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Land use dynamics in Sagara River Catchment in Dodoma Region, Tanzania

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Abstract

Context and background:

The Sagara hills provide key ecosystem services to the communities in Kongwa and Mpwapwa districts in Dodoma region. In particular, the hills provide watershed services which is vital in a challenging semi-arid condition. However, the current situation suggests that the watershed services are at risk due to anthropogenic activities.

Goal and Objectives:

This study assesses the dynamics of land use and land cover changes in Sagara catchment and its implication to watershed services for the surrounding communities.

Methodology:

Remote sensing and Geographical Information System (GIS) techniques were used to analyze changes in land use and land cover in the catchment between 2013 and 2021. The study used two categories of data: Landsat 8 layers and reference data. Landsat 8 layers were used as input data for change detection and quantification of vegetation cover and other land uses at Sagara hills, while field data and higher resolution Google Earth Pro Historical images were used to create reference data for training the classifier and accuracy assessment.

Results:

Results show that the built area increased from 249.4 ha in 2013 to 504.2 ha in 2021 with a net gain of 254.8 ha. Farmland increased with a net gain of 3108.1 ha whereby the farmland area was 10900.7 ha in 2013, but increased to 14008 ha in 2021. It was further observed that there were significant changes in vegetation cover from 2013 to 2021. The woodland forest which was a dominant vegetation in 2013 with an area of 24187.5 ha has been reduced to 12439 ha. This means in 9years; 11,748 ha of forest have been lost due destructive human activities. Grassland area was also observed to decrease from 995.1 ha in 2013 to 751.9 ha in 2021 with a net loss of 243.2 ha. Closed bushes and thickets which increased significantly by 2021 has become the dominant vegetation. Bare land was also observed to have increased. This is attributed to poor farming methods which resulted into soil erosion and loss of land productivity in the catchment.

Keywords:

Sagara hills, land use/land cover change, GIS, catchment protection

1. INTRODUCTION

The pressure exerted by human and livestock on environment has resulted in to Land use change (Börjeson et al, 2008). Food crop production and livestock grazing are the land use types that conflict with each other, it has been a common practice that grasslands are now converted into cultivated land as well as settlement expansions (Börjeson et al, 2008) which in turn impact other land cover mostly vegetation cover. In past few years pastoral grazing lands of Maasai plains were converted into cultivation lands in Tanzania. Furthermore, changes in land use have been experienced in East Africa and all over the world. This was due to high demand of land for other activities such as farming and settlement (Börjeson et al, 2008).

Not only human and livestock induced factor but also natural factors have a role to play on land use changes as well as vegetation characteristics (Msofe et al, 2019). Loss of biodiversity and changes in natural ecological function of the environment and vegetation types have been reported (Börjeson et al, 2008, Msofe et al, 2019). Fortunately, no research has been conducted at Sagara hills in Kongwa and Mpwapwa district to assess the extent of vegetation cover and distribution. There are needs of research to be done in this point of view so as to assess and understand these dynamic changes for sustainable land resource management (Msofe et al, 2019).

Semi-arid ecosystem has been experiencing continuous and severe vegetation cover degradation, soil erosion, drought and other related issues which lead to biodiversity loss and climatic change. Global forest watch reported 14% loss of forest cover and 5.99Mt of CO_2e emissions in Dodoma region between 2001 and 2021 (Figure 1). Loss of woodlands leads to reduced availability of loosely dry wood for fuel which can be collected on foot which switch charcoal burning which affect green forests and hence deforestation (Allen, 1985). Deforestation in Dodoma region is influenced by human activities despite the fact that the region is semi-arid in nature (Chawene & Mayaya, 2016).

This study aimed to quantify the extent of forest cover loss, the root course of the forest cover loss, and suggest possible mitigation measure to reduce the rate of these degradation in Sagara River catchment which encompasses the Sagara hills.

2. MATERIALS AND METHODS

2.1 Study Area description

Sagara hills are the mountainous series that found at 6°17’37''N and 36°28’46E that covers approximately 50161.26 hectares, with a peek height reaching up to 1960m. The hills cover both Kongwa and Mpwapwa district whose people directly benefit from the mountainous ecosystem of these hills (Figure 1). Such hills contain a number of springs which act as the main source of water to a majority of population living in adjacent villages. These springs supply water throughout the year. Furthermore, some part of the hills contains beautiful scenery and tourists’ attraction such as Mt – Igae in Chamkoroma ward and water falls at Sagara wards.

The local communities around Sagara River catchment are engaged in agriculture (cultivating maize, millet, beans, ground nuts, sunflower and sorghum), livestock keeping, charcoal burning, bee keeping and others as a major source of livelihood. The increased population has resulted to uncontrolled harvesting of the mountainous ecosystems’ resources (Nyalus, 2021) with poor management strategies which endanger mountainous ecosystem thus becoming at higher risk of degradation. The

Sagara hills ecosystem is surrounded by village settlements including Sagara, Ibwaga, Mlanga, Ghambi, Chunyu, Mpwapwa, Chamkoroma, Chisokwe, Mazae, Lupeta, Tubugwe, Iduo, and Suguta whose population puts these ecosystems under extreme pressure and at great risk of destruction.

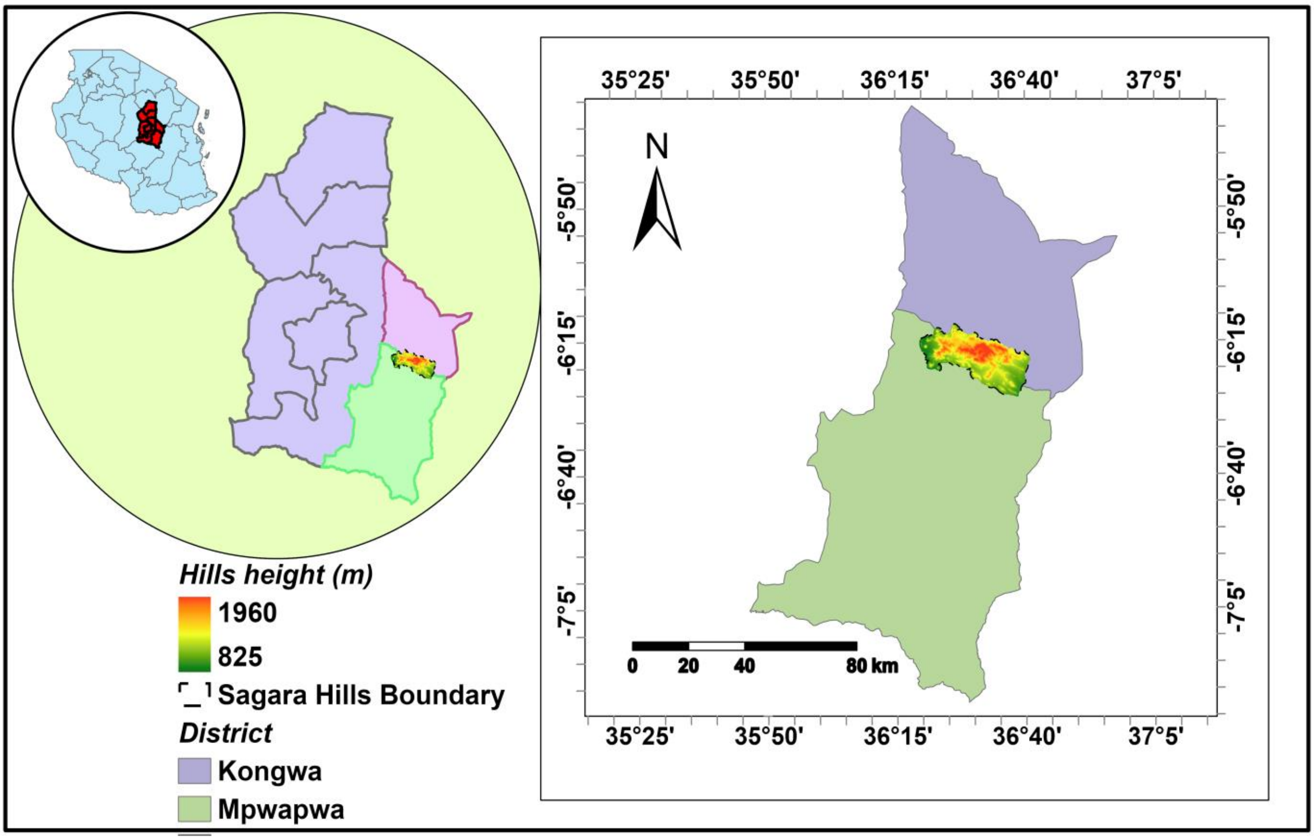

***Figure 1**: Location of Sagara hills in Mpwapwa and Kongwa district in Dodoma region*

2.2 Data sources

Two categories of data were used in this study. Firstly, the Landsat 8 layers of 2013 and 2020 was used as the input data for change detection and quantification of vegetation cover and other land uses at Sagara hills. Secondly, the field data and higher resolution Google Earth Pro historical image were used to create reference datasets for training the classifier and accuracy assessment. Field data were obtained during field visits.

2.2.1 Landsat 8 Layers

The Landsat 8 layers are produced by Landsat 8 satellite. The Landsat 8 has two sensors, the Operational Land Imager (OLI) with 9 spectral bands, including Band 1 Coastal Aerosol, Band 2 Blue, Band 3 Green, Band 4 Red, Band 5 Near-Infrared, Band 6 SWIR 1, Band 7 SWIR 2, Band 8 Panchromatic (PAN) and Band 9 Cirrus (Markham et al, 2014), all of these Bands have spatial resolution of 30 m except Band 8 (PAN) which has 15 m spatial resolution.

The second sensor is Thermal Infrared (TIRS) instruments with two bands, Band 10 TIRS1 and Band 11 TIRS 2. These bands have 100 m spatial resolution. The Landsat 8 satellite was launched on February 11, 2013.

For the purpose of this study, a single scene (path 168, row 64) of Landsat 8 collection 2 Tier 1 calibrated top-of-atmosphere (TOA) reflectance scenes on Google Earth Engine for 2013 and 2021 were used for Forest cover change detection on Sagara hills. This collection was chosen because Landsat data need to undergo Radiometric and Geometric correlation to ensure consistency and accuracy, to make sure that measured changes are due to Land surface changes (USGS, 2019).

Time series images that cover study area were selected between 1 July and 30 December for both 2013 and 2021 for classification. July to December is normally a dry season in Dodoma region, hence was chosen to avoid the effects of cloud cover on the images. The cloud cover was set to be less than 10% over the full scene in GEE platform.

2.2.2 Reference data

Field data collected during filed survey were used as ground control points for feature collection in GEE for training and validation of the 2021 image. While, High resolution Google Earth Pro historical images were used to create datasets for training and validation for 2013 Landsat image classification.

2.2.3 Land use/cover taxonomy

The classification schema for this study was established based on field survey conducted at the study area, 7 land cover types were observed to be dominant on Sagara hills, these included bare land, built area, farmland, grasslands, scattered bushes, closed bushes and thickets and forest cover. Table 1 below provides the description and characteristics of each land over.

Table 1. Classification Taxonomy

Class ID	Land Use/Cover type	Description
0	Bare land	Area of land with exposed soil, sand, dirt roads or rock contain very little or no vegetation
1	Built area	Include all manmade structure
2	Farmland	Included active crop fields, abandoned farms
3	Grasslands	Open areas covered with homogeneous grass with little to no tall vegetation
4	Scattered Bushes	Small cluster of plants or individual plant dispersed on landscape that shows exposed soil
5	Closed Bushes and Thicket	Cluster of plants and forest s less than six meter
6	Forest cover	Comprises of cluster of denser vegetation with closer and dense canopy, usually taller than six meters

Source: Modified from Brown et al. (2022)

2.2.4 Training and validation

Google Earth Engine provided very high-resolution image which was used for visual inspection and collection of training and validation datasets (Verhegghen et al,2022). Initially 210 square plots of 5 m by 5 m was randomly established in different locations of Sagara hills during the field survey conducted in June 2022 and 210 points (30 point per each land cover) were collected at the center of 5 m square plot to be used as ground control points during visual inspection of high resolution image of Google Earth Engine (Eskandari et al, 2020) where feature collection containing label for each land cover were created in GEE followed by collection of 200 point per land cover type which resulted to a total of 1400 sample points for all land covers.

Sample points were subdivided into two groups, the training and validation groups (Phan et al, 2020; Abu et al, 2021). For training, 70% of the total sample points (980 points) were used while 30% sample points (420 points) were used for validation. The classifier was trained by the image pixel at each sample point location for classification (Abu et al, 2021). The high-resolution GEE image was used as reference data for accuracy assessment of our classification.

2.2.5 Random Forest Classifier (RF*)*

After sample point collection, the Random Forest classifier was trained for image classification as explained above. RF is a machine learning algorithm that include multi-decision forest which provide class label to the pixel by classification (Ji et al, 2020). RF classification model have been widely used and is now termed as popular classification algorithm in remote sensing technology (Jin et al,2016). RF classifier was chosen based on its characteristics on land cover classification on satellite image. The RF classifier runs efficiently on larger data base, it can handle thousands of input variables, it is relative robust to outliers and noise (Breiman,1994; Dietterich, 2000; Galiano et al, 2011). The classifier was prompted to use 70% of sample points for image classification in GEE platform.

2.2.6 Accuracy assessment

The accuracy of image classification was tested by using validation sample points collected and very high-resolution GEE image as reference datasets, where confusion matrix was computed in GEE platform and producer accuracy (PA), user accuracy (UA) and overall accuracy (OA) were extracted (Phan et al, 2020) and the results were tabulated for presentation.

The area for each land cover class were computed in GEE and the results were noted in excel sheet for land cover change analysis, graphs and tables creation. Change detection was computed in GEE based on the principle of the formula below. The formula was also used in (Lin et al, 2020)

$$C_{gain} = L_b - L_a \quad \ldots\ldots\ldots\ldots(i)$$

$$C_0 = L_{b1} - L_{a1} \quad \ldots\ldots\ldots\ldots\ldots(ii)$$

$$C_{loss} = L_a - C_0 \quad \ldots\ldots\ldots\ldots\ldots (iii)$$

Where L_b and L_a are the land cover before and after a given time period respectively, Lb_1 and L_{a1} are unchanged area of the same land cover in the initial and at the end of time.

After classification the Land cover maps (Land cover in 2013 and 2021) produced were exported to google drive by using the export function in Google Earth Engine, which were then downloaded and imported into ArcGIS for land cover map layout creation.

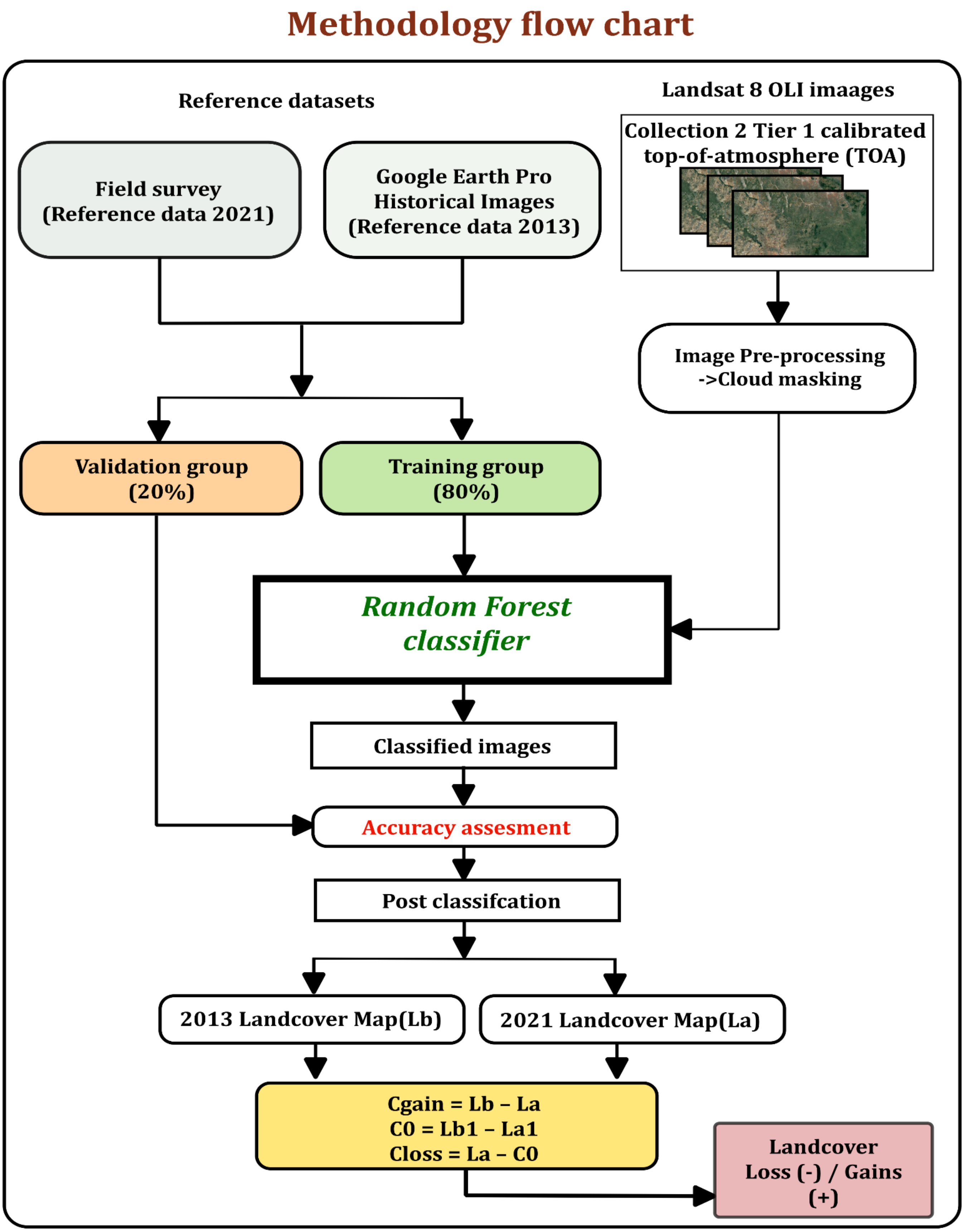

Figure 2: The work flow summary and illustration of the methodology used in this study

3. RESULTS

3.1 Accuracy assessment

The accuracy assessment results (Table 2) show the user and produced accuracy of classification of each land cover classified. The overall accuracy of classified image from 2013 was 92.4% and Kappa coefficient was 0.89, and that from 2021 revealed an overall accuracy of 95.2% and Kappa coefficient of 0.91. User's accuracy shows the percentage of classified object reality on actual ground while Producer's accuracy is based on classifier point of view (Barik, 2020).

Built area has lowest User's accuracy of less than 80% this was because of the type of building in study area, most of them were village settlements and hamlet and few of them were small towns which were poorly visible. Grasslands and farmland revealed high User's accuracy of greater than 95% from 2013 and 2021, closed bushes and thicket were classified with low User's accuracy of 72.2%. This was because some parts had greenness which were confused with forest cover greenness.

Table 2. Accuracy assessment

Class ID	Class name	2013		2021	
		User Accuracy	**Producer accuracy**	**User Accuracy**	**Producer accuracy**
1	Built area	70.0%	99.5%	77.4%	100%
2	Bare land	94.3%	97.6%	92.7%	95.3%
3	Scattered bushes	88.6%	92.9%	90.0%	92.9%
4.	Closed bushes and Thickets	72.2%	98.1%	73.4%	99.5%
5	Forest cover	95.8%	73.0%	95.9%	73.4%
6	Farmland	98.7%	96.6%	100%	96.6%
7	Grasslands	100.0%	73..7%	100%	85.8%
Overall accuracy		**92.4%**		**94.6%**	
Kappa coefficient		**0.89**		**0.91**	

3.2 Land cover maps and area estimation

3.2.1 Land use and vegetation cover distribution

The Figure 3 shows the map of classified land covers and vegetation distribution in 2013 and 2021. It shows spatial distribution of vegetation in both years and how forest cover has diminished within a time period.

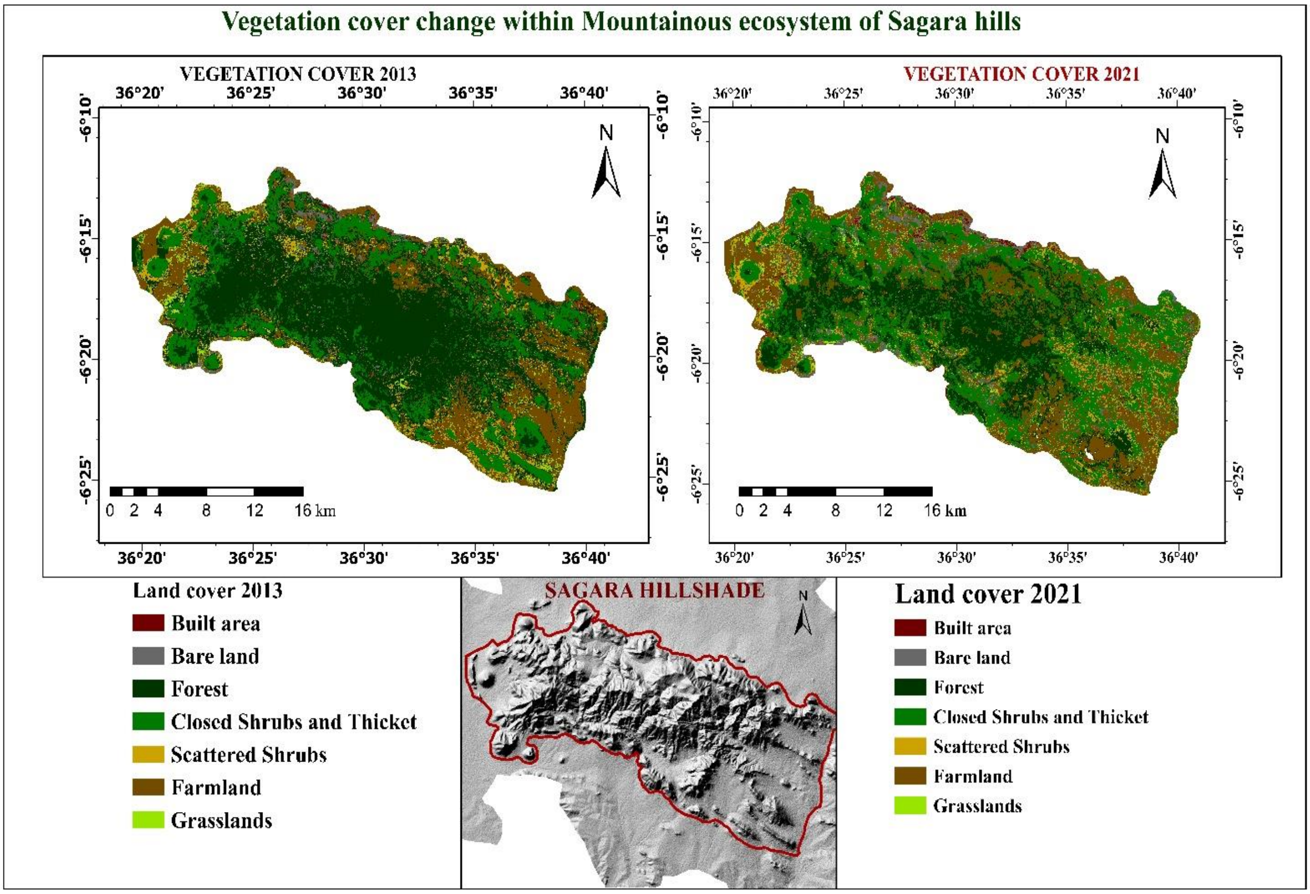

Figure 3. Land cover change at Sagara hills, (a) Vegetation cover in 2013 (b) Vegetation cover in 2021 (c) The hillside

Built area revealed to increase from 249.4 hectares in 2013 to 504.2 hectares in 2021 with a net gain of 254.8 hectares within a time period. Farmland increased from 10900.7 ha in 2013 to 14008 ha in 2021 with a net gain of 3108.1 hectares. Moreover, there were significance changes in vegetation cover from 2013 to 2021, whereby in 2013 forest cover was a dominant vegetation with 24187.5 ha. However, in 2021 following deforestation, the forest cover decreased to 12439.2 ha losing 11748 ha., Furthermore, grassland decreased from 995.1 ha in 2013 to 751.9 ha in 2021 with a net loss 243.2 ha.

Closed bushes and thickets increased significantly with a net gain of 6451.2 ha making it a dominant vegetation. Bare land increased by 1237.8 hectares, indicating a serious land degradation problem.

Table 3. Quantification of land cover, land cover loss and gain

SN	Land cover class	Area (ha)		Change in area (ha)
		2013	2021	(Loss (-)/ Gains (+))
1	Bare land	1095.8	2333.6	+1237.8
2	Built area	249.4	504.2	+254.8
3	Farmland	10900.7	14008.8	+3108.1
4	Grasslands	995.1	751.9	-243.2
5	Scattered Bushes	2331.2	3239.0	+907.8
6	Closed Bushes and Thicket	10401.5	16852.7	+6451.2
7	Forest cover	24187.5	12439.2	-11748

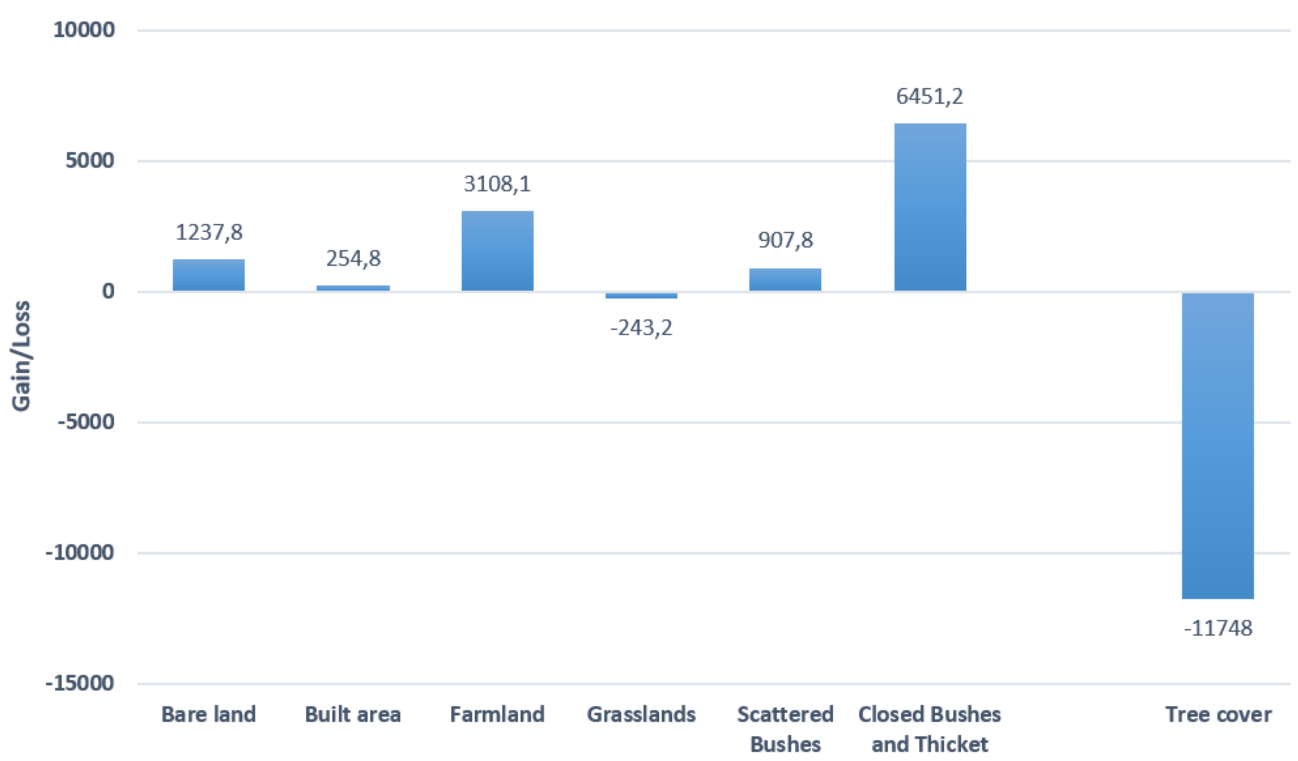

Figure 4. Overall Land cover loss and land cover gain in hectares from 2013 to 2021.

4. DISCUSSION

The results indicate that forest (tree) cover loss is the major vegetation cover loss in Sagara hills ecosystem in Dodoma region with 11, 748 hectares (48.57%) of forest cover lost in the past 9 years. According to global forest watch the total area of humid primary forest in Dodoma region decreased by 2.4% in 2021 in which 14% of forest cover was lost. This is equivalent to 5.99 Mt of CO_2e emission. Our results further indicate that 55% of forest cover loss was lost to closed shrubs and thickets. This is attributed to tree cutting for charcoal making, shifting cultivation, illegal logging and wildfire. This was also reported by Makero and Kashaigili (2016).

Furthermore, 30% of forest was converted to farmland owing to increased demand for land in the adjacent communities. It was reported by Sagara village chairman that the land available for crop farming is not sufficient for the village members.

The population has increased while the land productivity decreased due to poor farming practices (Serban et al, 2021). Such practices led to poor production per unit area which necessitated the people to search for other area for cultivation. The expansion of farmlands has also affected the grazing land found in foot hills leading to conflicts between farmers and pastoralists. The presence human activities around the hills causes disturbance to hills ecosystem (Serban et al, 2021). Need for fuel wood, improper harvest of forest product, agriculture, infrastructure and urbanization are the principal causes of vegetation conversion (Lal, 1987).

The vegetation cover change was observed to be a dynamic process of deterioration and natural regeneration. In this dynamic process it was observed that the rate of vegetation cover restoration(regeneration) was lower than the rate of deterioration, which resulted into increased loss of vegetation cover along the mountainous area. Natural vegetation restoration is difficult process which require long period of time to recover to its initial condition.

Deforestation results into to poor infiltration of rain water, increased lateral seepage, soil erosion and other related soil degradation issues which results into flood in lower area where farms are located. This was observed to be key characteristic feature of downstream portion of the Sagara River catchment whereby farmlands were converted to bare lands.

5. CONCLUSION

This study has demonstrated that there has been a significant land use dynamics in the Sagara River catchment over the past 9 years. Forest and grassland areas declined significantly with much of the area being converted into farmlands and bare lands. Poor farming practices upstream of the catchment contributed to massive soil erosion, washing out soi from the farmlands leading to low agricultural produce. This exacerbates deforestation and poverty as the farmers shifts to uncultivated lands in the forest area and the cycle continue thus forming a vicious cycle of deforestation. It is recommended that the Sagara hills be protected by Tanzania forest services agency for effective protection. Furthermore, sustainable land management education should be given to adjacent communities with a view of restoring the disturbed vegetation.

6. ACKNOWLEDGEMENT

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8. AUTHORS' CONTRIBUTIONS

The authors contributed equally in writing this paper

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10. KEY TERMS AND DEFINITIONS

Sagara hills - a geographical area in Kongwa and Mpwapwa districts in Dodoma region

Land use and land cover changes – Land cover change is a modification in the way land is used and the vegetation and other features that cover it. Land use change refers to human activities that modify the way in which land is used, such as forests area change into agricultural land, urban areas, or mining activities.

Remote sensing - the collection of information about an object or phenomenon without making physical contact with it, typically using satellite or aerial imagery

Geographical Information System (GIS) - a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data to support decision making

Landsat 8 - a satellite launched by NASA that captures images of the Earth's surface for scientific and commercial purposes

Random Forest classifier - a type of machine learning algorithm used for classification and regression tasks, often applied to remote sensing data analysis