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Vegetation Cover Changes due to Artisanal and Small-Scale Gold Mining in Bukombe-Mbogwe Forest Reserve in Geita Region, Tanzania

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ABSTRACT

Bukombe-Mbogwe Forest Reserve (BMFR) has substantially lost its vegetation cover following Artisanal and Small-scale Gold Mining (ASGM). The study aimed at examining vegetation cover changes in BMFR and surrounding villages due to ASGM in Mbogwe District. Purposive and random sampling were employed obtaining 138 respondents. Data was collected through remote sensing, participant observation, questionnaire survey, key informant interviews and focus group discussions. Landsat images of three window periods (1984, 2002 and 2020) were analysed qualitatively and quantitatively using Normalized Difference Vegetation Index (NDVI) and supervised classification of Maximum Likelihood (ML) algorithm techniques respectively. Descriptive and content analysis were conducted for quantitative and qualitative socio-economic data respectively. By using NDVI technique, median values decreased in BMFR from 0.57 (dense vegetation) to 0.34 (shrubs and grasslands). Land use/cover changes (LULCC) for 1984 to 2020 proved that there was decrease in dense vegetation from 46.4% to 25.62%, bare-land from 43.23% to 20.06% and increase in sparse vegetation from 9.4% to 46.86% and built-up land from 0.97% to 7.46%. Logs for pit construction were extracted from BMFR by 67.5%. Therefore; ASGM has negatively changed vegetation cover in BMFR and surrounding villages. The paper recommends increasing protection in BMFR by employing Joint Forest Management (JFM).

Key words: Vegetation cover - artisanal mining - Bukombe-Mbogwe - forest reserve - NDVI technique - land use/cover.

INTRODUCTION

Separating vegetation cover changes and artisanal and small-scale gold mining is inevitable (Kamga *et al.* 2020). This is due to the fact that mining activities require forest tree logs for pit construction, soil washing, pole constructions and mercury amalgamation. Forest reserves surrounded by communities and villages where mining activities are carried out possess a threat to its conservation (Kimijima *et al.* 2022). Vegetation cover is one among the environmental variables and essential in increasing soil compatibility there by decreasing soil erosion rates, regulating earth temperature and acting as habitat for most terrestrial animals (Melville *et al.* 2019).

Vegetation cover within forest reserve has been decreasing globally due to the increase in human population (Alam *et al.* 2020).

Forest reserve serve as a source of firewood for cooking, timber for building constructions, herb medicinal properties and in ritualism (Guzha *et al.* 2018). Vegetation cover in unprotected areas is undergoing decrease in its quantity due to human activities like agriculture and settlement (Xie *et al.* 2019). Artisanal and Small-scale Gold Mining (ASGM) is practiced globally as a potential source of revenue for millions of people in about 80 countries (Aizawa 2016). It is associated with hazardous working conditions leading to contamination and deforestation of the vegetation cover within and areas surrounding mine sites (Diringer *et al.* 2019).

Reports reveal that due to urbanization in growing African cities, a threat is encountered to vegetation cover for the past recent decades like in Burkina Faso (Yao *et al.* 2019). There are many factors influencing vegetation cover changes and these include climate change through its parameters of temperature and rainfall (M'mboroki *et al.* 2018). Topography influencing vegetation cover on the issue of settlement as most lowland fertile grounds are more favourable than hilly grounds (Hoffman *et al.* 2018). There are accessibility factors like water, food, health services, education provision, roads and settlement availability attract human invasion by clearing natural vegetation cover (Venter *et al.* 2018, Zoungrana *et al.* 2018). The need of natural treasures within the earth's surfaces like minerals specifically gold has led to clearing of vegetation cover for exploration and excavation purposes in order to obtain gold (Hilson 2016). The rate of ASGM is increasing regionally of which about 9 million ASGM operators are involved due to the rising price value of gold and increasing difficulty of obtaining money from other sources of income (Njabulo 2019).

Furthermore, the decreasing rate of vegetation cover in protected areas like in Serengeti ecosystem is due to human encroachment from 1975 to 2015 for settlement and agriculture (Kija *et al.* 2020). Despite the licensing and formalization of Artisanal and Small-scale Mining (ASM) in Tanzania, reports show inadequate awareness on environmental conservation due to increasing environmental degradation associated with it (Kinyondo and Huggins 2021). ASGM in Tanzania is practiced in different regions like Geita, Shinyanga, Kagera and Mara. In Geita Region, large number of miners are from other regions of Tanzania. Geita is one of the leading regions in gold mining operations with both large and small-scale mining operations (Lange 2006). There has been increased number of small-scale gold miners in Mbogwe District, Geita Region. They pose a serious threat to Bukombe-Mbogwe Forest Reserve (BMFR) and are likely to extend and cause damages to surrounding villages.

There is paucity of empirical studies on artisanal and small-scale gold mining activities to vegetation cover. The current study aimed at enhancing conservation of the BMFR and villages surrounding it, avoiding further destruction in order to enhance its survival. BMFR has been experiencing continuous deforestation reducing its coverage. Reports revealed that, 470 hectares of BMFR had been lost from its original 28.7 kha following severe deforestation of about 13% of its land cover in 2010 due to ASGM activities. Over 30 hectares of the forests were lost in favor of pits and logs for construction (IPP 2018, 2019, 2020). This led to serious vegetation cover problems extending to surrounding villages. Several researches focused on human health and education with little research on current state of BMFR and surrounding village's vegetation cover in Mbogwe District (Rite *et al.* 2020, Komba 2015).

The overall objective of this study was to examine vegetation cover changes resulting from artisanal and small-scale gold mining in Bukombe-Mbogwe Forest Reserve and surrounding villages. Specifically, it aimed at using Normalized Difference Vegetation Index (NDVI) technique to obtain vegetation cover changes over time, identifying land use/cover (LULC) classifications within the study area and determining the source of tree logs used in artisanal and small-scale gold mining.

MATERIALS AND METHODS

Description of the study site

The study was conducted at the Bukombe-Mbogwe Forest Reserve (BMFR) and the surrounding villages, located in Mbogwe District, Geita Region (Figure 1).

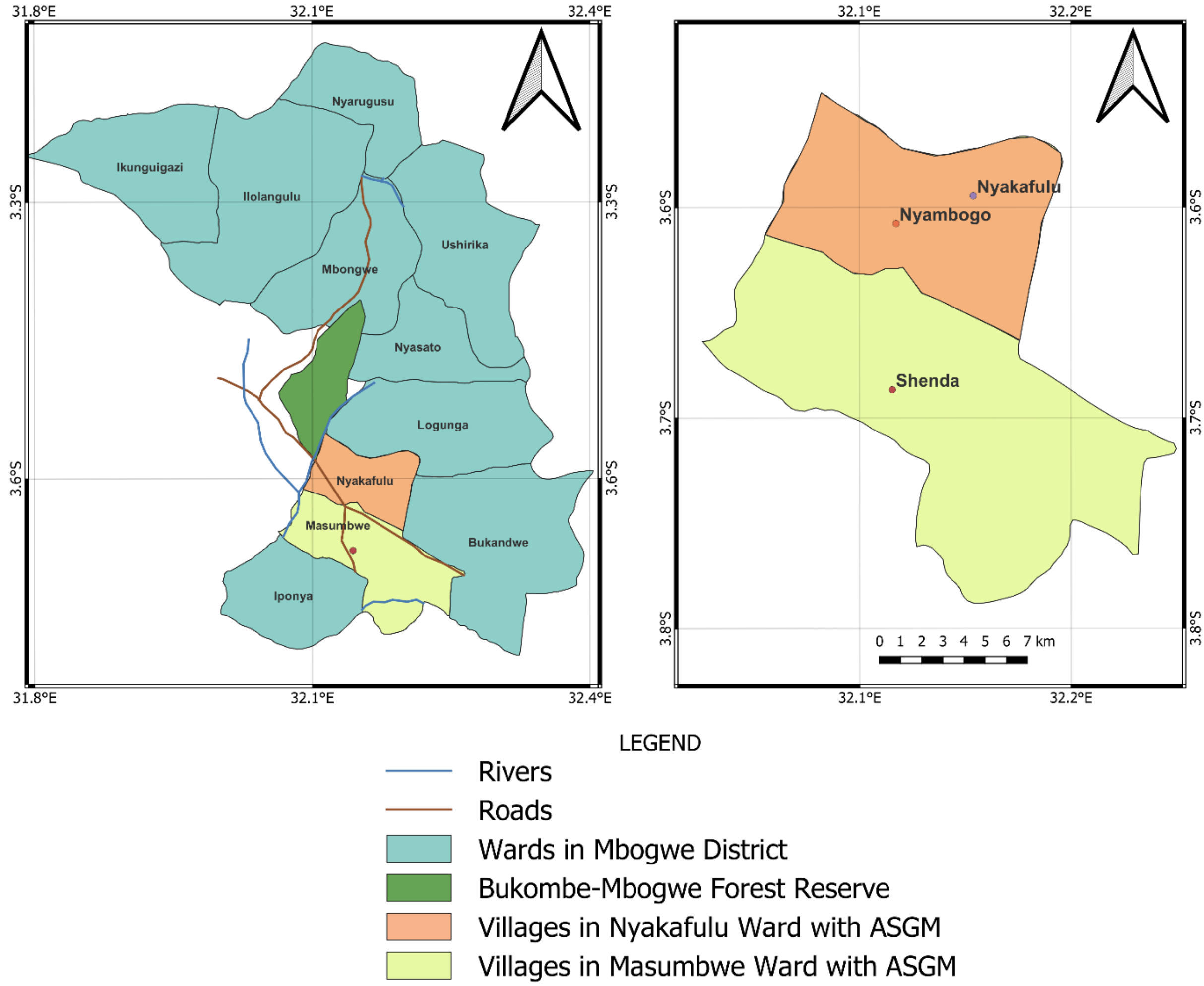

Figure 1: Map showing wards in Mbogwe District with villages surrounding Bukombe-Mbogwe Forest Reserve. *Source*: QGIS version 3.16.

The study covered the following villages: Nyakafulu and Nyambogo villages in Nyakafulu Ward and Shenda village in Masumbwe Ward. The study was focused on these wards because there were ASGM activities conducted surrounding BMFR. Mbogwe District has a tropical climate of mean rainfall of 22 °C with rainfall coverage from 900mm to 1200mm. It experiences biannual rainfall fairly distributed with short rains which starts from September to December, dry season from January to February, and heavy rains from March to May (Rite *et al.* 2020). Bukombe-Mbogwe Forest Reserve (BMFR) was declared as reserved area under the Government Notice in the year 1954 with area of 9324 Ha filled with miombo woodlands. BMFR is surrounded by eight villages namely Itunga and Ilalwe villages in Bukombe District and Nanda, Kasaka, Isungabula, Lubeho, Mgaya and Kasosobe villages in Mbogwe District in Geita Region. Majority of people speak Sukuma language. Other ethnic groups include Sumbwa, Zinza, Tutsi, Haya, Ha, and Hutu. Despite being protected by the government authority guided by by-laws and mother laws, BMFR has continually experienced destruction and disturbances due to continuous deforestation.

Data collection

Geospatial data acquisition

This study used three sets multitemporal satellite imageries with 18-year window period. Landsat Thematic Mapper (TM) of 1984, Landsat Enhanced Thematic Mapper (ETM) of 2002 and Operational Land Imager and Thermal Infrared Sensor (OLI-TRIS) of 2020. These Landsat images were obtained with 30m spatial resolution each freely downloaded from United States Geological Survey (USGS GLOVIS) website (https://earthexplorer.usgs.gov/). The months of data acquisition were taken during dry season (July and May) to reduce the effect of seasonal variation and cloud cover effects (0% and 1%) providing bright quality satellite images (Table 1).

Table 1: Downloaded satellite imagery for vegetation cover change. Source: QGIS version 3.16.

Satellite	Sensor	Path/Row	Acquisition	Resolution	Season	Cloud cover
Landsat 5	TM	171/062	16/06/1984	30m	Dry	1%
Landsat 7	ETM	171/062	07/06/ 2002	30m	Dry	0%
Landsat 8	OLI-TRIS	171/062	31/05/2020	30m	Dry	1%

Year 1984 imagery was taken as a study reference to know the status of vegetation cover in BMFR prior to artisanal and small-scale gold mining intensification within Mbogwe District. Year 2002 imagery was taken to get a clear view on the rate of ASGM activities invasion within the forest reserve since there commencement. Year 2020 imagery was taken to know the continual trend of vegetation cover change rate within the forest reserve since commencement of ASGM within the district. The study used a semi-automatic classification plug-in (SCP) in Quantum Geographical information system (QGIS) software (version 3.16) to perform satellite image pre-processing and classification. Thereafter, a map of BMFR was obtained from Google earth explorer and corrected to avoid anomalies by using QGIS.

Socio-economic study design, sampling and data collection

In this study, cross-section research design that involved collection of data at one point in time was employed. This is because it uses minimum cost and less time in determination of the relationship between independent and dependent variables (Bryman 2016). The design employed a mixed approach whereby both qualitative and quantitative methods were used in complementary for data accuracy. The study also involved multistage sampling procedure for the selection of sample households within the study area. Firstly, Mbogwe District was purposively selected as there are artisanal and small-scale gold mining and reported to have utilized BMFR as a source of its tree logs. Secondly, Nyakafulu and Nyambogo Villages in Nyakafulu Ward and Shenda Village in Masumbwe Ward were purposively selected because ASGM activities were conducted within. Thirdly, systematic random sampling technique was employed from the lists of village households provided by the village leaders of the three villages respectively. This technique was used since the population was large and it is cost- effective for its implementation (Abera *et al.* 2020). The study employed a sample size of 138 respondents using Cochran formula (Israel 2012);

$$n=\frac{Z^2 \times pq}{e^2}$$

Where n = required sample size; Z = Confidence level at 95% (standard value of 1.96); p = Estimated proportion of an attribute that is present in the population; q = 1 - p; e = Marginal of error at 5% (standard value of 0.05)

Therefore,

$$n = \frac{(1.96)^2 \times 0.1(1-0.1)}{0.05^2} = 138$$

A total of 138 household respondents were selected and this was started by randomly selecting households from the sample frame that proceeded after every 6th interval until the required sample size was attained. The interval size was determined using the formula (k = N/n) whereby, k is the interval size for selection, N is the total population and n is the required sample number (Mota *et al.* 2019).

The study involved questionnaire survey of which 40 questionnaire guides were provided to each village totalling to 120. The questionnaires involved both open and close-ended types collecting data on the extent of vegetation cover change attributed by ASGM activities. Two focus group discussions were employed each with seven participants involving artisans, business men and farmers on the issue at hand accompanied by the facilitator. This is because focus group discussion is favourable with participants ranging from 6 to 12 with knowledge on the study at hand (Deribsa 2018). Key informant interviews were involved in which checklists were provided to Mbogwe forest officer (1), Mbogwe environmental officers (2) and Mbogwe mining officers (2), village leaders (5), ASGM representative leaders (8) in order to obtain baseline information and more details of the interaction of artisans with the forest reserve (Table 2).

Table 2: Interviewed respondents in the study area

Participant's areas	Participant's affiliation	Number of participant responses
Nyakafulu Ward	Nyakafulu ASGM	40
	Nyambogo ASGM	40
	Village leaders	4
	ASGM representative leaders	4
Masumbwe Ward	Shenda ASGM	40
	Village leaders	1
	ASGM representative leaders	4
Mbogwe environmental office	Mbogwe environmental officers	2
Mbogwe mining office	Mbogwe mining officers	2
Mbogwe forest office	Mbogwe forest officer	1
Total		**138**

Data analysis

Satellite image processing and analysis

Image pre-processing

This involved clipping of the satellite image using forest and ward shape files of the study area from the website of Tanzania National Bureau of Statistics (http://www.nbs.go.tz). The clipped band images were then converted from Digital Number to surface reflectance. Dark Object Subtraction (DOS1) algorithm was used to perform image-based atmospheric correction to improve the satellite images to be classified (Mnyali and Materu 2021).

Image classification

During image classification, Regions of Interest (ROI) were created in order to define land use/cover classes in the study area. Then histogram equalization technique was used to enhance the visual interpretation of satellite image bands for classification. From the virtual raster band set Red, Green and Blue (RGB) colour composites were used interchangeably together with field data collected to identify ROIs which represented

LULC classes in the study area. For each LULC class, multiple ROIs were created and their spectral signatures were assessed to enhance the results of the classification. After identifying major LULC classes and assessing their spectral signatures, the supervised classification (Maximum Likelihood (ML) algorithm) method was applied for the classification of the Landsat images (Rimal *et al.* 2020). ML algorithm calculates the probability distributions for the classes related to the Bayesian theorem, estimating whether a pixel belongs to a certain land cover class. Before post-processing of the classification, multiple ROIs were reclassified to the LULC classes (dense vegetation, sparse vegetation, bare-land areas and built-up areas) as shown in Table 3.

Table 3: land use/cover (LULC) classes of the study area and their descriptions

LULC classes	Description
Dense vegetation	A vegetation type covered with dense tree growth and woodlands.
Sparse vegetation	Area covered with shrubs, grassland and agricultural fields.
Bare-land area	Area with exposed soil, un-vegetated lands, landfill sites, actively excavated lands and gold mining sites.
Built-up area	Land covered with residential settlements, commercial areas, man-made infrastructure and gold mining sites.

Change detection

Classified imagery that estimated the areas in hectares (ha) for each land use/cover class from 1984 to 2020 were generated by post-processing tools in the SCP. Estimation of the rate of changes for the different land cover use was computed based on simple image subtraction method (Mnyali and Materu 2021). The values were summarized and presented in terms of area change in hectares (ha), percentages (%) and rate of change (ha/year). The extent of area change (total change) for each LULC class was obtained by subtracting the area of initial year (1984) from the value of final year (final 2020) of the study period. According to Garai and Narayana (2018), area change, percentage area change and annual change rate of land use/cover change can be calculated using the following equations:

$$Area\ change = (Area\ of\ \beta\ in\ final\ year - Area\ of\ \beta\ in\ initial\ year)$$

$$\%\ Area\ change = \frac{(Area\ of\ \beta\ in\ final\ year - Area\ of\ \beta\ in\ initial\ year)}{Total\ area\ in\ the\ study\ area} \times 100$$

$$Annual\ change\ rate = \frac{(Area\ of\ \beta\ in\ final\ year - Area\ of\ \beta\ in\ initial\ year}{Years\ between\ initial\ year\ and\ final\ year}$$

Where; β is a land cover or land use class in the study area.

Normalized Difference Vegetation Index (NDVI) technique analysis

Landsat images were analysed using NDVI technique in QGIS for obtaining the trend of vegetation cover changes over time interval (Jiang *et al.* 2021). In this study it was used as an indicator for showing the availability of live green vegetation by assessing the vegetation health and density within BMFR (Hussain *et al.* 2020). This was done by observing the reduction of vegetation cover over time. Its index values range from -1 to 1 scaling from non-vegetation cover (lowest value) to healthy vegetation cover (highest value). NDVI values less than -1 indicate availability of water, from -1 to less than 0.2 indicate barren land (surfaces with little to no infiltration). From 0.2 to less than 0.4 indicate shrubs and grasslands, and from 0.4 to 1 indicate dense vegetation and forest (Mzava *et al.* 2019). This was obtained by calculating the difference between the red and infrared radiances reflected by the vegetation. The amount of radiation in both spectrums depends on the biophysical characteristics of the vegetation. To ensure the data was independent of the sun zenith angle, the calculated index was normalized by dividing it by the sum of radiance in both of the used channels.

$$NDVI = (\lambda NIR - \lambda RED) / (\lambda NIR + \lambda RED)$$

Where; NIR = Near-infrared reflectance, RED = Visible red reflectance.

Bands for NIR and RED are band 4 and band 3 respectively in Thematic Mapper (TM) sensor, while bands for NIR and RED are band 5 and band 4 respectively in Operational Land Imager (OLI-TRIS) sensor (Costa *et al.* 2020).

Socio-economic data analysis

Quantitative data obtained through questionnaire on the source of tree logs used in artisanal and small-scale gold mining activities were corrected, processed and coded. This was descriptively analysed using Statistical Package for Social Sciences (SPSS) version 20 and Microsoft excel for presentation of charts. Content analysis was used for qualitative data that was collected through focus group discussions and key informant interviews and summarized based on the themes (Lalika 2006).

RESULTS

Using NDVI in QGIS to obtain vegetation cover change over time

Three Landsat images were obtained in eighteen (18) years window period of 1984, 2002 and 2020. From the analysis conducted, BMFR vegetation cover is seen to persistently decrease as shown by the NDVI median values (Table 4).

From the above results of NDVI median values, for years 1984 and 2002 are represented by dense vegetation and forest despite of their mismatch in values. For year 1984 whose median value was 0.57 means BMFR was filled with dense green vegetation full of healthy miombo woodlands. There were minimal human intrusion and exploitation of resources from the forest reserve. For year 2002 with median value of 0.46 with a difference of 11% from year 1984 indicates a substantial decrease in vegetation health and density. This is followed by increase of human intrusion towards acquiring their own needs. For year 2020 with median value of 0.34 and a difference of 12% from 2002 with increase of 1% from (1984-2002) indicating increasing rate of vegetation cover change negatively due to overexploitation of resources in BMFR following the need of forest tree species for mining activities (Figure 2).

Table 4: NDVI median values of BMFR from different years of acquisition

Year of acquisition	NDVI median values	Interpretation of NDVI values
1984	0.57	Dense vegetation and forest
2002	0.46	Dense vegetation and forest
2020	0.34	Shrubs and grasslands

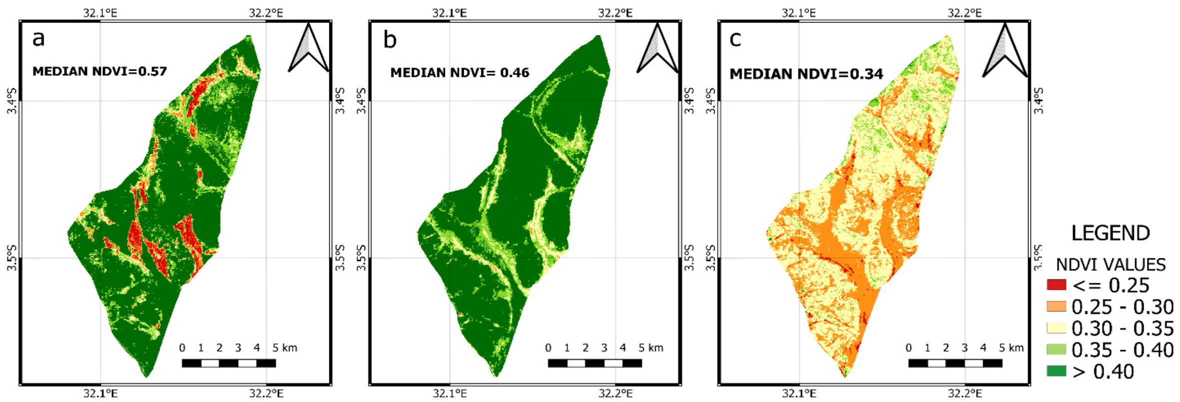

Figure 2: Bukombe-Mbogwe Forest Reserve variation in vegetation cover for (a) 1984 (b) 2002 and (c) 2020. *Source*: QGIS version 3.16.

The NDVI values of BMFR were highest in 1984 (up to 0.57) and continued to decrease to 0.46 in 2002 and highly decreased in 2020 (up to 0.34). This shows that the quality of vegetation greenness is continuously decreasing over time and the changes in the plant health of the forest is decreasing.

Identifying Land use/cover changes (LULCC) in the study area

Land use/cover changes ware mapped for the year 1984, 2002 and 2020 for analysis of change patterns that occurred in the study area. The result of satellite image analysis showed that in all study years, all four major classes identified were present (Figure 3). The study also obtained a comparison of LULC classes as shown in Table 5.

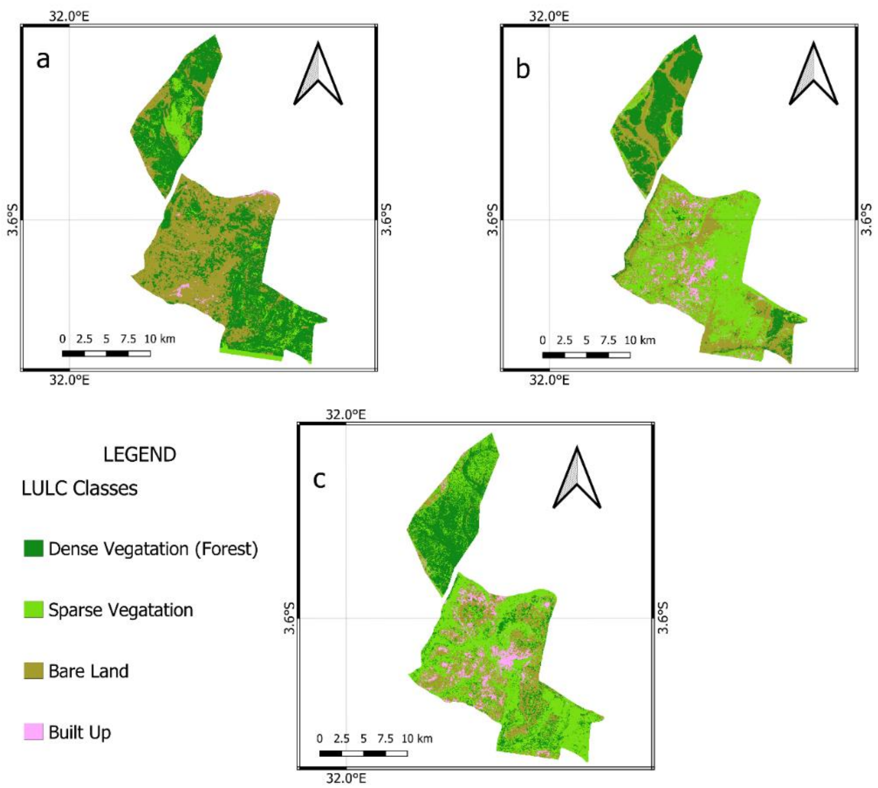

Figure 3: LULC maps of the study area for (a) 1984 (b) 2002 and (c) 2020. Source: QGIS Version 3.16

Table 5: Comparison of LULC classes from 1984 to 2020.

LULC classes	1984 (ha)	%	2002 (ha)	%	2020 (ha)	%	Changes between 1984-2002			Changes between 2002-2020		
							Area change (ha)	Area change (%)	Annual change rate (ha/year)	Area change (ha)	Area change (%)	Annual change rate (ha/year)
Dense vegetation	15355.08	46.4	6587.55	19.9	8492.76	25.62	-8767.53	-26.5	-487.085	1905.21	5.76	105.85
Sparse vegetation	3112.47	9.4	14178.78	42.85	15507	46.86	11066.31	33.44	614.795	1328.22	3.92	73.79
Bare land areas	14303.7	43.23	10426.05	31.51	6636.78	20.06	-3877.65	11.72	-215.425	-3789.27	-11.45	-210.52
Built-up areas	319.95	0.97	1898.82	5.74	2454.66	7.46	1578.87	4.77	87.715	555.84	1.68	30.88
Total	33091.2	100	33091.2	100	33091.2	100						

The increased and decreased amount of change in percentages (%) and hectares (ha) is shown by positive (+) and negative (-) signs respectively.

Dense vegetation (forest)

From the results obtained, dense vegetation was observed to be 46.6% (15, 355.08 ha) of the total area in 1984. It decreased to 19.9% (6,587.55 ha) in 2002 then increased up to 25.62% (8,492.76 ha) in 2020. The study area on average lost 26.5% (8,767.53 ha) of the dense vegetation at an average rate of 487.085 ha/year between 1984 and 2002. This is due to minimum human interaction with BMFR, ASGM activities had not started utilizing effectively tree species from the forest reserve and less population within the district. Then it gained dense vegetation by 5.76% (1,905.21 ha) at an average rate of 105.85 ha/year between 2002 and 2020. This is because of the decrease in tree species in BMFR for ASGM activities hence started using tree logs from man-made forests enhancing minimal natural regeneration within and outside Mbogwe District.

Sparse vegetation

The continuous decline in vegetation cover was observed in the study time period leading to increased sparse vegetation. In 984 sparse vegetation was 9.4% (3,112.47 ha) then increased to 42.85% (14,178.78 ha) in 2002 and finally to 46.86% (15,507 ha) in 2020. There was an average increase of 33.44% (11,066.31 ha) between 1984 and 2002 at an average rate of 614.795 ha/year. This was followed by an increase of 3.92% (1,328.22 ha) between 2002 and 2020 at an average rate of 73.79 ha/year. This is due to increased ASGM activities within Mbogwe District there by clearing vegetation and in need of settlement due to increased population. The need to obtain human needs led to vegetation clearance for agricultural purposes thereby increasing sparse vegetation.

Bare-land areas

There was a continual decrease in exposed soil, un-vegetated lands, and landfill sites within the study area. In 1984 bare-land area was 43.23% (14,303. 7 ha) this is because of minimum human invasion in the forest reserve with less population in the study wards. In 2002 bare-land area decreased to 31.5% (10,426. 05 ha) because of increased ASGM and population increase in the district. Then bare-land areas continuously decreased by 20.06% (6,636.78 ha). There was an average decrease in bare-land area by 11.72% (3,877.65 ha) at a rate of 215.425 ha/year between 1984 and 2002. This was followed by a decrease rate of 11.45% (3,789.27 ha) at a rate of 210.52 ha/year between 2002 and 2020. There is a decrease rate of 0.27% between the two window periods indicating bare-land is more prevalent in the study area due to increased ASGM activities.

Built-up areas

In 1984 built-up area was 0.97% (319.95 ha), in 2002 it increased to 5.74% (1,898.82 ha) then increase to 7.42% (2,454.66 ha) in 2020. The rate of increase of built-up areas increased by 4.77% (1,578.87 ha) at a rate of 87.715 ha/year between 1984 and 2002. This is because of population increase in need of residential settlements, commercial areas, man-made infrastructure and gold mining sites in the study wards. The rate decreased to 1.68% (555.84 ha) by 30.88 ha/year. This is due to the increase in bare-land for mining activities in the study wards.

Accuracy assessment

This aimed at quantitatively assessing how effectively the pixels were sampled into correct LULC classes. This study used the photointerpretation technique to assess the accuracy for classified images of 1984, 2002 and 2020. A total of 30 random points for each LULC class were clustered using the ISODATA algorithm which allows clustering of a different number of samples within a single LULC class. Thereafter, clustered random samples were photo interpreted using high spectral imagery from Google earth historical maps with 15 meters resolution and then reclassified to be used as reference raster for assessing the accuracy of classified images. Overall accuracy and Kappa statistics as described by Abera *et al.* (2020) were used to measure and test the accuracy of the classified maps of 1984, 2002 and 2020 as shown in Table 6.

Table 6: Producer's Accuracy (PA) and User's Accuracy (UA) of land use/cover changes 1984-2020.

LULC classes	1984		2002		2020	
	PA	UA	UA	PA	UA	PA
Dense Vegetation (Forest)	87.3	90.1	88.3	87.5	91.4	90.2
Sparse Vegetation	85.3	88.2	86.3	90.4	90.3	92.4
Bare land	90.4	88.3	87.5	92.4	90.7	90.6
Built up	84.8	87.9	89.4	86.1	88.5	89.5
Overall accuracy	87.8		89.3		91.2	
Kappa statistics	0.87		0.88		0.91	

Both producer's accuracy (PA) and user's accuracy (UA) of the LULC classes indicated with overall classification accuracies and their corresponding Kappa statistics. With kappa statistics of 0.87, 0.88 and 0.91 for LULC maps of 1984, 2002 and 2020 respectively. This showed that all maps met the recommended minimum accuracy of 0.85 and there was a strong agreement between the classified land use/cover classes and the reference data.

Source of tree logs used in artisanal and small-scale gold mining

BMFR has continuously been decreasing in its quality and quantity of tree species as most of them are extracted by man for gold mining. It is rich in miombo woodlands with favourable tree species needed for mining especially for pit construction in mine sites. From the results obtained; extraction of logs for mining activities is done highly in BMFR by 67.5%. This is because BMFR is the nearby source within the district that logs can be obtained and the trees are favourable for use. Trees extracted are not affected by moisture expecting less accidents of pit falls making it more favourable for continuous extraction. Since there is no strict protection to date against any human intrusion to BMFR this has contributed to its decline. Other sources of mine tree logs are from man-made forests outside Mbogwe District (15%) particularly eucalyptus trees (*Eucalyptus paniculata*). These are extracted from other forests that are not within Mbogwe District mostly from Kagera Region. There are other respondents that stated mine tree logs (*Eucalyptus paniculata)* are obtained from man-made forests within Mbogwe District (17.5%). This indicated the level of awareness of gold mining with environmental consciousness specifically on vegetation cover in BMFR is minimal (Figure 4).

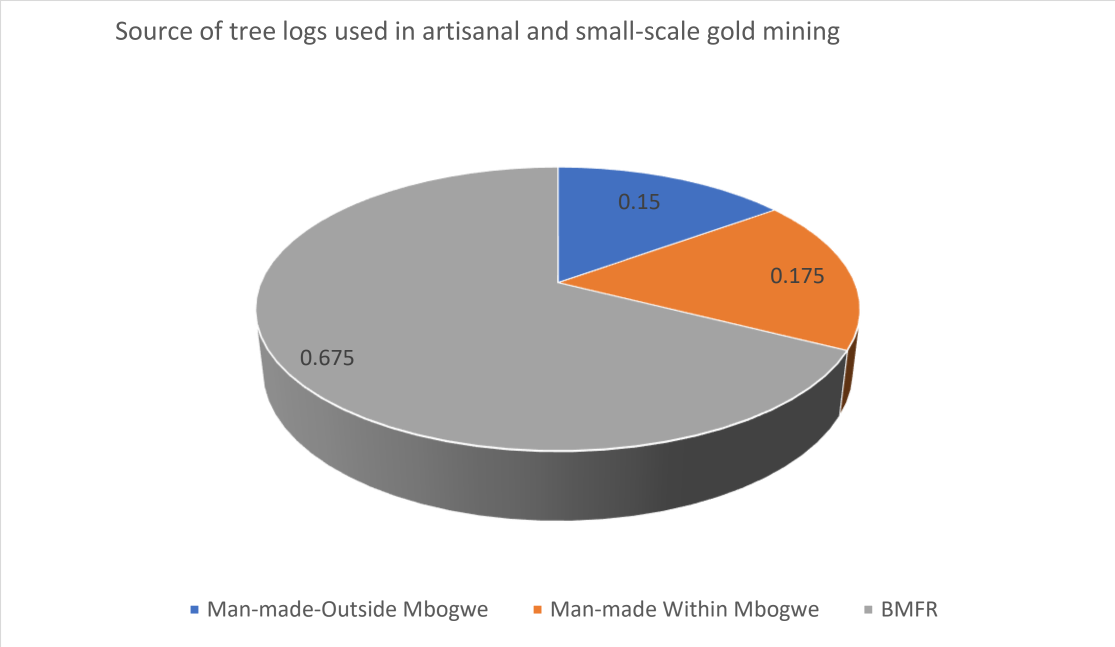

Figure 4: Responses on the area for log extraction during gold mining in Mbogwe District.

DISCUSSION

Using NDVI in QGIS to obtain vegetation cover change over time

Findings of this study confirmed that there was a decrease in vegetation cover by 11% from 1984 to 2002. And there was a decrease by 12% in vegetation cover from 2002 to 2020 showing a total decline of 23% in vegetation cover from 1984 to 2020. It was stated by the district environmental officer that there was a huge decrease in vegetation cover in BMFR from 1992 due to ASGM. The decrease was accompanied by the need of logs for pit construction in mining areas around Mbogwe District and other districts in Geita Region. At this time only whites owned the mine sites and they were interested in gold not in environmental conservation. Furthermore, ASGM activities have led to decrease in vegetation cover in Senegal because during mining, efforts are put in gold extraction other than conservation (Zoch 2019).

ASGM activities have potential to threatening and destructing forest resources like in Takwa, Ghana. This leads to displacement of wildlife, habitat loss, and ecological imbalance affecting ecosystem biodiversity (Dumakor-Dupev and Bansah 2017). The Atewa Forest Reserve in Ghana has been prone to deforestation of which 167.4 km^2 out of 1389 km^2 was cleared due to ASGM and agricultural activities from 2014-2017. High rate of deforestation over small range of time poses a threat for the forest reserve undergoing habitat loss (Lamboj *et al.* 2020). It is evidenced in Rwanda that the loss of vegetation is frequently due to ASM activities in their working sites particularly deforestation. Also in Zimbabwe there has been high rate of deforestation of which 100 kha of land was cleared for ASGM (Machacek 2019).

From 2016 the gold mining sites in Mbogwe District were provided and owned by Tanzanians and at this time the rate increased of destruction since most people were interested at having their own pits for obtaining gold. There was high rate of degradation and deforestation hence decrease in vegetation cover increased. Vegetation is cleared due to the need of good access to roads for transportation of tree logs to mine shafts (Kinyondo and Huggins 2021). The impact of ASM activities on vegetation cover has increased negatively due to increase of people engaging in mining as a result of increased unemployment like in Niger. This has led to expanse and density of vegetation cover reduction in recent years due to ASM activities increase (Liman *et al.* 2021). Knowing the status of vegetation health and density of BMFR as it has decreased by 23% from 1984 to 2020. This calls for attention in its protection of which the Tanzania Forestry (TFS) Services in collaboration with the Mbogwe council should join efforts for its conservation.

Identifying Land use/cover changes (LULCC) in the study area

LULCC is considered as a major indicator in environmental and ecological changes in understanding the interactions between nature and human (Mnyali and Materu 2021). The need to knowing how ASGM activities have led to vegetation cover changes within the study wards and in BMFR was essential for identifying change rates quantitatively.

From the study findings in the study period (1984-2020), four land use/cover classes of dense vegetation, sparse vegetation, bare land and built-up land areas were identified. There is substantial land use/cover changes due to artisanal and small-scale gold mining. The year 1984 was considered as a baseline of identifying the trend of vegetation cover change within the study area. It was evidenced that dense vegetation decreased from 46.4% (15,355.08ha) in 1984 to 19.91% (6,587.55 ha) in 2002 with decreasing rate of 487. 085 ha/year. This was a period of time when ASGM activities started intensively there by clearing vegetation in mine sites and extraction of logs for mining.

Due to over extraction of resources in BMFR indigenous forest tree species decreased highly making ASGM activities reduce utilizing its tree species and started to search for man-made forests tree species (*Eucalyptus paniculata*). This led to considerable increase in dense vegetation from 2002 to 2020 by 5.69% (1,905.21 ha) with increasing rate of 105.85 ha/year. There was increase in dense vegetation but decrease in its vegetation health as it was filled with middle class diameter trees and extraction of tree logs kept on increasing in BMFR as stated by Mbogwe district environmental officer. Sparse vegetation has increased from 9.4% (3,112.47 ha) in 1984 to 42.85% (14,178.78 ha) in 20002 with increasing rate of 33.44% (614.795 ha) this is due to increase in ASGM activities within the study area there by increasing population and clearing of vegetation cover. In 2020 sparse vegetation kept on increasing by 46.86% (15,507 ha) with increasing rate of 3.92% (73.79 ha/year) followed by increase in mine sites like Shenda mine site. Bare land decreased substantially from 1984 to 2002 from 43.23% to 31.5% (14,303.7 ha to 10,426.05ha) with decrease rate of 11.72% (215.425 ha/year) then decreased by 210.52 ha/year in 2020. And built-up area increase rate was higher by 4.47% (87.715 ha/year) from 1984-2002, followed by lower increase rate of 1.68% (30.88 ha/year) from 2002-2020. Major activity conducted within the study area is ASGM acting as a source of revenue for people around mine sites.

It was reported by Diringer *et al.* (2019) that deforestation has increased substantially since the early 1980s in Peru due to ASGM activities conducted. This was followed by the need of area for mining by clearing vegetation and extraction of tree resources to be used during gold mining. ASGM is associated with intensive resource extraction accompanied with environmental and health problems like in Ghana (Guenther 2018). There has been continuous land degradation increasing sparse vegetation and reducing dense vegetation within mining sites. ASGM is always associated with decrease in agricultural activities, increase in population and settlement with infrastructure constructions there by increasing land degradation (Basir-Cyio 2020). Hence, there is need of preserving and increasing protection of vegetation cover specifically within BMFR thereby reducing its degradation in order to enhance its conservation.

Source of tree logs used in artisanal and small-scale gold mining.

For the past two to three decades, ASGM used only miombo tree species from BMFR for pit construction, soil washing and during mercury amalgamation as stated by the district environmental and forest officers. This has resulted to BMFR currently being dominated by middle class diameter trees ranging from 157mm to 455mm (Gi-Young *et al.* 2013). Nyakafulu gold mine used only natural trees from BMFR since its existence in the early 1980s till the late 1990s because of log scarcity recently within the forest reserve. Like in the southern Peruvian Amazon, it was evidenced with time from 1984 to 2017 that 100 kha of deforestation was due to ASGM (Espejo *et al.* 2018). This has put the forest biodiversity and the world climate under threat towards being endangered since the amazon forest largely contributes in controlling climate change.

Increased deforestation in protected areas due to ASGM activities is alarming as 90% of the vegetation has been cleared from 2017-2020 in the Brazilian Amazon. Such rate is expected to increase in the coming years if no proper measures are taken towards conservation of protected areas (Siqueira-Gay and Sanchez 2021). It takes about 100 years for a fully matured tree to be harvested since they do natural regeneration in BMFR. This has made the forest reserve to look bear with only young trees unfit for log activity. Deforestation due to ASGM activities in Peru has been reported to increase from 2006 to 2009 about 20 km^2 of amazon forest was cleared each year (Esdaile and Chalker 2018). This has led to increase in loss of vegetation cover in the amazon forest affecting climate variability.

To date mining sites like Shenda still use natural trees like *Brachystegia spiciformis, Pterocarpus angolensis, Pterocarpus chrysothrix* and other forest tree species. From the analysis conducted 67.5% respondents said logs are obtained from BMFR, 15% from man-made forests outside Mbogwe District and 17.5% from man-made forests within Mbogwe District. The use of tree species (*Eucalyptus paniculata*) from man-made forests is due to the scarcity of natural trees in BMFR used during mining. ASGM is accompanied by clearing of vegetation cover for conducting its activities. It tends to leave the land bare causing degradation and erosion of degraded land. Pits from which gold is obtained is normally constructed using logs. Logs used can be obtained in forests and other restricted areas (Takyi *et al.* 2021). Results from this study proved the decrease of vegetation cover in BMFR due to ASGM activities hence continual degradation. There is need of applying Joint Forest Management (JFM) as one among the types of Participatory Forest Management (PFM) in Tanzania (Suluo *et al.* 2020). This is by involving adjacent villages in the management of resources by sharing management responsibilities in order to avoid further degradation of its vegetation cover. The current state of BMFR is not convincing as there is slow regeneration rates of forest tree species (Plate 1).

Plate 1: Bukombe-Mbogwe Forest Reserve showing deforestation state of tree species (2022).

CONCLUSIONS AND RECOMMENDATIONS

Findings of this study have proved that vegetation cover in Bukombe-Mbogwe Forest Reserve is continuously decreasing. Vegetation cover has decreased by 23% from 1984 to 2020 in its quality of greenness and density. Dense vegetation in the study area decreased from 46.4% to 25.62%, sparse vegetation increased from 9.4% to 46.86%, bare land areas decreased from 43.23% to 20.06% and built-up land areas increased from 0.97% to 7.42% from 1984 to 2020. Most tree logs used in mining activities in Mbogwe District is from BMFR by 67.5% there by increasing its deforestation rates. ASGM activities in Mbogwe District increased in the late 1990s decreasing dense vegetation at a rate of 26.5% annually. New mine sites are being discovered and the recent one is Nyambogo mine site increasing exploitation of trees contributing to the increase of 1% decrease in vegetation health and density in BMFR. Recently the forest reserve is filled with secondary trees of miombo woodland vegetation of middle-class diameter of which they have to be preserved against extinction. There is need of increasing protection by applying JFM approach within BMFR against human invasion and over exploitation of its tree species to allow natural regeneration enhancing its conservation.

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