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Article

LULC changes in the region of the proposed Pwalugu hydropower project using GIS and remote sensing technique

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Abstract: Proper understanding of LULC changes is considered an indispensable element for modeling. It is also central for planning and management activities as well as understanding the earth as a system. This study examined LULC changes in the region of the proposed Pwalugu hydropower project using remote sensing (RS) and geographic information systems (GIS) techniques. Data from the United States Geological Survey's Landsat satellite, specifically the Landsat Thematic Mapper (TM), the Enhanced Thematic Mapper (ETM), and the Operational Land Imager (OLI), were used. The Landsat 5 thematic mapper (TM) sensor data was processed for the year 1990; the Landsat 7 SLC data was processed for the year 2000; and the 2020 data was collected from Operation Land Image (OLI). Landsat images were extracted based on the years 1990, 2000, and 2020, which were used to develop three land cover maps. The region of the proposed Pwalugu hydropower project was divided into the following five primary LULC classes: settlements and barren lands; croplands; water bodies; grassland; and other areas. Within the three periods (1990–2000, 2000–2020, and 1990–2020), grassland has increased from 9%, 20%, and 40%, respectively. On the other hand, the change in the remaining four (4) classes varied. The findings suggest that population growth, changes in climate, and deforestation during this thirty-year period have been responsible for the variations in the LULC classes. The variations in the LULC changes could have a significant influence on the hydrological processes in the form of evapotranspiration, interception, and infiltration. This study will therefore assist in establishing patterns and will enable Ghana's resource managers to forecast realistic change scenarios that would be helpful for the management of the proposed Pwalugu hydropower project.

Keywords: land use land cover; change detection; GIS and remote sensing technique; Pwalugu

1. Introduction

Land use and land cover changes are used interchangeably for different purposes. Studies by researchers have therefore made abundantly clear the distinction between land cover and land use Quentin et al. [1] Lambin et al., [2] Chrysoulakis et al. [3] Zubair [4] and FAO [5] The activities carried out by man, such as the clearing of arable land for settlement, farming, mining, the construction of dams, and the destruction of forests for other purposes, are some of the activities that lead to the alteration of the land, which can be seen in many communities. The widespread consumption of land results in an increase in soil erosion, floods and droughts.

Several studies have identified different factors as drivers of land use and land cover changes. For instance, Lambin et al. [2] identify socioeconomic development, population growth, and pressures on land for agricultural use as the primary drivers of land use and land cover changes. Mather and Needle [6] also identify deforestation as having a high link with poverty as well as population growth in developing countries. The works of Campbell et al. [7], Briassoulis et al. [8], Auch et al. [9] and Kanianska et al. [10] classify the factors that drive land changes into distinct categories. The distinct categories were economic, cultural, social, and political. They again stated that the classifications may include two or more categories at the same time.

It is evident from previous studies that changes in LULC have an effect on the fundamental processes that govern the Earth System. For instance, Sanderson et al. [11] stated that deforestation leads to an increase in albedo as well as a reduction in evapotranspiration (ET). Perugini et al. [12] also stated that deforestation causes a warming effect due to a larger decrease in the ET. This happens as a result of changes in the latent and sensible heat fluxes due to the reduced leaf area index. Mariye [13] postulated that population growth, settlement patterns, and the expansion of farmlands can all be linked to the increase in cropland. Mehari [13] further stated that the increase in cropland has occurred as a direct result of the demand for more food. Moreover, Reid et al. [14] stated that the dynamics of LULC are the result of complex interactions between a number of different biophysical and socio-economic conditions. In addition, these interactions can take place on a variety of different temporal and spatial scales.

According to Sterling et al. [15], land use and land cover changes have an indirect impact on water cycles as a result of changes in albedo. They concluded that the changes alter the partitioning of precipitation into different components. The components are evaporation, transpiration, runoff, interception, and infiltration, which in turn affect soil moisture contents and the energy cycle. The works of Trimble and Crosson [16] mentioned changes in LULC as the primary source of soil degradation, while Sala et al. [17] indicated that it influences biotic diversity globally. In addition to this, it alters the functions of ecosystems and reduces the capacity of biological systems to meet the requirements of humans Vitousek et al. [18] and Praveen [19].

The findings of a number of other studies indicate that an increase in agricultural activities, as well as afforestation or deforestation, have a significant influence on the processes of hydrology. The processes specifically mentioned include interception, infiltration, and evapotranspiration. According to the findings of the studies, such processes also result in changes to the flows at both the surface and subsurface levels. Examples of such studies can be found in the following publications: Gashaw et al. [20] Jaksa and Sridhar [21] Ahiablame et al. [22] Kidane and Bogale [23] Wang et al. [24] Niraula et al. [25] Seong and Sridhar [26] Sridhar and Wedin [27] Sridhar and Anderson [28].

1.1. Relationship between LULC changes and hydrology

According to the findings of Wang et al. [29] the variations in the land surface are dependent on the changes that occur in the vegetation, the soil, and the climate. The study conducted by Mango et al. [30] agrees with Wang et al. [29]. The findings of Mango et al. [30] show a visible run-off reaction occurred in Kenya as a result of an increase in rainfall as well as an increase in temperature. Woyessa and Welderufae [31] discovered that an increase in forest cover could result in a reduction in yearly flow by up to 15% and yearly surface runoff by up to 30%. These findings were based on the fact that more trees would cover the land. As a consequence of this, the level of peak flow that occurs during floods may be reduced. On the other hand, this strategy can only be implemented in catchment areas that feature fully developed forest covers.

Other studies across the globe have studied the relationship that exists between LULC and hydrology [32–35]. They are of the opinion that the characteristics of land use changes are linked to the effects that the hydrologic cycle has on the catchment area.

In Ghana, Awotwi et al. [36] investigate the effect of shifting land cover on the various components of West Africa's White Volta Basin's water balance. The results show that grasslands and savannahs were being converted to farmlands at a faster rate than was previously thought. They also held the view that land use and land cover changes contribute to a range of effects on both the annual water yield and ET in the basin. In the Pra River Basin of Ghana, Awotwi et al. [37] discovered that there has been an increase in anthropogenic activities beginning in 1986 to a projected 2025. This leads to an increase in the surface runoff as well as water yield and a reduction in the base flow as well as ET.

1.2. The use of Remote Sensing (RS) and Geographic Information System (GIS) in determining LULC changes

Since the 1970s, remote sensing (RS) has been a source of data used to monitor and analyse LULC changes Chang et al. [38]. Several studies (e.g., Ayala-Silv et al. [39]; Rawart and Kumar [40]; Berrick [41] have suggested that the use of RS aids in determining land cover changes that have occurred in a short period of time, at a low cost, and with greater precision. According to Chaikaew [42], the Geographic Information System (GIS) in conjunction with RS is the preferred method for determining land cover changes. Halefom et al. [43], concurred, stating that both RS and GIS have been widely used to provide accurate and timely geographical data for the LULC change analysis.

There have been several studies conducted across the globe where RS and GIS were used to determine the trends of LULC changes. El-Kawy et al. [44], for instance, utilised Landsat imagery to provide current and historical LULC conditions for the western Nile delta. Dymond et al. [45] also utilised RS in New Zealand to estimate the change in forest cover and, thus, the area of afforestation and deforestation. Md Islam et al. [46] conducted a study on NijhumDwip National Park (NDNP) to determine the decadal changes in forest cover utilising freely accessible satellite RS data and GIS tools. In the southern district of Ethiopia, Mariye [13] used

RS, field observations, in-depth household interviews, key informants, and focus group discussions to determine LULC change dynamics on the Ojoje watershed.

Using RS and GIS at various locations, a number of studies have also been conducted in Ghana to evaluate the land changes that have occurred over time (e.g., Braimoh and Vlek [47]; Alo and Pontius [48]; Kusimi [49]; Kleeman et al. [50]; Karki et al. [51]; Kpienbaareh and Oduro-Appiah [52]; Oduro-Appiah et al. [53]. Although there are copious studies on LULC assessment across the globe and in Ghana, a search through the literature revealed a gap of no LULC change assessment in the region of the proposed Pwalugu hydropower project (PHP). LULC change assessments across regions and locations have not been the same across the board but differ from one location to another with their own consequences. Additionally, it has been recognised in literature (e.g., Mango et al. [30]; Woyessa and Welderufae, [31] that LULC changes have an influence on hydrology. LULC changes also have implications for water availability. Information on LULC changes has also served as a very important constituent for modelling and understanding the earth as a system. As a result, LULC studies have therefore become vital in enhancing our understanding and monitoring of environmental change. Therefore, the study of LULC changes in the region of the proposed PHP is justified.

The findings of LULC changes over the thirty-year period would aid governments and policymakers in providing optimal measures to meet the increasing demands of human needs, especially as the population increases. It would also help to aid environmental policy formulators and implementers in the adoption of more sustainable development strategies in line with sustainable development goals (SDGs) 11, 13, and 15.

2. Materials and methods

2.1. Description of the study area

The location of the proposed PHP is on the White Volta River, around 30 kilometres to the southwest of Bolgatanga, and lies between the Upper East and the North-East Regions of Ghana. This location may be found using the following coordinates: 10°34′59.54″ N, 0°41′33.81″ W [54].

According to the Ghana Statistical Service [55] the study area is covered with Guinea Savannah Forest with thin, small deciduous trees and grassy ground flora. As a result, the area is densely forested with trees such as acacia, baobab, dawadawa, and sheanuts [55]. Cereal crops such as maize, guinea corn, millet, beans, rice, and sorghum are cultivated in the catchment area. Based on the 2021 population and housing census of Ghana, 72.2% of the total population in the two regions lives in rural areas. It is not surprising that the main economic activity of the people in the catchment area is agriculture (farming and animal rearing).

The area has two climate seasons: dry and rainy. The rainy season is between May and October, and the dry season begins from November to April [55].

The main purpose of this study is to assess LULC changes in the region of the proposed PHP. This study is being conducted as the government of Ghana prepares to construct the three-throng project. These are solar, irrigation, and hydroelectric, all known as the Pwalugu Multipurpose Dam (PMD) project (**Figure 1**). To achieve the aforementioned, three objectives were established: first**,** to define and classify the various LULC kinds; second, to quantify the LULC changes. third, to determine the rate of LULC changes over the thirty-year period. The study area is shown in **Figure 2**.

Locations of the solar project site and the project site for the proposed PMD:

Figure 1. Scoping report (VRA).

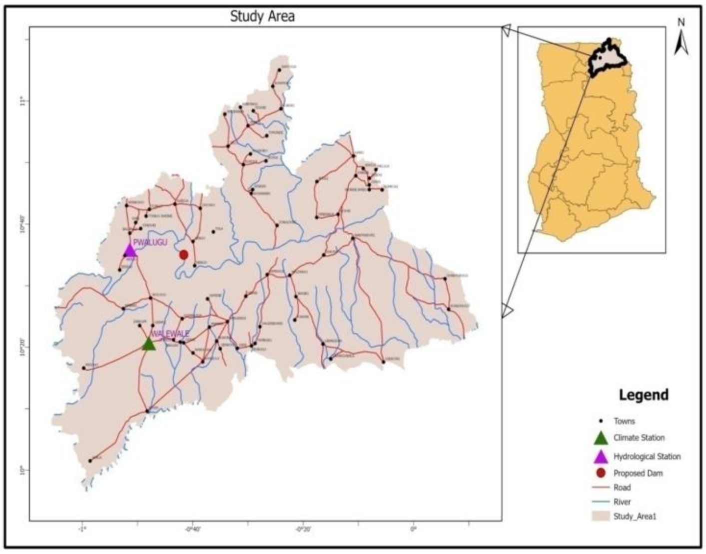

Figure 2. The study area (left) and Ghana map (right top).

2.2. Field data collection

Landsat Imagery

In fulfilling the purpose of this study, two sorts of data, namely satellite and ancillary data, were utilised. The satellite data consists of three (3) multi-temporal satellite images from different years. Landsat 5 images from 1990, whereas Landsat 7 and 8 images from 2000 and 2020 were acquired from the United States Geological Survey (USGS) GLOVIS website (**Table 1**). These Landsat pictures were selected to reflect the LULC conditions of the area. Ancillary data includes ground truth data for the LULC classes in the form of reference points gathered using the Global Positioning System (GPS) for the 2020 picture analysis. The observed land use conditions and recorded GPS locations were used for image classification and an overall accuracy assessment of the classification results. This satellite data is produced by the USGS and is freely accessible at the website [56].

The particular research strategies and conceptual frameworks that were utilised for this investigation are depicted in **Figure 3**.

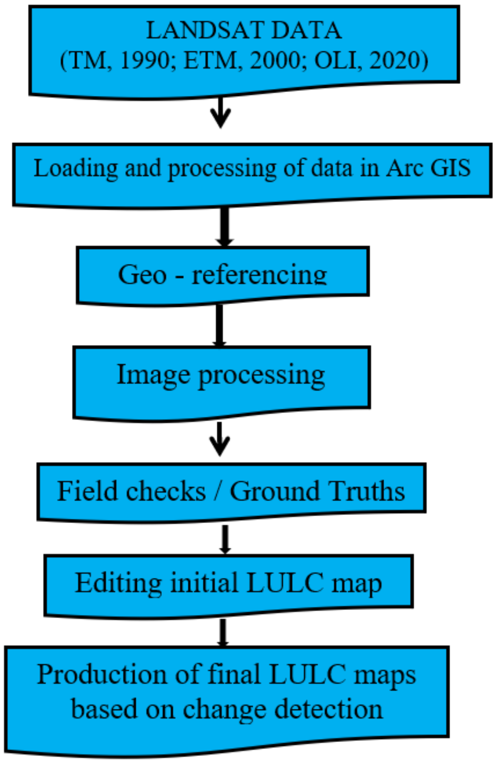

Figure 3. A Flow chart of LULC Change detection at the catchment area of the proposed PHP.

Table 1. Characteristics and properties of the Landsat images used.

Acquisition Date	Path/Row	Landsat	Sensor	Resolution	Source
5 October 1990	194/53 and 194/52	Landsat 5	TM	30 m	USGS
22 September 2000	194/52 and 194/53	Landsat 7	ETM+	30 m	USGS
16 May 2020	194/52 and 194/53	Landsat 8	OLI–TIRS	30 m	USGS

3. Results and analysis

As indicated earlier, our intention was to assess the LULC changes in the region of the proposed PHP using GIS and RS. After obtaining the raster image of LULC classes for Landsat 5, 7, and 8 images for classifications, three LULC maps were produced. **Figures 4–6** represent the LULC maps for the various years (1990, 2000, and 2020). Information on LULC definitions and classifications for supervised classifications in line with the first objective is in **Table 2**. A quantitative analysis of the LULC changes in line with the second objective can be seen in **Table 3**, which is further detailed in **Figure 7**. The third objective is to determine the rate of LULC changes over the thirty-year period. **Figures 8–10** are in fulfilment of the third objective of this study. The **Figures 8–10** show a graphical explanation of the rate of

LULC changes over the thirty-year period. Thus, LULC changes between 1990–2000, 2000–2020, and 1990–2020.

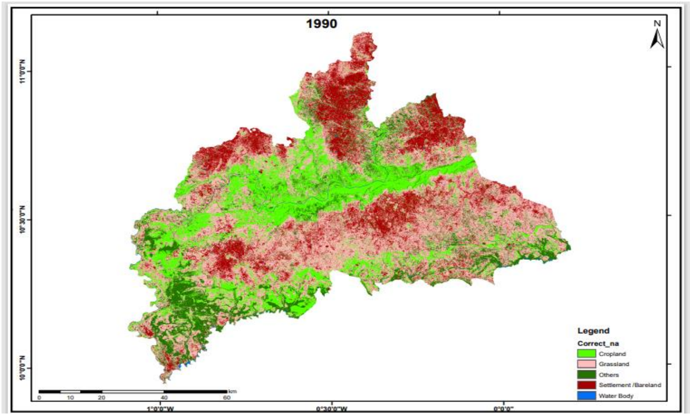

Figure 4. LULC classification map of the study area for the year 1990.

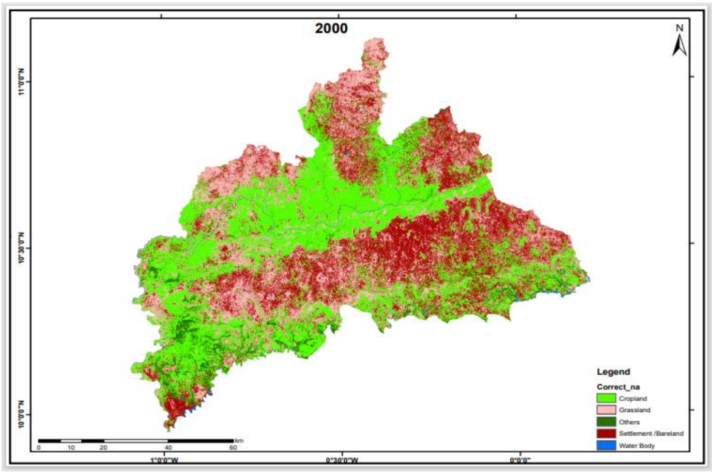

Figure 5. LULC classification map of the study area for the year 2000.

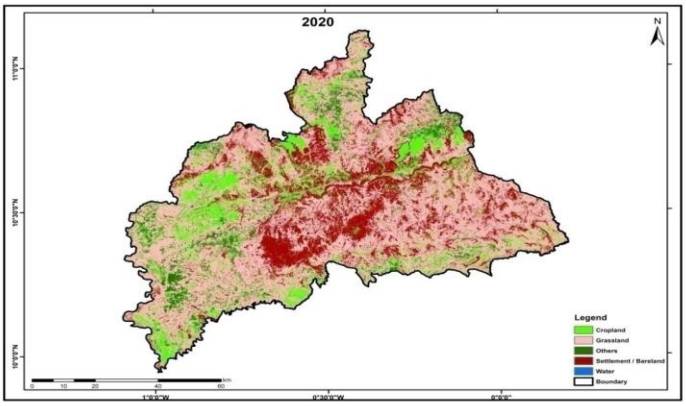

Figure 6. LULC classification map of the study area for the year 2020.

Table 2. LULC definition and classifications for supervised classifications.

Land cover	Description
Cropland	This land is used primarily for cultivating food crops such as corn, onions, beans, cassava, cabbages, carrots, Sorghum, millet, and mangoes. This region's crops are either irrigated or rain-fed.
Grassland	This category of land cover identifies grass as the predominant plant cover.
Settlement/Bare-land	This class describes the rural and urban land covered by buildings. It contains facilities for commerce, residence, industry, and transportation. It also refers to the land that is devoid of flora.
Waterbody	This category of land cover describes places covered with water along the riverbed or within earth dams, sand dams, and ponds created by humans.
Others	This defines the areas with evergreen trees primarily growing naturally on the reserved land, along the rivers, and on the hills, as well as the sparsely forested and shrubby regions.

Table 3. Area transition for LULC classes between 1990, 2000 and 2020.

LULC type	1990		2000		2020	
	Area (km^2)	% Area	Area (km^2)	% Area	Area (km^2)	% Area
Cropland	1781.94	21.92	3217.89	39.58	729.27	8.97
Grassland	3515.01	43.24	3845.06	47.30	4833.31	59.45
Settlement/Bareland	1303.83	16.04	338.44	4.16	720.19	8.86
Water body	29.69	0.37	43.26	0.53	23.07	0.28
Others	1498.97	18.44	684.78	8.42	1823.59	22.43
Total	8129.43	100.00	8129.43	100.00	8129.43	100.00

The figure below (**Figure 7**) shows the total area (in percentage) covered by each LULC class in 1990, 2000, and 2020.

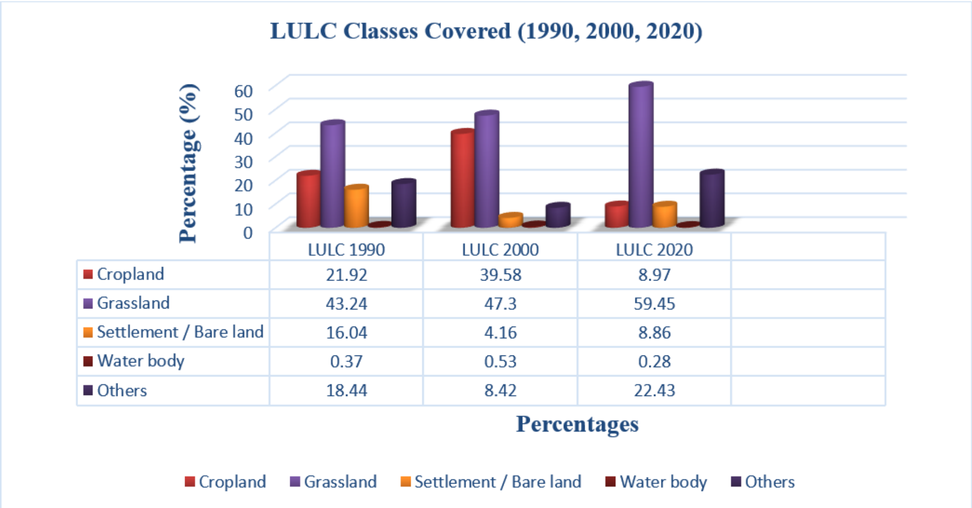

Figure 7. Total area (in percentage) covered by each LULC class in 1990, 2000, and 2020.

Figures 8–10 show the rate of LULC changes (gains or losses) between the period of years under consideration within the thirty-year period that the study lasts.

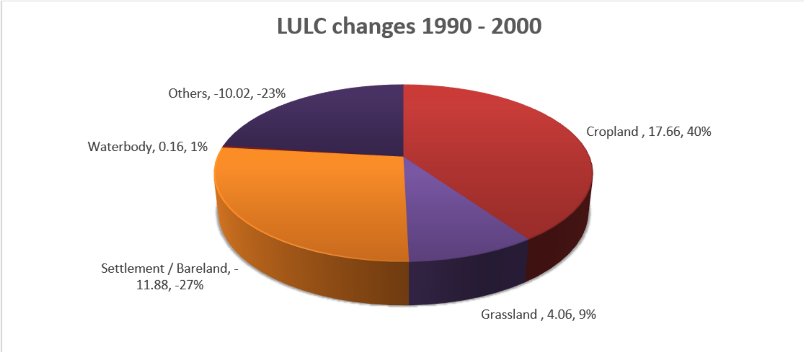

Figure 8. Graphical representation of the LULC changes (1990–2000).

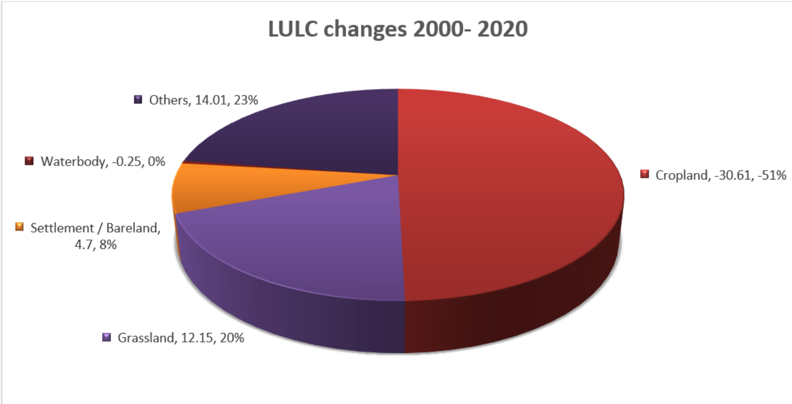

Figure 9. Graphical representation of the LULC changes (2000–2020).

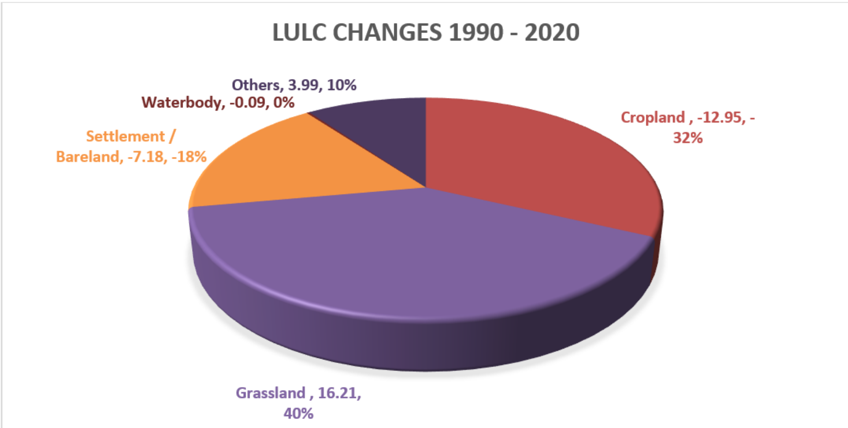

Figure 10. Graphical representation of the LULC changes (1990–2020).

The region of the proposed PHP always gets flooded, especially due to the spillage of the Bagre dam in Burkina Faso. Owing to climate variability coupled with human activities in the region of the proposed PHP, the water bodies are the most stressed natural resources (**Figures 8–10**). Thus, rivers, dams, and other dugouts in the region show significant morphological variations due to climate change. As the water body shrinks, this leads to an increase in the areas classified as others.

The rates of change of LULC within the region of the proposed PHP show an explicit net change in the form of gains and losses for each class during the periods (**Figures 8–10**). The first period (1990–2000) saw settlements, bare land, and areas classified as others record 27% and 23% losses, respectively. Within the same period, water bodies, grassland, and cropland had 1%, 9%, and 40% gains, respectively. The spatial analysis in this period (1990–2000) therefore indicated that cropland was the principal LULC (**Figure 8**).

The pattern of LULC changes in the second period (2000–2020), however, saw losses in cropland (49%) and water bodies (0%). The losses noticed in the two LULC classes could be due to early harvesting of crops, changes in climate, and anthropogenic activities. During the same period, settlements, bare land, grassland, and areas classified as others recorded 8%, 20%, and 23% gains, respectively. The area classified as others is the principal LULC change for the period 2000–2020.

Again, in the third period (1990–2020), water bodies, settlements, bare land, and cropland recorded (–0.09) 0%, 18%, and 32% losses, respectively. The period also registered 10% and 40% gains in grassland and areas classified as others, respectively. The net change for the period 1990–2020 shows grassland as the principal LULC change.

The area classified as others is defined as the areas with evergreen trees primarily growing naturally on the reserved land, along the rivers, and on the hills, as well as the sparsely forested and shrubby regions (**Table 2**). These LULC classes of area have a positive trend over the three periods. It increases from a 23% loss in 1990–2000 to a 23% gain in 2000–2020 and a further appreciation of 10% in the 1990–2020 periods. This means that the proposed region has vegetation that shows a positive trend.

The region of LULC classified as grassland has seen a steady increase or gain over the three periods. On the contrary, cropland as well as water bodies have seen a drastic shrink over the years. This implies that climate change has greatly impacted the region of the proposed PHP. It further shows that afforestation has also impacted the region, as the LULC classified as others remains stable throughout the period. It can therefore be concluded that climate change and afforestation would play a major role in the sustainability of the proposed PHP.

Charcoal production is one of the occupations of people living in rural Ghana. This could be the reason why the area classified as others increased from 2000–2020 (23%) but shrank in 1990–2020 (10%). Deforestation, a growing population, and a changing climate could be responsible for the changes.

Again, the findings suggest that, during this thirty-year period, cropland, settlements, bare land, water bodies, and areas classified as others shrank. The reason attributed to the shrinking of the settlement or bare land class could be due to the immigration of people to urban areas. Whereas it further suggests that climate change could be responsible for the shrinking of cropland and water body areas.

The housing and population figures of Ghana show that a great number of the populace lives in rural areas, especially in the study area. Since the main occupation of the populace in the study area is fishing and farming, the beginning and completion of the construction of the three-throng project (solar, irrigation, and dam), also known as the PMD, would go a long way towards boosting the economic activities of the farmers. It therefore behoves the government and other policymakers to take steps to make all-year-round farming a possibility for the many farmers in and around the proposed PHP.

4. Conclusion

This study analysed LULC changes for the years 1990, 2000, and 2020 using RS and GIS in the region of the proposed PHP. The utilisation of RS and GIS tools was helpful in detecting changes in the LULC that have taken place in the region of the proposed PHP over the period. This study unveils five LULC classes that has transformed significantly over this thirty-year period.

It is detected that grassland has increased from 9%, 20%, and 40% within the three periods (1990–2000, 2000–2020, and 1990–2020), whilst the remaining four (4) classes varied. The key factors responsible for the variations in the LULC classes are: population growth, changes in climate, deforestation and the decline of water bodies during this thirty-year period. In summary, LULC changes in the region of the proposed PHP are driven by natural and human activities. The variations in the LULC would have a significant influence on the hydrological processes in the form of evapotranspiration, interception, and infiltration.

The study also revealed that the combination of RS and GIS comes at a low cost, with greater precision and therefore have proven to be a powerful device for prompt decision-making in determining LULC changes in any area.

The decline in water bodies has resulted in irrigation problems thereby affecting all-year-round agriculture. It is therefore recommended that the preservation of the environment and the expansion of agriculture must be given precedence to help mitigate the challenges.

Author contributions: Conceptualization, EKA; methodology, EKA; software, EKA; validation, EKA; formal analysis, EKA; investigation, EKA; resources, EKA; data curation, EKA; writing—original draft preparation, EKA; writing—review and editing, EKA; visualization, EKA; supervision, ATK and SG. All authors have read and agreed to the published version of the manuscript.

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