MAPPING LAND COVER CHANGE IN SPATIAL PATTERNS OF SEMI-ARID REGION ACROSS WEST KORDOFAN, SUDAN USING LANDSAT DATA

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Abstract. Land cover change information is fundamental to support environmental change studies, land management, and many other societal benefits. Here, we assess and quantify the spatial and temporal land cover changes in West Kordofan, Sudan. With (30 m) imagery from Landsat ETM+ for the entire West Kordofan, land cover maps were created to explore the changes in spatially explicit way. The results suggest that land cover changes observed in West Kordofan for 2000 to 2015 reflect emerging environmental risks such as rapidly sand encouragement and land degradation. Sand plain, burnt area and forest increased by approximately 7733.28 km^2, 810.27 km^2 and 258.99 km^2, respectively. The largest relative land cover change over the entire study period was the increase of sand plain. Expansion of sand plain resulted mainly from desert encouragement towards south direction. Accurate information on the patterns of land cover in West Kordofan may contribute to the future establishment of better land use and land cover polices for an effective land management. In addition, land cover information may also help decision-makers to understand and respond appropriately to emerging environmental risks for the inhabited people.
Keywords: *land cover, remote sensing, image classification, change detection, GIS, West Kordofan*

Introduction

Land cover represents an important factor in environmental change analysis, from physical environmental studies to spatial planning approaches (Huang et al., 2017; Lambin and Ehrlich, 1997; Padonou et al., 2017). It is a dynamic variable that reflects the interaction between human activities and environmental changes, and therefore, it is necessary to be mapped (Brown et al., 2018; Higginbottom et al., 2018). Mapping land cover changes in ecologically sensitive environment (semi-arid zone) is essential to locate, assess, and rank areas at risk (Higginbottom et al., 2018; Lambin et al., 2003). Furthermore, analyzing vulnerability, and improving land use planning to meet sustainable goals are required for an effective land management (Akinyemi and Mashame, 2018; Dimobe et al., 2015).

West Kordofan has been experienced some considerable amount of pressure during last two decades due to desertification and land degradation (Ayoub, 1999). Desert encroachment and intensive human activities induced dramatic changes in land cover across the region (Dawelbait and Morari, 2012). During last 17 years, desert south border has moved into south part of the region with an average of 90-100 km (Ayoub, 1998). Consequently, this rate of desert encroachment leads to gradual and prolonged

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vegetation loss over extensive areas in the region. According to (Ayoub, 1998) desert is continued moving to south at rate of 5-6 km per year. As the result, desertification across the region has transformed a vast area into arid zone and therefore created large area that has no sufficient quality life-supporting natural resources base and climatic conditions. Importantly, this permanent loss of vegetation cover leads to declining of *Acacia Senegal* natural stands, which is an important indigenous tree species in the region (Yagoub et al., 2017), but up to date detailed land cover map for West Kordofan and their spatial coverage still unknown. Therefore, mapping West Kordofan land cover is an urgent to public and scientific society, ranging from societal needs to sustainable land management.

Remote sensing has long been identified as an effective tool for large-scale land cover monitoring (Foody, 2001; Hansen and Loveland, 2012; Rogan et al., 2003; Schulz et al., 2010), and they are useful for land cover mapping (Petropoulos et al., 2012). It was, therefore, used efficiently in a number of land cover classification, mapping, and change detection studies using different satellite images with various resolutions (Badjana et al., 2017; Baker et al., 2006; Friedl et al., 2002; Leiterer et al., 2018; Salih et al., 2017). This success of remote sensing satellites is attributed to a range of advantages including wide range of geographical coverage and multi-spectral bands in each image (Liu et al., 2018). Moreover, premise of using remote sensing data is basically based on availability and accessibility of freely Landsat archived data, which offers a unique opportunity for mapping land cover of almost any region on Earth and assess both natural and human disturbances (Costa et al., 2018; Ehrlich et al., 1997). Therefore, combination of Landsat Enhanced Thematic Mapper (ETM+) images and geographic information system (GIS) techniques is a practical option to classify and map the land cover in West Kordofan area.

This study aims to quantify and describe the spatial and temporal patterns of land cover change in West Kordofan between 2000 and 2015. Maps that document accurately the patterns of land cover change in West Kordofan can form the basis for future land cover and land use planning and protection. This spatially explicit information on land cover change may also help to understand and respond rapidly and effectively to emerging environmental risks such as sand encouragement and desertification.

Materials and methods

Study area

West Kordofan is located in semi-arid zone of Sudan, and its administrative boundary includes eight Landsat ETM+ images with the path/row: 174/53; 175/51; 175/52; 175/53; 176/50; 176/51; 176/52; 176/53 in World Reference System -2 (WRS-2) (*Fig 1*). The surface area covered is approximately 114389.6841 km^2, extending between north latitude 9°-14° and east longitude 27°-29°. West Kordofan is representative of semi-arid climate in terms of both landscape structure and land surface cover. The terrain varies highly from sea level to approximately 986 m, whereas the vegetation of the area also varies with altitude. The climate of the area is typical semi-arid, characterized by hot summers, and cool winters, with a long dry period starting in November and lasting until July (beginning of rainy season) (Elagib and Elhag, 2011). The north part of West Kordofan is covered mainly by sand and some farms land. South part is covered mainly by woodland as well as forest of different tree species. The study

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area experienced severe drought during 1983-1984, 1990-1991 and 2004-2005 (Elagib, 2015).

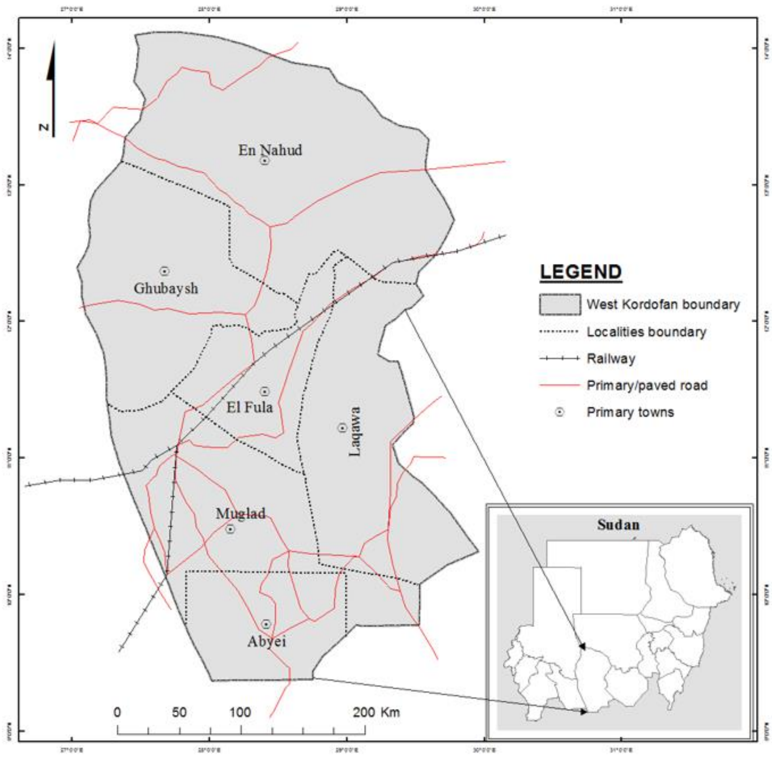

Figure 1. *Location of West Kordofan in Sudan*

Data acquisition

The primary data used in this study were acquired from Landsat Enhanced Thematic Mapper Plus (ETM+) for the years 2000 and 2015. A total of sixteen Landsat ETM+ images located by satellite path/row 176/50, 176/51, 176/52, 176/53, 175/51, 175/52, 175/53 and174/53 were used. These images were downloaded free of cost from archive database at http://glovis.usgs.gov/. In addition, a 30 m spatial resolution Digital Elevation Model (DEM) derived from the Shuttle Rader Topography Mission (SRTM) which provided an important non-spectral input for classification by characterizing elevation and slope related to different land cover categories (*Table 1*). Besides, training reference points on spatial location, land cover categories and topographic characteristics were collected form detailed field survey, which was carried out during dry season (January to March 2015). A total of 1173 points were collected using Global Positioning System (GPS) receiver (*Fig. 2*).

Data pre-processing

For land cover mapping, various requirements of pre-processing, for example, geometric correction, radiometric and atmospheric corrections are the most important to avoid spurious results produced from these issues (Lu et al., 2004). In this study, all downloaded images were level-1 products which were rectified, geometrically and topographically corrected. All images were converted from digital numbers (DNs) to

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top of atmosphere reflectance using the method suggested by Chander et al. (2009): Image pre-processing prior to classification is immensely needed and has a primary unique objective of establishing more direct affiliation between acquired data and biophysical features as well as for producing spatially corrected land cover map (Foody, 2010). Dark object subtraction was used to correct atmospheric effects. Layers stacking was performed to combine the spectral bands of Landsat ETM+ images. Mosaic was applied for the paths and rows: 176/50, 176/51, 176/52, 176/53, 175/51, 175/52, 175/53 and174/53. All the images pre-processing steps were carried out using software ENVI 5.1 and ArcGIS 10.2.

Table 1. *Characteristics of Landsat ETM+ images and SRTM data used in this study*

Datasets	Date	Spatial resolution scale, m	Spectral bands	Swath, km	Source	Format
Landsat 7 ETM+L1T	Nov. 2015	30	8 bands	183	http://glovis.usgs.gov/	GeoTiff
SRTM	Nov. 2015	30	1 band	Global	https://earthexplorer.usgs.gov/	GeoTiff

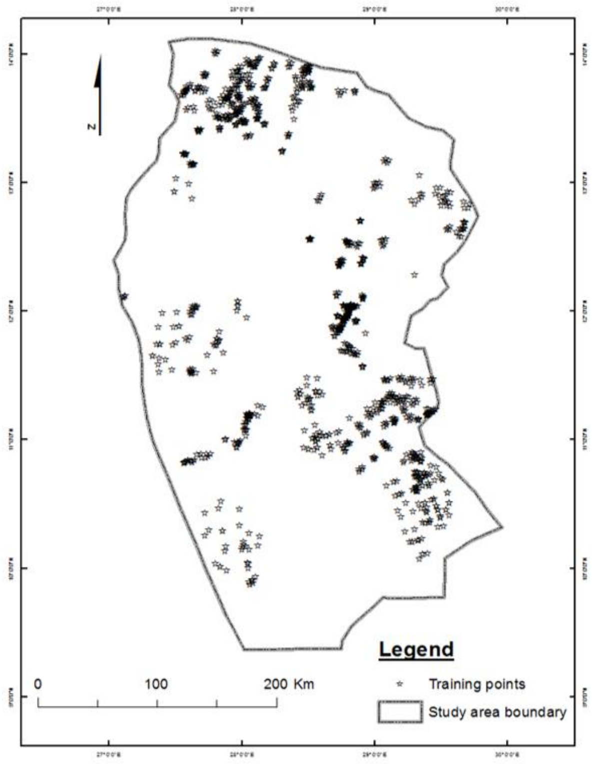

Figure 2. *Location of training reference points collected during the field survey that carried out from January to March 2015 in West Kordofan*

Selection of training pixels and classification

Land cover and, in particular, vegetation cover is dynamic, complex and change due to both the climate and human activities (Lambin et al., 2003). To map the land cover,

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and to enhance its classification, Normalized Different Vegetation Index (NDVI) was calculated to assess the extent and status of vegetation cover across the study area. The NDVI separates vegetated and non-vegetated areas and is a useful technique for normalizing the vegetation variable conditions (Sinha et al., 2016). The NDVI calculation is based on the ratio between red and near infrared regions of electromagnetic spectrum using *Equation 1* (Chamaille-Jammes et al., 2006).

$$NDVI = \frac{RED - NIR}{RED + NIR} \quad \text{(Eq.1)}$$

The given values range between -1 and +1, where values less than 0 represent areas that contain no vegetation and values greater than 0 represent pixels or areas in which vegetation is increasing (Madonsela et al., 2018).

Prior to the classification, the NDVI was produced for the images of 2000 and 2015 to facilitated to separate the spectral values and selection of training pixels process. The maximum likelihood classifier was the selected method for the process of supervised classification. It is the sort of image classification that is mainly controlled by the analyst as the analyst chooses the pixels that representative of the desired classes.

The classification was divided into six land cover categories included: natural water bodies, farm on sand, sand plain, forest, woodland and burnt area. The features sets used to generate the land cover maps were based on the spectral patterns of Landsat ETM+ images, NDVI and field survey observations.

To improve the classification accuracy and reduction of misclassified pixels, post-classification refinement was therefore applied for simplicity and effectiveness of the method (Yousefi et al., 2015). Importantly, using medium spatial resolution data such as that of Landsat ETM+ mixed pixels are a common issue (Lu and Weng, 2007); especially for the complex area characterized by complex features. The issue of mixed pixels was addressed by visual interpretation. To enhance the classification accuracy and therefore the quality of produced land cover maps, visual interpretation is very important. Thus, visual analysis, training reference points, and local knowledge, considerably improved the result derived by using maximum likelihood supervised classification technique.

Accuracy assessment

Assessment of classification accuracy of final produced land cover maps were carried out to determine the quality of information derived from the Landsat ETM+ images. For the accuracy two different methods associated with two independent validation datasets. The classified image of 2015 was assessed for accuracy by using 423 reference points that collected through the field survey. We then compared the observed (reference points) label of every sample to the map label and the results summarized in confusion matrix. In the second method, the accuracy assessment was carried out using stratified random sampling procedure to generate the reference points. Care was taken to create sample points for 2000 classification map.

As the extent of each land cover category different, the size of the sample points varied among different classes. A total of 138 reference points were collected and checked against Google Earth Pro image. Then a confusion matrices were calculated to assess the accuracy of the final land cover maps. A confusion matrix is a simple cross-tabulation of each mapped class vs. the reference point. Overall accuracy, user’s and

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producer's accuracies were then calculated for each land cover category as shown in *Table 2*. Moreover, Kappa statistic was also derived for estimating degree of classification accuracy as it not only account for diagonal elements but for whole confusion matrix elements.

Land cover change detection

Change detection is a very common and powerful application of satellite based remote sensing. Change detection entails findings the type, rate and location of land cover changes that are taking place (Kashaigili et al., 2006).

In this study, post-classification comparison was used to quantify the extent of land cover changes over the 15 years period (2000 to 2015). The merit of post-classification comparison is that it bypasses the difficulties associated with the analysis of the images that are obtained at different times of the year, or by different sensors and results in high change detection accuracy.

Table 2. *Classification accuracy assessment of 2015 Landsat ETM+ image using error matrix*

a) Year 2000								
Number of pixels	**Training reference points**							
Land cover	**NWP**	**FS**	**SP**	**F**	**WL**	**BA**	**Total**	**UA (%)**
NWP	**11**	0	1	0	2	0	14	78.6
FS	0	**23**	3	0	0	1	27	85.2
SP	1	2	**14**	1	1	0	19	73.7
F	0	2	1	**20**	1	1	25	80.0
WL	0	1	2	3	**34**	1	41	82.9
BA	0	1	0	1	1	**9**	12	75.0
Total	12	29	21	25	39	12	**138**	
PA (%)	91.6	79.3	66.6	80.0	87.1	75.5		
Overall accuracy = 80.4%, Kappa coefficient = 0.756								
b) Year 2015								
Number of pixels	**Training reference points**							
Land cover	**NWP**	**FS**	**SP**	**F**	**WL**	**BA**	**Total**	**UA (%)**
NWP	**29**	1	0	0	4	0	34	85.2
FS	0	**106**	5	0	0	0	111	95.4
SP	0	6	**60**	0	1	0	67	89.5
F	0	0	0	**40**	2	2	44	90.9
WL	0	1	0	5	**117**	3	126	92.8
BA	1	0	0	2	2	**36**	41	87.8
Total	39	114	65	47	126	41	**423**	
PA (%)	74.3	92.9	92.3	85.1	92.8	87.8		
Overall accuracy = 91.9%, Kappa coefficient = 0.897								

Natural water bodies (NWB), farm on sand (FS), sand plain (SP), forest (F), woodland (WL), burnt area (BA), User's accuracy (UA), and Producer's accuracy (PA)

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Results and discussion

Figure 2 shows the distributions of GPS location (training reference points) collected during detailed field survey. The analysis of digital elevation model (DEM) reveals that the terrain of West Kordofan sloping from northeast to south (*Fig. 3*). Maximum elevation occurs at eastern part of the study area approaching 986 m, while the minimum level of land ranges between 364 and 450 m.

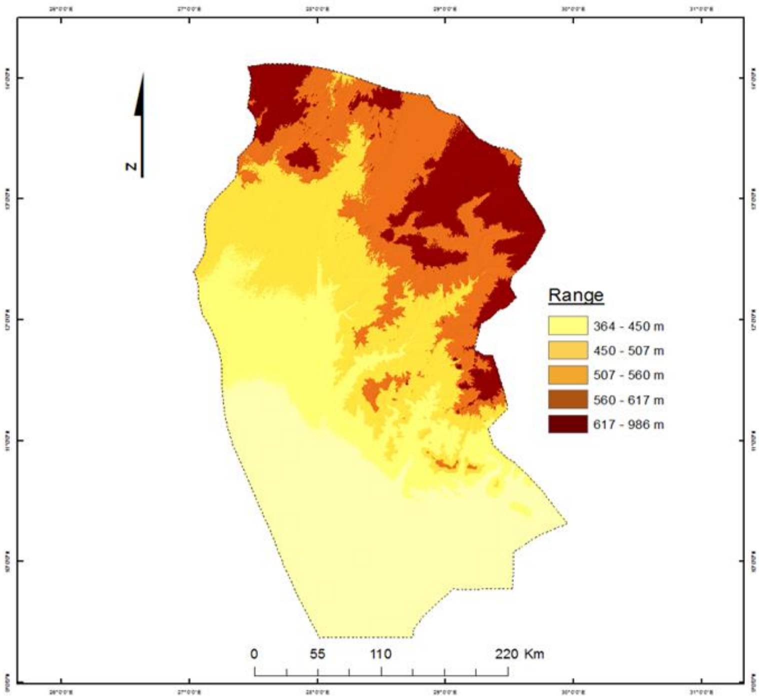

Figure 3. *West Kordofan topographic map produced from the SRTM DEM*

Confusion matrices showed that the overall accuracies of land cover maps for the year 2000 and 2015, which categorized six land cover classes (natural water bodies, farm on sand, sand plain, forest, woodland and burnt area) were higher or equal to 80.4% and 91.9%. The Kappa coefficient values were 0.756 and 0.897, respectively. Most user's and produce's of individual land cover categories were also generally high, ranging from 66.6% to 95.4% (*Table 2*). Single date land cover map was created for each year to show the spatial distribution of six land cover categories in West Kordofan (*Fig. 4*).

From 2000 to 2015, sand plain, burnt area and forest increased by approximately 7733.23 km^2 (43.93% of the total changed area), 810.27 km^2 (4.6%) and 258.99 km^2 (1.47%), respectively. Farm on sand decreased by 6625.73 km^2 (37.64%), woodland decreased by 2001.8 km^2 (11.37%) and natural water bodies by 175.78 km^2 (0.99%). The largest relative change for the period 2000-2015 was observed in the area covered by sand, which increased by 515.55 km^2 annually. Sand expanded consistently during the study period. This patterns of sand throughout the study area will be especially important for sand encouragement studies and land degradation as can be seen in *Figure 5*. The change in sand plain area was followed by the increase in burnt area, 54.02 km^2, and in forest, 17.27 km^2. Burnt area describes the areas that exposed to

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frequent occurrence of wildfires especially during the end of dry season. The increase in burnt areas are largely due to farm preparations, woody tree clearing, livestock grazing and might be because of ongoing conflict in the region. These making human and the ecosystem more susceptible to sever damage and risks associated with wildfires in West Kordofan. However, the increase in forest resulted mainly from planted and expansion of *Acacia Senegal* tree (known as gum-gardens). This finding are consistent with previous environmental monitoring and assessment conducted in the Gum belt in Kordofan region to identify the distribution of *Acacia Senegal* tree (Khiry and Csaplovics, 2007).

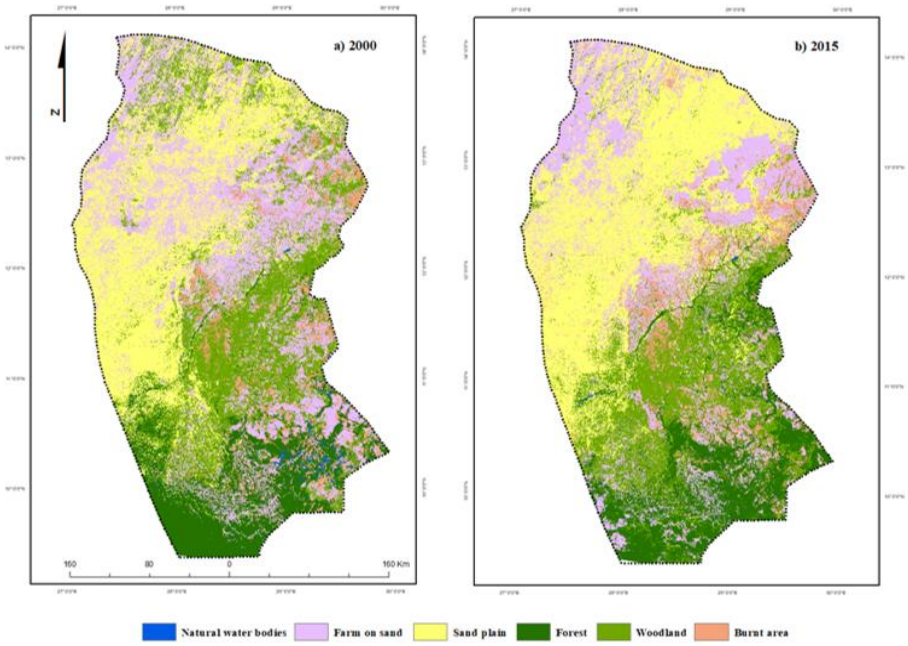

Figure 4. *Final land cover maps of West Kordofan for a) 2000 and b) 2015*

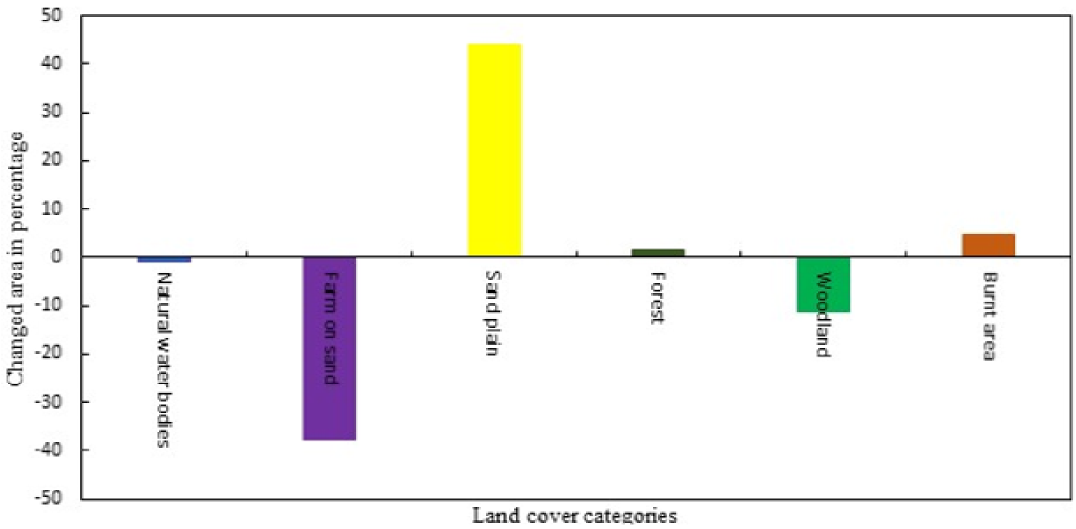

Figure 5. *Percentage of areas changed for the six major land cover categories in West Kordofan*

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Although the extent of natural water bodies may have changed from year to year due to annual variability in rainfall and temperature, the change (decrease) observed in this category is likely to be partially explained by classification errors.

Spatial coverage under each land cover category for the year 2000 and 2015 were depicted in *Table 3*. A general look at the final land cover maps shows that the total surface area of West Kordofan is almost 113788.11 km^2. The changes in land cover that occurred in West Kordofan between 2000 and 2015 were not spatially homogenous. The two land cover maps produced in the study area revealed that land cover changes varied among the different land cover categories. In general, the central desertified and the northern and northeast were most changed. Sand encouragement primarily occurred in the north and west of the study area, in areas of En Nahud and Ghubaysh in the north and west, respectively.

Forest growth mainly occurred in the south part of West Kordofan, southeast and around the margin of natural water bodies. However, vegetation cover density at the north part of the study area is rather low compared with the south part. In fact, in semi-arid areas, vegetation cover is often limited in diversity and complexity. Species like *Acacia Senegal* (locally known Hashab), is indigenous tree that comprises pure stands distributed over a vast area mixed with farm on sand, which play an important role in economic activities and sand encroachment stability.

The low density of vegetation cover in the north part are perhaps the most important factors in the context of conserving natural resources in West Kordofan. With the human activities, pressure on vegetation cover is increasing with growing demand for fuel wood, charcoal, agriculture expansion (both large and small scale farming) and grazing land covers. These might over time lead to severe deterioration or multidimensional environmental changes as already being reported by (Yagoub et al., 2017).

Table 3. *Area and amount of change in different land cover types in West Kordofan during 2000 to 2015*

Land cover categories	Spatial area coverage				Changed area		Annual rate of change
	2000		2015		2000-2015		2000-2015
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	(km^2/yr)
NWB	653.06	0.57	477.27	0.42	-175.78	-0.99	-11.72
FS	32148.88	28.25	25523.16	22.43	-6625.73	-37.64	-441.71
SP	33368.18	29.32	41101.47	36.12	7733.28	43.93	515.55
F	15629.98	13.74	15888.97	13.96	258.99	1.47	17.27
WL	25549.07	22.45	23548.03	20.69	-2001.03	-11.37	-133.40
BA	6438.94	5.66	7249.22	6.37	810.27	4.60	54.02
Total	113788.12	100	113788.11	100	17605.10		

Farm on sand class was typically used to describe farming practices on sandy soil that rely on rainfall. It was significantly decreased between 2000 and 2015 by almost 441.71 km^2 per year from the total changed area. West Kordofan is currently undergoing economic transition processes that affect the use of land directly and indirectly. Change in farms areas is linked directly to socioeconomic development due to the effect of economic growth, oil exploration and mining (Binuomote and Odeniyi,

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2013). Economic growth also influences positively the spatial structure of land cover and land use patterns by improving income opportunities form non-agricultural sectors. Oil exploration in West Kordofan has also been a major factor driving urban development processes, particularly in the south part of the study area. Consequently, some farms land has been transformed rapidly into mining infrastructure in the past two decades. Therefore, it is reasonable to conclude that the changes in different land cover categories are corresponded to economic development and of course desert encouragement towards the south direction of the study area. In this present study important changes in land cover were identified in West Kordofan between 2000 and 2015. These results raise the need for further studies to determine association of the changes and other potential drivers of land cover change with the observed increase in sand plain.

Conclusions

This study presents an initial attempt to filled current gaps in land cover datasets in West Kordofan of Sudan, and suggest high priority for ecologically sensitive environment (arid and semi-arid areas) do not currently have sufficient scientific information. The results demonstrate that combination of remotely sensed data and geographic information system (GIS) can provide an accurate, economical means to classify and map land cover in a large-scale area and statistics. The results of land cover change analysis conducted in this study concur with large-scale impact of expanding sand plain and burnt area coverage. These findings provide evidence that may help facilitate future land cover and land use planning, management and decision-making in West Kordofan region. In addition, this assessment of land cover changes may also help to explain and respond effectively to emerging environmental risks in West Kordofan region.

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