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MAPPING AND ASSESSMENT OF LAND USE/LAND COVER CHANGES IN WEST KORDOFAN STATE - SUDAN, USING REMOTE SENSING AND GIS

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ABSTRACT

This study was conducted in three localities (*El Salam*, *El Snout,* and *Babanousa)* in West Kordofan State, Sudan. The main objective was to identify, analyse, monitor, and map land use/land cover dynamics during the period from 1986 to 2014. Three Landsat images with multi-temporal dates: Thematic Mapper (TM) (1984), Enhanced Thematic Mapper (ETM)+ (2003), and Landsat 8 OLI (2014) were acquired during the dry season. The images were geo-referenced and radiometrically corrected. Image classification, change detection, and accuracy assessment were applied. A total of 200 control points was registered using the Global Positioning System. Remotely sensed data were processed and analysed using ERDAS 9.1 and ArcGIS 10.0 software. The land use/land cover classification results were grouped into six categories: dense forests, agricultural and bare lands, shrublands, rangelands, low-density forests, and water bodies. The overall transformation of LULC during the studied period (1986-2014) is indicated by the increase of water bodies from 0.01% to 0.19%, agricultural and bare lands from 31.39% to 44.6%, and range lands from 12.69% to 39.24%. However, during the same period, dense forests, low-dense forests, and shrublands showed a decreasing rate from 20.97% to 8.93%, 8.85% to 3.61%, and 26.09% to 3.41%, respectively. The overall accuracy assessment of classified imagery for TM, ETM+, and Landsat 8 OLI indicated Kappa statistics of 0.75, 0.81, and 0.88, respectively. The study recommended conducting periodic assessments and monitoring for LULC changes using remote sensing techniques to support strategic land-use planning.

Keywords: Landsat, land cover, land use, Remote Sensing, West Kordofan.

INTRODUCTION

Over the last twenty years, awareness has increased regarding Land Use/Land Cover (LULC) changes and their direct or indirect contributions to land degradation in sub-Saharan Africa (Symeonakis *et al*., 2004). The changes result from different practices such as farm and grazing abandonment and intensification of agriculture, among others (Symeonakis *et al*., 2004; Adam *et* *al*., 2023). Nonetheless, inappropriate and excessive land use across different regions of the country has caused changes in LULC. This reduced the density of plant species in the region. Some of these changes resulted from increased deforestation, agricultural, and overgrazing by people due to security unrest and violence, and recurrent drought in the regions. With current estimates indicating that approximately half of the country experiences recurring periods of drought (Symeonakis *et al*., 2004; Abbadi and Ahmed, 2006; Adam *et al*., 2023). Also, Human intervention and natural phenomena caused continuous changes in LULC cover. Availability of accurate LULC information is essential for many applications, such as natural resource management, as well as planning and monitoring programs for land resources. LULC change has become a central component in current strategies for managing natural resources and monitoring environmental change (Lillesand *et al.,* 2004; Gbenga, 2008; and Elamin, 2016).

Rapid development in the field of LULC mapping increases the studies and research on it, covering worldwide. That means, land has been the source of mankind's food, shelter, clothes, etc., which is why people have been using land in many ways, which have changed according to place and time, as well as the social and economic needs of people (Lillesand *et al.,* 2004, and Elamin, 2016; Adam et al., 2023). The LULC pattern of an area changes along with time, according to needs; the changes are related to the overall functional demand and physical environmental change. (Lillesand *et al.,* 2004; Elamin, 2016).

Land use is defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one or more pieces of land; also, several land uses may occur on the same piece of land (Meyer and Turner, 1994; Gregorio and Jansen, 1998; Adam, 2011; Adlan, 2015; and Elamin, 2016). Land cover is the observed physical cover, as seen from the ground or through remote sensing, including the vegetation and human constructions (buildings and roads) that cover the Earth's surface. Water, ice, bare rock, or sand surfaces are counted as land cover (Gregorio and Jansen, 1998; Adam, 2011; and Elamin, 2016). Remote sensing methods obtain information on vegetation attributes for resource assessment and are used in the quantitative description of vegetative growth (Li *et. al*., 2023). Remote sensing techniques have evolved from the initial assessment of vegetation classification and composition indicators to the current precise monitoring of various indicators such as coverage, Leaf Area Index (structural indicators), and primary productivity, vegetation health, and phenology (functional indicators) (Li *et. al*., 2023). Remote sensing is based on the principle that objects emit or reflect radiation differently across various wavelengths, resulting in unique spectral signatures for different materials (Abualgasim, 2010). The country's important natural resources include forests, wildlife, water, pasture and rangelands, coastal and marine resources, and arable lands. Sudan's forests are important sources of food, timber, firewood, and habitat (USAID, 2012; Elamin, 2016). Fuel wood and charcoal supply amount to more than 75% of the country's energy needs. Forests also provide fodder for livestock, marketable non-wood products such as honey, gum arabic, tubers, and roots. The climate of this Western Kordofan State is characterized by the semi-desert climate in the far north, the poor savannah in the center, and the rich savannah in the southern parts. It manifests a great deal of human activities, which could be the major cause of land degradation. However, only limited and fragmented information is available regarding land use and, consequently, LULC (Osman, 2011, and Elamin, 2016). There are many strong challenges faced by LULC in West Kordofan State, which necessitate the need for sound information systems and management plans. These challenges include: population growth and changes in demographic attributes such as rural/urban balance, agricultural dependency, income, changes in aspirations and expectations, such as greater interest in LULC. Accordingly, this study focuses on studying LULC dynamics in three localities (*El Salam, El Snout, and Babanousa*) in West Kordofan State. It aimed to identify, analyze, and mapping of LULC dynamics (temporal and spatial) (1986-2014) in West Kordofan State, Sudan.

MATERIALS AND METHODS

Study area

This study was conducted in three localities of West Kordofan State: *El Salam*, *El Snout*, and *Babanousa*. The area is situated within the path and row (175/52) in Zone 35 East, covering an area of 604.94697 hectares (Figure 1). The State is located between longitudes 28.20° and 29° E, and latitude 11.30° and 12.20° N, and bordered by North Kordofan State on the North, South Kordofan State on the East, East Darfur State on the West, and South Sudan on the South. The population of these localities is estimated as 436989 inhabitants. It is worth mentioning that 85% of the population were nomads while only 15% were settlers based on data from the 2010 census *(Foula* Statistics Centre, 2015).

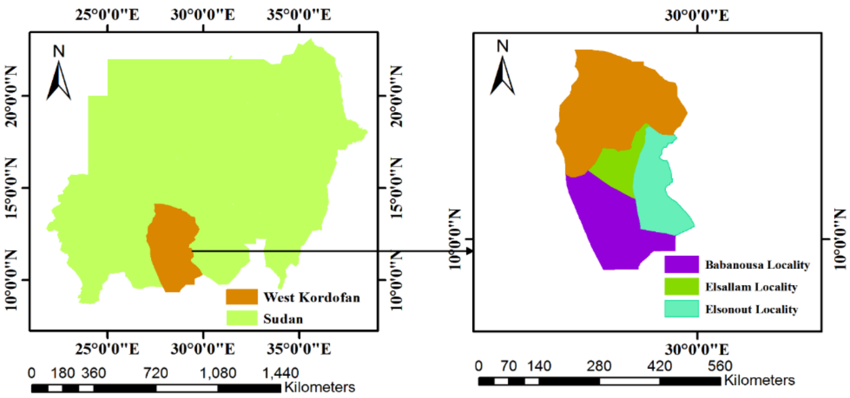

Figure 1: Location of the study area

Data Collection and Analysis

The study made use of different Landsat satellite images acquired from various periods to analyze spatial and temporal changes: Landsat TM 5 (1986), ETM+ Landsat 7 (2003), and ETM+ Landsat 8 (2014). The general resolutions of all these instruments are 30m*30m (Table 1). All images were downloaded freely from the United States Geological Survey (USGS) website. The images were geo-referenced to the (WGS84) datum and Universal Transverse Mercator (UTM) projection. The diagram illustrated in Figure 2 gives more detailed information about the materials and research methodology conducted in this study.

Table 1: Characteristics of Landsat satellite imagery used in the study

Satellites	Sensors ID	Bands	Path/Row	Zones	Ground Resolution (m)	Acquisition date
Landsat5	TM	1,2 and 4	175/52	35N	30*30	13/01/1986
Landsat7	ETM+	1,2 and 4	175/52	35N	30*30	13/01/2003
Landsat8 OLI	ETM+	2,3 and 5	175/52	35N	30*30	05/12/2014

Where: ETM+: Enhanced Thematic Mapper plus, TM: Thematic Mapper.

Supervised classification (maximum likelihood classification) was used because it gives more accurate class definitions and higher accuracy than unsupervised approaches. Accordingly, the classification process was carried out using the Parallelepiped decision rule for the nonparametric signatures (Adam, 2011; Adlan, 2015; and Elamin, 2016). Change detection and accuracy assessment were conducted for the three classified images.

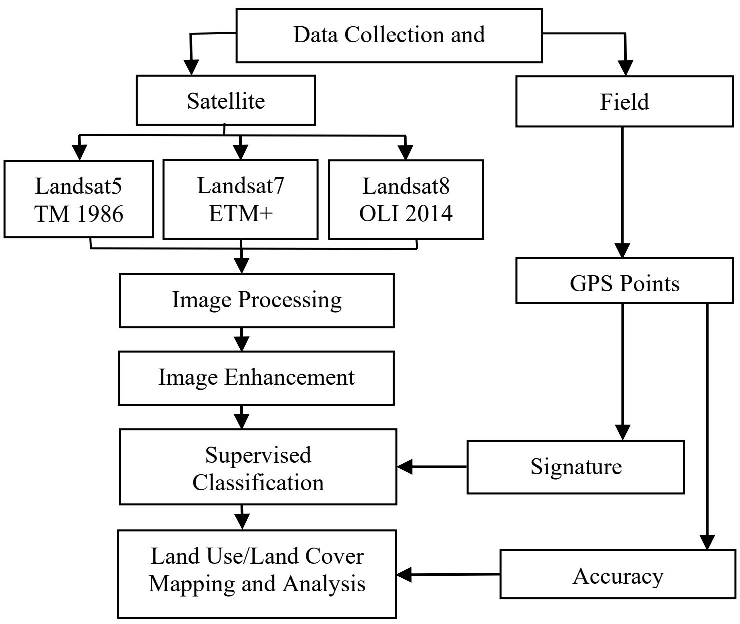

Figure 2: Workflow of LULC classification

RESULTS AND DISCUSSION

LULC distribution

LULC results showed that agricultural and bare land classes remained dominant over all other items during the period of 2014, 2003, and 1986, representing 44.60%, 39.45% and 31.39%, respectively (Table 2). The range land class is mentioned as the second dominant class in 2014, 2003, covering 39.24% and 25.87%, respectively. In the year 1986, the shrub shrubland class was the second dominant one (26.09%). The same class covered 17.96% and 3.43% in the years 2003 and 2014, respectively. The agriculture and bare land class and range land class revealed a gradual increase in the areas in 1986, 2003, and 2014, representing (31.39%, 39.45, 44.60%) and (12.69%, 25.87%, 39.24%), respectively. The low-density forest class also showed a minor reduction from 8.85% (1986) to 8.42% (2003) and to 3.61% (2014) (Table 2). The vegetation cover within the area is characterized by three main classes: dense forest, low-density forest, and shrubland. The dense forest class in the area is covering most reserved forests in the state, including (i.e., *Kaddam* reserved forest and forests *Elmanawara* and *Um lobanna* reserved forest), which showed a slight increase in the coverage from 8.28% (2003) to 8.93% (2014). This status demonstrates the existence of the protection; practices of agroforestry, a forestation and reforestation activities done by the FNC inside these reserved forests. This result is consistent with the findings of Olsson *et al*. (2005), who reported that the increase in vegetation cover in the arid and semi-arid regions of Sudan during the 1990s was attributed to higher rainfall and the consequences of migration, which often led to abandoned fields and reduced grazing pressure.

Table 2: Classification of LULC of Landsat images for 1986, 2003, and 2014.

Years	1986		2003		2014	
Class name	Area (ha)	%	Area (ha)	%	Area (ha)	%
Dense forest	126841.05	20.97	50089.95	8.28	53996.49	8.93
Agricultural & bare lands	189867.96	31.39	238663.62	39.45	269784.54	44.60
Shrub lands	157807.89	26.09	108638.64	17.96	20753.55	3.43
Range lands	76790.34	12.69	156473.01	25.87	237399.21	39.24
Low-density forests	53567.55	8.85	50958.36	8.42	21833.64	3.61
Water bodies	72.18	0.01	123.39	0.02	1179.54	0.19
Total	604946.97	100	604946.97	100	604946.97	100

The results indicated that rangeland areas increased by 12.09%, 25.87%, and 39.24% in 1986, 2003, and 2014, respectively. The expansion of rangelands in the area was driven by a reduction in vegetation cover, including trees and shrubs. The study observed the increase in water bodies in the periods 1986, 2003, and 2014, representing 0.01%, 0.02% and 0.19%, respectively. In the past, groundwater wells, sewage, seasonal creeks, and valleys occurred in the study area. Recently, the government established *El Snout* reservoir and some other dams and water bodies for horticulture and fish production in the study area.

Mapping of LULC

Supervised classification was carried out by selecting training samples for each information class from visual interpretation of imagery supported by field measurement according to Cohen *et al.* (1998) and Hayes and Sader (2001). These techniques use multi-date imagery from multi- and hyperspectral sensors in order to identify and quantify the differences reflected by objects or phenomena (Jensen, 1996; Copping *et al.,* 2004; and Adam, 2011). The post-classification approach generally requires substantial human supervision during the image classification process (Singh, 1989; Lunetta, 1999). Water bodies were merged clearly in the form of a reservoir in the *El Snout* locality, which was developed in 2005 as the main source of water for local communities. Shrublands decreased in the area in 2014 due to some factors, such as the cutting of trees, overgrazing, and agricultural expansion by local people in the study area. Dense and low-density forests remained largely unchanged during the last period, whereas agricultural and bare lands expanded significantly, covering large areas of the study region (Figure 3).

The results from the LULC map (ETM+ 2003) indicated that water bodies are located in a few areas, while range land spreads over the southeastern side, and dense forests are found in the southwestern parts of the region. The results for 2003 indicated an expansion of agricultural and bare lands, especially in the northern parts of the western area. This is due to the availability of the resident population in the area rather than at other sites (Figure 3).

The classified map of Landsat5 TM 1986 indicated that the water bodies, which appeared in blue, cover small areas compared to the maps of 2014 and 2003. The scattered low-density forest, which appeared in red color distributed in different areas. In the study area, dense forest, shown in dark green, was primarily found along valleys (*wadis)* and watercourses. The status of the dense forest covering the area in 1986 is better when compared to the years 2003 and 2014, due to the low population density at that time. Agricultural activity is observed to be practiced in the Northern areas where some villages are located (Figure 3).

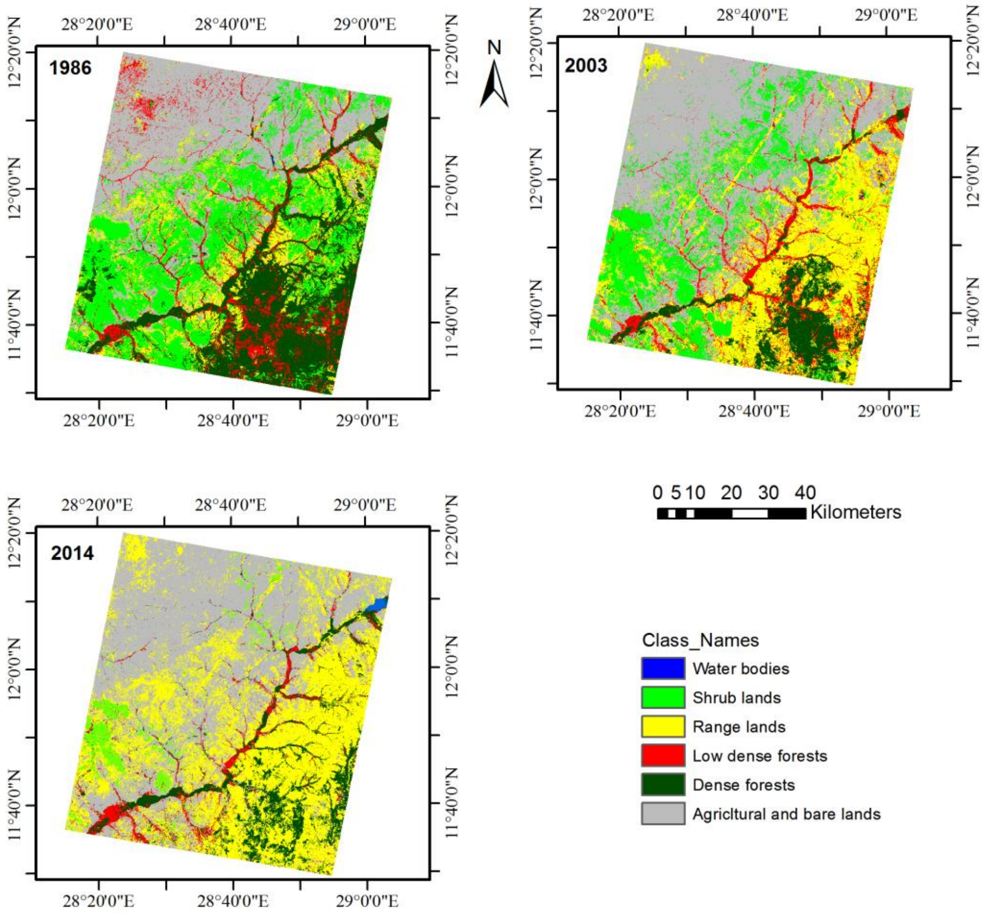

Figure 3: Map of LULC classes in the study area on (TM 1986)

Change and the relative annual rate (%) of LULC

The rate of change (%) for the dense forest class during the periods 1986–2003, 1986–2014, and 2003–2014 was recorded as -12%, 0.65%, and -12%, respectively (Table 4). The result indicated a decrease in the dense forest class from 1986 to 2014. Decrease in vegetation cover (dense forest, low-dense forest, and shrublands) in the study area is attributed to human activities such as cutting, overgrazing, and agricultural expansion, which are characterized as one of the reasons that caused degradation of forest land in Sudan. Agricultural and bare lands, and range lands classes were increased during the three periods (1986-2003), (2003-2014) and (1986-2014) as (8.07% and 13.17%), (5.14% and 13.38%) and (13.21% and 26.55%), respectively, this was in line with the general trend of increase of farm lands over of forest areas to meet the increase demand of crops (Hinderson, 2004 and Dafalla, 2006). Finally, the study indicated that water bodies have changed passively during the period (1986-2003), (2003-2014), and (1986-2016), estimated as (0.01%, 0.17% and 0.18%) respectively (Table 4).

Olsson *et al.* (2005) have explained the increase in vegetation cover in the Kordofan States as a result of an increase in rainfall and of migration consequences, which include often abandoned fields and reduced grazing pressure. Low-density forests decreased in the period 2014, 2003, and 1986, representing (3.61%, 8.42% and 8.85%), respectively. Rangelands gradually increased over the period 1986, 2003, and 2014, reaching 12.09%, 25.87%, and 39.24%, respectively. This increase in the range of land resulted in a decrease in vegetation cover in the area. The dense forests decreased by 12% during the period 1986-2003, then increased slightly by 65% in the period 2003-2014, referring to the forest protection and plantations activities conducted by FNC in the region. The study finds that the vegetation of dense forests, low-density forests, and shrub lands is degraded and reduced due to illicit cutting, overgrazing, agricultural expansion, conflict, and migration factors.

Table 4: Rate of change of LULC in the study area

Class name	1986-2003		2003-2014		1986-2014	
	Area/ha	%	Area/ha	%	Area/ha	%
Dense forests	-76751.10	-12.69	3906.54	0.65	-72844.56	-12.04
Agricultural & bare lands	48795.66	8.07	31120.92	5.14	79916.58	13.21
Shrublands	-49169.25	-8.13	-87885.09	-14.53	-137054.34	-22.66
Range lands	79682.67	13.17	80926.20	13.38	160608.87	26.55
Low-density forests	-2609.19	-0.43	29124.72	-4.81	-31733.91	-5.25
Water bodies	51.21	0.01	1056.15	0.17	1107.36	0.18

The relative annual rate change (%) for the LULC classes in the periods (1986-2003, 2003-2014, and 1986-2014) reflected the trends of change in LULC during these periods, showing the magnitude of change (Figure 3). The relative annual rate of change for the dense forest class was found to gradually decrease by 0.75% (1986-2003), 0.42% (1986-2014), and increase by 0.06% (2003-2014). Shrub lands and low-density forests decreased in all periods, by 0.48% and 0.03% (1986-2003), 1.32% and 0.44% (2003-2014), and 0.81% and 0.19% (1986-2014), respectively. Furthermore, the results showed an increase in range lands and agricultural, and bare lands classes increased throughout the three periods by 0.77% and 0.47% (1986-2003), 1.21% and 046% (2003-2014), 0.95% and 0.48% (1986-2014), respectively (Figure 3).

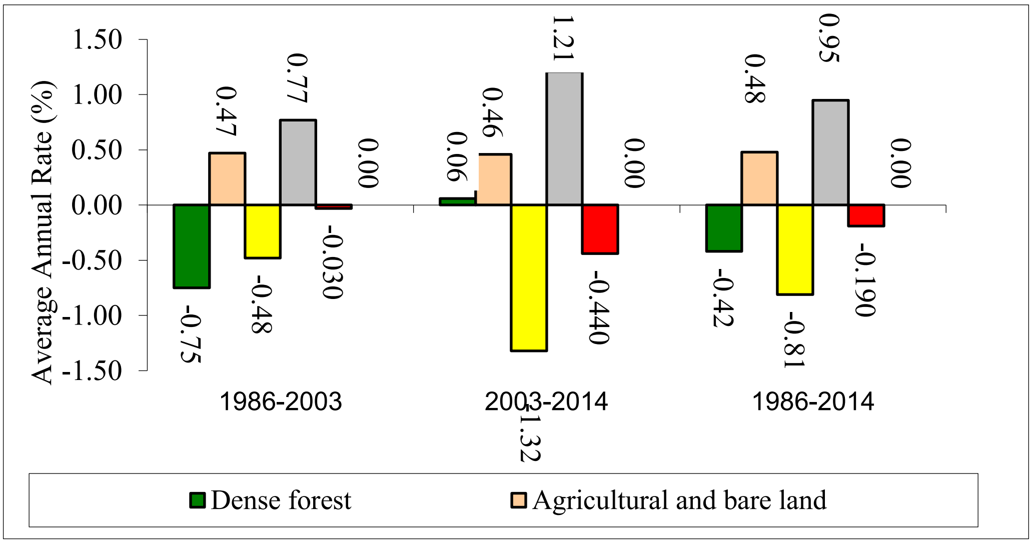

Figure 3: Relative annual changes (%) of LULC classes in the study area

Trends of LULC in the study area (1986-2014)

Figure 4 represents the trend of change for the LULC in the study area, indicating that the dense forests, low-density forests, and shrub lands classes' curves show a downward trajectory, while the dense forest slightly started to increase from 2003. The trends of changes showed the degradation and deterioration of the vegetation in the study area. From 2003 onward, the dense forests and low-density forest classes showed stability in the coverage. This might refer to the forests protected and planting programs. The range lands class and agricultural and bare curves showed gradual increases in areas over time (Figure 4).

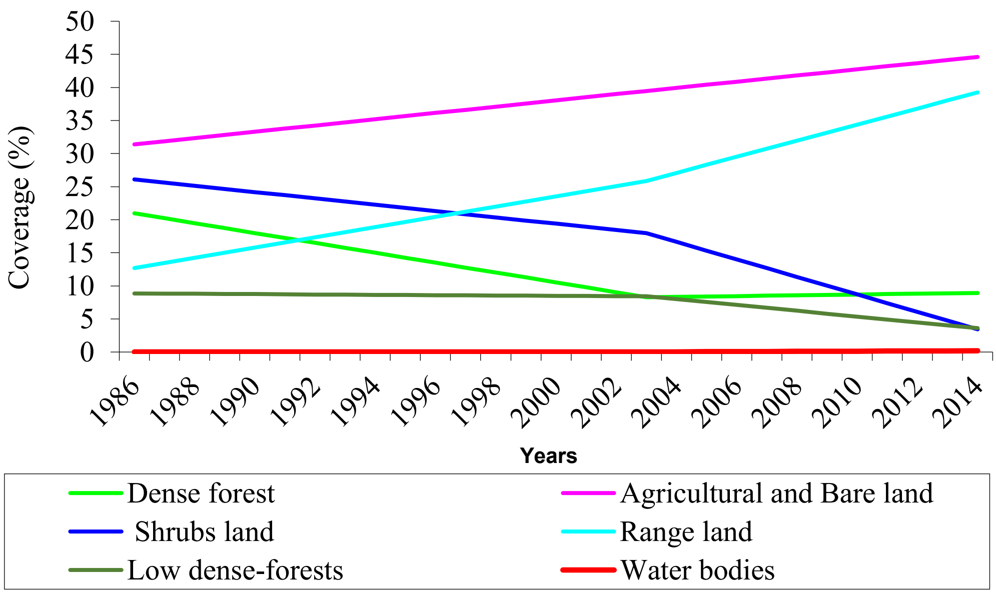

Figure 4: LULC trends (1986-2014) in the study area.

Accuracy assessment

The accuracy assessment of the post-change classified maps is estimated by multiplying the accuracies of each pair of individual classifications, which often reveals accuracies highly relevant to the product of the input classified dataset used (Mas, 1999). There are many reasons to use accuracy assessment, such as increasing the quality of information derived from remote sensing data (Congalton *et al*., 1999). The confusion matrix was created by comparing error values for each class that was classified with its respective value in the ground truth data. The Kappa statistics and overall accuracy results for the classified imagery for the years 1986, 2003, and 2014 were found to be (80%, 0.75), (86%, 0.81), and (90%, 88%), respectively (Table 3). According to Abdelkareem *et al.* (2018), a Kappa value higher than 0.5 can be considered satisfactory for the modeling of land use change. Landis and Koch (1977) characterized agreement for the Kappa coefficients as follows: values > 0.79 are excellent, values between 0.6 and 0.79 are substantial, and values of 0.59 or less indicate moderate or poor agreement. The user's accuracy in classified image (2014) for the agriculture and bare land class, shrub class, and low dense forests class was registered as 100% for each, while 80% is registered for the dense forests and range land classes. While the users' accuracy is stated as100% for the dense forests and low-density forest classes in the classified image (2003). The highest user's accuracy for the classified image (1986) is found as 91.67% for the agriculture and bare land class (Table 3). The accuracy assessment led to the classification of the classified imagery, with all varieties showing overall good results except the water bodies class, because imagery was taken in the dry season, where water bodies are not available.

Table 3: Accuracy assessment of LULC classification

Class name	Landsat5 TM 1986		Landsat7 ETM+ 2003		Landsat8 2014	
	Producers' accuracy (%)	Users' accuracy (%)	Producers' accuracy (%)	Users' accuracy (%)	Producers' accuracy (%)	Users' accuracy (%)
1	91.30	80.77	58.82	100.00	100.00	80.00
2	91.67	91.67	95.74	83.33	76.92	100.00
3	85.71	75.00	80.00	88.89	90.91	100.00
4	69.57	69.57	93.10	79.41	88.89	80.00
5	58.82	76.92	86.67	100.00	100.00	100.00
6	00.00	00.00	00.00	00.00	100.00	50.00
Overall Accuracy	80.99		86.05		90.38	
Kappa Statistics	0.7545		0.8126		0.8814	

1=Dense forests, 2=Agricultural and bare lands, 3=Shrublands, 4=Range land5=Low dense forests and 6=Water bodies.

CONCLUSION AND RECOMMENDATIONS

The integration of remote sensing and GIS technologies has increased the analysis of LULC changes, which positively affects the sustainability of environmental conservation. Based on satellite image, Landsat used in this study during the period 1986-2014, LULC was classified into six categories and including dense forests, agricultural and bare land, shrubs, rangelands, low-dense forests, and water bodies. The LULC changes in the West Kordofan study area indicated that agricultural and bare lands and range lands are increasing due to expansion of agriculture, illicit felling, overgrazing, and climate change, besides inappropriate sustainable management of natural resources. On the other side to the dense and low-dense forests are decreasing due to the increase in the local population and their activities, such as agriculture and firewood collection. The study recommends the application of remote sensing techniques as the most cost- and time-effective method for LULC mapping and assessment. Also, the use of appropriate planning and sustainable natural resources management in the areas should be used to avoid degradation and hazards facing LULC.

Ethics Statement

The authors affirm that this paper is their original work and has not been previously published or submitted elsewhere. It accurately acknowledges the meaningful contributions of all co-authors, fully discloses all sources used, and reflects the personal and active involvement of each author, who collectively accept public responsibility for its content.

Conflicts of Interest

The authors declare no conflicts of interest.

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