Evaluation of Land Use/Land Cover changes due to gold mining activities from 1987 to 2017 using Landsat imagery, East Cameroon

Abstract

Gold mining activities began around 1934 at the artisanal stage and became semi-mechanized around 2004 in eastern Cameroon, with the emergence of exploration and mining companies in the region. This paper aims at monitoring Land Use and Land Cover (LULC) changes between 1987 and 2017 among Bétaré-Oya, Ngoura and Batouri Districts which are witnessing extensive gold mining activities, assessing the dynamics between LULC types and understanding the anthropogenic impact of gold mining activities during this period. A series of Landsat images acquired in 1987, 2000, and 2016/2017 were used to examine LULC change trajectories at per-pixel scale with the post-classification change detection techniques based on the matrix of changes. A supervised classification by the maximum likelihood algorithm composed of five classes – Bare land, Settlements, Water bodies, Vegetation and Mine activities, was designed for this study, in order to classify Landsat images into thematic maps. This research revealed spatio-temporal change patterns, various composition and rates among the three study areas. Also, it shows the strong appearance and emergence of mining activities between 2000 and 2017 are coupled with increase in settlement surfaces and major changes in environment in the study areas. The LULC change analysis over time for the study areas have provide the current change trends. This study stresses the usefulness of Landsat TM/ETM+ and Landsat Data Continuity Mission (LDCM) data and highlights the data processing methods for long-term monitoring of artisanal mining activities impacts on the environment. The findings gathered from this research should be used to influence policy, legislation and decision-making in the mining and environmental sector.
Keywords: Landsat imagery, LULC changes, artisanal mining, current change trends, Eastern Cameroon

1. Introduction

The mining industry has often been perceived negatively because it can be hazardous to both public health and the surrounding environment, including the land, soil, water, and forests at local, regional, and global levels (Choi and Song, 2016).

In Cameroon, mining has been one of the fundamental pillars of the economy for over a long time, and the metallurgical sector has experienced substantial growth since the vote in 2001 and amendment in 2010 of the new mining code (Tehna et al., 2015). Indeed, Cameroon is endowed with abundant mineral resources of international value, including gold, uranium, diamonds, iron ore, nickel, cobalt, rutile, nepheline, wolframite and bauxite (Gazel and Gérard, 1954; Laplaine, 1969, Asaah, 2010, Penaye and Hell, 2013) which as of now are generally been exploited by artisanal and semi-industrial miners in the eastern part of the country (Milesi et al., 2006; George, 2009). A large proportion of artisanal miners are unaware of the laws governing mining activities and the environment in Cameroon (Funoh, 2014).

From environmental point of view, artisanal gold mining is very destructive causing severe deforestation, land degradation, destruction of the forest ecosystem. Environmental damage occasioned, posing a serious threat by altering the landscape and total environmental ecosystem both on land and in coastal waters (Jaelani et al., 2018).

According to previous studies carried out over the last century, easrtern Cameroon including Bétaré-Oya, Ngoura and Batouri has been recognized as a higher gold zone grade in the country (Mbianyor Bakia , 2014; Vishiti et al. 2015). The alluvial gold found in the soils of this area has led to a significant mining activity dating back to the beginning of colonization. Mines operated by small-scale miners of Bétaré-Oya have deeply contributed to the local production (Tehna et al., 2015).

Several recent studies have also established the impacts of artisanal mining on the human health and environment (land and/or water) in eastern gold mining sites (Tetsopgang et al., 2015; Pahimi et al., 2015; Tehna et al., 2015; Djibril et al.; 2017; Edith-Etakah et al., 2017; Rakotondrabe et al., 2017; Manga et al., 2017; Ralph et al., 2018, Kamga et al., 2018) (Fig.1). However, no relevant maps focusing on evaluation of land degradation over time due to mining activities have been realized in this region using remote sensing and GIS technologies. Nowadays, these tools are very powerful to assess the extent and environmental impacts of mining activities on landscapes and also the key technology for monitoring land use changes (Turner et al. 2007). It is therefore crucial to produce maps showing the status, global extend and severity of mining-induced soil degradation in the main gold mining sites; Bétaré-Oya, Ngoura and Batouri Districts.

The primary objective of this research is to present the impact of mining on the dynamics of LULC changes in Bétaré-Oya, Ngoura and Batouri mining sites. More specifically, this research is aimed at using Landsat images of 3 years (1987, 2000 and 2016/2017), to map spatial distribution and expansion of land use patterns and to identify and assess land use changes from 1987 to 2017 due to these gold mining activities. These actions will contribute in reducing the impacts of gold artisanal mining activities on the environment and helps in the decision making for land management and conservation following the implementation of mining projects in the study areas.

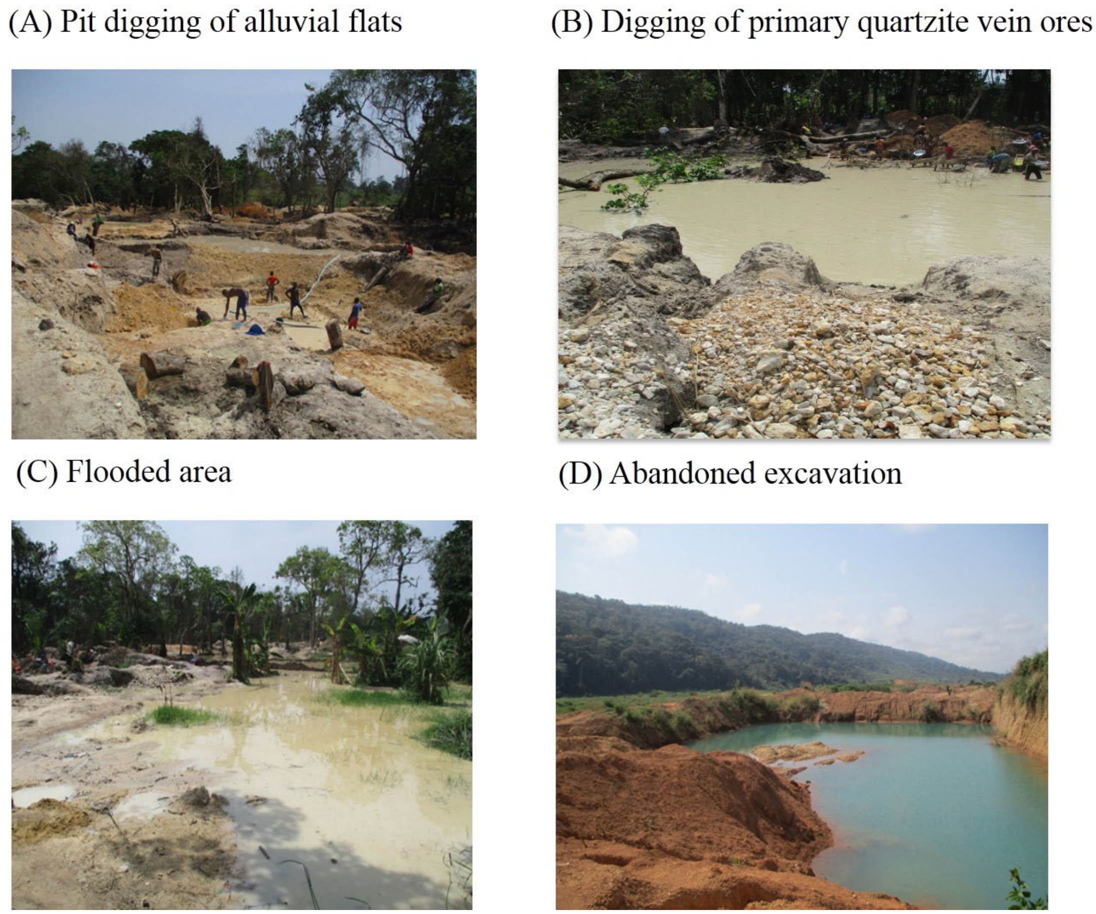

Fig. 1: Impacts of the gold mining activities on the environment in Eastern Cameroon

2. The study Area

The Eastern Region occupies the south eastern portion of the Republic of Cameroon (Fig.2). It is the largest of all ten regions covering a surface area of 109,011 km^2 and equally the most sparsely populated. The study area is located between 4°15'0"N and 6°0'0"N and 13°40'0"E and 14°40'0"E. It has a total area of about 9914 km^2 (Fig.2). The East region has a type A wet equatorial climate also known as a Guinea type climate. It experiences high temperatures of 24˚ C on average. The region is drained by several river channels: the Nyong, which drains the central-western area, the Dja in the southwest, the Lom in the northeast, the Kadey, which drains the northwest, the Boumba in the centre and southeast, and the Sangha and Ngoko, which drain portions of the southeast and form the border with the Central African Republic and Congo respectively. The Lom and Nyong rivers eventually empty into the Atlantic Ocean. All other rivers in the East form part of the Congo River basin. The different economic activities in the east region of Cameroon are Agriculture, hunting and gathering and industry. The vast majority of the inhabitants of the region are subsistence farmers. The major industry of the East is forestry and mining. The region has vast tracts of forest, and African and European companies have exploited these heavily.

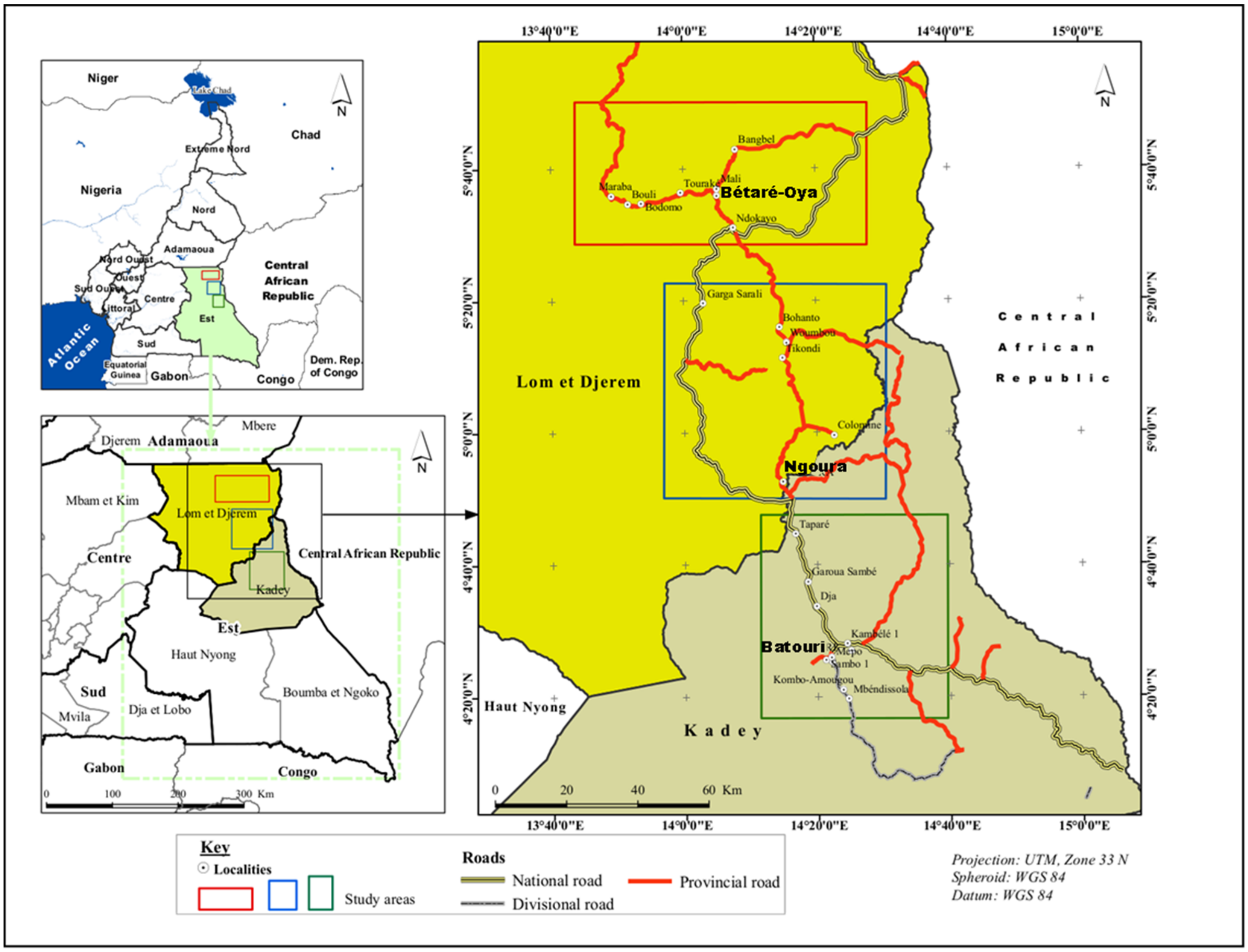

Fig. 2: Map of Cameroon showing the studied areas (modified after World Resources Institute, 2014)

3. Data/Methods

Landsat imagery have been providing multispectral images of the Earth continuously since the early 1970s. A unique 38-year data record of the Earth's land surface now exists (NASA 2000). These images can be freely downloaded from the website: [https://earthexplorer.usgs.gov/.](https://earthexplorer.usgs.gov/)

In this study, three scenes from sensors L5/TM5 (Thematic Mapper), L7/ETM+ (Enhanced Thematic Mapper Plus) and L8/DCM (Data Continuity Mission) of Landsat for each sector (Betare-Oya, Ngoura and Batouri) taken at the same period of the year and whose characteristics are summarized in Table 1 were used. The shooting period is in January (1987), February / March (2000) and January / February (2016/2017). Our choice was guided by the search for birthday images, good quality images and same phenological cycle, dry season. These Landsat images with the same spatial resolution (30 m) were used to map the main Land Use / Land Cover (LULC) categories, which include: vegetated areas, barren soil, water bodies, settlement and mine activity areas.

All images purchased and delivered with the Level-1 standard (L1TP) were already geometrically corrected and georeferenced to the WGS-84 datum and Universal Transverse Mercator zone 33N coordinate system. The software used for the Digital Image Processing (DIP) and analysis of the images are ERDAS IMAGINE 2014 and ArcGIS 10.2.

Table 1: Landsat data specifications

	Study Area	**Sensor**	**(Path/Row)**	**Year of acquisition**	**Date of image**
01	**Betaré-Oya**	TM	184/056	1987	Jan. 08, 1987
		ETM+	184/056	2000	Feb. 05, 2000
		LDCM	184/056	2017	Feb. 11, 2017
02	**Ngoura**	TM	184/056 184/057	1987	Jan. 08, 1987 Jan. 24, 1987
		ETM+	184/056 184/057	2000	Feb. 05, 2000 Feb. 05, 2000
		LDCM	184/056 184/057	2016/2017	Jan. 08, 2016 Feb. 11, 2017
03	**Batouri**	TM	183/057 184/057	1987	Jan. 01, 1987 Jan. 24, 1987
		ETM+	183/057 184/057	2000	Feb. 05, 2000 Mar. 01, 2000
		LDCM	183/057 184/057	2016	Jan. 01, 2016 Jan. 08, 2016

To prepare the input satellite images for further processing (classification and change detection procedures), the following pre-processing steps were performed: mosaicking, radiometric calibration and Image-to-image registration. The images need to be as comparable as possible in terms of geometric and radiometric qualities.

The images of each year for Ngoura and Batouri were mosaicked to generate new images covering the entire study areas. For this purpose, the mosaicPro tool (in Erdas Imagine software) based on georeferenced images was used.

Radiometric calibration was performed on the images, in order to reduce differences caused by changing illumination conditions and instrument errors (Chander et al., 2009)

Image-to-image registration method (1987, 2000, 2016 images registered based on 2017 image) was conducted to match the images. Each of the TM/ETM+/LDCM dataset was clipped to the extent of study.

Mapping and analysis of spatial distribution and expansion of LULC patterns

In this study, four LULC types were identified: vegetated areas, bare land, water bodies, settlement and mine activity areas (Table 2). Based on these LULC classes identified, tens representative pixels for each LC class were digitized on the images for each year. Based on three false colour composites (4-3-2, 7-4-3 and 4-5-3 bands, for RGB channels) and field knowledge, a signature, which contains the statistical information of the pixels within each training site was development using six bands (1-5 and 7 for TM/ETM+; 2-7 for LDCM), the thermal bands (6 for TM/ETM+; 10 and 11 for LCDM) being insignificant for the classification. After a satisfactory review of the signatures, they were classified using the maximum likelihood algorithm. Google Earth Pro (GE Pro) completed by visually comparing with 30 m three-band standard false colour composites of Landsat TM/ETM+/LDCM were employed as reference data in accuracy assessment of our classifications. However, using data having medium-spatial resolution such as that of Landsat, mixed pixels are a common problem (Lu and Weng, 2005); especially for the urban surfaces that are a heterogeneous mixture of features mainly including man made, grass, soil, water, mine sites.

The analysis of spatial distribution and expansion of LULC patterns was based on the presentation of the 1987, 2000 and 2016/2017 respective statistics in terms of the total area of each land cover category. The method consisted of calculation of area in square kilometre of the resulting land cover types for each study year.

Change detection of LC spatio-temporal from 1987 to 2016/2017

Following the classification of imagery from the individual years, a post-classification approach of subtracting the classification maps, 2000 – 1987 and 2016/2017 – 2000 was applied. Quantitative areal data of the overall land cover changes as well as gains and losses in each category between 1987 and 2017 were compiled.

Additionally, post-classification change detection techniques based on the matrix of changes generated by the intersection of the 1987, 2000 and 2016/2017 LULC maps was applied to Landsat images.

Table 2: Description of Land Use/ Land Cover classes in the study area

Class	Description
Bare Land	Land areas of exposed soil surface as influenced by human impacts and/or natural causes. Also, it includes areas with human-induced effects that result in exposing soil surface layers and/or changes in topsoil as well as areas with active excavation and mining.
Settlements	This includes areas with human settlements as seen with ground trothing. Also, it includes small area of mining activities as mining activities have been seen to influence settlements in certain localities.
Water bodies	This includes area covered by water bodies such as streams, rivers and dam.
Vegetation	The vegetation of the study area can be classified into nine life forms: annuals, perennial grasses, perennial herbs, evergreen succulent perennial sub-shrubs, evergreen non-

	succulent perennial sub-shrubs, partially deciduous perennial sub-shrubs, evergreen succulent perennial shrubs, evergreen non-succulent perennial shrubs and deciduous perennial shrubs. (Kasparek, 1993) and cultivated area with annual crops, vegetables, or fruit (Shalaby and Tateishi, 2007).
Mine Activities	These include the areas where mining activities are going on different scales.

4. Results and discussions

4.1. Spatial distribution and analysis of the evolution of LULC patterns in Bétaré-Oya district

Spatial distributions of the different LULC patterns, for 1987, 2000 and 2017 in Bétaré-Oya are displayed in Figure 3 (a–c).

The analysis of changes in LULC in the study area is based on the 1987, 2000 and 2017 maps and their respective statistics. A cross of the three maps will provide a matrix that will reflect the evolution of the different classes between these three dates.

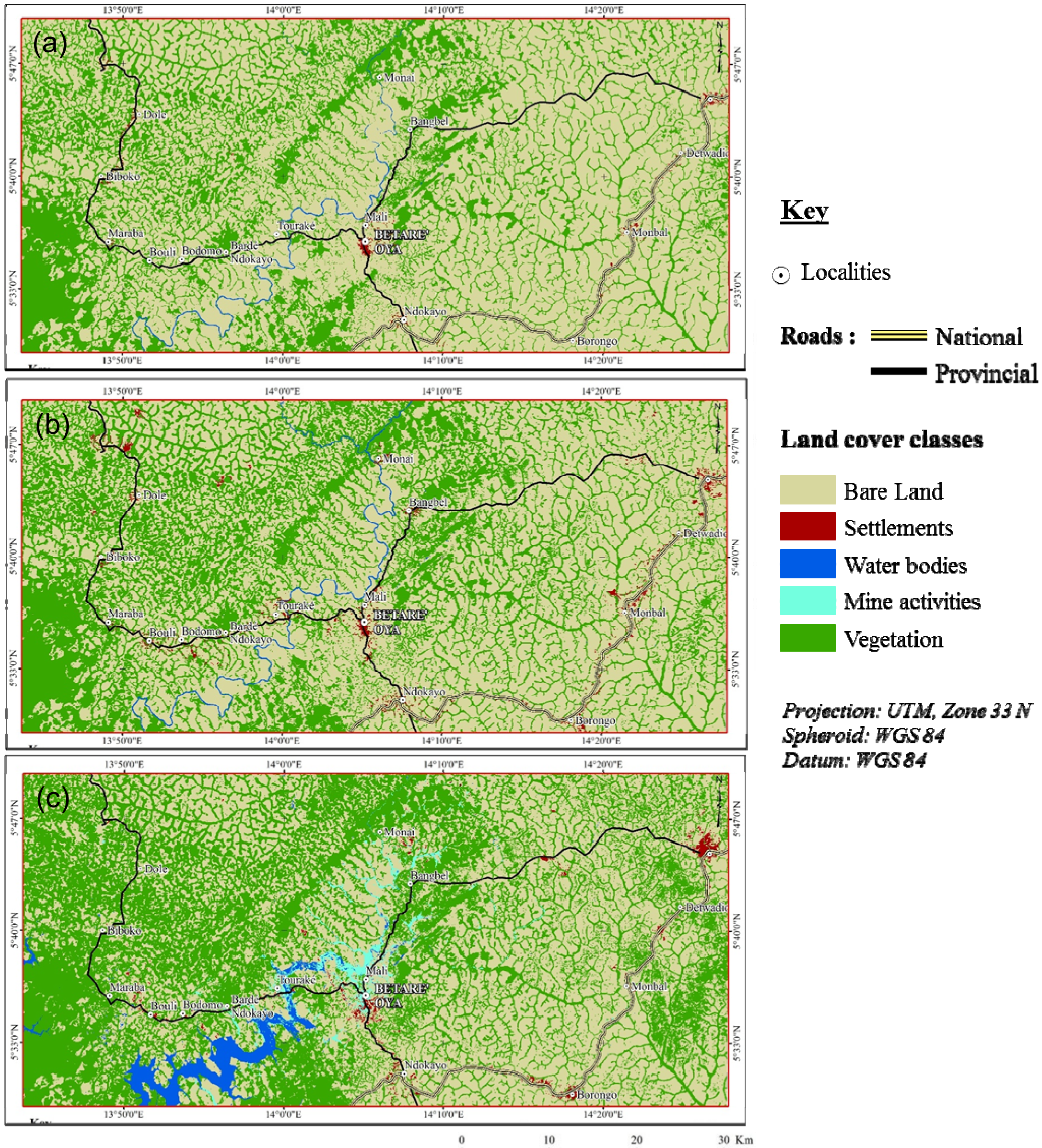

Fig. 3: Spatial distribution of LULC patterns in Bétaré-Oya district; (a) 1987, (b) 2000 and (c) 2017

In 1987, LULC of the study area were largely dominated by areas of bare land (Fig. 4, Table 3); the vegetation was also observed. In total, the classes are distributed as follows: bare land areas cover an area of 2216.84 Km^2 (70.46 %) of the study area, vegetation occupies about 915.64 Km^2 (29.10 %), settlements areas cover 7.53 Km^2 (0.24 %) and water bodies cover 6.03 km^2 (0.19 %).

In 2000, the study area is still dominated by areas of bare land (Fig. 4, Table 3). In total, the classes are distributed as follows: bare land areas cover an area of 2265.37 Km^2

(72.01%), vegetation occupies about 853.96 Km^2 (27.14 %), settlements areas cover 19.24 Km^2 (0.61 %) and water bodies cover 7.48 km^2 (0.24 %).

In 2017, the classes are distributed as follows: bare land areas cover an area of 1899.9 Km^2 (60.38 %), vegetation cover an area of 1062.8 Km^2 (33.78 %) of the study area, settlements areas cover 32.96 Km^2 (1.05 %), water bodies cover 69.31 km^2 (2.20 %), and mining sites occupies about 81.46 Km^2 (2.59 %).

The percentage area of different LULC in Bétaré-Oya district derived from the current analysis shows that bare lands are largely vegetated. The expansion of areas subjected to mining activities in this district is obviously confined to the period post-2000. This finding is in line with earlier reports sated that the mining activities in the region have been intensified during the 2000s of the last century. This agreement emphasizes the importance of remote sensing for monitoring the LULC changes, and in particular those changes related to mining activities. The mining sites are located in areas northern to Bétaré-Oya city, and they seem to be located in areas occupied earlier by vegetation and bare lands.

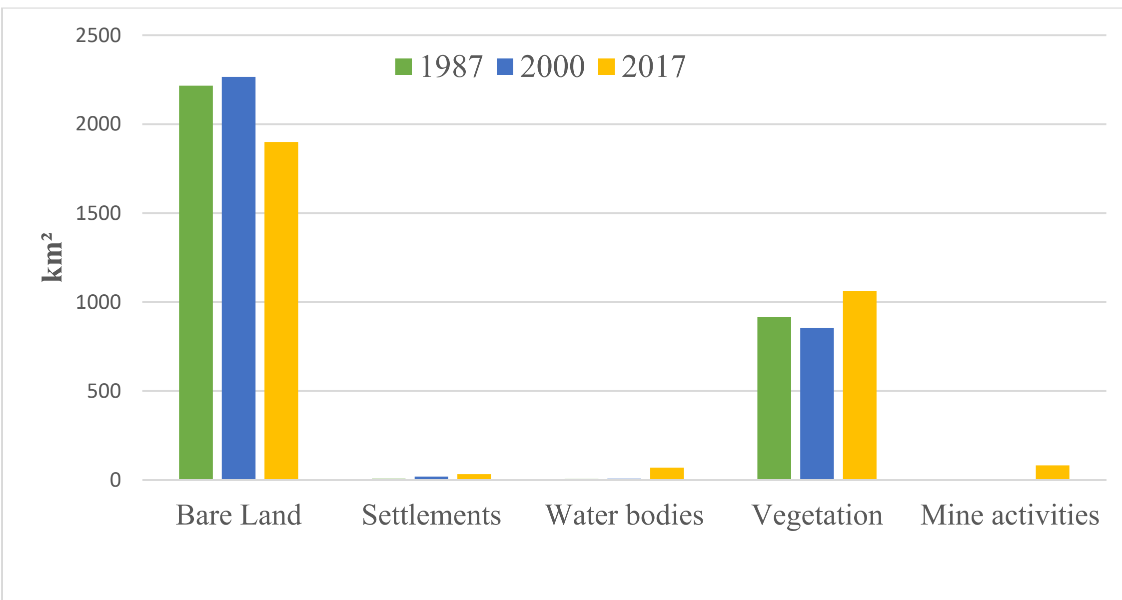

Fig. 4: Bar chart representing the LULC changes in 1987, 2000 and 2017 in Bétaré-Oya district

Table 3: Area and amount of change in different land cover categories in the Bétaré-Oya district during 1987 to 2017

Land cover categories	1987		2000		2017		1987-2000		2000-2017	
	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%
Bare Land	2216.84	70.46	2265.4	72.01	1899.9	60.38	48.52	1.55	-365.51	-11.63
Settlements	7.53	0.24	19.24	0.61	32.96	1.05	11.71	0.37	13.72	0.44
Water bodies	6.03	0.19	7.48	0.24	69.311	2.20	1.45	0.05	61.83	1.96
Vegetation	915.63	29.10	853.96	27.14	1062.8	33.78	-61.67	-1.96	208.80	6.64
Mine activities	-	-	-	-	81.46	2.59	-	-	81.46	2.59

4.*2.* Spatial distribution and analysis of the evolution of LULC patterns in Ngoura district

Spatial distributions and expansion of LULC patterns for 1987, 2000 and 2017 in Ngoura are displayed in Figure 5 (a–c).

As done in the last analysis on the Bétaré-Oya district, the analysis of changes in LULC in Ngoura district was based on the presentation of the 1987, 2000 and 2017 maps and their respective statistics. A cross of the three maps will provide a matrix that will reflect the evolution of the different classes between these three dates.

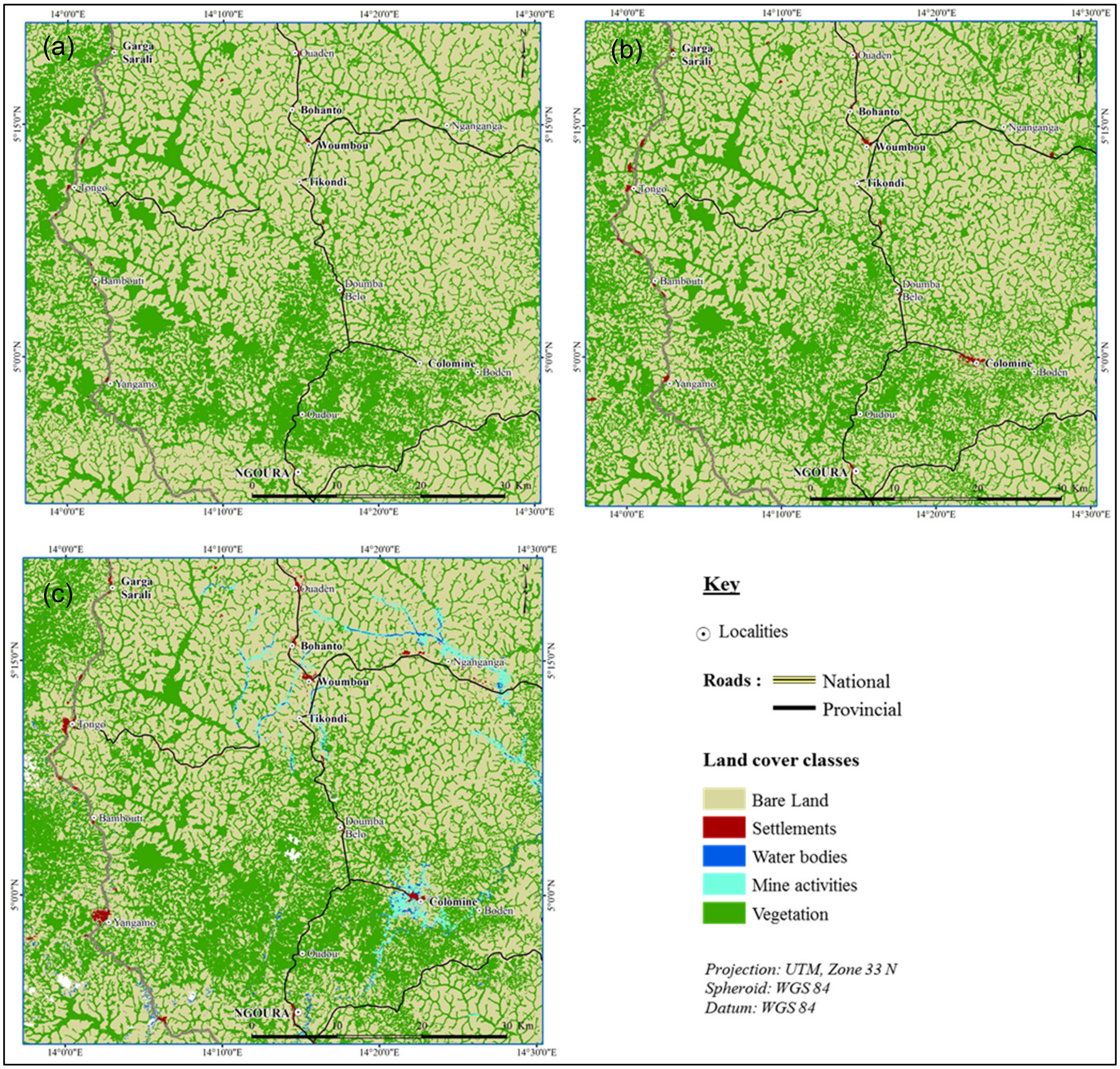

Fig. 5: Spatial distribution of LULC patterns in Ngoura district; (a) 1987, (b) 2000 and (c) 2017

In 1987, LULC of the study area were also largely dominated by areas of bare land (Fig. 6, Table 6) followed by the vegetation land cover. In total, the classes are distributed as follows: bare land areas cover an area of 2590.96 Km^2 (69.02 %), vegetation occupies about 1161.70 Km^2 (30.94 %), and settlements areas in the district represent only minor area of 1.46 Km^2 (0.04 %). Unlike Bétaré-Oya and Batouri, water bodies are not widely spread in Ngoura strict.

In 2000, the study area is still dominated by areas of bare land (Fig. 6, Table 4). In total, the classes are distributed as follows: bare land areas cover an area of 2606.392 Km^2 (69.42 %), vegetation occupies about 1139.25 Km^2 (30.35 %), settlements still poorly represented with areas cover 8.54 Km^2 (0.23 %), and water bodies cover 7.48 km^2 (0.24 %).

In 2017, the classes are distributed as follows: bare land areas cover an area of 2564.92 Km^2 (68.52 %), vegetation cover an area of 1130.036 Km^2 (30.19 %), and settlements areas cover 12.24 Km^2 (0.33 %). The mining activity with the cutting of trees favoured the highlighting of some water surfaces; water bodies cover 6.16 km^2 (0.16 %), and mining activities is less intense in Ngoura district; it occupies about 29.76 Km^2 (0.80 %).

These results draw a same conclusion such as that derived from Bétaré-Oya district on the recent introduction of mining activities Ngoura. However, their extent is much less than that observed in Bétaré-Oya district with an area percentage of only 0.8% compared to 2.59% during the period 2000-2016 in the two districts, respectively.

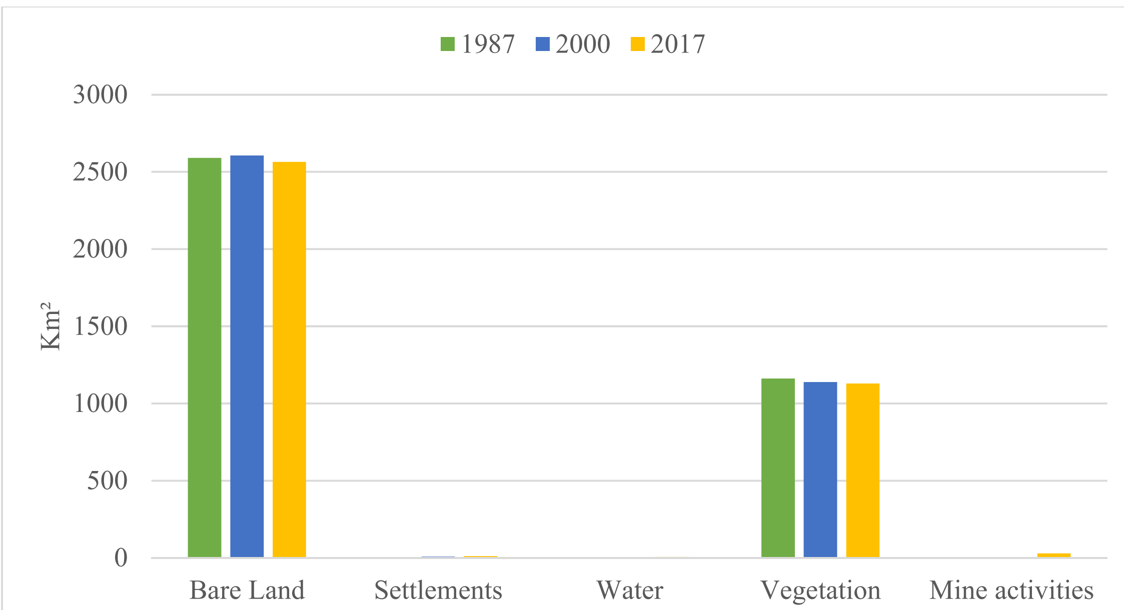

Fig. 6: Bar chart representing the LULC changes in 1987, 2000 and 2017 in Ngoura district

Table 4: Area and amount of change in different land cover categories in the Ngoura district during 1987 to 2017

Land cover categories	1987		2000		2017		1987-2000		2000-2017	
	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%
Bare Land	2590.96	69.02	2606.392	69.42	2564.92	68.52	15.44	0.41	-41.48	-0.90
Settlements	1.46	0.04	8.54	0.23	12.24	0.33	7.08	0.19	3.70	0.10
Water bodies	-	-	-	-	6.16	0.16	-	-	6.16	0.16
Vegetation	1161.70	30.94	1139.25	30.35	1130.04	30.19	-22.44	-0.60	-9.22	-0.16
Mine activities	-	-	-	-	29.76	0.80	-	-	29.76	0.80

4.3. Spatial distribution and analysis of the evolution of LULC patterns in Batouri district

Spatial distributions and expansion of LULC patterns, for 1987, 2000 and 2016 in Ngoura are displayed in Figure 7 (a–c).

The analysis of changes in LULC is based on the presentation of the 1987, 2000 and 2016 maps and their respective statistics. A cross of the three maps will provide a matrix that will reflect the evolution of the different classes between these three dates.

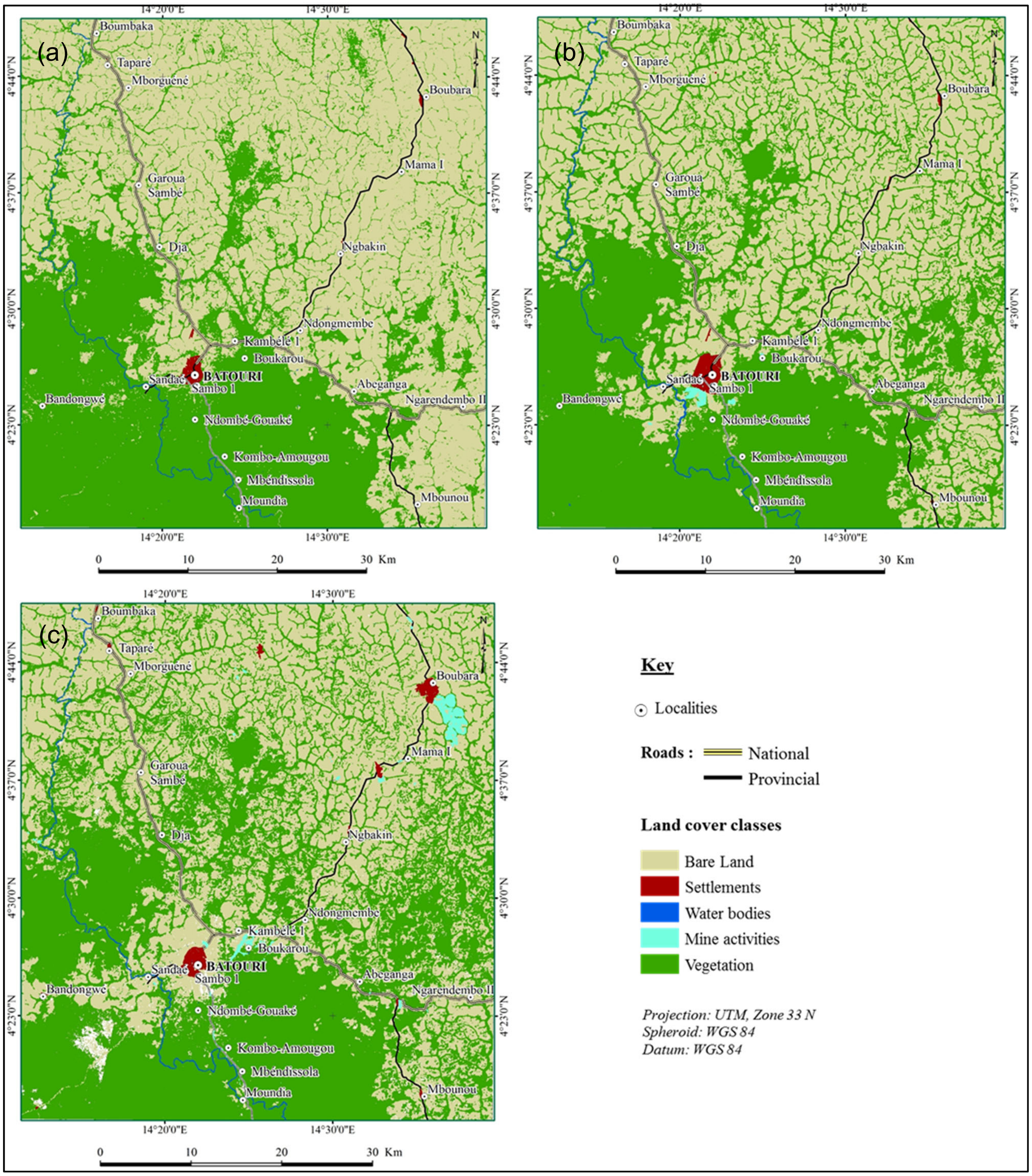

Fig.7: Spatial distribution of LULC patterns in Batouri district; (a) 1987, (b) 2000 and (c) 2016

In 1987, contrary to Bétaré-Oya and Ngoura Districts, LULC of Batouri district were dominated by areas of vegetation (Fig. 8, Table 5) and followed by the bare land areas. In total, the classes are distributed as follows: bare land areas cover an area of 1412.10 Km^2 (44.86 %), vegetation occupies about 1723.80 Km^2 (54.76 %), and settlements areas cover 5.58 Km^2 (0.18 %). The Kadey's river and its tributaries drain the study area, and the water bodies cover 6.53 Km^2 (0.21 %). In this area, no mining activity is identifiable on our images.

In 2000, the study area was now dominated by areas of bare land (Fig. 8, Table 5). In total, the classes are distributed as follows: bare land areas cover an area of 1742.86 Km^2 (55.48 %), vegetation occupies about 1378.99 Km^2 (43.90 %). We observe an increase of settlement areas due to the search of gold by the local population and mining companies, this class covers 13.29 Km^2 (0.42 %), water bodies coveraround 6.22 km^2, or 0.20 %, and the observed mining activities covers 6.62 Km^2 (0.22 %) of the area.

In 2016, the classes are distributed as follows: bare land areas cover an area of 1597.98 Km^2 (50.77 %) of the study area, vegetation cover an area of 1506.99 Km^2 (47.87 %). A continuity in the setting up of the houses with settlements areas cover 15.96 Km^2 (0.51 %). A significant mining activities is also observed; it occupies about 20.93 Km^2 (0.67 %). Water bodies covers 5.92 km^2 (0.19 %) area.

In Batouri district, bare land covers lesser portion compared to Bétaré-Oya and Ngoura. The mining activities in this district are concentrated mainly near Batouri and Boubara cities. Compared to Bétaré-Oya and Ngoura, mining activities in Batouri seems to be started during the period 1987-2000, with an area percentage of 0.21%. The mining activities were increased during 2000-2017 to cover around 0.45% of the total area of this district. The expansion of mining sites in Batouri seem to be on the expenses of vegetation during 1987-2000 and on the expense of bare lands during 2000-2016.

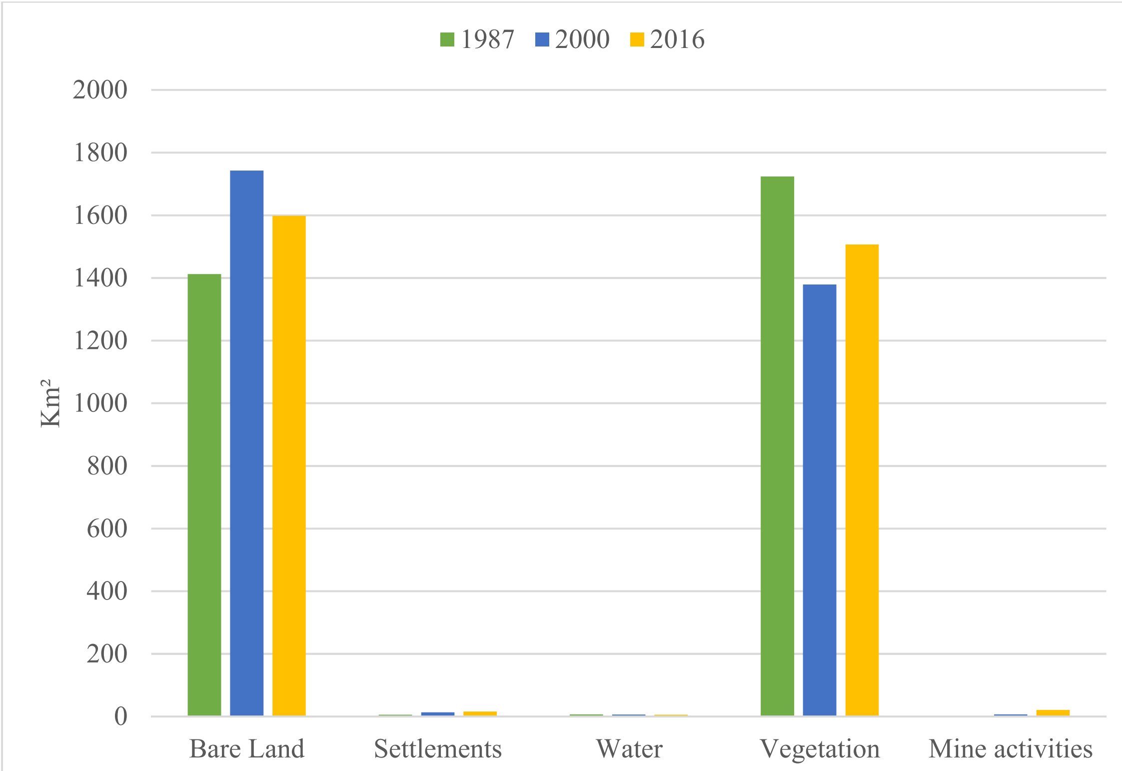

Fig. 8: Bar chart representing the LULC changes in 1987, 2000 and 2016 in Batouri district

Table 5: Area and amount of change in different land cover categories in the Batouri district during 1987 to 2016

Land cover categories	**1987**		**2000**		**2016**		**1987-2000**		**2000-2016**	
	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%	Area (Km^2)	%
Bare Land	1412.10	44.86	1742.86	55.48	1597.98	50.77	330.77	10.50	-144.88	-4.60
Settlements	5.58	0.18	13.29	0.42	15.96	0.51	7.71	0.24	2.67	0.08
Water bodies	6.53	0.21	6.22	0.20	5.92	0.19	-0.31	-0.01	-0.31	-0.01
Vegetation	1723.80	54.76	1378.99	43.90	1506.99	47.87	-344.80	-10.95	127.99	4.07
Mine activities	-	-	6.62	0.22	20.93	0.67	6.62	0.21	14.31	0.45

5. Conclusion

This study presents the contribution of Landsat imagery to the understanding of the influence of mining activities on the mutations observed in the environment of Bétaré-Oya, Ngoura and Batouri districts, Eastern Cameroon. The suppervised classification with maximum likelihood technique allowed mapping of LULC status in the study areas between 1987 and 2016/2017. This mapping of LULC revealed some modifications with an increase in human settlements, and the development of artisanal mining activity at the expense of vegetation. The growing interest of the people in the exploitation of gold is the main cause of the environmental transformations of these rural areas. The study areas have undergone significant changes in LULC as a result of development projects in the mining or agricultural sector. A considerable increase in mining activities has taken place as well as a considerable increase in the number of settlements. Natural vegetation declined significantly between 1987 and 2000, but appears to have been slightly reduced between 2000 and 2017, possibly due to growth in agricultural activities. Landsat TM / ETM + and LDCM images favored the diachronic analysis of change. To properly measure the magnitude of these changes in the LULC, further studies on a larger scale, with accurate and exploitable data on these sectors, should be conducted. Government should be more concerned and committed to the sustainability of the physical environment in both the rural and urban areas and not only the sustainability and survival of the economy in the eastern part of Cameroon. Conclusively, one of the viable, innovative and sustainable vision this article is proposing to African governments facing the problem of management and profitability of degraded areas due to the exploitation of mineral resources is to promote and encourage youth to invest in agro-pastoral activities at large scale. This will foster the migration from a traditional (small-scale) land economy to a more profitable modernized economy whose products could be exported beyond national borders.

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