Geospatial Analyses of Mining-Induced Land Degradation Sites in Jos South Local Government Area, Plateau State-Nigeria

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Keywords: Geospatial Analyses, Land Degradation, Land Use Land Cover (LULC), Mining Environment, Terrain

SUMMARY

The degraded areas within and around mining sites have raised some serious issues of great concern to the environment. Some of the major geospatial issues are the accurate delineation and usefulness of the degraded sites, and the nature of the terrain in relation to the degradation. This study thus analysed the geometrical characteristics of mining-induced land degraded areas of the Jos South LGA of Plateau State-Nigeria. The degraded sites of the study area were assessed using multi-sensor satellite imageries of Landsat 8 (2016), SPOT 5 (2012), and Quickbird-2 (2010). The onscreen digitization of the land degraded areas was carried out using the Quickbird-2 satellite imagery which was followed by the Maximum Likelihood Supervised classifications of land cover and land degradation features using the Landsat 8 and SPOT 5 imageries to determine the area of land that had been affected by mining-induced activities. The results of the study revealed that there were 235 land degraded sites with a total area of 11.58km² and covering about 2.26 % of the study area. The study also showed that the degraded sites were classified into 13 classes based on their usage (Active Mine sites, Agricultural Usage, Dormant, Fencing, Fish Stocking,

Inundated seasonally, Irrigation, Ownership, Partial inundation, Resort Centre, Tree planting, Waste dumps/Tailings, and Water treatment). The results of the Land Use Land Cover (LULC) classification revealed a total land cover of 512.10km^2 with mine ponds occupying about 10.01km^2. It was however suggested that certain land uses such as block industries, water treatment plants, and fish farms should be sited around the seasonally inundated mine pond, as well as the implementation and enforcement of the existing mining laws at all levels to safeguard the environment.

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1. INTRODUCTION

Land is one of the greatest tangible assets and foremost natural resource, but not a resource that automatically renews itself just like rainfall or sunlight, nor is it a simple commodity that can be warehoused and replaced, destroyed and redesigned, or recycled the same way as factory-made goods. The Food and Agricultural Organization (FAO) described the land as an area that can be delineated, including all features of the biosphere immediately above or below the earth surface, comprising the soil, terrain, surface hydrology, the near-surface climate, sediments, and associated groundwater reserve, the biological resources, as well as the human settlement pattern and infrastructure resulting from human activity (FAO, 2015). Additionally, the International Labour Organisation (ILO, 2007) reported that a major function of land to man is, agricultural activities that are carried out on it; this includes the food we eat and also provide the principal basis of living to 36% of the world`s total workforce. Land that suffered from man`s activities may be described as spoiled or degraded, disturbed or devastated, derelict, or damaged (Henssen, 2014). One of the major threats to the land is degradation because it destroys land resources (Christopher, 2015).

Degradation signifies a 'reduction to a lesser rank'; reduction denotes a problem emanating from the land usage, whereas the rank is a gauge to quantify the problem (Piers and Harold, 2015). Among other things, the output on degraded land is lesser than that on the same land short of degradation. Therefore, degradation is a result of several forces, rather than a one-way path; it is a product of an equation (see Eqn. 1), where both human and natural factors bargain a place (Piers and Harold, 2015):

$$Net\ degradation = (natural\ degrading\ processes + human\ interference) - (natural\ reproduction + restorative\ management) \quad \text{(Eqn. 1)}$$

The term degradation is perceptual and denotes at least a 'rank' scale of relative measurement. As a perceptual term, however, it is open to multiple understandings. To a hunter or herder, the replacement of forest by grassland with a greater capacity to carry ruminants would not be perceived as degradation; nor would forest replacement by agricultural land be seen as degradation by a settling farmer. Degradation is a perceptual term; hence it has diverse formations such as forest, soil, land, water, vegetation, and environmental degradations (Piers and Harold, 2015). Degradation can also be described as the consequence of physical, chemical and biological shifts determined by environmental, social, and economic forces (United Nations Environmental Program [UNEP], 1992). It thus covers the various forms of soil degradation, adverse human impacts on water resources, deforestation, and lowering of the productive capacity of rangelands.

Leonard *et al.*, (1989) as cited in Maiangwa *et al.*, (2007) reported that some studies show that nearly 80% of rangeland and dryland forest areas, 30% of tropical forests and around 50% of all irrigated cropland in developing countries are classified as degraded. However, Ravishankar and Sreenivas (2015) testified that there are several methods in which land degradation emerges: these comprise water erosion, wind erosion, waterlogging; acidification, and anthropogenic (mining, brick kiln, and industrial effluent-affected areas).

Mining and its subsequent activities have been found to degrade the land to a momentous amount (Sahu and Dash, 2011). Nevertheless, of these processes, the most noticeable in Jos South is the degradation owing to mining activities. Proper mining started on the Jos Plateau as far-off as 1902 for Tin and Columbite as the foremost targets (Gyang and Ashano, 2009). Some of these mining activities commonly referred to as informal or artisanal mining activities are still being carried out extensively in the study area. Mining exploration and exploitation, and the processing of tin ore known to be associated with the alluvial sediments have left behind numerous ponds, lotto, and mining pits, as well as heaps of mine waste in the study area. This harmful impact also comprises land degradation, mutilation of natural landscape and vegetation, erosion of soils, and degrading water quality. There are also problems of devastated, derelict lands and mine spoils depriving the inhabitants of fertile farmland in the study area. This is evident by the physical appearance of mining ponds, pollution by poisonous metals, erosions, and waterlogging in the area.

Related researches have been carried out in the past (Jonathan and Joshua, 2013; Edun and Davou, 2013; Adedeji *et al*., 2014; Igbokwe *et al*., 2008; Haruna and Solomon, 2011). These research attempts mostly centred on the assessment of the effects of post-mining activities and gully erosion on the environment. Major issues such as how accurate are the degraded sites being delineated; the features of the degraded sites and their economic values; the relationship between the nature of the terrain, and the degradation have yet been adequately addressed. Moreover, most of these research attempts were based on pixel-based supervised classification rather than delineation; these might have resulted in poor or mixed pixel classification, and the possibility of inaccurate delineation because of the lower resolution of satellite imageries used (Graw *et al.*, 2015). Therefore, this study focuses on the analyses of the geometrical characteristics of mining-induced land degraded areas of the Jos South LGA of Plateau State-Nigeria. This is achieved through the delineation and classification, and determination of the usefulness of the degraded areas in the neighbourhood of the mining sites.

1.1 Study area

Jos South Local Government area covers a total area of 512 km². It lies between Latitude (9°34'22" and 9°54'40") N of the Equator and Longitude (8°39'55" and 8°59'13") E of the Prime Meridian, and with an average altitude of about 1280m above sea level. The area is bounded in the Northwest by Bassa LGA, in the North by Jos North LGA, in the East by Jos East LGA, in the Southeast by Barkin Ladi LGA and Riyom LGA in the Southwest (see Figure 1). The National Population census projected figure of the area was 407,9500 as of March, 2016 (Brinkhoff, 2017). The human population density of the area stands at 778 inhabitants/km². It has a cool climatic condition known as mountain climate, due to its altitude. November to February is normally the peak of cold period whereas March and April are a warm period before the onset of rain, with 18°C being the average mean daily temperature, reaching up to 36ºC. The mean annual rainfall ranges from 1347.50 to 1460.00 mm in a year (Dawen, 2012). Northern Guinea Savannah vegetation is found in the area with the availability of trees such as Eucalyptus, Mangoes, Shrubs and other grasses. Agricultural activities also take place in the area especially near some inundated mine ponds (Dawen, 2012). The Berom are the largest ethnic group in Jos South LGA in Plateau State, with Hausa Fulani, Yoruba, Igbos, and other tribes believed to have settled in the area during the mining boom. Farming is still taking place, with maize, yam, cocoyam, sweet and Irish potatoes, Guinea corn and millet being the major crops cultivated. A variety of vegetables such as onions, cabbage, green pepper, carrots, cucumber peas, etc. are also being cultivated (Mackey *et al.*, 1949).

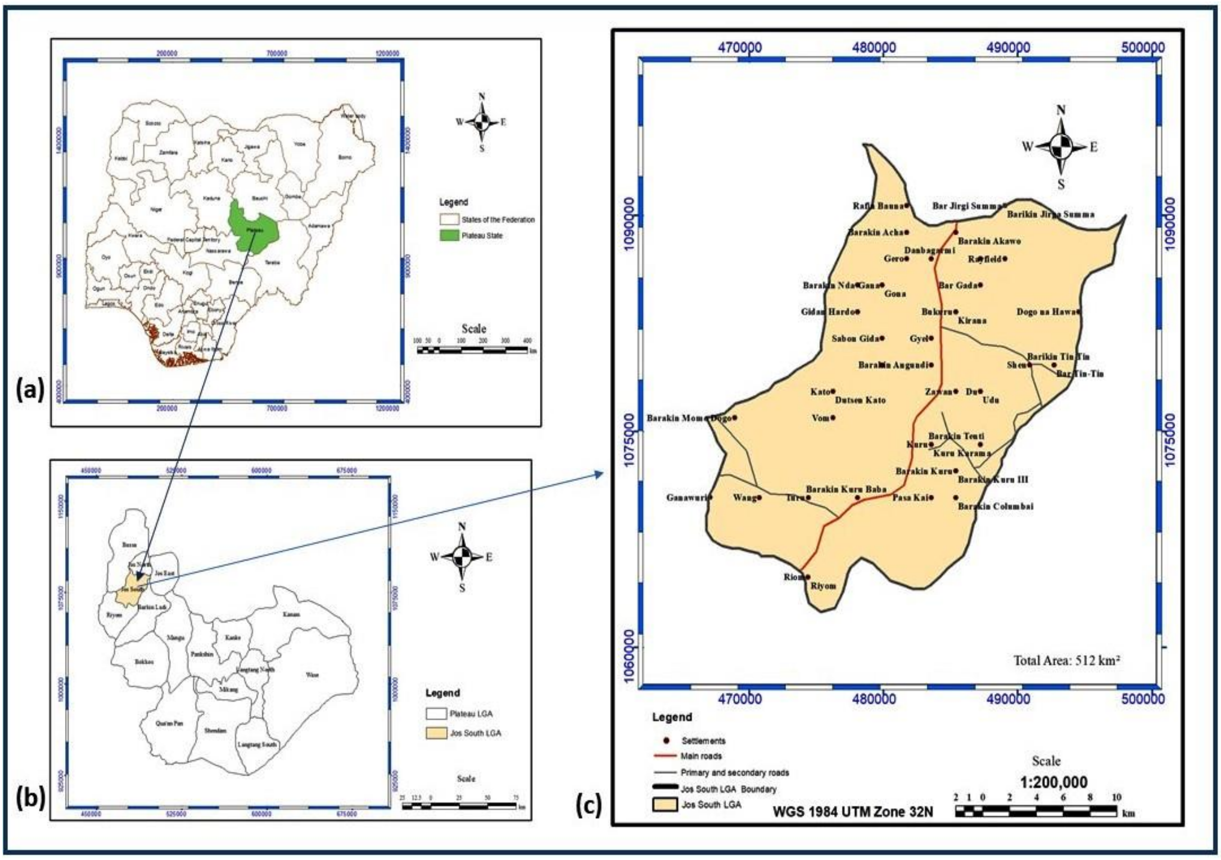

Figure 1: Study Location: (a) Nigeria (b) Plateau State (c) Jos South LGA (Bala, 2018)

2. MATERIALS AND METHODS

2.1 Materials

The software used in this study include the WinRAR version 3.7, MapSource, ERDAS Imagine 9.2, ArcGIS 10.4.1, and Microsoft office processing tools (Excel and Word) 2016. The equipment, tools and devices used for the fieldwork include the Garmin Handheld GPS (76CSX) receiver, a topographic sheet of the study area, digital camera, a two-metre measuring tape, and field record book.

2.2 Methods

The reconnaissance survey and field familiarisation of the study area were carried out as the first step of the research. The workflow diagram in Figure 2 is in three sections according to the stages adopted. The first stage entailed data collection (the process of acquiring data necessary for the research). The pre-processing and correction for errors of both the SPOT 5 and Landsat 8, were then carried out, trailed by layer stacking and merged resolution. Ground truthing and signature extraction were then carried out prior to the supervised maximum likelihood classification of the imagery, and the accuracy of the classification was assessed. The second stage was the pre-processing and correction for errors, mosaicking, subsetting and layer creation of high-resolution Quickbird-2. This was followed by on-screen digitisation of the degraded sites. The final products were the maps of the degraded sites together with analyses of their attributes.

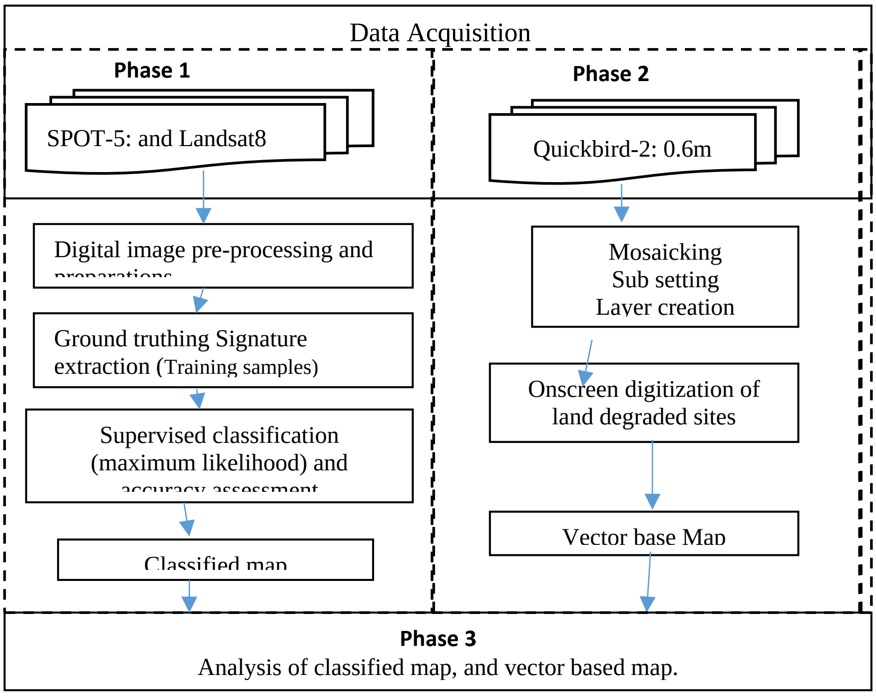

Figure 2: Methodology workflow diagram (after; Bala, 2018)

2.3 Data Sources

The datasets utilized in this study include remote sensing, ancillary data and numerous facilities, software, and tools (see Table1).

Table 1: Datasets and Sources

Data Name	Resolution	Data Date	Data Source	Purpose	Description
SPOT 5	2.5 m	7/12/2012	Office of the Surveyor-General of the Federation	Land degradation mapping and analysis	3 bands multispectral image: NIR, red and green

Landsat 8: OLI and TIRS	15, 30& 100m	11/2/2016	http://www.glovis.usgs.gov/	Collateral data for land degradation mapping	11 bands multispectral image acquired by OLI and TIRS
Quickbird image	0.6 meters	2010	National Centre for Remote Sensing, Jos	Data for polygonising the land degraded sites	3-band multispectral image: NIR, red and green.
Nigeria administrative map (Shapefile)	-	-	National Centre for Remote Sensing, Jos	To demarcate the study area	Jos South local government boundary shapefile
Google Earth Pro 7.1.2 2041 imagery	Variable resolution	2016	http://www.google.com/earth/download/ge/agree	Ancillary data for land cover mapping	Quick look mono-spectral image displayed over red, green and blue colour gun

2.4 Ground Truthing and Data Collection

Site visits and data collection were done in two phases: the reconnaissance survey, and the data collection for Ground truthing. Two days of exploratory reconnaissance field surveys were conducted. Firstly, to assess whether the areas degraded and devastated were worth studying, and secondly, to get familiarized with the general conditions in the area. Most of the places visited are areas affected by land degradation due to mining activities over time, and erosions. After the reconnaissance survey, ground-truthing was conducted in order to reconcile the features on the satellite imagery with the corresponding features on the ground.

In addition to the ground-truthing, at each degraded site, coordinates were observed and recorded. Photographs were taken during the field survey. The photographs were intended for satellite imagery interpretation, identification of land degraded sites and photographic evidence of land degradation in the study area. Some of these photographs were incorporated into the GIS database, geo-tagged to each degraded site.

2.5 Data Attribute Handling, Encoding, and Digitization of Degraded Sites

The coordinates of land degraded sites (abandoned mine and gully erosion sites) were downloaded using MapSource, imported into Microsoft Excel and exported to ArcGIS. These coordinates were used for two purposes: firstly, for on-screen digitization (polygonization) of the degraded site in the neighbourhood of the points and secondly, as samples for training maximum likelihood supervised classification of various degraded sites.

The adopted heads-up digitizing involves displaying the digital images from a satellite on a computer screen and drawing polygons around the land degraded site boundaries and classifying (labelling) them (Wang and Christiano, 2005). This method permits the interpreter to have a far-reaching control over how the degraded land is delineated and classified. On-screen digitization of degraded sites was carried out on top of the Quickbird-2 imagery in ArcGIS workspace. Thereafter, the polygons were classified.

2.5.1 Classification of degraded sites based on features

The Nigeria Erosion and Watershed Management Project (NEWMAP) criteria was adopted for the classification which is based on their functions. This is the criteria usually employed in carrying out ecological projects by the agency (NEWMAP, 2017); it is based on the rule of thumb, where each individual site was assessed based on its nature. The sites were characterised into agricultural, irrigational, recreational, fish stocking, inundated and fenced areas. The overall degradation rate was deduced using the formula (Adewuyi, 2009):

$$Overall\ Degradation\ Percentage\ = \frac{(Total\ Area\ Degraded)}{(Total\ Area)}\ x100 \qquad \text{(Eqn. 2)}$$

2.5.2 Mapping clusters of degraded sites

The Optimized Hot Spot Analysis and Getis Ord Gi* Hotspot Analysis tools in the ArcMap environment were used to analyse clustering, spatial distributions, patterns, and relationships between the degraded sites. Coordinates of each degraded site were used as the input features for the analyses. Fishnet polygons mesh of dimension 1km by 1km were overlaid on the incident point (coordinates of degraded sites) data and the number of incidents within each polygon cell of the study area were counted. The mathematical expressions for the Getis Ord General G statistical computations are stated in equations (Eqn.3), (Eqn.4) and (Eqn.5) respectively.

$$G_i^2 \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{x}\sum_{j=1}^{n} w_{i,j}}{s\sqrt{\frac{[n\sum_{j=1}^{n} w_{i,j}{}^2 - (\sum_{j=1}^{n} w_{i,j})^2]}{n-1}}} \qquad \text{(Eqn. 3)}$$

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \qquad \text{(Eqn. 4)}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \qquad \text{(Eqn. 5)}$$

Where:

x_i = the attribute value for feature j; w_{ij} = the spatial weight between feature i and j; n = total number of features.

2.6 Land Use Classification in the Neighbourhood of the Degraded Area

To relate the degraded areas to the neighbouring land use, land use classification in the neighbourhood of the degraded areas were carried out. Pre-processing of the imageries were carried out, followed by merge resolution of Landsat 8 and SPOT 5 imageries and the subsequent analyses to detect and map degradation features. Layer stacking was carried out for bands 1-7 and 9 of the Landsat 8, excluding bands, 8, 10 and 11. This is because band 8 is of 15-metre spatial resolution, whereas 10 and 11 are Thermal Infrared (TIR). Atmospheric correction was done on the SPOT 5 image to correct for atmospheric effect (clouds or haze). Image fusion was used for the improvement of Landsat 8 (30m) resolution with SPOT 5 (2.5 m) image (Olumide, 2007).

2.6.1 Image classification

In order to extract important information from the SPOT 5 and Landsat 8 multispectral images, the images were classified. The training sites corresponding pixels were selected and spread throughout the study area. In addition, Google Earth imagery of 2016 was used as ancillary data to give information and support interpretation of the latest degraded sites. The coordinates collected during the reconnaissance survey were plotted and appeared on different land cover and degraded sites on the merged imagery. The six (6) identified and selected classes are shown in Table 2.

A supervised classification was performed using the Maximum Likelihood Classification algorithm. It was chosen as a parametric (probability that a pixel belongs to a particular class) decision rule (Campbell, 2002). The Kappa statistic and the overall accuracy of the classification were assessed as described by Garba (2008).

Table 2: Adopted Land Classes

Training sample	**Code**	**Colour assign**	**Description**
Mine pond	1	Blue	Land surface occupied by stagnant water body without tributaries which are caused as a result of excavation/mining of earth material e.g. lake, waterlogged area.
Settlement	2	Red	Places where commercial, industrial, residential and government facilities are erected.
Bare exposed Rocks	3	Gray	Land consisting of rocky and stony materials.
Farmland	4	Lemon	Land occupied or related to agriculture or farming activities.
Bare degraded land	5	Yellow ish	A bare surface that consists of exposed excavated earth surface material with no vegetation. Open space and cleared area with no permanent water bodies.
Vegetation	6	Light green	Land consisting of shrubs and other vegetation which is not used for farming activities.

3. RESULTS AND ANALYSIS

3.1 Mining-Induced Land Degradation Sites

3.1.1 Land degradation as observed in the field

The detection of land degradation features is directly linked to the surface features affected by mining activities. The characterization of land degradation in the area was straightforward (based on field observation). One of the observable indicators of land degradation in the study area is the sign of extreme ponding and gullying, which is very prominent, exposing sub-surface areas. This could be due to excavation from mining activities and the topography of the area (Figure 4). There are huge deposits of mining wastes near some of the abandoned mine ponds, and logging of water for a relative period which affect the value and usefulness of the land, especially those for economic purposes. It was almost impossible to assess the depth of gully areas because of seasonal inundation in most of the sites. It was also observed that the removal of topsoil while mining for precious metals affected most of the surrounding agricultural fields, which resulted in land degradation. Inadequate rehabilitation and restoration after the closure of mining sites also led to the degradation of some sites while in other abandoned mined areas, thick eucalyptus trees were planted as a means of rehabilitation. The high altitude of the area and steep slopes make water erosion common, especially in the rainy season. It was observed that mining activities were still going on in some sites at the time of the visit (Figure 5).

Figure 4**:** Active Mining Site at Kuru Janta Mines (10/11/2015)

Figure 5**: S**earching for Tin and Columbite at the 'Rayfield' Resort Centre Site (03/06/2015)

3.1.2 Demarcation and delineation of degraded sites

A total mining-induced land degraded sites of 235 with a total area of 11.58 km² were delineated and classified based on their usages, functions, features and economic potentials. The results produced indicated that most of the sites are seasonally inundated with various uses such as irrigation, fish stocking, agricultural and recreational activities. Ten major degraded sites were summarized in Table 3. These ten sites constituted a total area of 2.02 km². Hence the total percentage of the ten degraded areas is:

$$Overall\ Degradation\ Percentage = \frac{(\mathbf{2019020.2})}{(\mathbf{11581829.825439})}\ x100 \quad \boldsymbol{=17.43\%}$$

Table 3: Summary Description of Ten (10) Selected Major Degraded Sites

S/No	Name	Total Area (km^2)	Coordinates	Remarks
1	The Rock and Clay Industry Limited Mines	0.66	9°41'49.12"N; 8°51'30.45"E	Active Illegal mine site
2	The Healthy Body Clinic site	0.01	9°45'24.10"N; 8°50'38.36"E	Resort centre; Block Industry; seasonal inundation
3	Rayfield Resort centre	0.53	9°50'24.91"N; 8°55'0.62"E	Resort centre; Illegal Mining
4	Dorowa Congo site	0.02	9°46'51.12"N; 8°52'25.53"E	Seasonal inundation; used as landfills; settlements built nearby
5	Zawan site	0.03	9°45'34.33"N; 8°51'51.87"E	Seasonal inundation, a threat to life; partially reclaimed
6	Consolidated Tin Mines Ponds	0.03	9°47'7.47"N; 8°51'38.05"E	Seasonal inundation; partially reclaimed through stone pitching
7	Jos International Breweries Mines Site	0.17	9°51'37.91"N; 8°54'26.95"E	Water used for block industry;
8	Yelwa Ponds Sites	0.05	9°48'5.40"N; 8°52'30.25"E	Water treatment plant; block industry
9	Rahwol Kanang sites	0.49	9°48'14.70"N; 8°54'3.77"E	Irrigation; Fish stocking; farming
10	Rennaj Fish and Integrated Farm Limited Pond	0.04	9°48'44.22"N; 8°54'20.07"E	Fish stocking; Farming; Source of water
	Total Area	**2.02 km^2**		

3.1.3 Field photographs and geotagging

The photographs integrated into the GIS database and geotagged to each degraded site can easily be queried as shown in Figure 6 and Figure 7. The outcomes aided in describing the true nature and photographic evidence of land degradation of the sites.

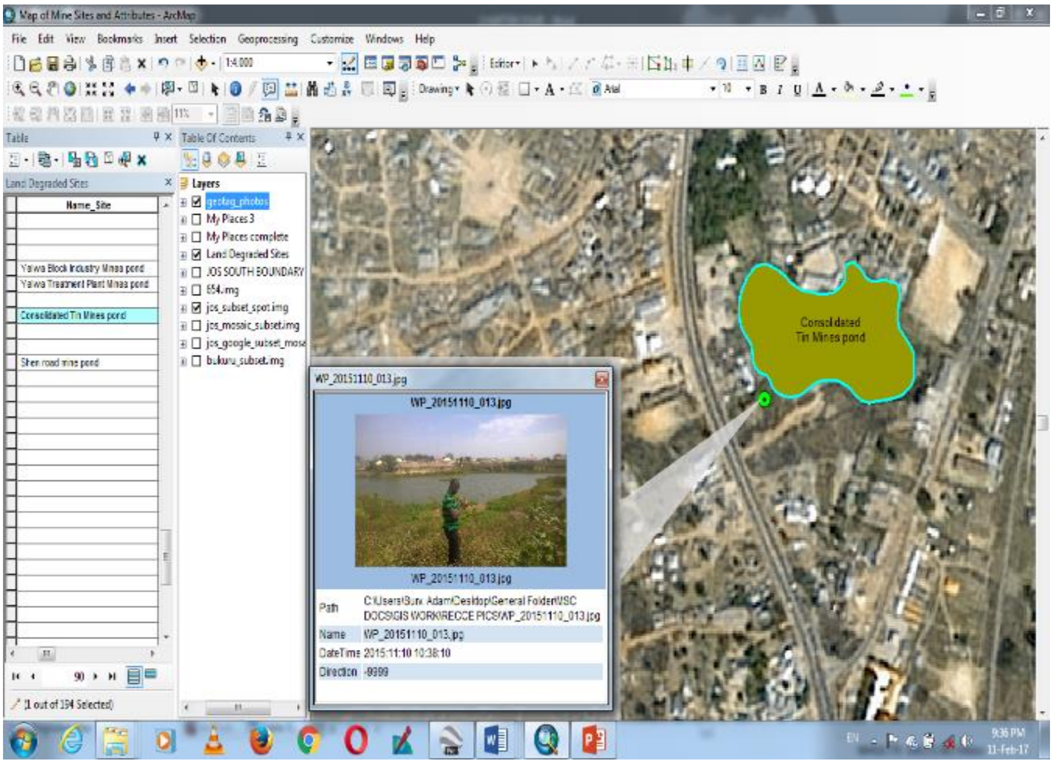

Figure 6: The Consolidated Tin Mines site;

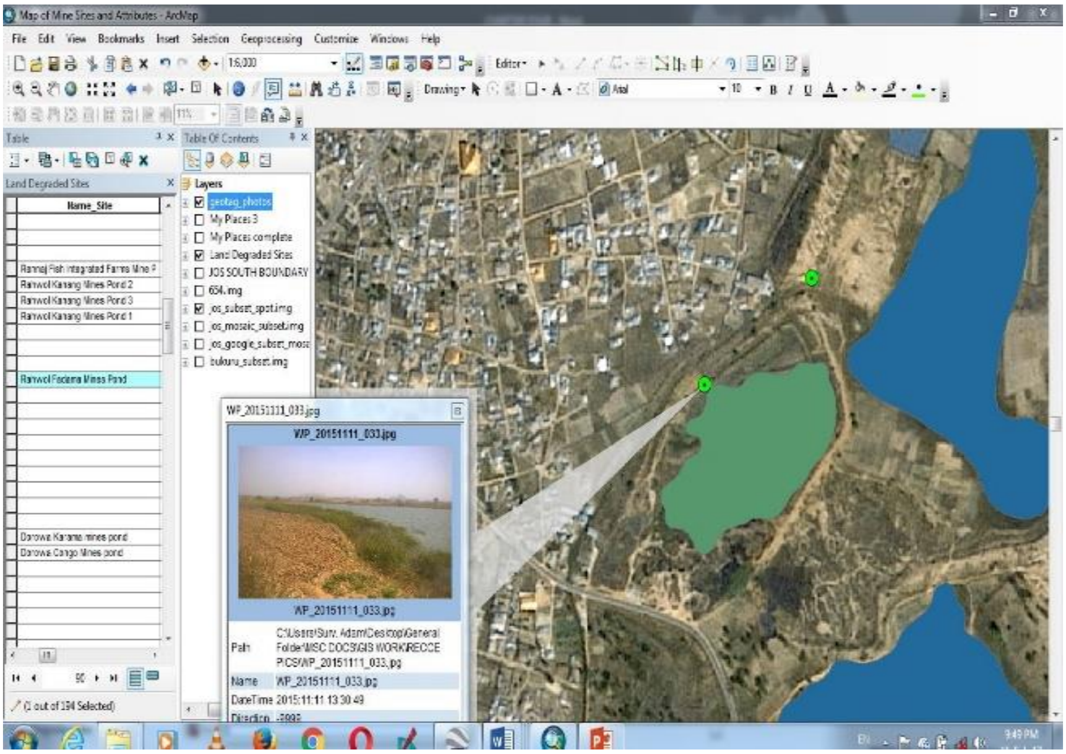

Figure 7: One of the Clustered Rahwol Kanang site

3.1.4 Classification of degraded sites based on features

The degraded sites were classified based on their functions, and the criteria for distinguishing them were based on the observed features during ground-truthing (Figure 8). From Table 4, the total area and percentage of the entire degraded sites in the study area were 11.58 km^2 and 2.26% respectively. This might appear small but it is actually devastating when compared with the percent total of the settlement cover of 6.99% (as shown in Table 6), which implies that the degraded area almost covered one-third of the entire settlement area.

Table 4: Summary of Attributes and Features of the Degraded Sites

S/No	Classes	Total Area (km^2)	Area Degraded (%)	Total number of Sites
1	Active Mine sites	1.32	11.38	9
2	Agricultural Usage	0.74	6.35	18
3	Dormant	0.78	6.76	25
4	Fencing	0.38	3.31	8
5	Fish Stocking	1.17	10.14	22
6	Inundated seasonally	1.80	15.50	29
7	Irrigation	1.55	13.36	50
8	Ownership	0.90	7.80	11
9	Partial inundation	0.46	3.93	13
10	Resort Centre	0.67	5.77	6
11	Tree planting	0.40	3.45	13
12	Waste dumps/Tailings	0.93	8.06	21
13	Water treatment	0.49	4.19	10
	TOTAL	11.58	100	235

3.1.5 Mapping clustered degraded sites

Figure 9 shows the hot and cold spot regions at different confidence levels of 90%, 95% and 99%. There are hot spot clustered sites around Rayfield, Bukuru, Du, Sabon Gidan Kanar and Gyero areas. In contrast, Kuru Janta, Ganawuri, Vom and Barikin Kuru Babba were the cold spot areas experiencing very few degraded areas. This is because the areas were mostly rocky hence there are fewer mining activities. There were also areas with no significant clustering as shown on the map. The z-scores and p-values ($P > 0.05$) returned by the pattern analysis indicated that the null hypothesis can be rejected. The reason being that the degraded sites (or the values associated with the sites) exhibited statistically significant clustering or dispersion instead of a random patterns.

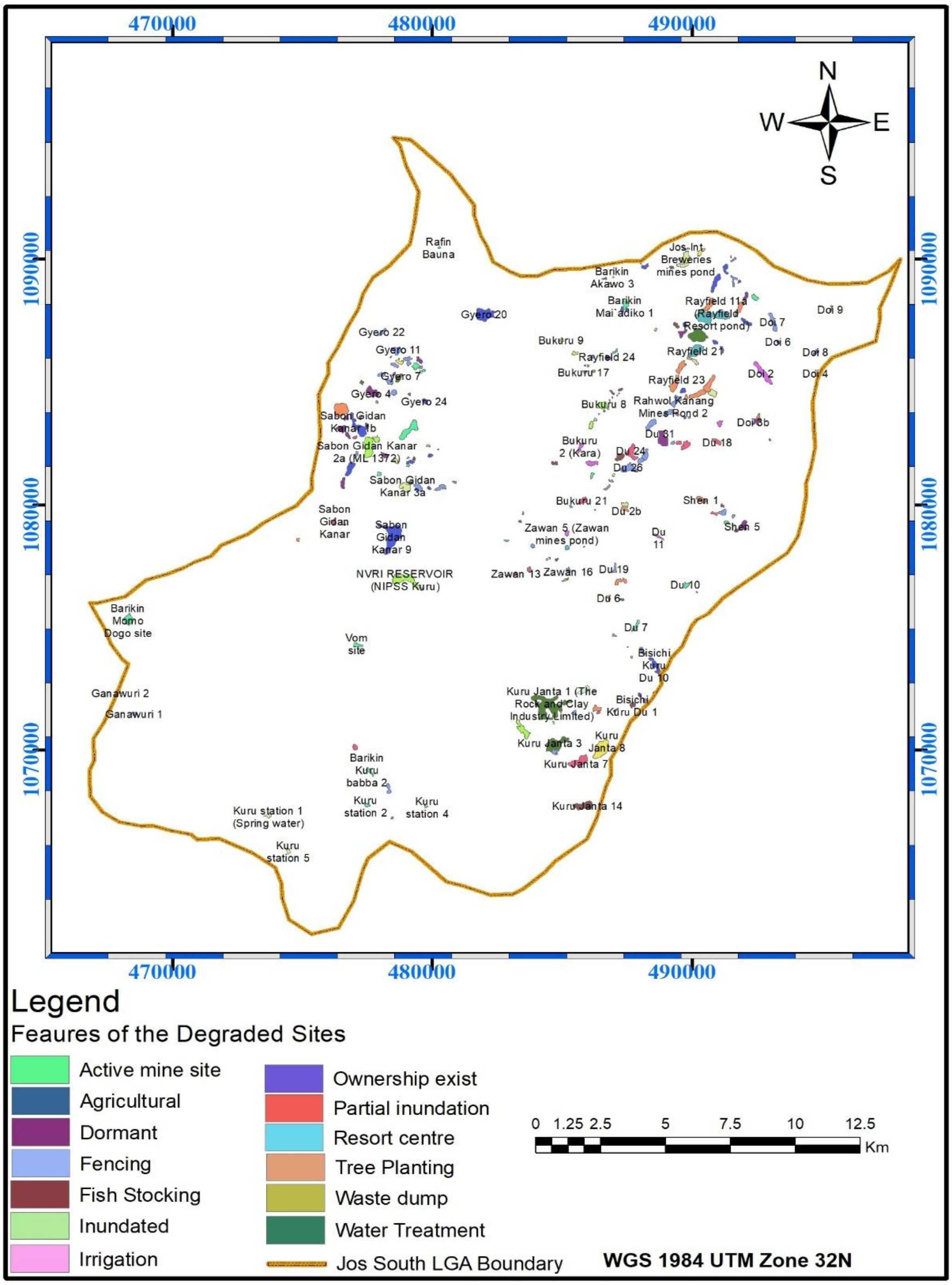

Figure 8: Degraded sites with their features

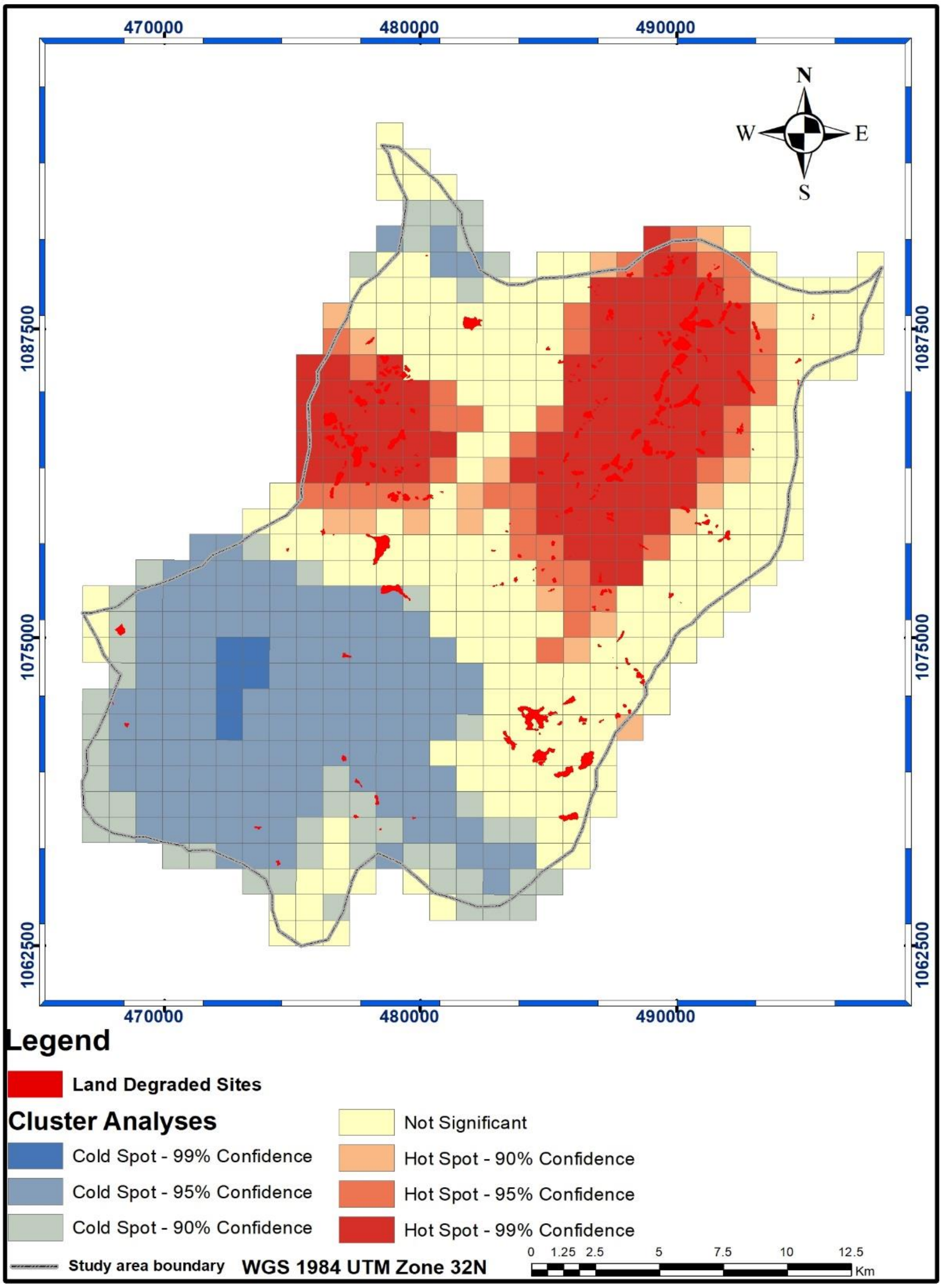

Figure 9: Hot and Cold degraded sites

3.2 Land Use Classification in the Neighbourhood of Degraded Area

In Table 5, the producer's accuracy of the mine pond is 98.51%, that is, there is a 1.49% omission error (error of exclusion) for the reference points. In the same vein, the user's accuracy for the mine pond is 78.26% and 21.74% commission error (error of inclusion) for the points. Thus, the producer's accuracy implied that the reference points for the mine pond were acceptably placed and the user's accuracy implied that the classification of the mine pond was acceptable.

Table 5: Simple descriptive statistics of the error matrix of the merged Landsat 8 & SPOT 5

		Reference									
		Rocky Areas	Vegetation	Farmland	Bare degraded land	Settlement	Mine ponds	Row Total	Number of Correct	Producers Accuracy	Users Accuracy
Classified Data	Rocky Areas	101	49	5	21	0	0	176	101	75.37%	57.39%
	Vegetation	5	184	8	4	3	1	205	184	59.55%	89.76%
	Farmland	0	37	107	0	2	2	148	107	81.06%	72.30%
	Bare degraded land	5	6	3	135	0	0	149	135	74.59%	90.60%
	Settlement	20	10	2	2	117	0	151	117	93.60%	77.48%
	Mine ponds	3	23	7	19	3	198	253	198	98.51%	78.26%
	Column Total	134	309	132	181	125	201	1082	842		

The resulting classification of the imagery had an overall map accuracy of 77.82% and the Kappa coefficient accuracy of 73.16%. This was a very good overall accuracy and accepted for the subsequent analysis.

The land use and land cover classified map in Figure 10 showed that settlement areas are concentrated in the central upper part of the area and are shown in red colour. Similarly, the mine ponds (degraded) are dispersed all over the area characterizing where mining activities are taking place and are shown in blue. Again, the presence of rocky covers indicated that the study is characterized by steep terrain and are shown in grey colour. Farmlands and vegetation covers are found all over the area and are displayed in light green and green. Settlement patterns, the nature of housing and infrastructural expansion contribute to the land degradation in the region.

Figure 11 shows the relationship between Settlements and Land degraded sites. Settlements are not properly planned; some houses are built indiscriminately near the abandoned mine pits without due consideration to dangers such may posit. This is because most of the area is rocky hence houses cannot be constructed easily. With rock outcrop largely occupying the area at 41.56%, there is likely to be high population pressure in housing, in areas without such rock outcrops. The total area covered by the settlement is 35.78km² at 6.99%.

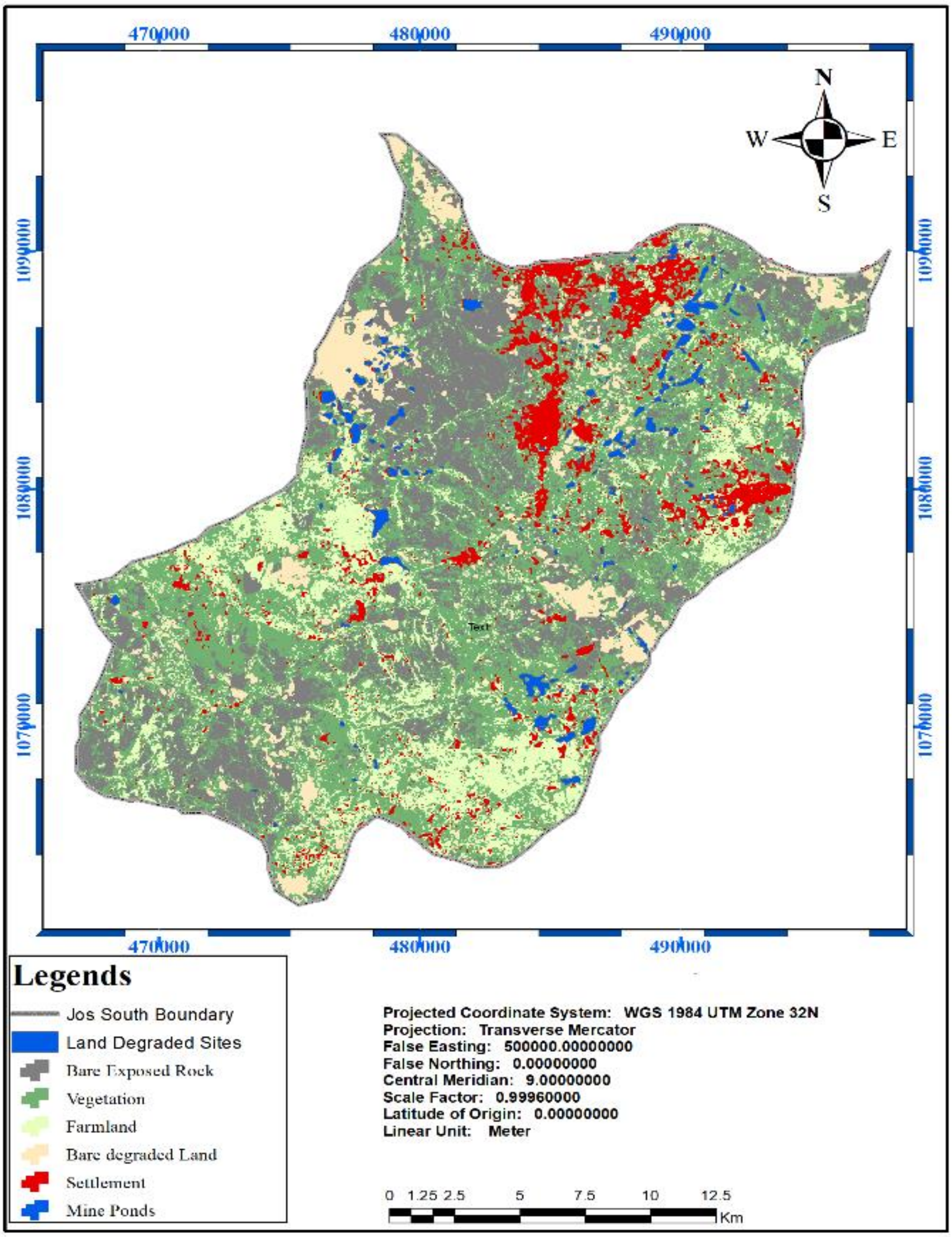

Figure 10: Land cover map of Jos South

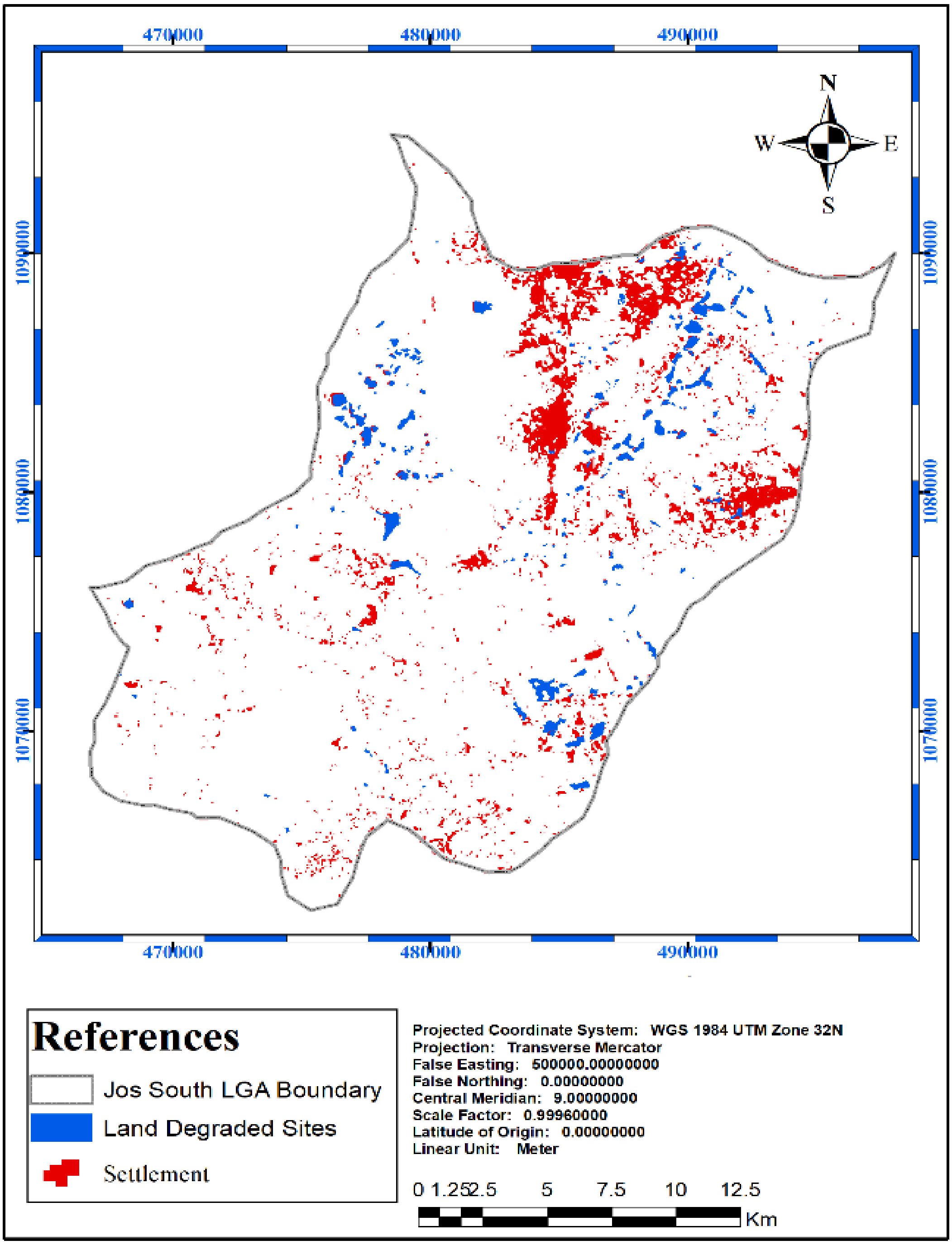

Figure 11: Settlements and Land degraded sites

3.2.1 Land cover distribution

The area and percentage of each class of the classified map of merged SPOT 5 and Landsat 8 of the study area are shown in Table 6. This was computed from the classified map in square kilometres. Much of the area mapped as degraded (9.45%) is the abandoned mine ponds and bare degraded land which primarily occurred as a result of illegal mining activities. It is comprised mainly of inundated ponds, bare lands, and grassland to a lesser extent.

Table 6: Extent of land use and land cover distribution of the fused imagery

LULC Class	Area (Km^2)	Area (%)
Mine pond	10.01	1.95
Settlement	35.78	6.99
Exposed Rock Outcrop	212.81	41.56
Farmland	92.94	18.15
Bare degraded land	38.41	7.50
Vegetation	122.16	23.85
Total	**512.10**	**100**

4. CONCLUSIONS

This research has demonstrated that satellite imageries with other ancillary data and proper methodologies can be used effectively for geospatial analyses of land degraded sites. The study has effectively analysed mining-induced land degraded sites using onscreen digitization, maximum likelihood supervised classification and digital elevation model data. It is evident from the findings that mining not only alters the land cover and vegetation but also leads to erosion and degradation of land and deposition of the mining wastes in the nearby lands. Furthermore, with the spread of mine ponds, and other degradation, there are still active land uses such as settlements, rocky areas, farmlands, and vegetation on a total area of 512.10km^2. The information on demarcated mining-induced degraded areas as derived from the digitized sites and the land cover map were used to analyse areas affected by mining and overburden dumps.

Moreover, there are certain appropriate LULC in the neighbourhood of the degraded areas that could be utilized productively and be increased. For example, block industries, water treatment plants, fish farming, and other commercial activities could be sited around the seasonally inundated mine pond. The mine ponds could be demarcated or reclaimed to curtail prevalent accidents. The illegal mining going on in some degraded sites aggravates the degradation rate, it is recommended that urgent priority be given to the implementation and enforcement of the existing mining and other environmental protection laws at all levels. Ecological funds being provided by the Federal Government should be utilised for rehabilitation, reclamation and remediation of the existing dormant land degraded sites in the study area. Future research works should focus on land degradation monitoring by integrating GIS and satellite remote sensing with soil properties such as soil pH, texture, water capacity contents, etc. to analyse accurate degradation of soil especially farmlands.

REFERENCES

Adedeji, O. H., Adebayo, H. O. and Sotayo, E. I. (2014). Assessment of Environmental Impacts of Inland Sand Mining in Parts of Ogun State, Nigeria. *Ethiopian Journal of Environmental Studies* and *Management, 5* (7). doi: http://www.dx.doi.org/10.4314/ejesm.v7i5.2

Adewuyi, T.O. (2009). Land Degradation Assessment in the Peri-Urban Area of Kaduna Metropolis, Nigeria. *Indonesian Journal of Geography, 41*(1): 37-51.
ASTRIUM, (2013). *SPOT Imagery*. Retrieved from http://www.intelligence-airbusds.com/files/pmedia/public/r233_9_geo_0013_spot_en_low.pdf. Accessed on 4th. August, 2017.
Bala, A. (2018) "Geospatial Analyses of Land Degradation Sites in Jos South LGA of Plateau State". M.Sc. Thesis submitted to the Ahmadu Bello University, Zaria. Available on http://kubanni.abu.edu.ng/jspui/handle/123456789/11107
Brinkhoff, T. (2017). *City Population: Jos South Local Government Area*. Retrieved from: https://www.citypopulation.de/php/nigeria-admin.php?adm2id=NGA0320 06 . Accessed on 5th. January, 2021.
Campbell, J.B. (2002). *Introduction to Remote Sensing* (3rd edition). London: Taylor and Francis
Christopher O. A. (2015). Land-Use management. Available on http://www.unaab.edu. ng. Accessed on 17th June, 2015.
Dawen, D.P. (2012). *Geochemical Analysis of Soil, Vegetation and mine water samples in Jos town and environs: A case study of Guarum (Mista Ali), mining resources community centre, west of mines and Rayfield mining area*, (Unpublished PGD Project). Nigerian Institute of Mining and Geosciences, Jos.
Digital Globe. (2003). *QuickBird scene 000000185959_01_P005, Level Standard 2A, Digital Globe*. Colorado: Longmont. Accessed on 4th. August, 2017. Retrieved from http://glcf.umd.edu/data/quickbird/.
Edun, E. O., and Davou, D. D. (2013). Inventory of Abandoned Mine Ponds/Dams on the Jos-Bukuru North-Central Nigeria Using G.I.S and Remote Sensing Technique. *The International Journal of Engineering and Science, 2*(5): 62-71.
FAO. (2015). *Land degradation in South Asia: Its severity, causes, and effects upon the people*. Retrieved from http://www.fao.org/docrep/v4360e/v4360e03.htm. Accessed on 20th November, 2015
Federal Republic of Nigeria 'FRN' (2010). Population distribution by sex, state, LGA and senatorial district. Accessed on 6th November, 2015. Retrieved from http://www.population.gov.ng/images/Vol%2003%20Table%20DSx%20LGAPop%20by%20SDistrict-PDF.pdf. Pp41.
Garba, S.S. (2008). *Assessment of Land Cover Change in North Eastern Nigeria*. (Doctoral dissertation, University of Cranfield). Retrieved from https://dspace.lib.cranfield.ac.uk/handle/1826/3489. Accessed on 27th. March, 2015.
Graw, V., Smale, M., Menz, G. and Olwande, J. (2015). Land Tenure, Poverty, and Land Degradation – Geospatial Analysis in Western Kenya. 2015 World Bank Conference on Land and Poverty, Washington DC. Retrieved from: http://www.worldbank.org/en/.../using-geospatial-data-for-analysis. Downloaded on: 28 December, 2015.
Gyang, J.D, and Ashano, E.C (2009). Effects of Mining on Water Quality and the Environment; a case study of parts of the Jos Plateau, North Central Nigeria. Continental *Journal Environmental Sciences, 3:* 33-42.
Haruna, M.D. and Solomon J.N. (2011). An Assessment of Mining Activities Impact on Vegetation in Bukuru Jos Plateau State Nigeria Using Normalized Differential

Vegetation Index (NDVI). *Journal of Sustainable Development, 4*(6). doi:10.5539/jsd. v4n6p150

Henssen, J. (2014). *Basic Principles of the Main Cadastral Systems in the World*. Retrieved from https://www.fig.net/commission7/reports/events/delft_ seminar_ 95/paper2.html. Accessed on 23rd. September, 2015.

Igbokwe, J. I., Akinyede, J. O., Dang, B., Alaga, T., Ono, M. N., Nnodu, V. C. and Anike, L. O. (2008). Mapping and Monitoring of the Impact of Gully Erosion in South-eastern Nigeria with Satellite Remote Sensing. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37*(8).

International Labour Organization (2007). *Employment by Sector. In Key Indicators of the Labour Market (KILM).* 5th Edition. Retrieved from www.ilo.org/public/ english/employment/strat/kilm04.

Jonathan O. and Joshua B. (2013). Geospatial application in mapping gully erosion sites in Jos, Plateau State, Nigeria. *Journal of Scientific Research and Essay (SJSRE), 2* (6): 85-95.

Leonard, H.J., M. Yadelman, J.D. Stryker, J.O. Browder and A.J. De Boer, (1989). Environment and the poor: Development strategies for a common agenda. Transaction Books, New Brunswick.

Mackay, R.A., Greenwood, R., and Rockingharm, J.E. (1949). The Geology of the Plateau Tin field resurvey. Geological Survey, Nigeria bulletin II (32): 116.

Maiangwa, M.G., Ogungbile, A.O., Olukosi, J.O. and Atala, T.K. (2007). Land Degradation: Theory and Evidence from the North-West Zone of Nigeria. *Journal of Applied Sciences, 7:* 785-795. doi: 10.3923/jas.2007.785.795.

NEWMAP, (2017). Jos Plateau Mining Ponds. Nigeria Erosion and Watershed Management Project, Plateau State Office, No 17, Apollo Crescent, GRA Jos, Plateau State, Nigeria

Olumide, M.A. (2007). *Land use and land cover change detection with remote sensing and GIS at metropolitan Lagos, Nigeria (1984-2002).* Leicester, England: ProQuest LLC.

OSGOF. (2016). Office of the Surveyor General of Nigeria. Yawuri Street, Abuja.

Piers, B. and Harold, B. (2015). Land Degradation and Society. Routledge 2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RH and by Routledge 711 Third Avenue, New York, NY 10017.

Ravishankar, T. and Sreenivas, K. (2015). Soil and Land Degradation. In Roy, P.S., Dwivedi, R.S., and Vijayan, D. (n.d.). *Remote Sensing Applications*. National Remote Sensing Centre, India.

Sahu, H. B., and Dash, S. (2011). Land Degradation due to Mining in India and its Mitigation Measures. Proceedings of Second International Conference on Environmental Science and Technology, Singapore. Retrieved from www.googlecom/mining. Accessed on 5th December, 2015.

UNEP. (1992). United Nations Environment Programme. Rio declaration on environment and development. Made at the United Nations Conference on Environment and Development, Rio de Janeiro, Brazil. Available on www.unep.org/Documents/ Default .asp?DocumentID=78&ArticleID=1163.

USGS, (2016). United State Geological Survey Agency. Available on https://earthexplorer.usgs.gov/

Wang Y.Q. and Christiano M. (2005). *A Protocol of Using High Spatial Resolution Satellite Imagery to Map Salt Marshes: Towards Long-Term Change Detection*. The University of Rhode Island, Department of Natural Resources Science. Kingston: National Park Service.

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