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Integration of Landsat, Climate and Field Data for Land cover Mapping in South Corridor of Sudan

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Abstract
Analyzing land cover change over semi-arid region with complex land surface features is a central challenge facing the earth science society. One such region is West Kordofan State in semi-arid zone of Sudan. Here, we monitor and quantify the spatio-temporal land cover change dynamics of this area over the years 2005 and 2015. A supervised classification of Landsat data, complemented by detailed field survey data for the entire area, land cover maps were created to explore the changes in the major land cover categories in spatially explicit way. Subsequent change analysis between these years found extensive conversions of natural environment as the result of climate variability and anthropogenic related activities. Water body, bare land and shrub land decreased by approximately 45.9 km^2, 1979.5 km^2 and 3366.9 km^2, respectively. The largest relative land cover change over the entire study period was the decreased of shrub land. Woody land and sand area increased by nearly 2319.3 km^2 and 3073.3 km^2. Woody land growth resulted mainly from the conversion of water body (9.4%) and shrub land (15.2%), while sand area expanded due to the rapid desert encouragement. Despite limited data availability, this study fills the gap of much needed detailed and updated land cover change information for the semi-arid zone of Sudan. These multi-temporal datasets would be a valuable baseline for local land use managers and decision-makers in the region to understand and respond appropriately to emerging environmental risks like desertification.

Keywords: Land cover, Landsat data, Classification, Change dynamics, West Kordofan

1. Introduction

Natural and unguided human activities are increasingly affecting the biophysics, biochemistry and biogeography of Earth's surface and atmosphere (Pongratz *et al.*, 2009; Reick *et al.*, 2013; Sterling *et al.*, 2013) [27, 29, 33]. Land cover and land use are significant in shaping the structure of ecosystem (Lambin and Geist 2008) [19]. Changes in land cover are fundamental elements of environmental change, and are the major determinant of sustainable development and human adaptation to global change (Restrepo *et al.*, 2017; Turner *et al.*, 2007) [30, 36]. These changes are occurring at a range of spatial scales from local (Kalnay and Cai 2003) [17] to global and at temporal frequencies of days to millennia (Foley *et al.*, 2005; Townshend *et al.*, 1991) [10, 35]. Land cover changes has the potential to impact on climate at local and regional scales (Lambin *et al.*, 2001) [21] and also at global scale (Jetz *et al.*, 2007) [14].

Some extensive human activities may also contribute to reduce or accelerate land degradation and subsequent loss of biodiversity (Seto *et al.*, 2012) [32]. These changes effects have the potential to alter the natural environment to such extent that the welfare and vulnerability of humans to social and environmental stressors may be positively or negatively affected (Carpenter *et al.*, 2006) [3]. The need for understanding the distribution and dynamics of land cover can never be underestimated due to its huge implications to human welfare. A huge-bulk of researches (Diouf and Lambin 2001; Lambin *et al.*, 2003; Verburg *et al.*, 2011) [6, 20, 37] emphasizes the need for timely, accurate observations documenting land cover change to be more pressing than ever given the changing situation of global climate. However, there have been relatively few efforts to identify the spatio-temporal patterns of land cover change in semi- arid zone of Sudan as general and West Kordofan State in particular.

Located in the semi-arid zone of Sudan which is priority region for environmental change studies. The high local poverty rate, the difficult natural environmental conditions and the over exploitation of natural resources in West Kordofan State have contributed to the deterioration of local environment during the past decade. Land cover mapping of the entire Kordofan region including West Kordofan State has previously carried-out by United Nations Food and Agriculture Organization (FAO) inits Africover project by creating single time frame multipurpose land cover map of Sudan, using combination of high and medium-resolution imagery dated 2006-2010 (Ottichilo 2006) [26]. On the other hand, the priority of a number of researchers has been monitoring desertification in the region. For example, (Dawelbait and Morari 2012) [5] assessed the desertification processes in the region from 1987 to 2008 using Landsat imagery. However, that important research is exclusively focused on the impacts of desertification on both natural resources and man's livelihood. No detailed land cover change analysis for West Kordofan State has been accomplished. Therefore, work still required to explore the additional environmental and climatic consequences that can be result of these changes.

Remotely sensed data such as Landsat images provides an efficient and cost effective tools of generating information on temporal trends and spatial distribution of land cover (Yuan *et al*., 2005) [39]. Remote sensing data have been used extensively to map and monitor a range of land cover at various spatial and temporal scales (Foody 2002) [11]. Landsat data constitutes the longest record of global scale medium-spatial resolution earth observation data which is an online data services provisioning since 2008 (Foody 2002) [11]. Landsat program provided successive satellite generation since 1972 to monitor and explore earth resources on a systematic and repetitive basis (Hansen and Loveland 2012) [13]. More specifically, due to its finer spatial resolution than many other global satellite imagers, Landsat images has been the data source of choice used in a number of land use and land cover researches (Raj *et al*., 2013) [28]. Landsat has been used widely to study the dynamics of different earth surface like urban areas (Raj *et al*., 2013) [28], forest cover (Woodcock *et al*., 2001) [38], rangelands (Gong *et al*., 2013) [12], and arid and semi-arid areas (Tanser and Palmer 1999) [34].

In this study, Landsat data are used to monitor and assess the complex land surface in West Kordofan State. However, data gaps and a very complex land cover features make this area a very challenging site to analysis the land cover changes. Access of appropriate data in terms of spatial and temporal is one major limiting factor for land surface observation in semi-arid zone. The region also suffers from low Landsat acquisition frequency for the early Landsat sensors due to the fact of lack of ground station coverage in the region and limited onboard image storage capacity, reducing temporal coverage for the application of land cover change studies (Ju and Roy 2008) [16]. Furthermore, the Landsat ETM+ SLC-off acquisitions suffer from wedge shape gaps reducing 22% of the usable data after 2003 (Arvidson *et al*., 2006; Markham *et al*., 2004) [1, 24].

This study aims to quantify and describe the spatio-temporal patterns of land cover change in West Kordofan State between 2005 and 2015. Thematic maps document accurately the local patterns of land cover change in this State can form the baseline for decision-makers and local land use managers in the region to understand and respond appropriately to emerging environmental risks such as desertification.

2. Materials and methods

2.1 Study area

West Kordofan State is a big state located on semi-arid zone of Sudan in southern border between latitudes 9˚28` N and 14˚10` N, and between Longitudes 27˚12`E and 30˚5`E. West Kordofan State shares borders with North Kordofan State in the north, North Darfur State in the northwest, East Darfur State in the west, South Kordofan State in the east and Republic of South Sudan in the south (Fig. 1). From north to south, the state territory stretches 530.7 km, and from east to west between 247.4 km and 292.2 km, with a total area of approximately 114,453 km^2. West Kordofan lies at 367 m above sea level. The land surface is complex and geographically consists of two major natural regions that have distinct natural resources: the northern desertified part with extensive rain-fed agricultural and grazing and the southern part with rain-fed agricultural and dense vegetation cover. Elevation increases from north to south with the highest altitude at 986m. In general, West Kordofan State has a semi-arid climate and three distinct seasons. Temperature varies from 20.4 C˚ in winter to 39.3 C˚ during summer with an annual average of 35.8 C˚. Rainfall varies from 183 to 340 mm yearly increasing from north to south (Elagib and Mansell 2000) [8]. Most rainfall occurs during July and August (80% of the total precipitation in the entire study area). The annual average rainfall is 265 mm yearly.

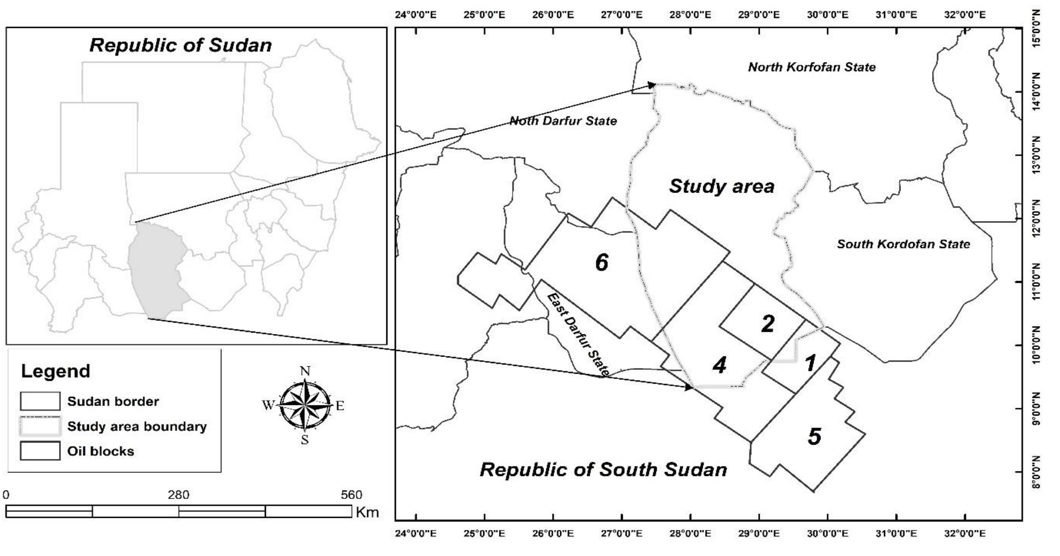

Fig 1: Map of the West Kordofan State covered by eight Landsat scenes and location of the State within Sudan

2.2 Landsat data and preprocessing

The primary remote sensing data used in this study were Landsat 7 (Enhanced Thematic Mapper Plus) ETM+ imagery. Because the technique developed for the study will be applied to the entire study area, it is important to develop a consistent protocol for selection of the remote sensing data and pre-processing. By following the protocol, we created a single mosaicked image to the entire study area for 2005 and 2015, respectively. The image selection takes into consideration the amount cover of cloud and image acquisition date. The images selection was made using United States Geological Survey (USGS) Global Visualization Viewer (GloVis;http://glovis.usgs.gov/), with Landsat WRS2 swath mode. Swath mode allows users to choose a number of cloud-free or nearly cloud-free images acquired from the same or different date. These can then be used to form image mosaic for the study area so that a higher efficiency for land cover change mapping can be achieved. For each year 2005 and 2015, eight images were downloaded for the period (November) at ten-year intervals (Table 1). This time period was selected due to available images with minimal cloud cover. All selected images were filled the missing pixels due to collapse of Landsat7 sensor. Then the images were radiometrically and geometrically calibrated and converted from digital number (DN) to top-of-atmosphere reflectance (TOA) using technique previously used by Chander *et al*., (2009) [4]. All images were also terrain-corrected and co-registered to one another with root mean square error (RMSE) less than 0.5 pixels. After this processing, the images with cloud were detected, masked out, and then filled using the technique developed by (Jin *et al*., 2013) [15]. Additional reference image dated Dec 3, 2000 was used in this method to fill the masked-out area in order to obtain a final cloud-free image. Those processed cloud-free images of the same year were then mosaicked to form the entire image of the study area.

2.3 In situ meteorological data

The 29-year historical data record (1986-2015) of monthly climatic data (Rainfall and temperature) for 6 local meteorological stations in West Kordofan State were collected from Sudan Meteorological Authority (SMA) and records with no missing data were selected. These local stations include: *En Hahud* in the north, *Laqawa* in the east, *Abyei* at south, *Ghubaysh* in west, *El Fula* in the center and Muglad at southwest of the State (Fig. 3). After we have verified the data, annual average rainfall and annual average temperature were calculated. We entered spatial coordinates for the meteorological stations along with climate data in ArcMap. Data from these stations were then used to create maps that showed the range of annual average rainfall and annual average temperature across West Kordofan State (Fig. 4) by assign fraction values to missing locations based on surrounding measured values. However, this was accomplished with interpolation using the Inverse Distance Weighted (IDW) method in ArcGIS 10.2.

Table 1: Specifications for Landsat images used for land cover classification and change detection analysis in West Kordofan State from 2005 to 2015

Year	Data type	Landsat scene	Path/row	Date acquired
2005	Landsat 7 ETM+	LE71760502005329ASN00	176/050	2005/11/25
		LE71760512005329ASN00	176/051	2005/11/25
		LE71760522005313ASN00	176/052	2005/11/09
		LE71760532005329ASN00	176/053	2005/11/25
		LE71750512005306ASN00	175/051	2005/11/02
		LE71750522005306ASN00	175/052	2005/11/02
		LE71750532005322ASN00	175/053	2005/11/18
		LE71740532005315ASN00	174/053	2005/11/11
2015	Landsat 7 ETM+	LE71760502015325SG100	176/050	2015/11/21
		LE71760512015325SG100	176/051	2015/11/21
		LE71760522015325SG100	176/052	2015/11/12
		LE71760532015325SG100	176/053	2015/11/21
		LE71750512015318SG100	175/051	2015/11/14
		LE71750522015318SG100	175/052	2015/11/14
		LE71750532015318SG100	175/053	2015/11/14
		LE71740532015327NPA00	174/053	2015/11/23

2.4 Reference data for image classification

Due to the lack of reference data on land cover information for West Kordofan State during the study period, multiple data sources were required to produce reference data sets for land cover classification and accuracy assessment. ArcGIS software was used to generate random samples of reference points for the year 2005. A total of approximately 617 reference points were selected. In this way, it was possible to ensure that all land cover classes were adequately represented in the training statistics. All the selected reference points were cross-checked against image of 2005 from Google Earth Pro (GEP). Google Earth archive display various forms of imagery obtained from different sources such as Landsat and QuickBird satellite sensors. GEP software is a widely-used platform for the collection of high resolution geo-referenced data on land cover, and also for the validation of land cover classification maps. For the year 2015, a total of 329 reference points were collected through extensive field survey which carried-out between September and November 2015 using hand held Global Positioning System (GPS). The reference points for 2015 were also checked against GEP 2015 image. Both, reference points and images were used to determine visually if land cover had changed between the period 2005 and 2015. For all images, visual interpretation of Landsat images was also implemented to improve image classification and producing of final thematic maps. Visual comparisons of multiple sets of three spectral band combinations were conducted using ENVI software version 5.1. This method was applied to better discriminate the different land cover categories within the study area.

2.5 Image classification and accuracy assessment

We developed a comprehensive method to map West Kordofan State land cover during 2005 and 2015. The method was designed to map the major land cover categories and detect the changed areas. The method includes four main steps: 1) identify the major land cover categories in the study (Table 2); 2) assign an initial land cover label using reference points collected from the field survey, local familiarity and GEP high resolution geo-referenced data; 3) perform supervised land cover classification; 4) refine miss-classified pixels to reduce errors in the classification process. However, maximum likelihood classifier (MLC) was the selected method of supervised classification. Assuming a normal data distribution, this classifier considers both the variance and covariance of class signatures to assign unknown pixels to a specific land cover category (Lillesand *et al*., 2014) [23].

The land cover classes were grouped into five major categories (water body, bare land, woodyland, shrubland and sand). The classification scheme adopted (Table 2) was established based on GEP images and reference data that obtained primarily from the field survey.

Table 2: Identified land cover categories

Class	Description (land cover type)
Water body	Natural streams with seasonal water coverage which considered as main source for domestic uses.
Bare land	Land consists of open spaces and areas with little or no green vegetation present.
Woodyland	Areas characterized by tree cover or semi-natural woody vegetation with canopy cover 10% and height > 5 m.
Shrubland	Open general shrubs (0.5 – 4 m) with scattered grasses and sparse trees in between.
Sand	Areas that characterized by ongoing or recent sand encroachment.

Post-classification refinements were performed to reduce errors in the classification process. Due to significant confusion among the land cover categories, vegetated areas (forests, rangeland, shrubs) these classes were merged and represented as woodyland and shrubland) in the final maps and subsequent analyses.

Using the ENVI software, 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 points (Lillesand *et al*., 2014) [23]. The overall accuracy, kappa coefficient, user's and producer's accuracies were derived from the confusion matrices. The kappa coefficient reflects the different between actual agreement between data and classified maps and the agreement expected by chance. A high kappa value indicates perfect agreement, while a low value indicates no agreement (Foody 2002; Lillesand *et al*., 2014) [11, 23]. User's accuracy provides an estimate of the probability that a pixel from the land cover map matches the same category in the reference data (it measures errors of commission), whereas the producer's accuracy estimates the probability that a reference pixel has been mapped correctly (it measures errors of omission) (Foody 2002) [11].

2.6 Land cover change detection

Change detection is a very common and powerful application of remotely sensed data. Change detection entails findings the type, amount and location of land cover changes that taking place. In this study, post-classification comparison was performed to quantify the extent of land cover change over a decade (2005 and 2015). The Table indicate the number of pixels of a given class at time t_1 that are classified as the same class at time t_2 (from-to). However, estimation for the rate of different land cover categories was computed based on the following equations (Kashaigili and Majaliwa 2010) [18].

$$\%\ Change_{year\ x} = \frac{Area_{i\ year\ x} - Area_{i\ year\ x+1}}{\sum_{i=1}^{n} Area_{i\ year\ x}} \times 100 \quad (1)$$

$$\text{Annual rate of change} = \frac{Area_{i\ year\ x} - Area_{i\ year\ x+1}}{t_{years}} \quad (2)$$

$$\%\ Annual\ rate\ of\ change = \frac{Area_{i\ year\ x} - Area_{i\ year\ x+1}}{\sum_{i=1}^{n} Area_{i\ year\ x}\ x t_{years}} \times 100 \quad (3)$$

Where $Area_{i\ year\ x}$ is area of cover *i* at the first-time date, $Area_{i\ year\ x+1}$ is area of cover *i* at the second date, $\sum_{i=1}^{n} Area_{i\ year\ x}\ xt_{years}$ is the total cover area at the first date and t_{years} is period in years between the first and second image acquisition dates.

The merit of post-classification comparison is that it bypasses the difficulties associated with the image analysis are acquired at different times of the year, or by different sensors and results in high change detection accuracy (Li *et al*., 2007) [22].

2.7 Anthropogenic activities data collection and analysis

Detailed field survey has been conducted as mentioned earlier for assessment of anthropogenic activities using visual observation and key informant interviews. At random, 47 plots with an area of 0.12 ha were established and their coordinates were taken using hand held Global Positioning System (GPS). The spatial distribution of sample plot in the entire study area among different land cover categories are: 4 sample plots in water body, 9 in bare land, 24 in woody land, 7 in shrub land and 3 in sand area. In each plot an assessment of anthropogenic activities was conducted (Table 3).

Both descriptive and inferential statistical techniques were used to analyze the quantitative data. Descriptive statistics such as frequencies were used to explain the primary causes of anthropogenic activities in the study area. Inferential data analysis was conducted to determine the extent of anthropogenic activities per plot and to test the significance between frequency and extent of anthropogenic activities within the study area. The frequency and extent per ha were computed using the following equations:

$$F_{ha} = \frac{f}{p\ X\ n} \quad (4)$$

Whereby F_{ha} is frequency per ha of individual anthropogenic activity, *f* is frequency, *p* is the plot size and *n* are the number of plots surveyed.

$$E_{ha} = \frac{Ab}{p\ X\ n} \quad (5)$$

Where is E_{ha} is the extent per ha of individual anthropogenic activity, *Ab* is abundance of anthropogenic activity, *p* is the plot size and *n* is number of plot surveyed.

$$RAb = \frac{ni}{n} \times 100 \quad (6)$$

RAb is relative abundance of individual anthropogenic activity, *Ab* is abundance of anthropogenic activity, *n* is the total number of individual anthropogenic activities recorded in the area.

Table 3: Summary of anthropogenic activities categories recorded in the West Kordofan State

S. No	Land cover anthropogenic activity	Primary causes of land cover anthropogenic activity	Indicator	Extent of land cover anthropogenic activity			
				Absent	Low	Moderate	Severe
1	Wood collection	Building materials	Stumps > 13 cm	None	1-6	6-11	> 11
		Firewood	Stumps > 8 cm	None	1- 3	4 -7	>7
		Charcoal	Charcoal kiln and stumps close to charcoal kiln	None	1- 3	4 - 7	>7
		Farming	Cleared area for growing crops	None	1 -3	4 -6	>6
2	Grazing	Grasses and water bodies	Livestock feces and browsing traces	None	1 -2	3 -5	>5
3	Fires	Cleared areas for cultivation	Burnt stumps and ashes	None	1 - 4	5- 7	>7

3. Results

3.1 Land cover classification and change detection analysis

Confusion matrices showed that the overall classification accuracies were higher or equal to 90% and the total Kappa statistic were >0.8. These results represent a considerable agreement between the reference data sets and the classified maps. The Kappa statistic for 2005 and 2015 were 0.879 and 0.920, respectively. Most user's and producer's accuracies of individual land cover categories were also generally high, ranging from 73% to 97% (Table 4).

Table 4: Summary of Landsat TM/ETM+ images classification accuracies (%) for 2005 and 2015

Land cover category	2005		2015	
	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)
Water body	85.71	73.47	83.33	75.51
Bare land	97.30	87.80	87.24	73.21
Woodyland	88.64	97.56	92.81	90.90
Shrub land	82.00	91.11	83.33	97.56
Sand	92.24	81.63	97.63	95.14
Overall accuracy	90.78		93.58	
Kappa coefficient	0.879		0.920	

Single date land cover maps were created for each study period to show the spatial distribution of five land cover categories in West Kordofan State (Fig. 2). The spatial coverage by each individual category and the change statistics for 2005 and 2015, which were temporal extremes of this study were calculated (Table 5). From 2005 to 2015, water body, bare land and shrub land categories decreased by approximately 45.9 km^2 (0.1% of the study area), 1979.5 km^2 (1.73%) and 3366.9 km^2 (2.9%), respectively. Woody land category increased by 2319.3 km^2 (2%) and sand increased by 3073.3 km^2 (2.7%). The largest relative change for the period 2005-2015 was observed in the area covered by shrub land, which decreased by 3366.9 km^2. Shrub land shrinks with greatest decrease occurring between 2005 and 2015. The change in shrub land was followed by the increase in woody land, 231.9 km^2, and in sand, 307.3 km^2, whereas water body decreased by 4.6 km^2. Although the extent of water body may has changed from 2005 to 2015 due to annual variability in rainfall and temperature (Fig. 4), the minor change observed in water body category is likely to be partially explained by classification error. Because woody land was covered the water body, it is difficult to interpret the change observed in this land cover category over the study period. Further evaluate the results of different land cover conversions, cross-tabulation of the pair maps of 2005 and 2015, were created (Table 6).

In Table 6, the land cover categories of the first map (vertical) are compared with those of the second map (horizontal) and tabulation is kept of the number of pixels in each combination. The results suggest that the area covered by sand increased in the interval 2005-2015. Although shrub land decreased over the entire study period, while woody land was extended. The increase in areas covered by sand is the direct outcome of desert encouragement, human induced, as well as biophysical and climatic drivers during the study lifespan. Of the 3073.3 km^2 of total increase in sand area between 2005 and 2015, 15.9% was converted from shrub land. Although it is not possible to estimate the amount of land conversion, the increase in woody land could mainly attributed to conversion of shrub land and water body land cover categories.

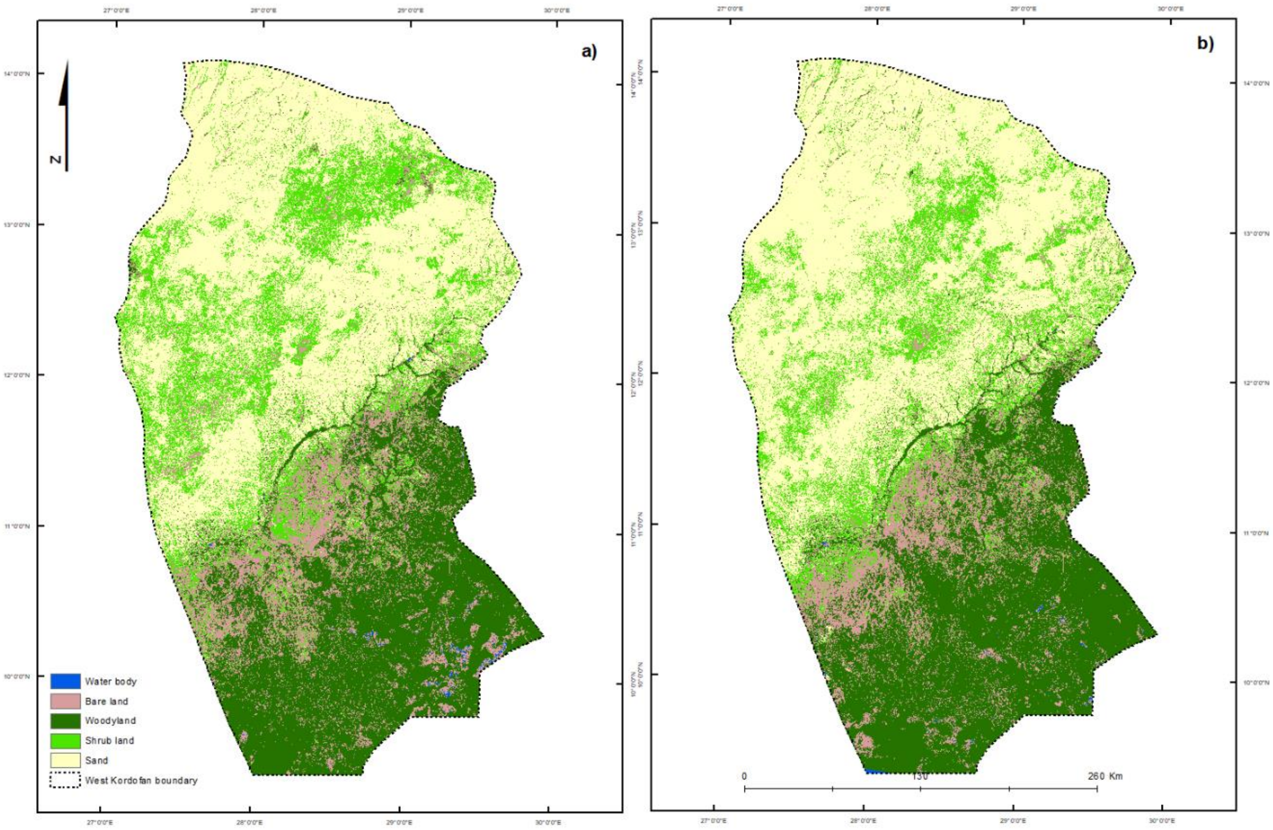

Fig 2: Land cover classification maps for West Kordofan State from (a) 2005 and (b) 2015.

Table 5: Area and amount of change in different land cover types in West Kordofan State during 2005 to 2015

Land cover category	**Surface land area covered**				**Net area of change**		**Annual rate of change**
	2005		2015		2005-2015		2005-2015
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	(km^2/yr)
Water body	185.6	0.3	139.6	0.2	-45.9	-0.1	-4.6
Bare land	15670.1	13.6	13690.5	11.9	-1979.5	-1.73	-197.9
Woody land	30928.5	27	33247.7	29	2319.3	2	231.9
Shrub land	20565.3	17.9	17198.4	15.1	-3366.9	-2.9	-336.7
Sand	47103.6	41.2	50176.9	43.8	3073.3	2.7	307.3
Total	114453.1	100	114453.1	100			

The matrix created to show the land cover change in West Kordofan State during the entire study period (2005 to 2015) indicates that the decrease in water body (45.9 km^2) resulted mainly from conversion of shrub land (Table 6). The changes in land cover that occurred in West Kordofan State between 2005 and 2015 were not spatially homogeneous. The two land cover maps produced for the study area revealed that land cover changes varied among the different land cover categories.

Table 6: Land cover change matrix showing land encouragement (in %) of West Kordofan State during 2005 to 2015

Land cover category		**2005**				
		Water body	**Bare land**	**Woody land**	**Shrub land**	**Sand**
2015	Water body	21.5	0.2	3.5	13.6	0.0
	Bare land	67.3	35.9	13.7	1.9	0.0
	Woody land	9.4	58.3	69.1	15.2	1.2
	Shrub land	1.4	1.8	13.7	49.3	15.9
	Sand	0.4	3.8	0.0	20	82.9
	Total	100	100	100	100	100

In general, the north, northeast and west are desertified and most transformed. Woody land growth primarily occurred in the south and along the water bodies, in areas of Muglad, Abyei and Laqawa, respectively. The permanent expansion of sand was mainly occurred around the center, north, northeast and west directions of the State. Sand dominated the landscape on a vast plain of the northern part of West Kordofan State with a progressive expansion to south.

3.2 Anthropogenic activities influencing land cover changes in West Kordofan State

Despite existence of laws and regulations enforced by Forest

National Corporation (FNC), State Office and other local authorities aiming at protecting and managing the natural resources, anthropogenic activities are still taking place. Table 7, shows the major causes of anthropogenic activities in West Kordofan State. The causes vary significantly between the anthropogenic activities, for example wood extraction has a large number of causes as compared to other. The number of occurrences of the causes for wood extraction (Table 7) involves (43) for firewood collection, (31) for poles that are mainly used as construction materials, (17) for wood and shrub clearing that are attributed to farming, and (12) for charcoal kiln. The presence of fodder and water (42) which attracted livestock grazing, while woody tree clearing and shrub land are largely causing the fires (29) in West Kordofan State. Livestock grazing, firewood collection and poles extraction showed sign of sever anthropogenic activities compared to other activities.

Table 7: Anthropogenic land cover activities, their causes and the number of occurrences in West Kordofan State

S. No	Anthropogenic activities	Main causes	No. of occurrence per plot
1	Wood collection	Building materials	31
		Firewood collection	43
		Charcoal kiln	12
		Clear areas for growing crops	17
2	Grazing	Fodder and water	42
3	Fires	Woody tree clearing and shrub land	29

4. Discussion

Over the last decade, land cover in West Kordofan State underwent significant changes being result of human induced and climate variability. The results of this study are consistent with previous land use and land cover change assessments carried out in great Kordofan region of Sudan in order to describe the changes in land use and land cover that have been occurred in the region where environments are characterized by repeated periods of drought, desertification and continuous sand encouragement, a rapid increase of vegetation lose was reported by Salih *et al*., (2017) [31]. Similar findings were reported in other areas such as Umrowaba located at north Kordofan, where more than 120,000 km^2 were estimated as being subjected to a medium-high desertification rate (Dawelbait and Morari 2012) [5]. Also the land cover changes observed in West Kordofan State are in agreement with land use and land cover analysis conducted in semi-arid area of North Kordofan State using remote sensing (Atia *et al*., 2018) [2]. However, these land cover changes were reported by researchers as positive or negative effects on the local environment based on the environmental needs of the entire region. As a consequence of climate variability, rapid sand encouragement and anthropogenic activities in West Kordofan State, a vast areas of shrub land were converted to sand plain. The intensive grazing of livestock contributed significantly to the degradation of the local environment. However, the spatial variation in the distribution of the five major land cover categories and changes in West Kordofan Sate between 2005 and 2015 can be explained partially by contrasting climatic characteristics of semi-arid region. However, there are also other anthropogenic activities that may influence the local land use practices and lead to land cover changes. West Kordofan State is most susceptible, sensitive and vulnerable to numerous natural disaster and meteorological hazards that have potential to change the land cover. Climate changes were some of the most important driving forces of land cover changes in West Kordofan State by intensification of extreme climatic events. For example, recurrent and prolonged periods of droughts, rainfall variability and high temperature are particularly frequent in the region. Between 2006 and 2010, a severe drought affected the region causing a significant reduction in the water availability and rain-fed agricultural productivity (Elhag and Zhang 2018) [9]. This drought event had important environmental consequences for the region, some of which were evident in this study. Increase of 3073.3 km^2 of sand area were observed between 2005 and 2015, particularly in the north, northeast, west and central part of the West Kordofan State, where sand mainly drifted from the desert. These results are in consistent with those mentioned previously in a research that promotes better adaptation strategies to combat the future impacts of desertification (Nuri *et al*., 2016) [25].West Kordofan State is currently undergoing environmental transition processes that also affect the use of land directly or indirectly. Land cover conversions is linked directly to anthropogenic activities due to the effects of extensive livestock grazing and expanding population associated with heavily land use practices. Consequently, some shrub land has been transformed rapidly into sand plain in the past decade. Therefore, it is reasonable to conclude that most of the decrease in areas covered by shrub land corresponded to a reduction in bare land. In this study significant changes in the major land cover categories were identified in West Kordofan State between 2005 and 2015. Although some effects of land cover changes can be anticipated, most of the impacts depend on local vulnerabilities and the execution of an effective strategies for adaptation (El Tahir *et al*., 2010) [7]. Precise and accurate monitoring of land cover can only be investigated when there is an adequate availability of local socio-economic and baseline data. This study allowed us to identify spatial and temporal patterns in land cover change trends in West Kordofan State during a decade. The results provide accurate information, in space and time, and visual presentations of the areas that are most affected by land cover change. Therefore, these findings are sensible starting point from which to conduct future research in semi-arid zone of Sudan to explore, monitor and predict future environmental changes and its short- and long-term effects on the population well-being.

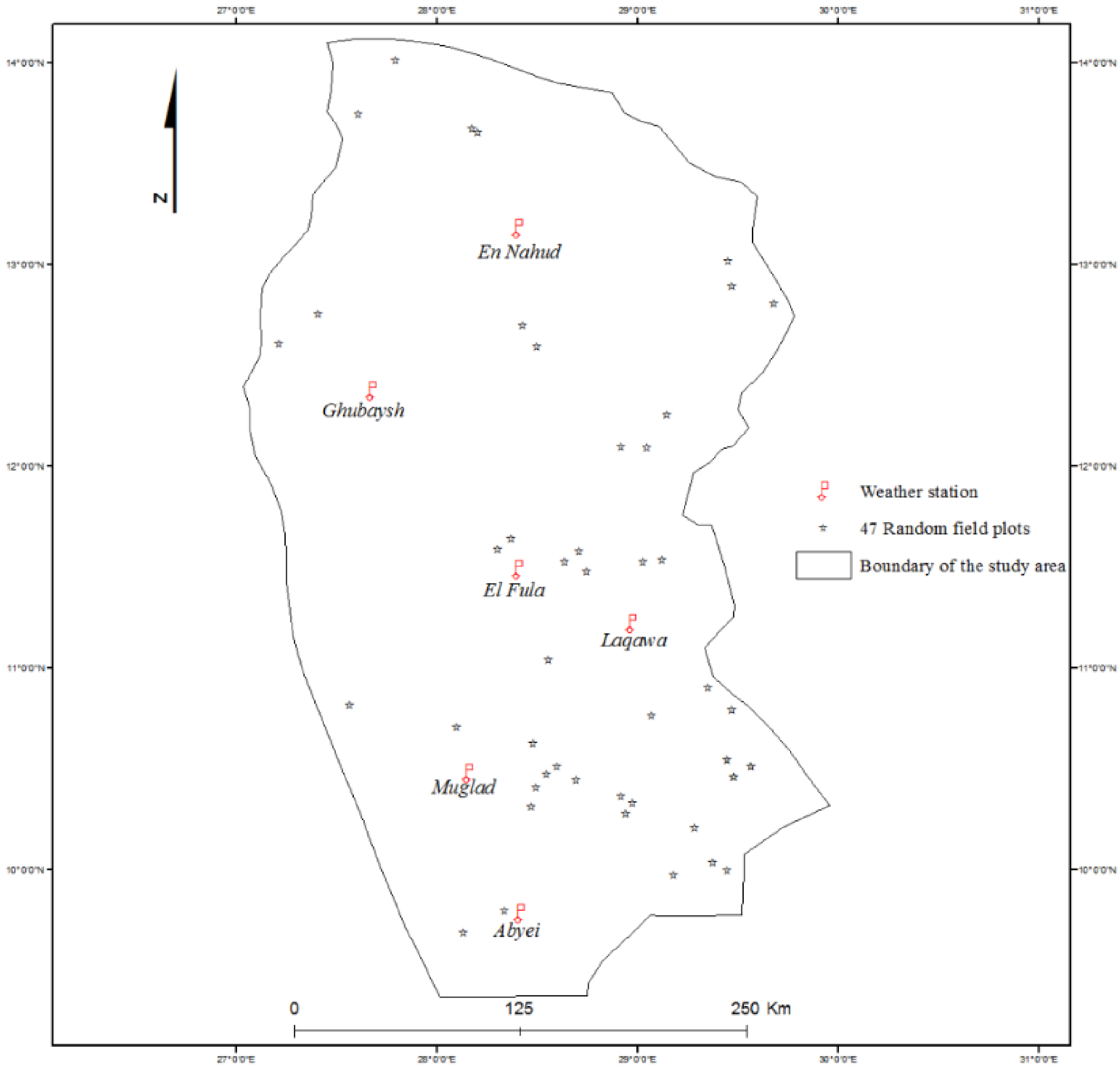

Fig 3: Location of the Weather station and random field plots with in West Kordofan State

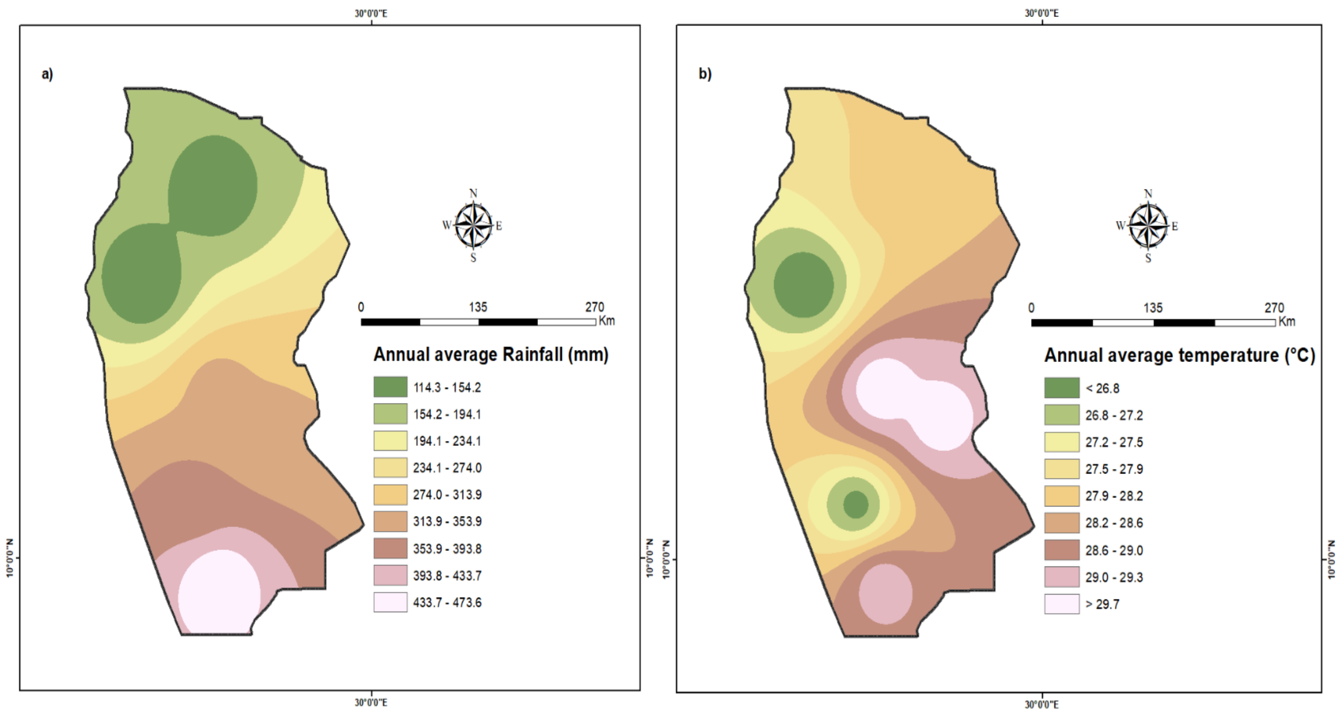

Fig 4: Average rainfall map (a) and average temperature map (b) of West Kordofan State

5. Conclusions

Using Landsat data, we monitored, quantified and analyzed the spatio-temporal changes in the major land cover categories that occurred in West Kordofan State between 2005 and 2015. Data gaps and complexity of land surface features is a major hindrance to monitoring a semi-arid zone of Sudan like West Kordofan State. The post-classification change analysis of two time periods (2005-2015) allowed us to describe the spatio-temporal dynamics of land cover change in details. The results found severe conversions of different land cover categories in the study area as the result of human related activities and climate variability. The dominant land cover change that took place during the study period (2005 to 2015) concur with large-scale impact were increasing sand area coverage and decreasing of shrub land area. The expansion of sand for 2005 – 2015 period was 307.3 km^2, signifying significant sand encouragement and relatively high rate of desertification in the region. Shrub land are also depleted at high rate of 336.7 km^2 over the study period and that attributed to intensified livestock grazing.

This present study reveals that Landsat data can provide immense insights into land cover changes over time in semi-arid areas of Sudan despite limited data availability. However, these results provide useful information to decision-makers and local land use managers in the region interested in developing ecologically sustainable land management. In addition, this analysis of land cover change may also help to explain and respond effectively to emerging environmental risks like desertification and land degradation.

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7. References

1. Arvidson T, Goward S, Gasch J, Williams D. Landsat-7 long-term acquisition plan. Photogrammetric Engineering & Remote Sensing. 2006; 72:1137-1146.
2. Atia AYM, Ibrahim IS, Dafalla MS, Csaplovics E. Analysis of Land Use/Land Cover Changes in Elodaiya, Kordofan, Sudan, Using Remote Sensing and GIS. Sudan Journal of Desertification Research, 2018, 3.
3. Carpenter SR, DeFries R, Dietz T, Mooney HA, Polasky S, Reid WV, *et al*. Millennium ecosystem assessment: Research needs, 2006.
4. Chander G, Huang C, Yang L, Homer C, Larson C. Developing consistent Landsat data sets for large area applications: The MRLC 2001 protocol. IEEE Geoscience and Remote Sensing Letters. 2009; 6:777-781.
5. Dawelbait M, Morari F. Monitoring desertification in a Savannah region in Sudan using Landsat images and spectral mixture analysis. Journal of Arid Environments. 2012; 80:45-55.
6. Diouf A, Lambin E. Monitoring land-cover changes in semi-arid regions: Remote sensing data and field observations in the Ferlo, Senegal. Journal of Arid Environments. 2001; 48:129-148.
7. El Tahir BA, Mohammed Fadl KE, Fadlalmula AGD. Forest biodiversity in Kordofan Region, Sudan: Effects of climate change, pests, disease and human activity. Biodiversity. 2010; 11:34-44.
8. Elagib NA, Mansell MG. Climate impacts of environmental degradation in Sudan. Geo Journal. 2000; 50:311-327.
9. Elhag K, Zhang W. Monitoring and Assessment of Drought Focused on Its Impact on Sorghum Yield over Sudan by Using Meteorological Drought Indices for the Period 2001-2011. Remote Sensing. 2018; 10:1231.
10. Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, *et al*. Global consequences of land use. Science. 2005; 309:570-574.
11. Foody GM. Status of land cover classification accuracy assessment. Remote Sensing of Environment. 2002; 80:185-201.
12. Gong P, Wang J, Yu L, Zhao Y, Zhao Y, Liang L, *et al*. Finer resolution observation and monitoring of global land cover: First mapping results with Landsat TM and ETM+ data. International journal of remote sensing. 2013; 34:2607-2654.
13. Hansen MC, Loveland TR. A review of large area monitoring of land cover change using Landsat data. Remote Sensing of Environment. 2012; 122:66-74.
14. Jetz W, Wilcove DS, Dobson AP. Projected impacts of climate and land-use change on the global diversity of birds. PLoS biology. 2007; 5:e157.
15. Jin S, Homer C, Yang L, Xian G, Fry J, Danielson P, *et al*. Automated cloud and shadow detection and filling using two-date Landsat imagery in the USA. International Journal of Remote Sensing. 2013; 34:1540-1560.
16. Ju J, Roy DP. The availability of cloud-free Landsat ETM+ data over the conterminous United States and globally. Remote Sensing of Environment. 2008; 112:1196-1211.
17. Kalnay E, Cai M. Impact of urbanization and land-use change on climate, Nature. 2003; 423:528.
18. Kashaigili J, Majaliwa A. Integrated assessment of land use and cover changes in the Malagarasi river catchment in Tanzania. Physics and Chemistry of the Earth, Parts A/B/C. 2010; 35:730-741.
19. Lambin EF, Geist HJ. Land-use and land-cover change: local processes and global impacts. Springer Science & Business Media, 2008.
20. Lambin EF, Geist HJ, Lepers E. Dynamics of land-use and land-cover change in tropical regions. Annual Review of Environment and Resources. 2003; 28:205-241.
21. Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, *et al*. The causes of land-use and land-cover change: Moving beyond the myths. Global Environmental Change. 2001; 11:261-269.
22. Li LJ, Zhang L, Wang H, Wang J, Yang JW, Jiang DJ, *et al*. Assessing the impact of climate variability and human activities on streamflow from the Wuding River basin in China. Hydrological Processes: An International Journal. 2007; 21:3485-3491.
23. Lillesand T, Kiefer RW, Chipman J. Remote sensing and image interpretation. John Wiley & Sons, 2014.
24. Markham BL, Storey JC, Williams DL, Irons JR. Landsat sensor performance: History and current status.

IEEE Transactions on Geoscience and Remote Sensing. 2004; 42:2691-2694.
25. Nuri AAF, Hamid AA, El Abbas Doka MA, Salih EM. Assessment of Vegetation Cover Degradation Using Remote Sensing and GIS Techniques along Sudanese Red Sea Coast (Suakin to Ashad). Journal of Geography and Geology. 2016; 8:55.
26. Ottichilo WK. Regional centre for mapping of resources for development (RCMRD): Geo-information capacity building activities in Africa. Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science, 2006, 36.
27. Pongratz J, Reick C, Raddatz T, Claussen M. Effects of anthropogenic land cover change on the carbon cycle of the last millennium. Global Biogeochemical Cycles, 2009, 23.
28. Raj R, Hamm NA, Kant Y. Analysing the effect of different aggregation approaches on remotely sensed data. International Journal of Remote Sensing. 2013; 34:4900-4916.
29. Reick C, Raddatz T, Brovkin V, Gayler V. Representation of natural and anthropogenic land cover change in MPI‐ESM. Journal of Advances in Modeling Earth Systems. 2013; 5:459-482.
30. Restrepo AMC, Yang YR, Hamm NA, Gray DJ, Barnes TS, Williams GM, *et al*. Land cover change during a period of extensive landscape restoration in Ningxia Hui Autonomous Region, China. Science of the total environment. 2017; 598:669-679.
31. Salih AA, Ganawa ET, Elmahl AA. Spectral mixture analysis (SMA) and change vector analysis (CVA) methods for monitoring and mapping land degradation/desertification in arid and semiarid areas (Sudan), using Landsat imagery. The Egyptian Journal of Remote Sensing and Space Science. 2017; 20:S21-S29.
32. Seto KC, Güneralp B, Hutyra LR. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences. 2012; 109:16083-16088.
33. Sterling SM, Ducharne A, Polcher J. The impact of global land-cover changes on the terrestrial water cycle. Nature Climate Change. 2013; 3:385.
34. Tanser FC, Palmer AR. The application of a remotely-sensed diversity index to monitor degradation patterns in a semi-arid, heterogeneous. South African landscape. Journal of Arid Environments. 1999; 43:477-484.
35. Townshend J, Justice C, Li W, Gurney C, McManus J. Global land cover classification by remote sensing: present capabilities and future possibilities. Remote Sensing of Environment. 1991; 35:243-255.
36. Turner BL, Lambin EF, Reenberg A. The emergence of land change science for global environmental change and sustainability. Proceedings of the National Academy of Sciences. 2007; 104:20666-20671.
37. Verburg PH, Neumann K, Nol L. Challenges in using land use and land cover data for global change studies. Global Change Biology. 2011; 17:974-989.
38. Woodcock CE, Macomber SA, Pax-Lenney M, Cohen WB. Monitoring large areas for forest change using Landsat: Generalization across space, time and Landsat sensors. Remote Sensing of Environment. 2001; 78:194-203.
39. Yuan F, Sawaya KE, Loeffelholz BC, Bauer ME. Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing. Remote Sensing of Environment. 2005; 98:317-328.