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Land Use Land Cover Change Detection of Oil Exploration and Production in Melut County, Upper Nile State, South Sudan

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Abstract: This study explores the Land Use Land Cover Change (LULC) of oil industry on environment and local communities in Melut County located in Upper Nile State in South Sudan; as well as engaging the stakeholders in oil sectors to adopt the best techniques of sustainable oil exploration and production in the area. This research is based on remote sensing imageries collected for 2000 and 2018. The satellite imageries data were collected from Landsat-5 TM and Landsat-8 ETM+ for the two points. These satellite imageries were used to reach inaccessible areas in the Area. ENVI 5.1 software was used to analyze the satellite imageries. The results reveal tremendously significant environmental degradation as a result of land use changes over time that leads to deterioration of the livelihoods of the oil producing communities in Melut County. The main contributions to LULC were from exploration and production activities such as drilling, and oil processing. Produced water and oil well pads were the major catastrophes that lead to destruction of croplands, damage of vegetation cover, and contamination of surface and ground water in the area. There are inadequate social services in the areas around oil fields; hence, the areas are characterized by poverty, lack of access to resources, unimproved social amenities and vulnerability to the poor unhealthy conditions in the oil environment. Furthermore, the government should regulate the oil industry by scrutinizing any environmental violation, and heavily fine the non-complying individuals and companies.

Keywords: Oil Exploration and Production, LULC, Environment, Oil Industry, Remote Sensing

1. Introduction

Sustainable oil industry development requires a systematic effort towards the planning of land use activities in the most appropriate way, apart from several other institutional and policy programme initiatives [1]. Remote sensing of images has been successfully applied in many fields, such as classification and change detection. However, remote sensing image processing involves a few preprocessing procedures in addition to classification and change detection [2]; furthermore, it is highly dependent on the method that is applied. Hence, the remote-sensing community is always committed to developing remote-sensing methods for improving the performance of aspects, such as preprocessing, segmentation, and classification [3]. Image classification is the process of assigning land cover to pixels [4, 5]. Digital images are composed of pixels that record the amount of radiations reflected from the objects apart from the electromagnetic spectrum. Pixels become visible to human eyes when zoom to the full extent where they become small visible squares using remote sensing tools such as ENVI. There are three principals image classification techniques in remote sensing that include [6]; 1 unsupervised image classification, 2 Supervised image classification, 3

Object-based image analysis. Based on the advancements of remote-sensing technologies [7, 8], "the remote sensing communities had moved its focus from neural networks to support vector machine (SVM) and ensemble classifiers," random forest (RF), for image classification and other tasks (e.g. change detection). SVM has become popular due to its ability to carry out high dimensionality data and accomplish tasks with limited training samples, among others, while RF gained approval and ease of use with high accuracy [3, 9]. Global oil discovery leads to population expansions of oil producing areas that result into short and long-term socio-economic and environmental challenges which modify the existing land uses [10]. Crude oil exploration in Africa since in the mid-19th century has become the source of income to many economies, hence resulting in improved living standard in African's nations as well as devastating the environment through land use change policies [11]. Oil revenue in South Sudan contributes to 98% of the Gross Domestic Product (GDP) and that make oil exploration and production to be at the climax of natural resource exploitation's activities [12]. The indigenous people of Melut County are mixed farmers, thus, the land use before the discovery of oil in the area revolved around agricultural activity which was the core of the livelihood. In contrast, land use changes as a result of oil industry operations in the area have become detrimental to both the ecosystem and human settlement that hindered agricultural activities in the area. Therefore, oil development in Melut Basin begins when Chevron first discovered oil in 1981 at Adar Yale located 75 km south-east of Paloich Oilfield. Nevertheless, Chevron suspended its activities in 1984 and left Sudan in 1990 as the civil war of 1983 intensified between Sudanese government and Sudan People Liberation Movement/Army (SPLM/A). [13] explains, 'two years later, a new consortium, Gulf Petroleum Corporation was awarded a contract for Block 3 and 7, and reopened Chevron's wells in 1996'. Moreover, the Sudan exported her first crude oil in March 1997 from Melut by barges to Port Sudan because of lack of pipeline infrastructure connecting oilfields and the Port. Furthermore, the production increased from 5,000 bpd in 1997 to 10,000 bpd in 1998. [13] noted that the shares of Block 3 and 7 were sold to Petrodar Operation Company Ltd (PDOC), a consortium of Chinese Nation Corporation Company (CNPC, 41%), Petronas (40%), Sudan Petroleum Company (Sudapet 8%), Sinopec (6%), and Althani Corporation (5%). However, this consortium was the dawn of the large-scale oil development in the Upper Nile (Figure 1). The construction of the facilities started with; 31,000 bdp Field Production Facility (FPF) at Adar Yale and Agordeed fields, airfield [14], all weathered roads, and the network of the feeder pipes for oil production were constructed ready for the services. In April 2006, the 1,392 kilometer pipeline connecting oil field to Port Sudan was inaugurated. This made Kotolok (renamed as Majamah, an Arabic word for center of operation) village west of Paloich Town the center for operation. In addition, the productions reached the pick of over 200,000 bpd. The upstream oil industry in Melut Basin was developed during the Great War (1983-2005) between Sudanese government and the SPLA. This made the Khartoum government to forcefully drive out the civilians in order to carry out full exploration and production processes in the free land hence making much land use land cover changes in Melut Area. However, this tactic was to enhance no future complaint of land compensations and to pave ways of security of the oil facilities and infrastructures.

2. Materials and Methods

2.1. Study Area

The majority of South-Sudanese oil reserves are located in the oil-rich Muglad and Melut rift basins, which extend also into the Republic of Sudan [14]. The study area (Figure 1) is located in Upper Nile state, which covers large parts of the Melut basin [15]. The Melut rift basin covers most parts of Melut County, one of the thirteen counties of Upper Nile State. The areas of concession are situated in the north east of South Sudan and south east of Sudan, between longitude 31°E and 34°E and latitude 8°N and 10°N with a total area of about 72,000 Km^2 [14]. Melut County is comprised of seven payams including 478 villages [16] with an approximate population of 70,000 [17]. The county borders Renk County to the north, Maban County to the east, Fashoda County to the south west, Akoka County to the south east and Manyo County to the west. According to the local people, the word Melut originates from 'Meyor Luth' which means Grey Bull in Dinka. Melut County historically has been inhabited by Dinka tribe [13]. Dinka in Melut County is divided into seven sections governed by paramount chiefs. These sections include; Ageer Bai, Ageer Rer, Beer, Ramba, Aboya, Boweng, and Adora. Besides, these seven sections were promoted to seven payams after the signing of the Comprehensive Peace Agreement (CPA) in 2005. The payams include; Melut, Paloich, Gomochok, Goldora, Thiangrial, Panomdiet, and Won Amom [13, 16].

2.2. Study Design

The two Landsat Imageries were collected from USGS websites to carry out geospatial analysis on Remote Sensing tool; ENVI 5.1 for Classification of Land Use Land Cover Change (LULC). The remote sensing data were collected from Landsat-5 TM and Landsat-8 ETM+ respectively. The paths and rows covering the Area of Study include; 173, 053 respectively; two points in time were selected (2000 and 2018) which covered land change of the period of eighteen years. The collection of remote sensing data represent one year after the drilling of oil in Melut County and 2018. The exercise was conducted to examine the LULC change in Melut County as per the oil development (Table 1).

Table 1. *Bands of Landsat-5 and Landsat-8.*

Satellite Image	Sensor Type	Acquisition Date	Spatial Resolution	Path/Row
Landsat-5	TM	2000/05/06	30 M	173/053
Landsat-8	ETM+	2018/10/31	30 M	173/053

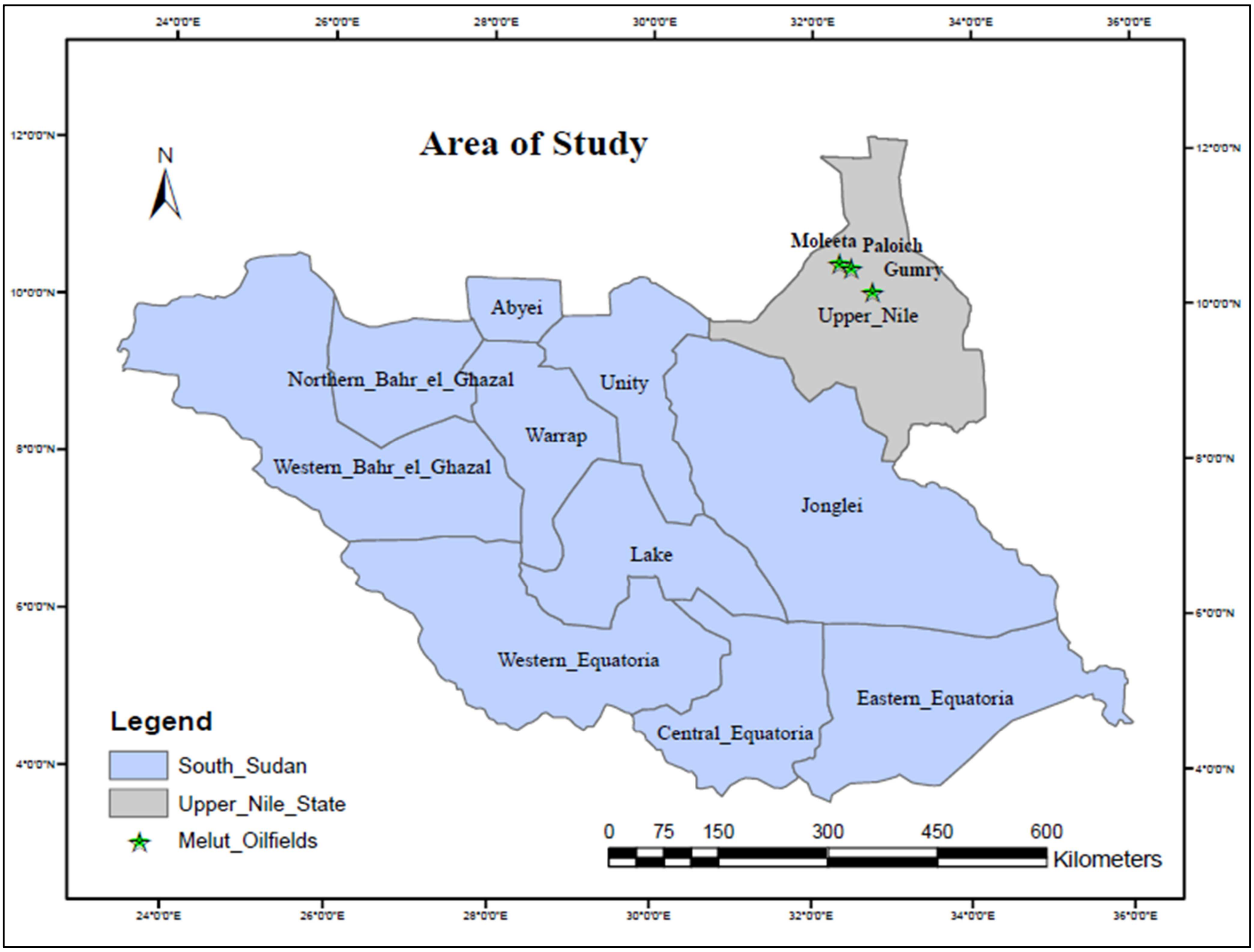

Figure 1. *Location of the Area of Study.*

2.3. Remote Sensing Process and Classification

Classification of area of interest gives the tremendous support to the survey data because of its wider view on the spatial information of the areas that could not be reached on the survey due to inaccessibility or insecurity. These exercise of classification involve; 1. Preprocessing, 2. Classification, and 3. Geospatial Analysis. The imageries were preprocessed with layer stacking of the bands before Classification processes. Then, the area of interest was extracted based on the appropriate coordinates of Melut County. Also, the spectral accuracy was checked prior of the digitization. Six features were identified as classes namely; Oil well pad, Waste Pond, Vegetation, Croplands, Residential, and Roads. These classes were digitized and then Supervised Classification was run through Support Vector Machine. Finally, the Change Detection was carried out through Thematic Change Detection on Oil Well Pad, Waste Pond, Road, Residential, Cropland, and vegetation cover, hence detecting how all these classes have change overtimes since the year of 2000 (Figure 2).

2.4. Data Analyses

Also, ENVI 5.1 and Google Earth software were used to analyze the land use and land cover change in the pollution affected areas in Melut County. This software is tremendously powerful to extract and analyze any geospatial imagery. Moreover, these analysis processes cross-referenced to the interpretation of satellite imageries collected from the Remote Sensing in the area of study.

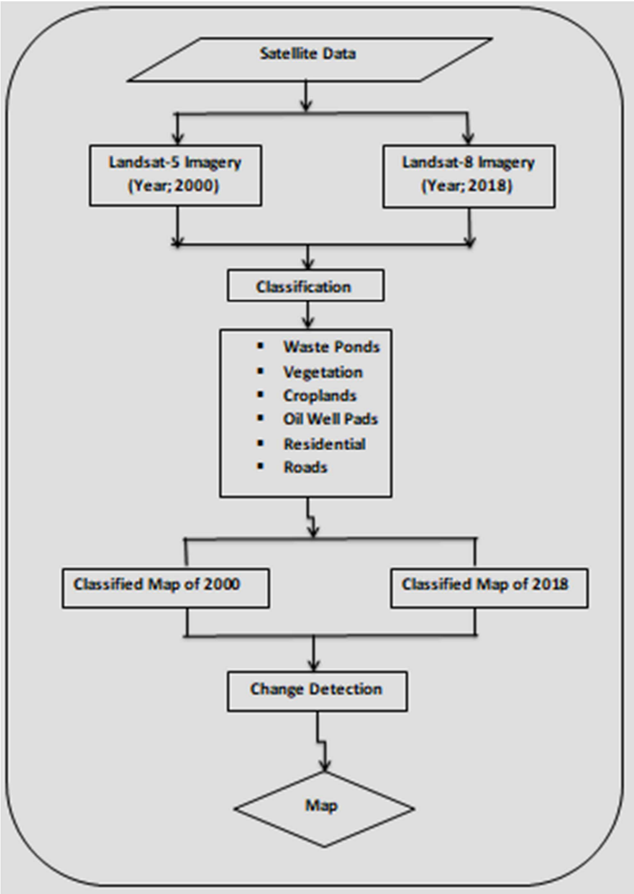

Figure 2. *Methodological Workflow of Remote Sensing Process and Classification of Melut County; 2000 & 2018.*

3. Results

3.1. Land Use Classification in Melut Oil Fields

Oil industry locations should incorporate the surrounding land use pattern based on both local and international regulations on the siting of petroleum industry. It is tremendously important to carry out the state of the environment such as conducting the Environmental Impact Assessment (EIA) on the land use. Figure 3 a & b shows the Land Use Land Cover (LULC) change of Melut County for the year of 2000 and 2018. The two classified imageries show the state of the LULC one year after the commencing of oil drilling and the year, 2018 covering the duration of eighteen years (18). There were six classes of LULC using ENVI 5.1 software to examine the task. These classes include; Oil Well Pads, Vegetation, Waste Pond including water bodies, Roads, Residential, and Crop lands. However, there is a great land change overtimes in which some of the classes change into the new classes as a result of oil business e.g. vegetation changed into well pads or croplands.

3.1.1. Land Cover in the Year 2000

Based on the evidence from the map of Land Classification, Roads (24.61%) covered the biggest area in Melut county and oil well pads (2.28%) covered the less area (Figure 3 a, 4 a). The other classes include; Residential (19.85%), Vegetation (13.18%), Crop lands (24.38%), and Waste Pond/water (15.72%) respectively. The largest area covered with the road networks indicate the exploration processes in the year 2000 which had led to clearing of most vegetated lands and the loss of farm lands and residential. Besides, the area had huge volume of water because it is lying on the eastern bank of White Nile River, hence flooding during the rainy season. However, the area is susceptible to any kind of pollution if care is not taken because its water bodies such as Adar River which enters into White Nile may be a media of pollution transfer from the oil fields into White Nile. Additionally, residential covering more land than vegetation can be associated with the exploration of oil and subsistence agricultural farming which involves clearing of vast vegetated lands. Furthermore, there were cluster of well pads in Adar Yale located in South Eastern part of Paloich. These well pads cluster both include the exploratory wells and the oil producing well.

3.1.2. Land Cover in the Year 2018

Oil business in Melut County after the independence of South Sudan in July 2011 has attracted population explosion in the area due to job opportunities in the oil industry sector. The results of LULC in 2018 indicate the biggest change, Vegetation (35.08%), Croplands (27.45%), roads (22.91%), residential (12.37%) and oil well pads (0.38%) respectively. Vegetation covered the largest land compare to the other classes; this can be attributed to many areas occupied by pipe lines (Figure 4b). Besides, most of the lands have been turned into croplands and the others into vegetation, and residential. Also, many water covered areas have been reclaimed and turn into crop land and residential. Moreover, there was evidence that the population and cropland have increased because of the high security provided by the oil industry. However, the increase in waste ponds for discharging the produced water has created high risk of contaminants leaking into the ground water and contaminating the surface water as well.

3.2. Comparison Between LULC in 2000 and 2018

Before oil business in Melut County, there was no huge population except of the indigenous who were agro-pastoralists. However, the discovery of oil has initiated both threats and merits to the local population. Over the period of eighteen years, the LULC in Melut County has changed drastically (Figure 3a&b). For example, water level has decreased as a result of high demand for both domestic and industrial purposes. These high uses of water include injected water for oil recovery, and irrigation in the dry seasons. It was observed that there was huge increase in vegetation cover and crop lands as the area covered by oil well pads, roads, and residential decreases in the year 2018. This indicates that there was a land cover distribution as some of the classes transformed into new classes. Also, reduction in oil well pads land covered can be associated with the completion of oil exploration in the area as well as the decommissioning of the exhausted oil reservoirs. Moreover, the increase in oil drilling technology has improved the trial and error methods of oil exploration which is expensive to remediate if oil is not found, hence making the oil companies to cluster many wells in small areas with economically oil reservoirs.

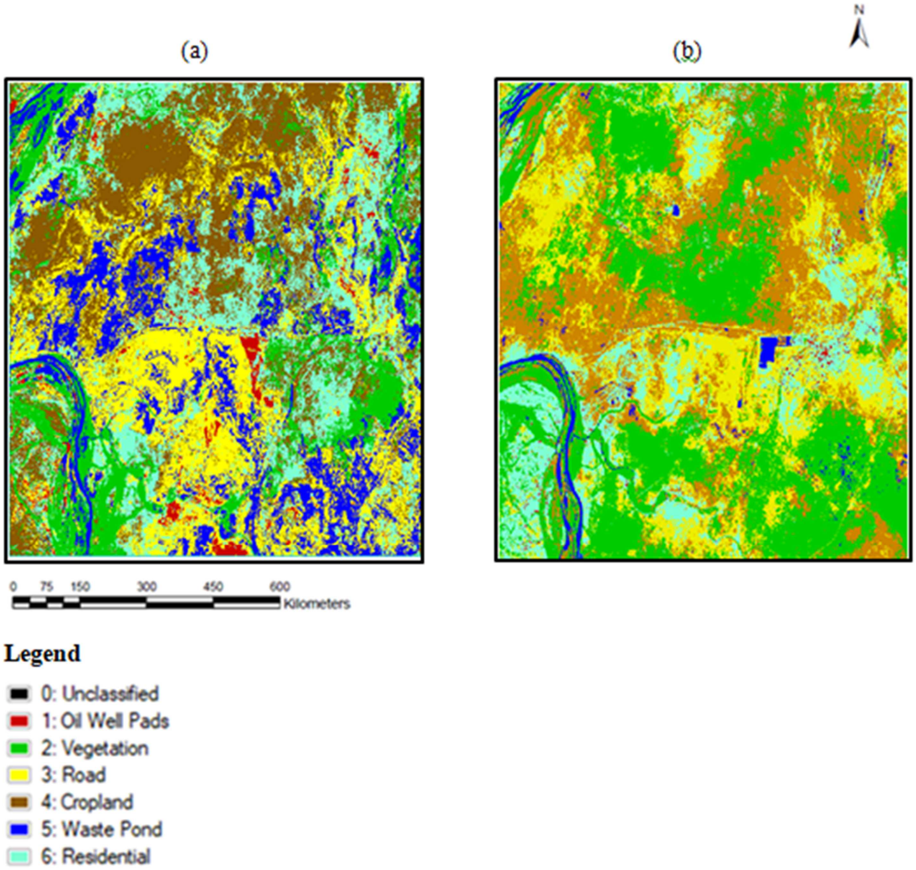

Figure 3. *a & b: Classification Maps of Melut County for the year 2000 and 2018.*

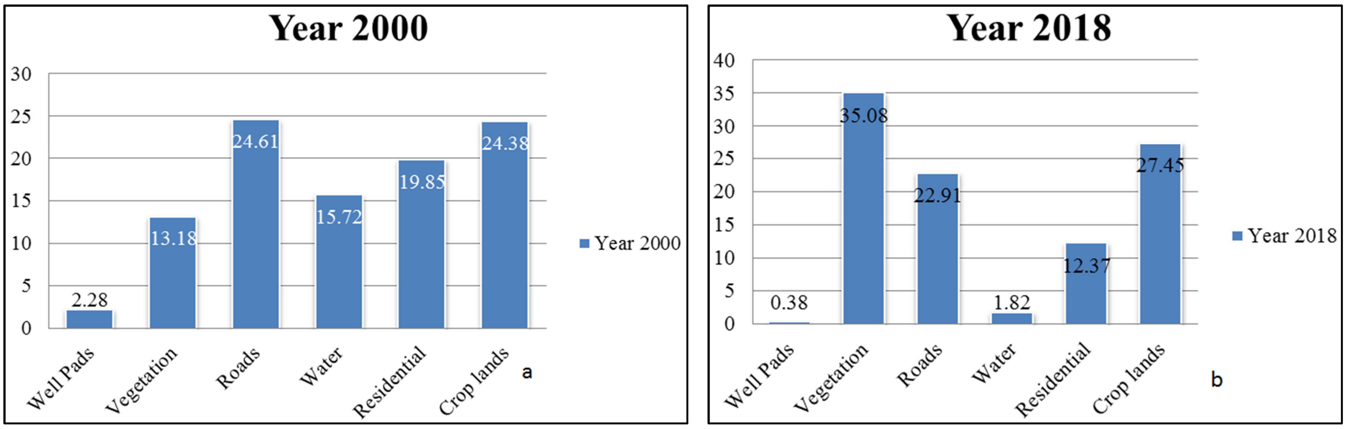

Figure 4. *a & b: Class Distribution (%) of LULC in Melut County in 2000 and 2018.*

Table 2. *Class Distribution for the Year 2000 and 2018 in Melut County.*

Class Distribution Summary for the Year 2000 and 2018 Classification							
Class	Year 2000			Year 2018			Change Detection
	Points	%	Km^2	Points	%	Km^2	Km^2
Oil Well Pad	40968	2.28	36.87	6887	0.38	6.2	30.67 decrease
Vegetation	236818	13.18	213.14	635976	35.08	572.38	359.24 increase
Road	442236	24.61	396.01	415343	22.91	373.81	22.2 decrease
Cropland	438164	24.38	394.35	497405	27.45	447.93	53.58 increase
Waste Pond	282471	15.72	254.22	32945	1.82	29.65	224.57 decrease
Residential	356679	19.85	321.01	224284	12.37	201.86	119.15 decrease
Total	1797336	100	1615.58	1812840	100	1631.83	809.41

3.3. Class Change Detection for LULC in Paloich Oilfield (2000 to 2018)

Class change detection was examined using ENVI in order to determine the LULC change over the period of eighteen years. This was done through putting Landsat imageries for 2000 and 2018 in change detection tool using thematic change detection for oil well pads, cropland, residential, and vegetation cover. It was observed that great decrease of vegetation cover in Paloich Oilfield happened near the waste pond where vegetation cover changed into waste pond and oil well pads (Figure 4a & b). These could be attributed to the clearing of vegetation for oil exploitation and production as evidenced by the visibility of produced water pond (Figure 5). Also, it can be observed that the cropland cover have been changed into oil well pads, roads, and waste pond. Moreover, the former residential were transformed into oil well pads and waste pond. It could be conclude that the oil business in Melut County has a great influence on environmental pollution and the livelihoods of the local population because of the displacement of the population and the clearance of vegetation to pave ways for drilling of the new oil wells and the lying of the oil pipe lines.

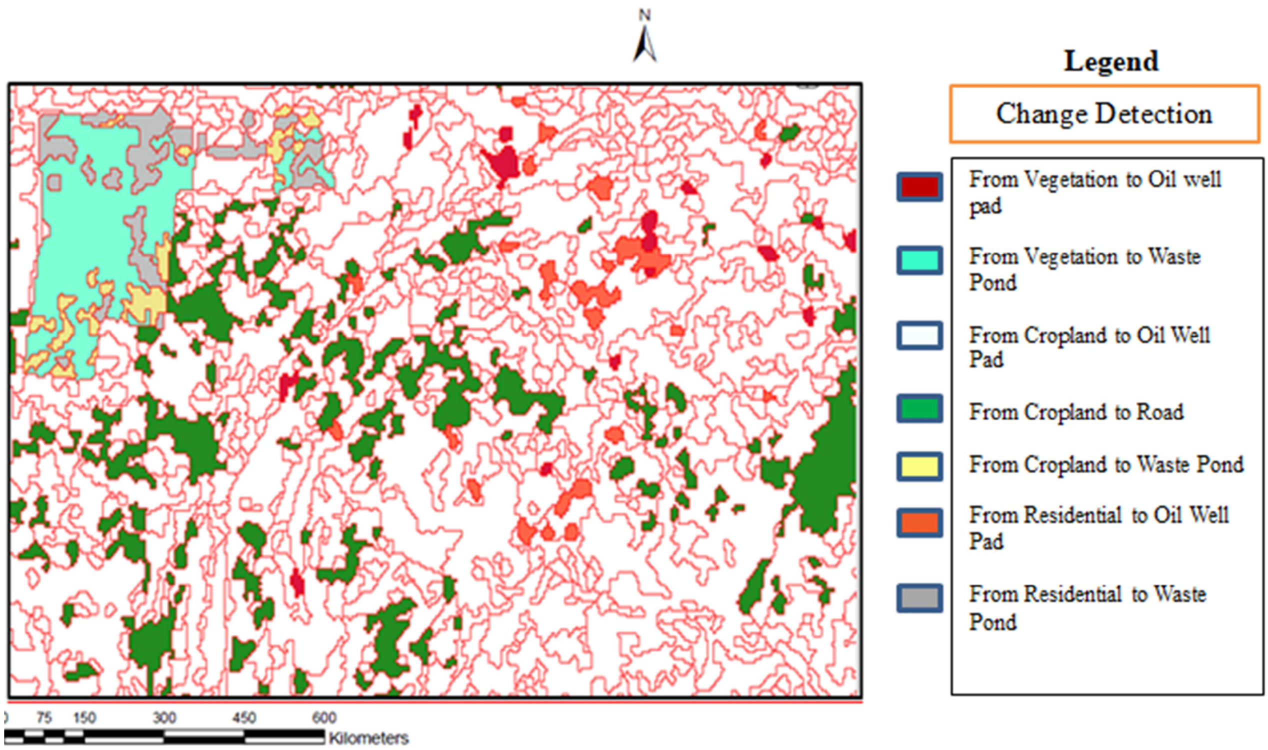

Figure 5. *Change Detection for LULC in Paloich Oilfield (For 2000 & 2018).*

4. Discussions

Melut County in Upper Nile State experienced numerous LULC change because of its location in oil rich rift of Melut Basin. Oil business has been fueling political turmoil between the Khartoum based government and the SPLM/A in the south. Besides, oil exploitation and production took place in two main phases; the first phase involved Adar Yale in 1999 and Paloich Second Phase in 2001. However, there was evidence from the maps of the transformation of one class into the other between the year 2000 and 2018. For example, there was a great increase in croplands area covered in 2018 than 2000 (Figure 4a). Likewise, there was visualization of produced water ponds in the area in 2018 which did not exist in 2000. Still, there was evidence of previous residential which have turned into oil well pads and the others into vegetation cover in 2018 (Figure 3 a&b, and Figure 5). As the oil production expands, many lands were converted into well pads, and roads (Table 2). Nevertheless, the oil business attracts creation of small towns along the oil fields which encourage immigration of the village people into new residential in order to access services, hence abandoning the former villages. The villages left overtimes transformed into vegetated grounds (Figure 3 a & b). Conversely, these findings are in line with previous documented situation of displacement of people in order to pave ways for oil exploitation and production [19, 20]. Also, the series of wars that occurred between 2000 and 2018 had led to the transformation of the land use pattern in Melut County. These series of conflicts are related to the study of oil and gas pipeline development along China-Myanmar border town of Ann in Rakhine State where deforestation took place during the construction [21]. Additionally, after the signing of CPA accord that gave independence to South Sudan in 2011 brought many benefits such as the transformation of the livelihood of some communities who have got access to services such as roads, education, clean water, and health services which did not exist before in 2000. On the other hand, oil business has created deleterious impacts on human and environment, as in the cases of health complication such as birth defect, eyes irritation, respiratory diseases, and stomach disorders among others. Also, cases of mishandling of oil waste such as produced water has posed threats to human and wildlife. Furthermore, the Remote Sensing based information has added weight on the previous household surveys as it is accurate and covered the inaccessible areas of interest in the study area.

5. Conclusion

This study contributes to the body of knowledge in enlightening the concern individuals, public, and government on the areas that need improvement in oil industry sector, not only in Melut County, but also in the other oil producing areas in South Sudan. The results indicate that the oil activities such as drilling and service rigs operations, waste ponds, waste pits/mud pits, oil and chemical spills, produced water, road constructions are the potential sources of land use change overtime in Melut County. These sources generate colossal amount of contaminants into the environment and degrading large areas, hence harms to human and wildlife. Moreover, environmental degradation is at its peak due to government and oil companies inadequate monitoring and supervision. This was shown by the presence of large ponds which were used to excavate soil for the constructions of the well pads on the roadside along Paloich-Melut highway which no one carried out the ecological restoration after mining of the soil. Besides, oil exploration and production cause serious deforestation as a result of the exploration processes, such as constructions of roads linking oil wells, and erecting of the new well pads. These oil industry's activities leads to the clearing of the vegetation and extent to new forested areas that become prone to the agent of erosion. The satellite imageries of Land Use Land Cover Change (LULC) of 2000 and 2018 have shown the great difference within the period of eighteen years of oil industry's operation in the area. However, land use cover such as vegetated land, croplands, and residential have turned into oil well pads, roads, and waste ponds in 2018. Furthermore, the results have shown that there is a dense road network in Paloich and Gumry which has attracted settlement around the oil wells within the distance range of less than 100 meters which is less than international recommended distance of 200-300 meters away from the wells. This settlement led to the high risk of exposure to hydrocarbons for the residents that are residing near the oil wells. In conclusion, it is of great concern for the government to regulate the oil industry and try to put restricted rules and regulations on the oil companies when violating the environmental protection laws and proper land use. Also, there should be modern environmental laboratories in the oil fields with environmental experts to monitor the environmental degradation processes. These will pave ways for further decision making on sustainable oil business management in South Sudan.

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