Survey (USGS) Global Visualization Viewer site (http://glovis.usgs.gov). The satellite images for the Tono Reservoir were taken in the month of March for both 1985 and 2016. The choice of the dry season is to obtain images with minimal cloud cover to distinguish the spectral signatures of the different land-cover types especially, the bare areas. Delineation of the catchment area was done based on an automated river network overlay [30]. In this approach, the basic unit is a river stretch which is referred as the length between two nodes. Each cell of a grid is allocated to river stretches using the shortest distance algorithm.

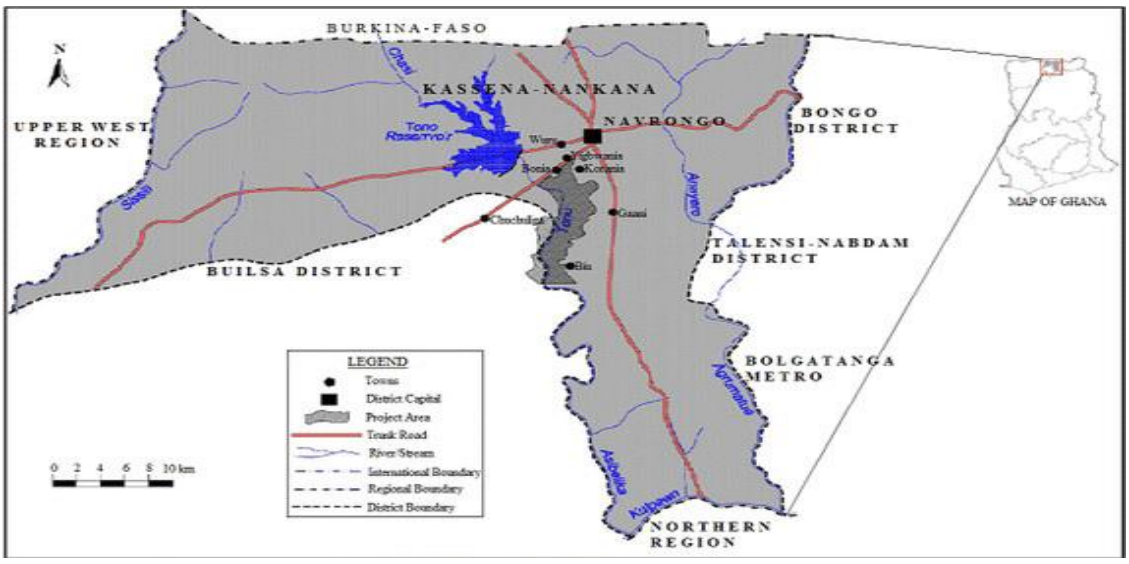

Fig. 1. Map of Tono Reservoir in the Upper East Region. Adopted from [26]

2.3 Data Analysis

Simple linear regression analysis was performed to find the decreasing or increasing trends in rainfall, temperature and water levels. The Landsat images were extracted and imported into ERDAS 2010 for processing. Layer stacking was performed to put all the bands together as one file. Sub-setting was done to extract the Tono Reservoir and its environs.

Classification accuracy was evaluated using ground-truth data obtained from GPS field surveys existing maps, Google Earth and the Landsat image as the reference to generate the confusion matrices, which comprise the omission error, commission error, and kappa statistic. Stratified random sampling was used for the point selection. A minimum of 60 samples for each class was taken based on the rule-of-thumb theory suggested by [30]. Two kinds of data were picked for each land use and land cover feature: classification data and validation data. The maximum likelihood algorithm (MLA) was used to perform the supervised classification using ArcGIS10.2.1. Six classes in all were obtained. The Accuracy Assessment Tool (AAT) was used to measure how accurate the classification was [31].

The change matrix tool in the ERDAS Imagine 2010 was used to produce the change conversions that had taken place in the land use and land cover features. The ArcGIS 10.2.1 was used to prepare the final maps of the land use and land cover classification. The maximum likelihood algorithm (MLA) of the ERDAS Imagine 2010 was used to perform the supervised classification of the land use and land cover features of the Tono Reservoir and its environs. In supervised classification, the MLA is one of the most popular methods used with remote sensing image data [32]. The MLA uses a method that is based on the probability that a pixel belongs to a particular class. This method relies heavily on a normal distribution of the data in each input band and tends to over-classify signatures with relatively large values in the covariance matrix, hence, requires long time of computation. Ground verification was done to confirm images that were not clear on the satellite images using Geographic Positioning Systems (GPS) coordinates. Based on the ground truthing, the misclassified areas were corrected using the recode option in ERDAS Imagine. The land use features of the Tono Reservoir environs were classified into six (6) classes which are closed forest, open Forest, shrub land and bushes, grassland, farmland and water bodies. The change matrix was done to determine the changes that have occurred in the catchment area over the 30-year period (1985-2016). This matrix gives an idea of which land feature is being changed into the other land features.

3. RESULTS AND DISCUSSION

3.1 Trend of Rainfall in Upper East Region of Ghana

The trends in rainfall was linear and moving downward with R^2= 7, R^2 adjudsted= 5 and suggest that the model could not explain much of the variation in rainfall (Fig. 2). The trend in rainfall was a decreasing polynomial trend with the equation:

$$90.29 - 0.044t + 0.000044t^2 \quad (1)$$

Where, t is the number of years. The equation shows that, the decreasing trend of rainfall is a quadratic and hence not uniform.

The mean annual temperatures for maximum temperature were increasing with R^2 = 84.5 and R^2- adjusted = 83.8. The regression equation for maximum temperature was:

$$34.078 + 0.03037t - 0.00002t^2 \quad (2)$$

Where t is time in years.

Fig. 3 suggests that the annual maximum temperatures were increasing and this would result in an increased number of hot days in the future. Surface water bodies such as dugouts and reservoirs would reduce in volumes due to high evaporation losses.

Temperature affects transpiration rates and other environmental physiological activities. Whilst organisms may adapt to these changes, the combined effect of decreasing rainfall and rising maximum temperatures may have dire consequences on the biodiversity of the area.

3.2 Water Levels in the Tono Reservoir

Raw water from reservoirs and dugouts in the Upper East Region is used for irrigation, building and construction, drinking and watering animals [26]. The Tono reservoir is the largest reservoir in

the Upper East Region of Ghana. The study shows that the Tono reservoir had an average minimum and maximum water depth of 3.7 and 8.0 m respectively, with a mean water depth of 4.9 m. This study found that the water level was decreasing with R^2=79.5% and R^2 adjusted =78.4%. The equation describing the water level at the Tono Reservoir at any time was:

Water level (m) = -0.0829t + 171.4 m (3)

Where t= number of years

Whilst abstraction could affect reservoir level, the intensity of these water abstraction activities does not lend credence to it causing a significant effect on the water level. The reduction in the water level of water in the Tono reservoir could therefore be attributed to excessive evaporation because of siltation and the resulting increase in the rate of evaporation due to increase maximum temperature. The reduction in the water level led to the occasional closure of the reservoir in some particular years [33]. Aside from the significant impact on livelihoods, these drastic environmental changes would affect the natural environment, especially wetland and riparian flora and fauna.

3.3 Land Use and land Cover Distribution and Change

It was noticed that in 1985 the closed forest was predominant in the then Kassena Nankana East District. The open forest dominated the North-East of the Tono Reservoir. Only some small patches of farmland could be noticed within the closed forest and the open forest. Fig. 5 shows the land use and land cover in 1985.

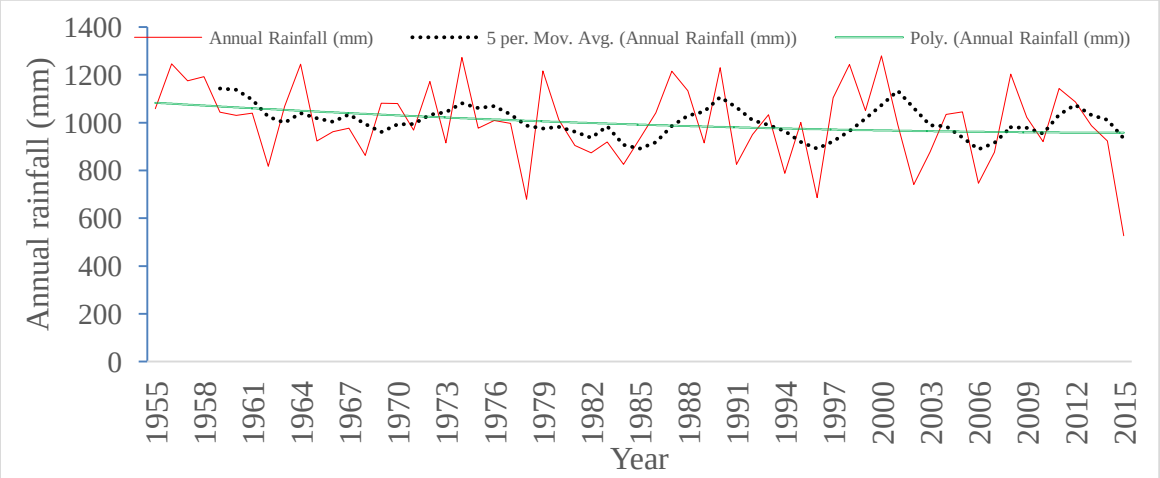

Fig. 2. Rainfall trend in the Upper East Region of Ghana (1954 - 2014)

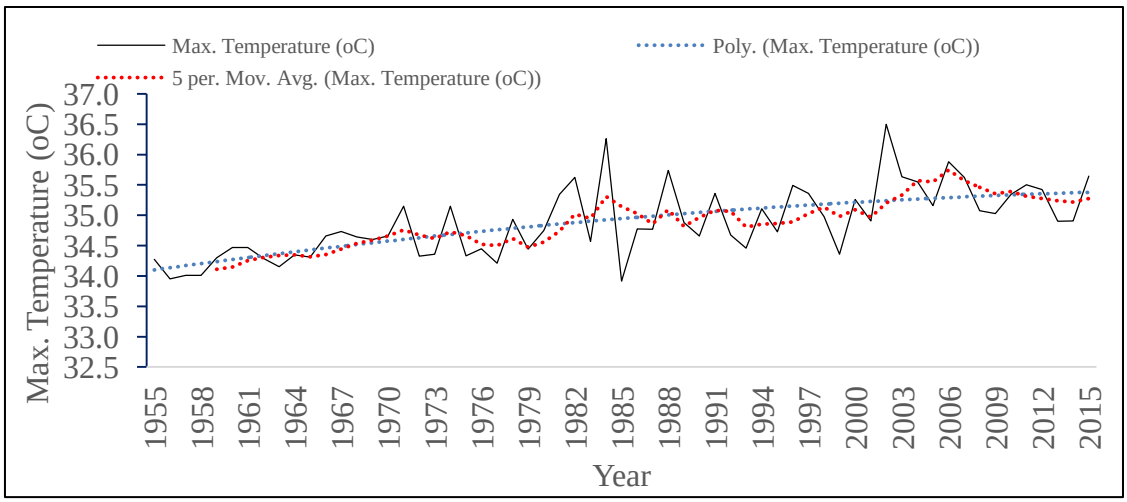

Fig. 3. Trend of maximum temperatures in the Upper East Region, Ghana (1954-2014)

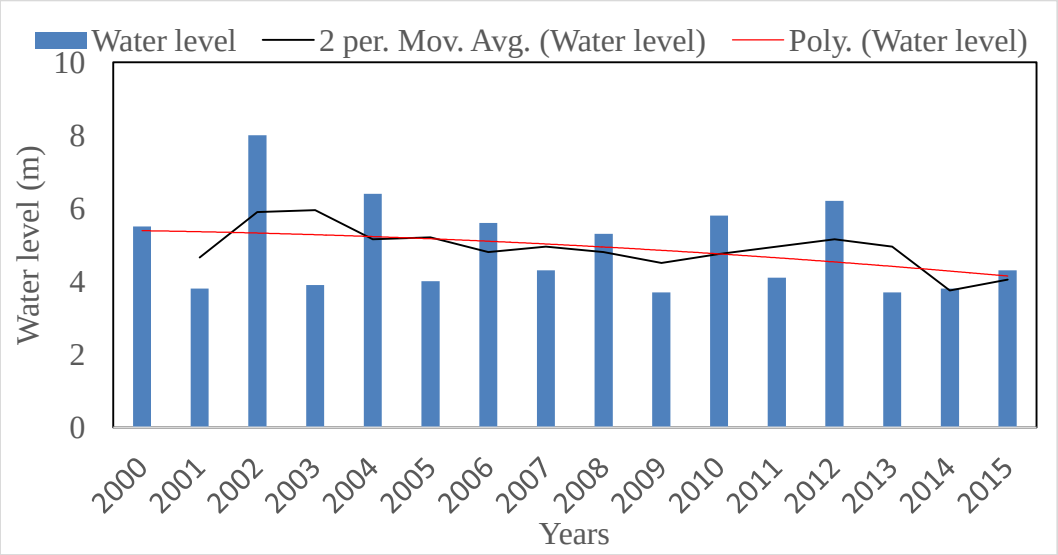

Fig. 4. Mean annual water level of Tono Reservoir (2000-2015)

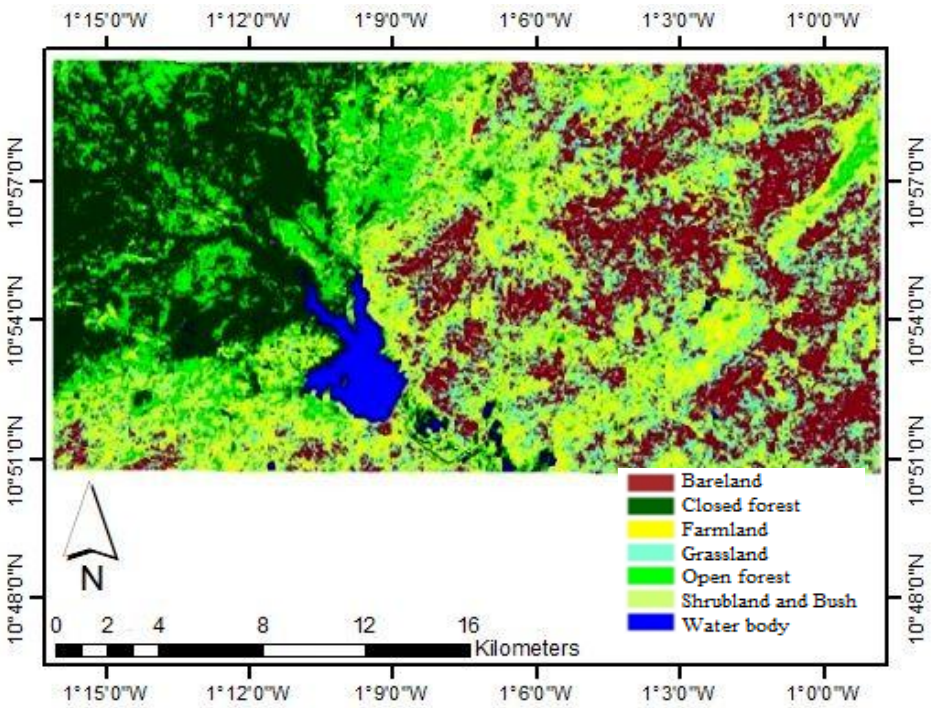

Fig. 5. Shows the land use and land cover in 1985

The total catchment area of the Tono Reservoir is about 650 km^2 and grassland covers 21.66%. The closed forest also covered approximately 20% of the total land area whereas water bodies covered only 2.35% of the total land area under consideration in the year 1985. Fig. 6 shows the changes that took place in 2015.

However, in the year 2016, the closed forest and grassland had reduced and both now covered about 14% of each of the land area. Farmland that covered about 14% of the area in 1985 had now increased to about 21% in 2016. Fig. 7 indicates the changes that occurred between 1985 and 2016. The population of the region has seen substantial growth [34]. Agriculture, which is the main economic activity of the study area is a major driver of land use and land cover change. According to [35], when the population grows more lands are used for food cultivation.

According to [36] due to urbanisation a lot more lands are needed to meet the housing needs of the growing population. Without diversification of economic activities in the Upper East Region, residents are glued to agriculture, wood harvesting and charcoal production. These findings are similar to [37] in their study of the Kakum National park of the Assin South District of Ghana. The Kassena Nankana Municipal Assembly, the Irrigation Company of the Upper East Region and the Irrigation Development Authority of Ghana have failed to look at the linkages between LULC change and the sustainability of the Tono dam which is very important to the development agenda of the Upper East Region and support initiatives that contribute to achieving sustainable communities by 2030 [38].

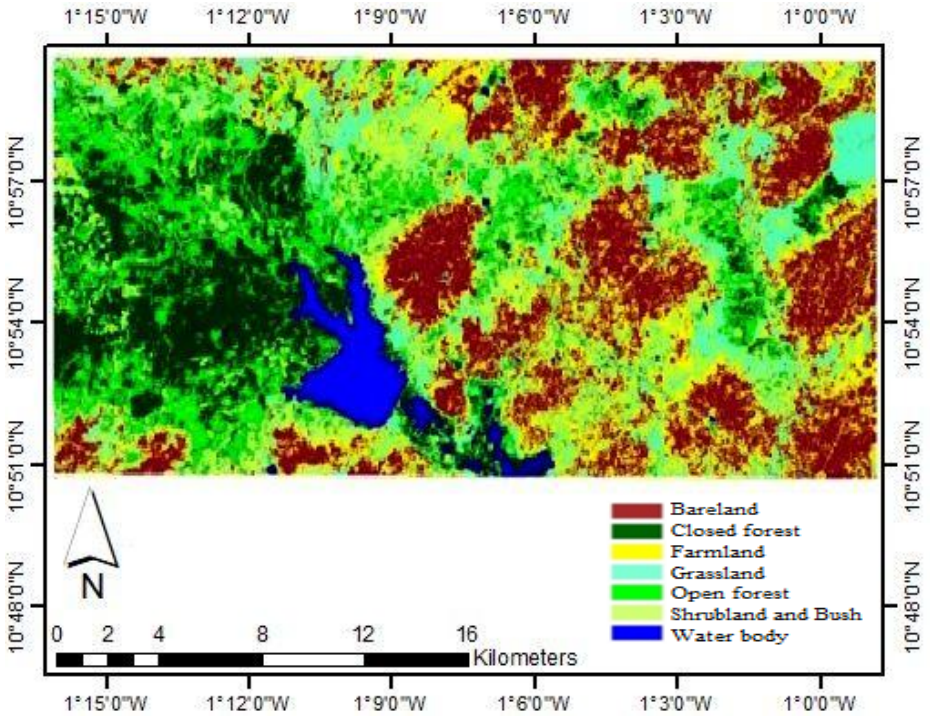

Fig. 6. Shows the changes that took place in 2015

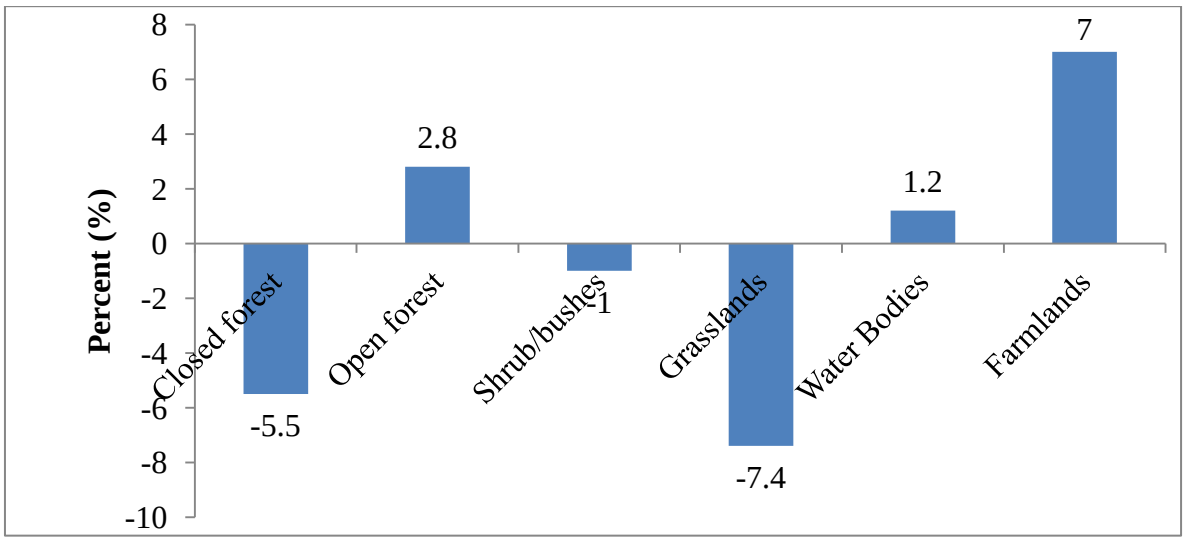

Fig. 7. Percentage change in land use between1985 and 2016 around the Tono Reservoir

Table 1. Accuracy assessment between ground-truth and classified land use and land cover patterns in 1985 and 2016

		Closed forest	Open forest	Shrub and bushes	Grassland	Farmland	Water bodies
2016	User accuracy	90.12	92.06	93.83	91.77	93.54	96.09
	Producer accuracy	86.00	88.34	90.37	93.67	95.10	92.55
	Class kappa	0.88	0.91	0.90	0.93	0.92	0.96
	Overall accuracy	93.28					
	Overall Kappa	0.92					
1985	User accuracy	91.51	88.54	93.50	96.11	95.93	93.66
	Producer accuracy	93.27	89.30	94.98	91.09	93.43	94.03
	Class kappa	0.91	0.89	0.95	0.87	0.94	0.92
	Overall accuracy	95.73					
	Overall Kappa	0.91					

Table 2. Changes in the land use features between 1985 and 2016

	CF	OF	SB	G	F	WB	Total	PA (%)
CF	4553.9	3001.7	872.4	797.4	559.5	368.1	10153.0	44.9
OF	1548.8	2129.6	1253.4	994.6	664.4	154.0	6744.8	31.6
SB	555.1	1252.5	1129.4	1204.7	893.9	110.8	5146.4	21,9
G	241.1	701.7	952.6	1687.0	4290.2	18.0	7890.6	21.4
F	382.9	977.0	1079.9	1887.1	2441.5	55.2	6823.7	35.8
WB	50.7	12.2	5.1	0.8	0.6	1161.5	1231.0	94.4
Total	7332.5	8074.7	5292.8	6571.6	8850.1	1867.6	37989.5	
CA%	62.2	26.4	21.3	25.7	27.6	62.2	36.6	

Closed forest (CF); Open forest (OF); Shrub and bushes (SB); Grassland (G); Farmland (F); Water bodies (WB) and Cumulative accuracy (CA)

3.4 Accuracy Assessment of the Classification of Land Use Features (1985 and 2016)

According to Table 1, the classified 2016 map (Figure) is in good agreement with the ground-truth data revealing an overall accuracy of 93.28 % and an overall kappa index of 0.92. Apart from the producer's accuracy of open forest and closed forest, the remaining classes had both user's and producer's accuracies > 90% (Table 1). With kappa indices > 0.93, grassland and water bodies attained the best agreement. With overall accuracy of 95.73 % and an overall kappa index of 0.91, the 1985 classified map shows a good agreement with reference to the ground-truth data. With exception of the user's and the producer's accuracies of open forest, the remaining classes had both user's and producer's accuracies > 91% (Table 1). Again, the shrubs and bushes and farmlands classes had a good agreement with the corresponding ground-truth classes.

3.5 Change Detection between 1985 and 2016 Classification

The change matrix shows that between 1985 and 2016, 3001.7 ha of the closed forest (CF) was converted to open forest (OF), 872.4 ha of the closed forest to shrub lands and bushes (SB), 797.4 of the closed forest as grasslands (G) 559.5 ha of the closed forest as farmlands (F) and 368.1 ha of the closed forest as water bodies (WB) (Table 2).

Accuracy assessment is important for maps generated from remotely sensed data. An error matrix is a common way to present an accuracy assessment of the classification. Overall accuracy, user's and producer's inaccuracies and the Kappa statistic were then derived from the error matrices. The Kappa statistic incorporates the diagonal elements (Table 3) of the error matrices and represents agreement obtained after removing the proportion of agreement that occurred by chance.

Table 3. Product matrix for calculating cohen's Kappa coefficient

	CF	OF	SB	G	F	WB
CF	74446669	81983444	53738002	66720947	89855573	18962352
OF	49455965	54462750	35698907	44323659	59692315	12596956
SB	37735802	41556070	27238916	33819759	45546324	9611707
G	57857593	63714936	4.18E+09	51853407	69832905	14736939
F	50034571	55099932	36116563	44842220	60390680	12744333
WB	9026430	9940240	6515567	8089709	10894712	2299127

Production matrix = 74446669 + 54462750 + 27238916 +51853407+60390680.1+ 2299126.81 = 270691548.4
Cumulative sum = 5578819132

Production matrix/Cumulative sum = 270691548.4/ 5578819132
= 0.049

Kappa coefficient= (Observed – Expected) / (1- Expected)
= (0.345- 0.049) / (1 – 0.049)
= 0.296/0.951
= 31.1%

The result of Cohen's Kappa coefficient indicates that nearly 31% of the results of the satellite images obtained were better than would have been obtained by chance.

A reduction in tree cover of the catchment area of the Tono Reservoir was an indication of human activity around the reservoir. A representative of the Ministry of Food and Agriculture indicated that:

> *Water Resources Commission requires that farmers must farm 50 m away from the banks of water bodies. However, many farmers in the Upper East Region rather farm close to the river banks.*

The implication is that the soil is loosened and eroded and washed into the reservoir. To reduce runoff and erosion of sediments into the reservoirs, farmers and community members are encouraged to plant trees along river banks. Trees are also planted to reduce grass cover which fuel wildfires in the Upper East Region. The people are also being discouraged from logging trees. An official from the Department of Game and Wildlife in Bolgatanga reported that:

> C*ommunity cooperation and education were important in the sustainable management of natural resources. Education is necessary to foster understanding between the Department of Game and Wildlife, Forest Commission, Water Resources Commission and the community members. However, understanding does not ensure cooperation since they may not show any interest. For example, Mr. Moses Gambila, a former Member of Parliament for Nabdam in the Upper East Region, was quoted by Mr. Gabriel Donkor (16th May 2017) to have reported on the floor of parliament that, the Forest Commission of Ghana should release forest reserves in his constituency for his people to farm because his people were poor and suffering.*

A Game and Wildlife Division representative reported that, the department was partnering with community members to pilot the Community Resource Management Area (CREMA) concept along the Sisili River. This is a management strategy to prevent siltation of the river and which is spear headed by community members.

An official of the Forestry Commission said "an enrichment planting strategy is being considered to improve soil fertility*"*. This is enriching the soils in degraded lands and then planting trees thereafter. *Senna siamea,* for example, thrives very well in degraded lands and farmers are encouraged to plant them on degraded lands. Farmers are also encouraged to do replacement planting. In this practice, the trees that were cut down, especially in closed forested areas, are being replaced. This policy needs to be enforced and community members must be motivated to replace cut trees.

Deforestation and bush burning which is prevalent in the Upper East Region expose the land surface and hasten soil erosion. The demand for food also resulted in a reduction in closed forests and an increase in farmlands due to increasing population and economic benefits as indicated by [39]. Tigrek and Aras [40] in their study of environmental degradation in northern Ghana also concluded that the forest cover protects the watershed from wind and rain

erosion and also holds the soil firmly together. The removal of vegetation from some portions of the watershed, therefore, resulted in the transportation of debris and soil particles into the reservoir. An accumulated effect is an increase in the surface area of water bodies. The reduction in the closed forest was also partly due to the perennial burning of the Upper East Region, a characteristic of the Savannah Zone, due to drought and windy weather conditions [41].

4. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the water level of the Tono reservoir was reduced by 8.2% per decade due to the reduced rainfall (-4.4% per decade) pattern and increasing maximum temperature (3.03% per decade) as a result of land use change. The study also concludes that between 1985 and 2016, 3001.7 ha of the closed forest was converted to open forest, 872.4 ha of the closed forest to shrublands and bushes, 797.4 of the closed forest as grasslands 559.5 ha of the closed forest as farmlands and 368.1 ha of the closed forest as water bodies. The decrease in the closed forest and grasslands were partly due to the conversion of forested lands and grasslands into farmlands as a result of bush burning and deforestation. These changes are contrary to the objectives of the sustainable development goals (SDGs) especially Goal 11 (sustainable cities) which calls for preservation of the natural vegetation in city's physical landscape to enhance the quality of life of urban dwellers.

It is recommended that minimization of human activities such as deforestation, bush burning and farming along river banks could reduce erosion and siltation rates, and also decrease the evaporation rate of surface water in the Upper East Region. Cooperation and ownership of natural resources by community members and the government are necessary for the sustainability of forest ecosystems. Land use and land cover management should be a collective effort, between the Department of Town and Country Planning, Forestry Commission, Water Resources Commission, Ministry of Food and Agriculture and community leaders. Community members must also be given legislative support to protect and use plants on their lands. This study could not look at the collaboration, coordination and cooperation of the relevant stakeholders who are mandated to protect the Tono dam and the preservation of natural resources in the Upper East Region.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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