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Evaluation of Land use and Land Cover Changes in the Gold Mining Enclaves of Zamfara Sahel, Nigeria

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ABSTRACT: Understanding land use and land cover changes and their underlying dynamics is critical to land reclamation and biodiversity management in mining enclaves and deceleration of desertification in the vast Zamfara Sahel of Northwestern Nigeria. This paper presents a quantitative analysis of land cover changes in the gold mining enclaves of Anka, Bukkuyum and Maru Local Government Areas in Zamfara State, Nigeria. Data were aggregated from field trips, remote sensing and geographical information system technologies and archives. Data and satellite images from three time periods of 1987, 2002 and 2020 were used for the analysis. The images were captured on yearly degradation rates of LULC classes within 100m, 200m and 300m of protected areas. Five LULC classes were identified and twenty-five transition classes were mapped out using GIS technology. Analysis shows bare ground/ built-up/rock outcrop LULC class expanded as mining activities had deleterious impacts on the land cover of the enclaves.

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Keywords: Biodiversity; land use /land cover changes; gold mining; Zamfara Sahel.

Land is a dynamic canvas on which human and natural systems interact (Parker et al., 2003). Land use/land cover (LULC) is an amalgam of two different dimensions of certain processes that involves the earth's surface. Land cover refers to the biophysical attributes of the earth's surface and immediate subsurface which include vegetation (physical and artificial), rocks, water and ice and artificial structures such as building and pavements, while land use refers to the human intent to which the land cover is put and the anthropogenic impacts that results in changes to the land cover, while land cover change (LCC) denotes a change in some continuous characteristics of land which include vegetation types and soil properties, amongst others (Patel et al., 2019). Land use change (LUC) is a nonlinear process by which human activities transform the natural landscape. LUC is a regular and global phenomenon that combines natural and anthropogenic systems and influences air, soil and water (Lambin et al., 2000). LUC can impact population development, socioeconomic development, infrastructural development and disrupt peaceful coexistence of communities and nations. Ecotourism development and wildlife economics can be affected by LUC (Kusi et al., 2020). Land use can also affect land cover and vice versa. All forms of interventions that alters land to satisfy human and developmental needs can be considered as LULC change. The dynamics of LULC have been explored by researchers in different regions and countries including China (Liping et al., 2018), Iraq (Edan et al., 2021), Togo (Akodéwou et al., 2020), and Nigeria (Ajibola et al., 2021). Geographical Information System (GIS) and remote sensing technology have been used extensively in LULC change research, vegetation and landscape mappings (Chaplin and Brabyn, 2013), urban sprawl (Shahraki et al., 2011), landslide land suitability (Nurmiaty & Baja, 2014), soil erosion (Baja et al., 2014) amongst others. Globally, the mining of mineral resources has played

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a crucial role in the development of nations, as the extracted minerals such as gold and diamond amongst others are capitals in the foreign exchange markets. However, the exploitation of mineral resources comes with the risks of environmental degradation, deforestation, air pollution, health hazards that results from unrecyclable wastes, biodiversity loss and human conflicts and is therefore a critical issue in sustainable development (Mhlongo et al., 2018). This is the prevailing trends in developing countries where mining regulations and policies are weak, unsustainable or non-existence, consequently leaving room for illegal mining and resultant armed conflicts in African countries (Gunn et al., 2018), In Nigeria where legal mining activities have receded during the past decades, most scientific studies have focused on the impacts of toxic chemicals such as arsenic, cyanide, lead and mercury deposited in water, soil, and food crops that are grown in the host communities (Salisu et al., 2016), while relegating their impacts on LULC to the background. Land cover changes are inevitable in mining enclaves and as a global phenomenon, has been evaluated in various countries and regions including India (Garai & Narayana, 2018), Canada (Latifovic et al., 2005), China (Liu et al., 2016), and Nigeria (Ajibola et al., 2021) amongst others. It has also been extensively studied from different perspectives such as its biophysical impact on natural ecology (Ndace and Danladi, 2012), vegetation composition (Unanaonwi and Amonum, 2017), mining waste challenges (Carmo et al., 2020), biodiversity loss and impact on humanity and impact on flora (Adesipo et al., 2020), possibility of acid mine drainage cause by coal mine waste on rocks (Qureshi et al., 2016) and shrinking plant diversity (Macauley, 2014). Spatially explicit and detailed quantitative analysis of LULC changes due to gold mining in the mining enclaves of the Zamfara Sahel is lacking in the literature. To bridge the gap, this paper evaluated the impact of mining activities on land use/land cover (LULC) changes in the mining enclaves of Anka, Bukkuyum and Maru, Zamfara State, Nigeria.

MATERIAL AND METHOD

Study area: Zamfara State (also known as Zamfara Sahel) in Northwestern Nigeria, has the following GPS coordinates: Elevation: 452.93 meters (1485.98 feet), latitude 12ºo10'0''N, and longitude 6º15'0''E. With a landmass of 38,418 square kilometers, Zamfara is bordered in the South by Kaduna State, to the North by the Niger Republic, to the West by Sokoto and Niger States respectively and to the East by Katsina State. Zamfara falls under an eco-climatic zone known as the Sudan Sahel (Umoh and Lugga, 2018, 2019). Topographically, a vast expanse of the Zamfara Sahel is a combination of sandy and mildly undulating plains covered by sparse tree stocks with vegetation of the hybrid Southern Sudan and Northern Guinea savanna types. The open plains are mostly composed of scattered base rocks and shallow gorges (Umoh, 2000; Umoh and Alaka, 2007). A map of Zamfara State showing the study areas with communities hosting mining activities is shown in Fig. 1.

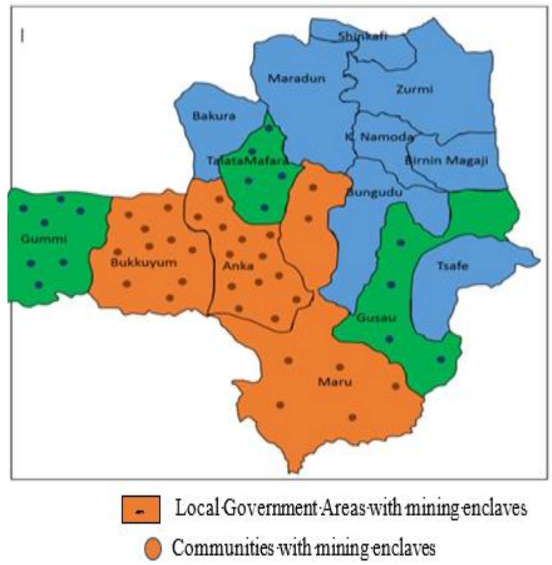

Fig. 1. Map showing Zamfara, Local Government Areas and mining enclaves

The mining enclaves are situated in three Local Government Areas, namely Anka (comprising 13 communities), Bukkuyum (comprising 10 communities) and Maru (comprising 8 communities) as tabulated in Table 1.

Data and method: The mining enclaves were visited severally to collect data for image classifications. ArcGIS® and training samples were used in the image classification. Earth Pro® Software was used for the validation of the coordinates of the mining enclaves and surrounding localities, while GLONASS® receivers were used to determine the user's position and velocity. GPS (Global positioning systems), GIS (Geographical information systems), and RS (Remote sensing) were used to investigate the resource use transition and flora loss in the mining enclaves. Time series data for satellite imagery with a spatial resolution of 10 meters for the three periods 1987, 2002 and 2020 was downloaded from archives of the United States Geological Survey (USGS). The satellite data sets were subjected to image pre-processing operations (Geometric and Radiometric Correlations) and supervised. Image classifications using the maximum likelihood classification algorithm was also used in data analysis. Accordingly, twenty-five percent (25%) of the ground truth was used to compute the error matrices and Kappa statistics of the classified images. The study used post-classification comparison and GIS analysis on the acquired satellite images to track the LULC changes. The images were subsequently sorted separately and classified at a different time and compared to generate a full matrix (Lu et al., 2004). The yearly degradation and/or restoration rate for each LULC class was calculated based on the relationship described in (Puyravaud, 2003).

Table 1: Coordinates of mining enclaves and their composite communities

Local Government Area (LGA)	Communities	Latitude	Longitude
Anka	Abare	12°05'35.1"N	5°54'59.6"E
	Bagega	11°51'47.2"N	6°00'15.1"E
	Bawa-Daji	12°06'26.5"N	5°54'29.7"E
	Dusa	12°07'38.2"N	5°54'22.9"E
	Barayan-Daji	12°10'00.0"N	5°47'00.4"E
	Tungan Daji	12°03'54.6"N	5°59'10.4"E
	Kirsa	12°06'25.6"N	5°54'41.3"E
	Jarkuka	12°05'26.3"N	5°55'31.7"E
	Dan-Kamfani	12°05'26.3"N	5°55'31.7"E
	Maigalma	12°06'12.1"N	5°55'28.2"E
	Sunke	12°08'51.6"N	5°59'26.7"E
	Kurukuru	12°14'58.6"N	5°49'27.7"E
	Kwali	12°04'40.8"N	5°54'27.4"E
Bukkuyum	Dan-Gurumfa	12°04'47.9"N	5°29'30.7"E
	Gaude	12°07'31.9"N	5°38'56.5"E
	Yalgalma	11°41'11.3"N	5°38'29.8"E
	Kyaram	11°55'23.6"N	5°31'32.3"E
	Dogon-Daji (Maibaka)	11°54'43.2"N	5°27'00.6"E
	Gwashi	11°56'15.6"N	5°46'30.8"E
	Fura-Girke	12°14'46.1"N	5°32'00.4"E
	Tungan Guru	12°2'36.6"N	5°23'12.5"E
	Kairu	12°14'46.1"N	5°32'00.4"E
	Godai	12°12'30.6"N	5°28'37.1"E
Maru	Malele	12°20'33.2"N	6°24'47.6"E
	DanJikko	12°19'31.5"N	6°23'43.1"E
	Dukki	12°23'19.9"N	6°19'46.4"E
	Tushe	12°18'54.6"N	6°25'14.5"E
	Bindin	11°36'45.3"N	6°21'30.1"E
	Kanoma Central	12°13'54.8"N	6°17'56.2"E
	Zaman Gira	12°19'44.5"N	6°25'45.3"E
	DanKurmi	11°36'40.5"N	5°58'45.5"E

$$R = \left(\frac{1}{t_2 - t_1}\right) \times \text{in} \left(\frac{A_2}{A_r}\right) \quad (1)$$

Where R is the yearly change, A_2/A_r is the class areas at the commencement and ending respectively for the time of assessment and $t_2 - t_1$ is the time span of assessment. The rate of change of LULC area for the three periods of 1987, 2002 and 2020 in the mining enclaves was computed based on the following relationships:

$$\text{Absolute change} = \text{Final time matrix} - \text{Initial time matrix} \quad (2)$$

$$\text{Percentage change} = \frac{\text{Absolute change}}{\text{Initial time Matrix}} \times 100\% \quad (3)$$

Sampling technique and population size: 1,405 communities with a population of 78,726 people are clustered in the mining enclaves of Anka (28,122), Bukkuyum (20,261) and Maru (30,342) (National Population Commission/National Bureau for Statistics, 2017). The sample size of 384 respondents were selected from 31 communities with established cases of mining-related health challenges and is made up of Anka (137), Bukkuyum (99) and Maru (148) based on the approach described in (Krejcie and Morgan, 1970). The relationship between the sampling variables is given by:

$$S = X^2NP(1-P) - d^2(N-1) + X^2P(1-P) \quad (4)$$

Where S is the required sample size, $X^2$is the table value of Chi-Square for 1 degree of freedom at 95% level of significance/confidence level (3.841), *N* is the population size, *P* is the population (assumed to be 50), *D* is the degree of accuracy expressed as a proportion (0.5).

Data analysis: The aggregated data was analysed with Statistical Package for Social Sciences (SPSS-23). Based on the objectives of the study, data were analysed with the One-way ANOVA test and the Duncan post-Hoc test (Armstrong, 2002).

RESULTS AND DISCUSSION

Results of classification and analysis: In this section, the dynamics of LULC changes in each mining enclaves are presented. The five LULC classes are tabulated in Table 2. *LULC changes in the mining enclaves for the periods of 1987, 2002, and 2020:* The classification maps which show the LULC changes for the respective years of 1987, 2002 and 2020 in the three mining enclaves are shown in Fig. 2, while the classification maps showing the net change in LULC for the accumulated periods of 1987-2002 and 2002-2020 are shown in Fig. 3. Fig. 2: Classification maps showing the LULC changes in the mining enclaves for the periods of 1987, 2002 and 2020.

*Location 1: Anka mining enclave***:** Anka has a land area of 2,746 km^2. The area distribution of LULC for the periods of 1987, 2002 and 2020 is given in Table 2, and the proportion in percentage of area distribution of LULC classes is shown in Fig. 4. The Anka mining enclave was composed of grassy savanna and built-up areas, which subsequently experienced changes on a yearly degradation rate. Shrubby savanna composed of 33.91% in 1987. The wooded savanna which was noticeable in 1987 was transformed to bare ground in

2002, with a decrease in grassy and shrubby savanna due to population expansion, deforestation and low-scale infrastructural development. Twenty-five transition attributes were established and all land areas are measured in km^2 as tabulated in Table 3. An analysis of the LULC transition classes for the period under review shows that there was no noticeable transition from C1-C5 between 1987-2002. However, there was a noticeable transition from C5-C3 which covered a land area of 625.18km^2 (22.77%) between 1987-2002 and subsequently decreased to 0.08km^2 (0.00%) in 2020. This was followed by C1-C3 (20.53%) between 1987-2002 to 0.00% between 2002-2020. The Anka mining enclave was composed of grassy savanna and built-up areas, which subsequently experienced changes on a yearly degradation rate. Shrubby savanna composed of 33.91% in 1987. The wooded savanna which was noticeable in 1987 was transformed to bare ground in 2002, with a decrease in grassy and shrubby savanna due to population expansion, deforestation and low-scale infrastructural development. Twenty-five transition attributes were established and all land areas are measured in km^2 as tabulated in Table 3. An analysis of the LULC transition classes for the period under review shows that there was no noticeable transition from C1-C5 between 1987-2002. However, there was a noticeable transition from C5-C3 which covered a land area of 625.18km^2 (22.77%) between 1987-2002 and subsequently decreased to 0.08km^2 (0.00%) in 2020. This was followed by C1-C3 (20.53%) between 1987-2002 to 0.00% between 2002-2020.

Table 2. LULC classes in the mining enclaves

LULC classes	Abbreviations	Description
Shrubby savanna	ShrubbySav	These are grassy plains with few tree stocks
Bareground/built-up/rock outcrop	Bareground/Bu/RO	These are portions of the land cover that are stripped of vegetation covers. This includes areas with infrastructural development, houses, road and other anthropogenic alterations.
Wooded savanna	WoodedSav	These are portions of the land covers that have wooded plants with hard stems. In the Zamfara Sahel, these tree stocks have open canopy despite their density.
Waterbody	Waterbody	This includes all inland open water areas which generally have less than 25% soil and vegetation such as seasonal watercourse ways, rivers, stagnant ponds, perennial streams.
Grassy savanna	GrassySav	These are grassy plains with few trees

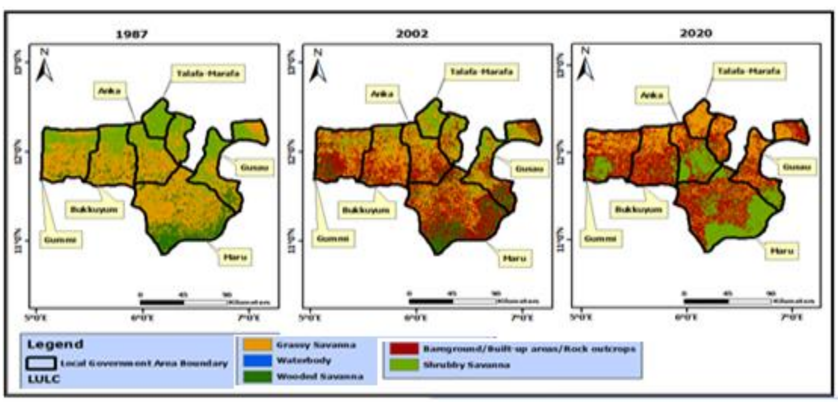

Fig. 2: Classification maps showing the LULC changes in the mining enclaves for the periods of 1987, 2002 and 2020.

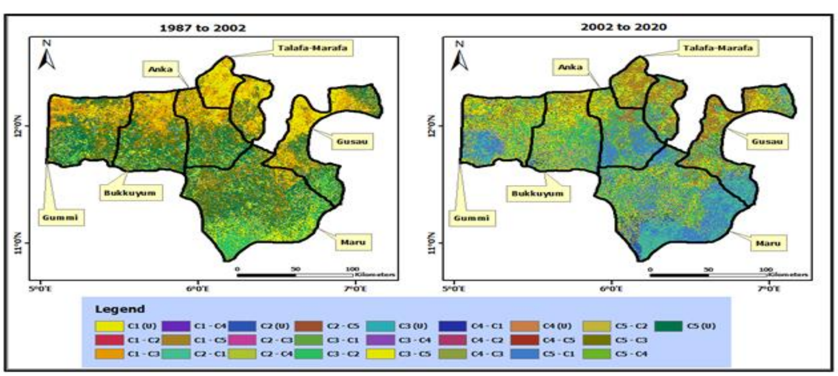

Fig. 3: Classification maps showing the land use/land cover changes in the mining enclaves for the periods spanning 1987-2002 and 2002-2020.

C1 = Shrubby savanna, C2 = Bare-ground/built-up areas/rock outcrops, C3 = Wooded savanna, C4 = Waterbody and C5 = Grassy savanna (C5). C(.) – C(.) represents a transition from one class to another.

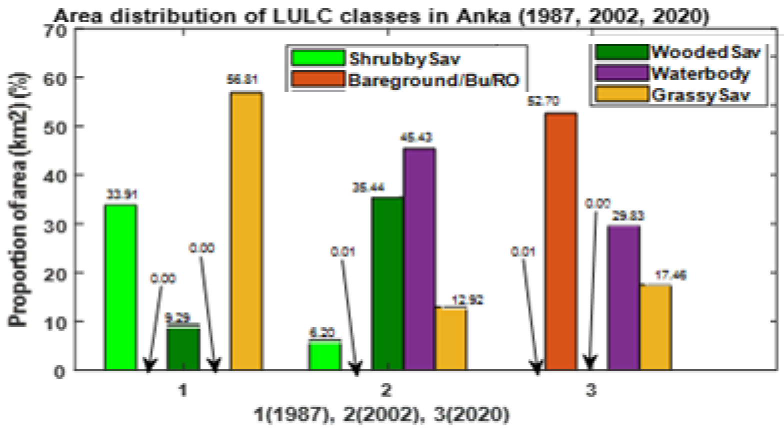

Fig. 4. Proportion in percentage of area distribution of LULC classes in Anka for the periods of 1987, 2002 and 2020.

Table 3: Area distribution of LULC classes in Anka for the periods of 1987, 2002 and 2020

Land use/land cover classes	1987 Km² (%)	2002 Km² (%)	2020 Km² (%)
Shrubby Savanna	931.06 (33.91%)	170.25 (6.20%)	0.35 (0.01%)
Bare-ground/Built-up areas/Rock outcrops	0.00 (0.00%)	0.25 (0.01%)	1447.04 (52.70%)
Wooded Savanna	254.92 (9.28%)	973.23 (35.44%)	0.00 (0.00%)
Waterbody	0.00 (0.00%)	1247.37 (45.43%)	819.18 (29.83%)
Grassy Savanna	1560.01 (56.81%)	354.89 (12.92%)	479.43 (17.46%)

*Values in parenthesis indicate percentage of land cover, measured in km²

Table 4: Area distribution of LULC classes in Bukkuyum for the periods of 1987, 2002 and 2020

Land use/land cover classes	1987 Km² (%)	2002 Km² (%)	2020 Km² (%)
Shrubby Savanna	1049.12 (32.64%)	110.76 (3.45%)	0.59 (0.02%)
Bare-ground/Built-up areas/Rock outcrops	0.00 (0.00%)	1.09 (0.03%)	389.02 (12.10%)
Wooded Savanna	384.87 (11.97%)	1080.19 (33.61%)	0.02 (0.00%)
Waterbody	0.01 (0.00%)	1629.07 (50.69%)	1765.46 (54.93%)
Grassy Savanna	1780.00 (55.38%)	392.89 (12.22%)	1058.92 (32.95%)

**Values in parenthesis indicate percentage of land cover, measured in km².*

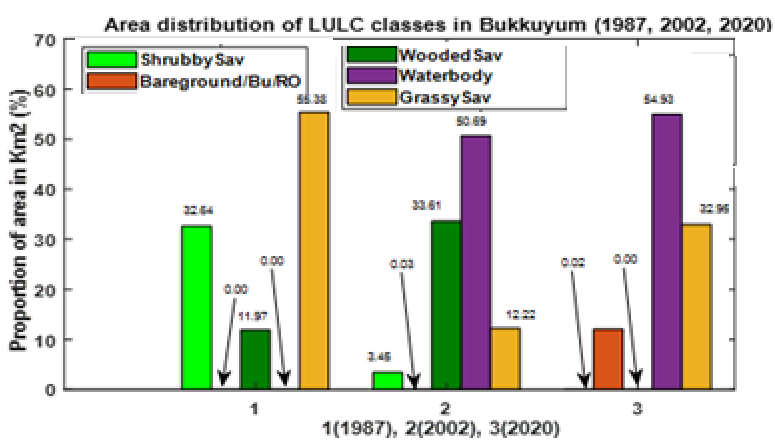

Fig. 5. Proportion in percentage of area distribution of LULC classes in Bukkuyum for the periods of 1987, 2002 and 2020.

Table 4 shows the area distribution of LULC classes for Bukkuyum mining area covering a land area of 3,214 km² for the periods that spanned 1987-2002 and 2002-2020 respectively. Grassy savanna and waterbody experienced a decreased in LULC changes from 26.87% between 1987-2002 to 0.00% between 2002-2020. This was followed by grassy savanna with a proportion of 24.92% between 1987-2002 to 3.56% between 2002-2020. The wooded savanna witnessed a decrease in LULC from 11.97% in 1987 to 0.06% in 2020.

Location 3: Maru mining enclave: The area distribution of LULC changes in Maru with a land area of 6,654 km^2 for the periods of 1987, 2002 and 2020 are tabulated in Table 5. The proportion in percentage of transition among the different classes of land covers are shown in Fig. 6.

Table 5: Area distribution of LULC classes in Maru for the periods of 1987, 2002 and 2020

Land use/land cover classes	1987 Km^2 (%)	2002 Km^2 (%)	2020 Km^2 (%)
Shrubby Savanna	17.65 (62.42%)	11.45 (40.49%)	3.57 (12.62%)
Bare-ground/Built-up areas/Rock outcrops	0.00 (0.00%)	1.72 (6.07%)	9.16 (32.41%)
Wooded Savanna	3.91 (13.83%)	9.57 (33.86%)	0.00 (0.00%)
Waterbody	0.00 (0.00%)	0.04 (0.13%)	0.00 (0.00%)
Grassy Savanna	6.72 (23.75%)	5.50 (19.45%)	15.54 (54.97%)

*Values in parenthesis indicate percentage of land cover, measured in km^2

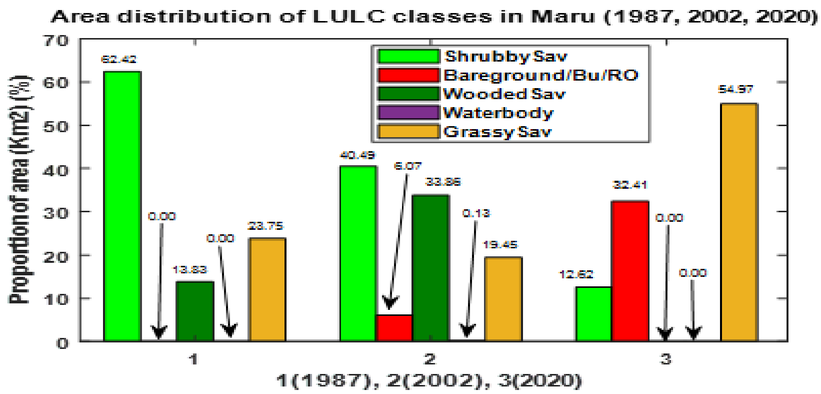

Fig. 6. Proportion in percentage of area distribution of LULC classes in Maru for the periods of 1987, 2002 and 2020. Table 5 shows the LULC transition classes for Maru for the periods of 1987-2002 and 2002-2020.

Transition C1-C5 changed the land covers from 1.32% between 1987-2002 to 22.09% between 2002-2020. This was followed by C3-C2 which changed from 12.62% to 17.46% during the period of 2002-2020. The loss of flora species during the periods under review was evident because a transition from one vegetation type to bare ground implied a loss of floristic areas. Bare ground/built-up areas expanded during the periods under review. Gold mining in the enclaves transformed the lands from eco-friendly to eco-harsh land types and the resultant habitat destruction has continued unabated.

Conclusion: This work represents a pioneering effort aimed to give a first-hand information on the land use/land cover dynamics of mining areas of Zamfara State, Nigeria. The study provides baseline data and area-specific information on the dynamics of LULC change in the gold mining enclaves, which is lacking in the literature, due to obvious reasons of locational insecurity of the mining enclaves and related factors. It also provides baseline information for future efforts on land reclamation and biodiversity management in the study settings.

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