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THE CITY CHALLENGES AND EXTERNAL AGENTS.
METHODS, TOOLS AND BEST PRACTICES

Vol.13 n.2 August 2020

print ISSN 1970-9889 e-ISSN 1970-9870
University of Naples Federico II

TeMA

Journal of
Land Use, Mobility and Environment

THE CITY CHALLENGES AND EXTERNAL AGENTS. METHODS, TOOLS AND BEST PRACTICES

2 (2020)

Published by
Laboratory of Land Use Mobility and Environment
DICEA - Department of Civil, Architectural and Environmental Engineering
University of Naples "Federico II"

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Editor-in-chief: Rocco Papa
print ISSN 1970-9889 | on line ISSN 1970-9870
Licence: Cancelleria del Tribunale di Napoli, n° 6 of 29/01/2008

Editorial correspondence
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TeMA Journal of
Land Use, Mobility and Environment

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2 (2020)

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LUME (Land Use, Mobility and Environment)

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TeMA
Journal of
Land Use, Mobility and Environment

TeMA 2 (2020) 169-190
print ISSN 1970-9889, e-ISSN 1970-9870
DOI: 10.6092/1970-9870/6739
Received 3rd April 2020, Accepted 14th July 2020, Available online 31st August 2020

Assessment of land use/land covers changes linked to oil and gas exploration

Developments under changing climatic conditions in Lokichar Basin, Turkana County

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Abstract
Understanding land use/land cover changes (LU/LC) linked to oil and gas exploration under changing climatic conditions in South Lokichar Basin is crucial. This knowledge will inform policy makers on appropriate sustainable vegetation cover management strategies for the sake of pastrolism practiced in the area. The LU/LC changes were assessed using multi-spatial and multi-temporal remotely sensed imageries acquired through Landsat 5TM and Landsat 8OLI/TIRS by use of ArcGIS. The study assessed medium resolution spatial imageries acquired for the area in both rainy and dry seasons, before oil and gas exploration developments begun in South Lokichar Basin between 2006-2011 and after commencement between 2012-2017. The study established that the average area in hectares under vegetation cover had declined since oil and gas exploration developments begun. A one sample t-test statistics indicated that the area under forest, shrubland and grassland cover had significantly reduced at 90% confidence interval with a p-value of 0.072, 0.074 and 0.061 respectively. The study established a decline in NDVI from 1 to 0.433 for the rainy season and 0.411 to 0.122 for the dry season between 2006 and 2017 with a p-value of 0.009 <0.05 on paired t-test implying a significant change on vegetation cover. Sustainable management of vegetation cover is important to safeguard livestock forage.

Keywords
Land cover; Land use change; NDVI; Oil; Gas; Exploration.

How to cite item in APA format
Mugendi, D. M., Mireri, C., Kibwage, J., & Oyoo, D. (2020). Assessment of land use/land covers changes linked to oil and gas exploration. Tema. *Journal of Land Use, Mobility and Environment*, *13* (2), 169-190. http://dx.doi. org/10.6092/1970-9870/6739

1. Introduction

Oil and gas exploration developments have been documented to cause extensive changes on LU/LC changes in regions perceived to host crude oil reservoir (Ogwu, 2011). These developments directly affect the biodiversity, hydrology of the area, agricultural activities, fishing and water quality (Stanley et al., 2013). The activities such as clearing of vegetation, emission of natural gases from the opening of the earth crust during drilling and flaring of gases that ensues oil well testing causes indirect impact including alteration of global and local climate (Huang & Huang, 2014). The impacts resulting from the oil and gas exploration developments are felt in both long term and short term. Food insecurity, human vulnerability to hazards, health challenges, are experienced in the short terms. In the long-term climatic changes that may affect the viability of the mother nature arise if proper environmental management approaches are not taken (Kuch et al., 2019). According to Elum et al. (2016) community goals immensely changes when recreational, educational, religious and grazing lands gets turned into oil and gas exploration fields. Oil and gas exploration developments globally have been seen to alter the nature of the landscape from a rural to a more urbanized setting (Ogwu, 2011). Even though climate change is being attributed to LU/LC changes, the rate at which this happens is gradual and in the absence of drastic change in rainfall and temperature, the LU/LC changes may take time to detect (Khosravi et al. 2017).

Traditional techniques for gathering and analysis of environmental samples are not sufficient for complex environmental studies. Satellite Remote Sensing and Geographical Information Systems (GISs) usage in this field of study is playing a very critical role. These technologies are able to avail data for studies and monitor the dynamics of natural resources for sustainable environmental management (Adamu et al., 2018). In modern studies remote sensing is proofing to be an important tool relevant in developing and comprehending the global, physical processes affecting the planet. Current growth in usage of satellite data is to capitalize on growing amounts of geographical data accessible in conjunction with Geographical Information Systems to help in analysis and interpretation (Mierzejowska & Żogała, 2018). Geographycal Information Systems is a unified system of computer software and hardware that can capture, store, retrieve, analyze and potray spatial data for the purpose of aiding in decision making processes in resource utilization, planning and management (Sokoła-szewioła et al., 2016). Several studies have focused on land use land cover changes because of their adverse effects on ecology in addition to socio-economic characteristics of the locals (Seki et al., 2017). The area of study falls under arid and semiarid regions of Kenya and grass, shrubs and dry forest vegetation are the predominant flora species. 84% of the locals in South Lokichar Basin oil region depends on pastoralism as their main economic activity hence vegetation cover which 60% consist of grassland and 25% shrubs land forms the basis of the locals source of livelihoods (Opiyo et al., 2015). Understanding LU/LC changes in South Lokichar Basin oil fields is very significant even as oil and gas exploration developments intensifies in the region. This is because it will inform appropriate planning and management of vegetation cover mostly grass and shrubs resources that the pastoralist depend on. It is of great interest to mention that there are few academic studies on oil and gas exploration impacts on LU/LC changes that have been conducted in the study area since the discovery of oil and gas in 2012 and therefore this study adoptated an exploratory case study research design approach. The study endeavors to establish the level of contribution of climatic factors changes to LU/LC changes in the area by assessing the changes in both dry and wet seasons in the area before oil and gas exploration developments began and after. The paper is structured as follows. An overview of the impact of oil and gas exploration developments on land use/land cover achieved by systematically reviewing empirical studies from a global scene. Effects of changing climate on land cover vegetation.

The effects of land use land cover changes linked to oil and gas exploration on climate and socio-economic characteristics of the surrounding communities, methodological approach, result and discussion, conclusion and recommendations on sustainable oil and gas exploration approaches to safeguard vegetation cover.

2. Literature review

Exploration of oil and gas has been there since 2, 000 BC (Kuch et al., 2019). The first modern oil and gas exploration and drilling was done in Titusville, Pennsylvania in 1859. This triggered a significant explosion in the oil and gas industry and this marked the beginning of the modern oil and gas industry (Hassan, 2013). According to ADB (2018), oil history in post-independent Africa stretches over a period of six decades. The report indicates that 16 of the 54 countries in Africa are exporters of oil and gas with Angola, Algeria, Nigeria and Libya being members of the Organization of the Petroleum Exporting Countries (OPEC). East African countries have only depended on agriculture as the primary economic activity for a long time until 2006 when oil was discovered in Uganda (Zhou et al. 2013). In Kenya, commercial crude oil quantities discovery was made in 2012 in Oil Block 13T South Lokichar Basin, Turkana County (Eliza et al., 2015). This discovery has brought with it LU/LC changes within the study area and these changes are expected to rise as more oil and gas exploration developments gets carried out in the area.

Concerns for the modification, loss, and fragmentation of indigenous vegetation species such as grassland and shrubland has been articulated in an array of scientific literatures (Yu et al., 2015; Sonter et al., 2014; Takeuchi et al., 2017). However, few studies have quantified landscape-scale alterations as a result of oil and gas development (Garman, 2018). In addition to land fragmentation due to well pads construction and development of access roads, highways and trails that tampers with the wildlife habitats and biological systems, vehicles traffic colossally affects wildlife (Oduro et al., 2020). An empirical study carried out by Osei et al., (2006), in Niger Delta ecosystem by use of geospatial data processing and analysis observed that oil and gas exploration developments between 1985-2005 had resulted to a slight decline in water bodies from 343, 654 to 343, 513 hectares, mangrove and closed forest showed a decline from an initial estimate of 55, 410 hectares in 1985 to 37, 117 hectares and closed forest from 250, 161 hectares in 1985 to 175, 609 hectares and the Settlement/bare areas increased from 52, 738 to 108, 725 hectares. However, the land use land cover changes cannot be attributed to oil and gas developments alone in the mentioned oil field as climatic changes too resulting from anthropogenic activities do play a role in these changes (Galderisi, 2014). A study done by Larry et al., (2020) observes that climate change causes extra stresses on land, intensifying prevailing risks to biodiversity. However, Yin et al. (2014) observes that the link between climate and land cover changes is complex. First, the land cover is changed by changing land use such as oil and gas exploration developments, which affects the atmospheric concentration of greenhouse gases. On the other hand land use change is a key driver to climate change, a changing climate, can cause LU/LC changes.

Nonetheless the rate at which this happens is gradual and in the absence of drastic change in rainfall and temperature parameters, the LU/LC changes may take time to be detected (Khosravi et al., 2017). This implies that in an area where precipitation variation and other weather conditions are minimal the LU/LC changes resulting from climatic conditions are insignificant. According to Bhatt et al. (2013) through analysis of Advanced Very High Resolution Radiometer (AVHRR)-derived (NDVI), the index trend in arctic tundra vegetation cover was observed to be consistent with increasing temperature and precipitation in the entire arctic. The observation is consistent with Frost et al. (2014) who noted that substantial tall shrub extension had been reported in the past five decades at a number of undisturbed sites in West Siberia and and this was attributed to stable local climatic warming. These studies imply that areas with little climatic variations, the status quo of the land cover vegetation remained while; fluctuating climatic conditions such as precipitation and temperatures proportionately affected the vegetation cover. However, with the human impactive interventions, assessment of long-term vegetation change due to climate change at the regional scale is complex (Klostermann et al., 2018). According to Wang et al. (2018), economic and social infrastructures is always associated with disruption that clears natural vegetation cover, modifies surface and subsurface hydrology, soil structure and texture. Larsen et al., (2014) observes that, anthropogenic induced LU/LC changes can aggravate impacts of climate change, triggering potentially harmful consequences for ecosystems. It is worthy noting that anthropogenic induced land cover land use change is gradual, and it has cumulative effect in the long run to the environment. Engineering works, such as transportation corridors entailing pipelines for oil and gas transportation, oil and gas production fields, power plants and boom towns that around the oil rich regions normally get developed (Kumpula et al., 2012). In addition a broad network of vehicle tracks and fundamental trails, crosses the areas outside of engineering facilities to evacuate the oil and gas resources to the potential users. It is such anthropogenic stresses that causes extensive land degradation in most oil and gas rich regions (Kumpula et al., 2011). The observations made above are consistent with Al-haleem et al. (2013) who underscores that colossal clearance of vegetation emerging from oil and gas exploration developments results to instant LU/LC changes of the surrounding ecosystems. Kadafa & Ayuba (2012) established that LU/LC changes in the oil rich Niger delta region in Nigeria resulting from oil and gas exploration developments affected immensely the regions' ecosystems, which affected communities' livelihoods. Many communities were dependent on land and water resources for their livelihoods through agriculture, pastoralism and fishing. Although there were some positive effects such as improvement of social amenities, the cutting down of trees and other vegetation cover during oil seismic surveys and construction of roads and pollution of water bodies by the oil-exploring companies affected people's livelihoods immensely (Julius et al., 2011).

A similar empirical study on how LU/LC changes emanating from oil and gas exploration developments can negatively impact people's socio-economic aspect is that of West Kordofan State in Sudan as recorded by Chavunduka & Bromley (2011). The researchers observed that the economy of West Kordofan State was predominantly dependent on agricultural production consisting of rain-fed cultivation and traditional livestock practiced by nomadic and semi-nomadic agro-pastoral and sedentary groups. However, Ibrahim et al., (2013) established that the communities lives began to change as a result of oil and gas exploration developments that resulted to drastic LU/LC that could not sustain their pastoralism way of live. According to Anis et al., (2015) sustainable environmental management strategies has been a mirage in many oil and gas producing countries. They further note that the focus has always been on oil and gas resource exploration and its economic benefits with little attention on its ecological effects and its implication on the pre-existing sources of livelihoods. As a result, the resulting LU/LC changes affect negatively people's sources of livelihoods and this can cascade to other social challenges. It is imperative for any developer on the environment to appreciate the nexus between the social cultural, economic and ecological environmental systems since, negligence in one will result to unsustainable development (Papa et al., 2015). Globally there are mitigation measures that are being adopted to minimize land use land cover changes emanating from oil and gas exploration. Key among these approaches entails restoration of the dry wells encountered during exploratory drilling and landscaping of the excavated areas with indigenous plant species within the globally acceptable period. In addition oil explorers in conjunction with oil and gas resources host governments are adopting horizontal well drilling technology. This approach is minimizing the ecological footprints on the ecosystems and this fuses well with the concept of sustainable developments where utilization of ecosystems resources does not outstrip the regeneration process (Salvati et al., 2013). According to Zhao, Xu. (2019) horizontal drilling technology enhances sustainable management of vegetation cover in well-drilling. Vandenberg, observes that horizontal drilling is the method used in drilling a well from the outward to a subsurface point just overhead the aimed oil reservoir commonly referred to as a kickoff point. The process entails deviating the wellbore around the curve from the vertical level to interconnect the reservoir with a near-horizontal inclination and the drill continues until the bottom hole needed is reached. Zhao, Xu. (2019) records that horizontal wells are superior producers than the vertical wells and are more suitable when it comes to the aspects of environmental conservation. A single horizontal well can penetrate and produce oil from multiple parcels and single horizontally drilled pad can be used to drill several wells, and this minimizes the footprint of drilling operations (Salleh et al., 2019). According to Vandenberg (2015), the University of Texas at Arlington drilled 22 wells on a single platform from an area spanning to 1,100 acres and hence conserving on surface biodiversity and infrastructures. Horizontal drilling approach has also been adopted in East African Countries in the biodiversity-rich region of Albertine Graben in Uganda whose sedimentary rock geologic formations forms part of the East Africa Riftvalley Tertiary Basin whose South Lokicar Basin falls in on the republic of Kenya side (MacKenzie et al., 2017). The technology was used in drilling Jobi-6 appraisal well in the environmentally sensitive Albertine Graben in Uganda. According to Lokeris et al(2014), the reason behind the adoption of this technology was in the spirit of wildlife conservation in this ecosystem zone. Manshad et al. (2019) notes that horizontal well drilling is more costly than the vertical drilling for it can cost over 300% more to drill one horizontal well than a vertical one. However, he reveals that the distance of penetration of the pay zone can go up to a distance of 10 kilometres.

Commercial oil quantities were first discovered in Kenya in 2012 in South Lokichar Basin, Turkana County (Eliza et al., 2015). According to Opiyo et al., (2015), South Lokichar Basin, Turkana County is among the arid and semi-arid regions of Kenya with harsh environmental conditions unsuitable for rain-fed agriculture. They further point out that pastoralism is the primary economic activity of the communities dwelling in this area; hence sustainable management of land and existing vegetation resources is of paramount importance. Changes on land use and land cover resulting from oil and gas exploration developments in the absence of proper ecosystems management strategies will have extremely negative implications for the well-being of the locals pastrol way of life in the study area as noted from the cited publications.

3. Materials and method

3.1 Area of study

The main aim of this study was to determine the impact of oil and gas exploration on vegetation cover in South Lokichar Basin and make recommendations on sustainable vegetation management practices. This is because the locals depend on the grassland and shrubs vegetation for their livestocks since pastoralism is the main economic activity in the area. The South Lokichar Basin is found in the Tertiary Rift Basin a Cenozoic sedimentary basin in Kenya. It is part of the East African Tertiary Rift system. The basin is approximately 25 Km wide, 80 Km long and has a maximum depth of above 7 km (Repubic of Kenya, 2016). The Tertiary Rift basin is divided into 9 oil blocks and among them is oil block 13T whose this study was carried out purposively because it is the oil block with the highest number of drilled and developed oil wells hence suitable to show the oil and gas developments impacts to the environment. Block 13T straddles in three sub-counties of Turkana County, i. e., Loima, Turkana Central and Turkana South. The study was carried out in Turkana South Sub county, Lokichar Ward located at latitude 02. 3838o N and Longitude 35. 6478o E as shown in figure 1 below. The total surface area of the Ward is 2, 899 km² and by 2017, 38 well pads with a total of 320 oil wells had been drilled (Repubic of Kenya, 2017). The study examined 11 randomly sampled constructed well pads and assessed their impacts within a distance of 10 kilometres equidistance from each well pad. The rationale for sampling the 11 well pads was due to the fact that, the well pads were far apart from each other, an average of 20 kilometres posing a limitation of accessibility. The study in addition evaluated the well pads access roads network within the study area.

The area has diverse vegetation cover including, dwarf shrubs, shrubs and dry forest trees. The grazing areas are dominated by Cadaba farinosa mellifera, Tribulus terrestris, Dactyloctenium aegyptium, Boscia coriacea, and Digitaria milanjiana. Among the Dwarf shrubs includes the condyloclada Balanites orbicularis, Aristida mutabilis and Tragus berteronianusTetrapogon cenchriformis, Mollugo cerviana, Seteria sphacelata173irgate173te and Becium obovatum. The shrubs found in the area includes Enneapogon cenchroides, Chloris virgata173irgate, Aristid mutabilis, Acacia reficiens and Cordia sinensis as shown in Fig. 1 (Schilling et al, 2015). The study adopted a combination of case study and exploratory descriptive research design in describing the trends of land cover changes in the study area, by use of digital imagery acquisition and analysis an approach adopted from Huang & Huang (2014).

3.2 Sampling and data analysis procedure

Document analysis, observation through ground trothing/mapping and digital imagery acquisition and analysis were used as data collection methods.

The study acquired rainfall data from 2006 to 2017 from the Meteorological Department of Kenya for the region for both long and short rain and this data was used to determine the rainy and dry seasons. The dry and rainy seasons determinism was crucial in assessing the implication of climate variability on LU/LC changes in the study area comparative to the oil and gas exploration developments induced impacts. ArcGIS was used in remote sensed digital satellite Imagery analysis and classification.

According to Pande et al. (2011), Arc-GIS has two ways of classifying digital imageries that is supervised and unsupervised. The study adopted the National Land Use Landcover classification system model and made use of supervised classification, which mostly depends on the researchers understanding of the study area to achieve the set objectives. The classification process entailed imagery restoration, classification, and enhancement.

The analysis was carried out as follows band composite imageries where the bands of interest which were ([Band 4=Near Infrared] and [Band 3=Red]) and ([Band 2=Green, for Landsat 5T. For Landsat 8 OLI/ TIRS the bands of interest were=[Band 5=Near Infra-red] and [Band 4=Red] and [Band 3=Green] were exhibited followed by selecting of symbolic training samples for the preferred classes.

The signature file was made, managed and appraised. Maximum likelihood classification tool was implemented, and categorized imageries were color coded and displayed. For higher precision, imageries were further processed to eliminate noises and insulated areas for enhanced output quality. These further processing involved smoothing and clumping, filtering and simplifying output maps. Apart from the land cover imageries classified, the NDVI for the study area was determined and compared for the periods before and after commencement of oil and gas exploration developments using the ARCGIS image analysis NDVI window. Yin et al. (2012), denotes that the NDVI process creates a single-band dataset that mainly represents greenery.

The negative values represent clouds, water and snow and values near zero represent rock and bare soil. The Red and NIR represent the spectral reflectance value as noted in the Red and Near-infrared (NIR) ranges in the spectrum. The value for NDVI ranges between -1 and +1. Vegetation have an NDVI range of between 0. 1 and 1 according to Wang & Gong (2009). They further indicate that the higher the NDVI, the higher the fraction of live green vegetation found in a given area. The documented and default NDVI equation according to Kaspersen et al., (2015) is; NDVI = (IR - R)/(IR + R).

The IR is the pixel values from the Infrared band, and the R is the pixel values from the Red band. In calculating the NDVI using Landsat 5 TM imagery the equation applied is; NDVI = ([Band 4] – [Band 3]) / ([Band 4] + [Band 3]) while that of Landsat 8 OLI/ TIRS is NDVI = ([Band 5] – [Band 4]) / ([Band 5] + [Band 4]). Low values (0. 1 and below) of NDVI correspond to barren areas of rock, sand, or snow. NDVI make use of the green colouring matter existing on plants leaves. Chlorophyll takes in light energy at 0.65 ~L (red) and ~0.45 ~L (micron) (blue). It moderately reflects ~0.55 L. (green) and intensely reflects ~0.86 ~L (NIR). This accounts for the green colouration of most plants.

According to Huang & Huang (2014), NDVI makes use of this distinctive spectral pattern of chlorophyll for visualization, described by the difference amid determined solar reflection from a satellite band very sensitive to chlorophyll (~0.65~L) and a band in the red part of the visible spectrum (~0.65 ~L).

The procedure for data collection entailed mapping the eleven oil well pads purposively sampled in the study area and other excavations done such as access roads by use of a GPS mapper.

The mapped coordinates were then used to acquire the Landsat 5TM, Landsat 8OLI/TIRS satellite imageries with 10 km radius being used to determine the areas of interest, six years before the oil and gas exploration activities began, and six years after the oil and gas exploration activities began for both rainy and dry seasons from the United State Geological Survey (USGS) earth explorer. The study compared the imageries of the dry and rainy season pre and post oil and gas exploration activities commencement. The imageries were processed using the ArcGIS 10.3 software and Erdas. The study made use of pearson linear correlation and paired t test to test significant change on NDVI. One sample t test was used to determine significant change on area under vegetation cover. Simple linear regression was in addition used to analyse the relationship between the increase in the bareland and the NDVI value in the study area

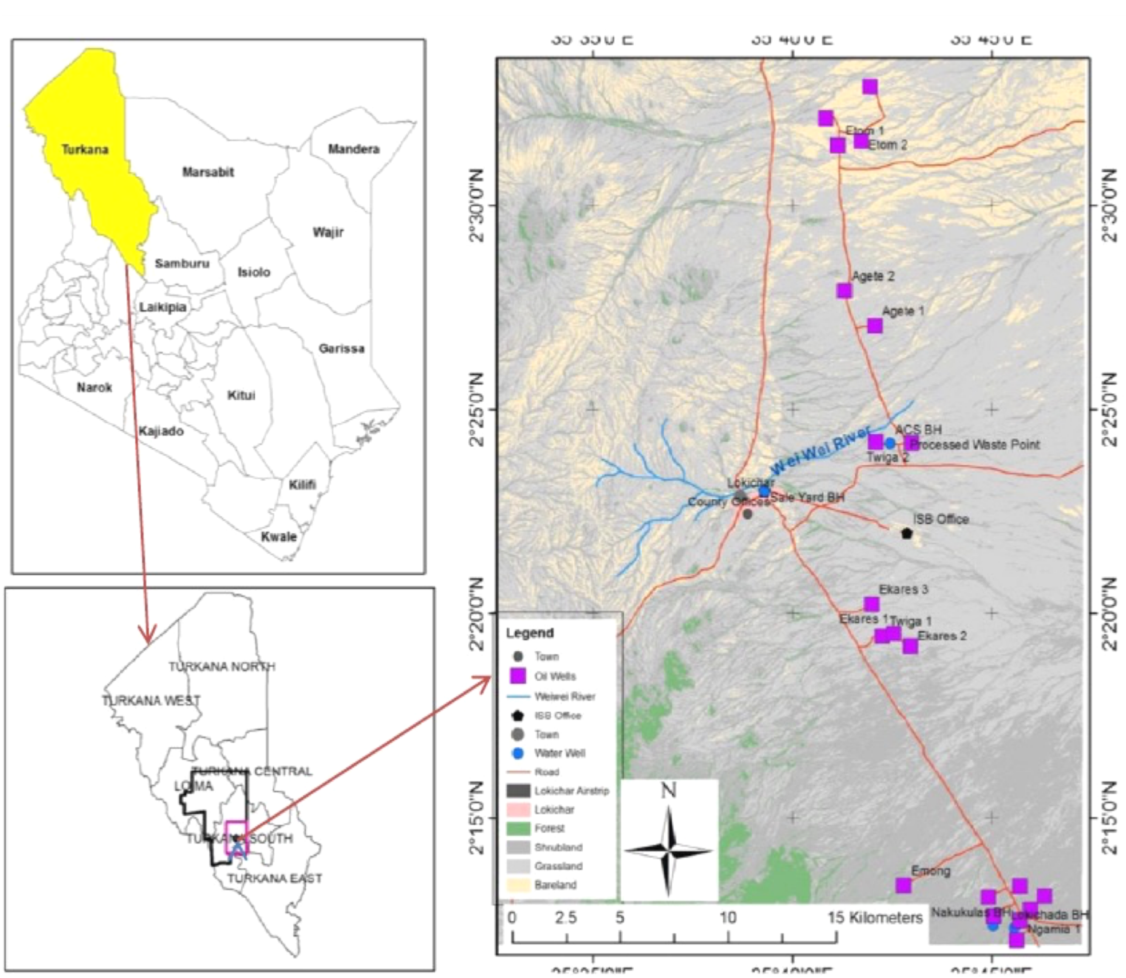
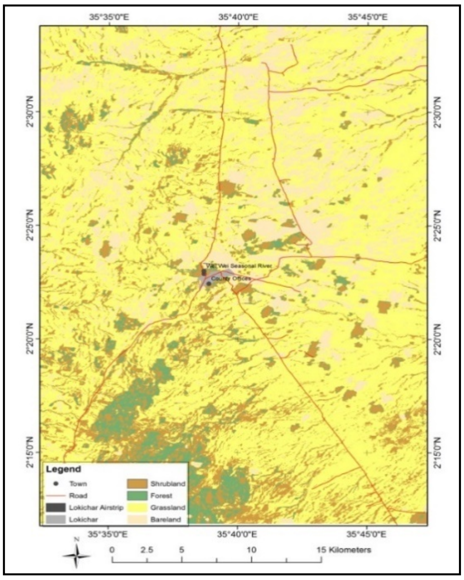


Fig. 1 Map of the study area made in 2017 showing Turkana County marked in yellow and ballooned out to show Oil Block 13T marked in black border line. The study was carried out in Lokichar Ward marked in purple borderline and ballooned out and pointed by a red pointer. The polygons shaded in purple shows the well pands across the study area whose the study focused on. The map also shows various land use land cover with the dorminant land cover being grassland and shrubland marked in grey

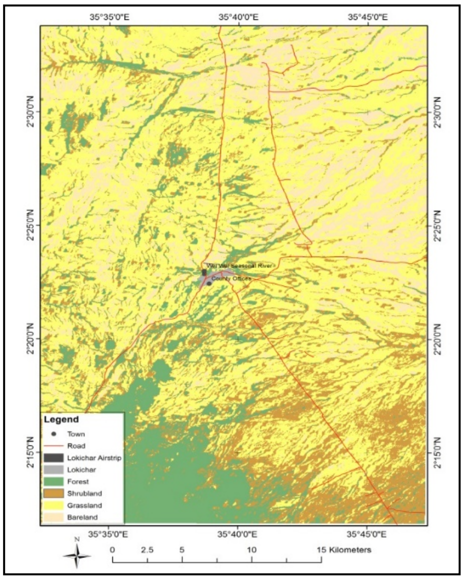
4 Results and discussions

Plate 1(k1; k2, l1; l2, m1; m2, n1; n2, and o1; o2) (Figs. 1 and 2) shows the land use land cover changes maps of the study area for years 2006, 2008/2009 2012, 2015 and 2017 for both dry and rainy seasons**.** Plate 1(*k*1 and *k*2, *l*1 and *l*2) (Fig. 1) shows the classified maps for both dry and rainy seasons of the study area for the year 2006 and 2009/2008.

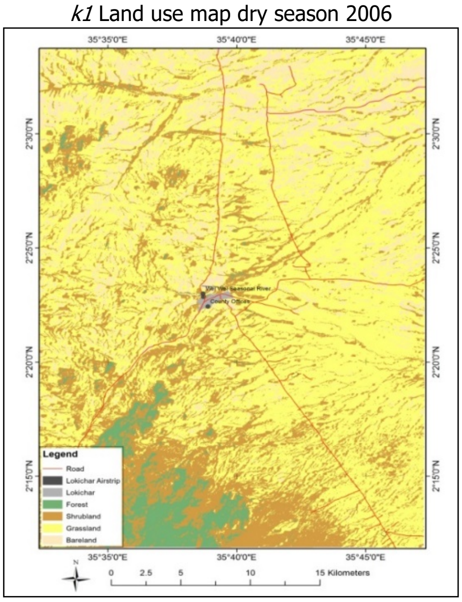
The area is covered with shrubs, riverine forest, and grassland which are the predominant vegetation cover in South Lokichar Basin, Turkana County.



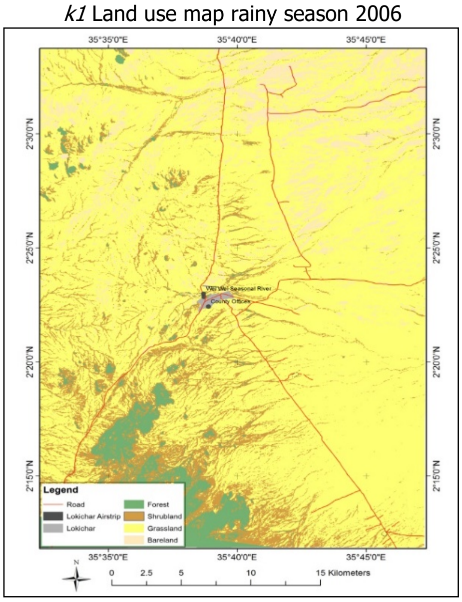
k1 Land use map dry season 2006



k1 Land use map rainy season 2006



l1 Land use map dry season 2009



l2 Land use map rainy season 2008

Fig.2 Plate 1 (k1, k2, l1, l2)

YEAR 2006

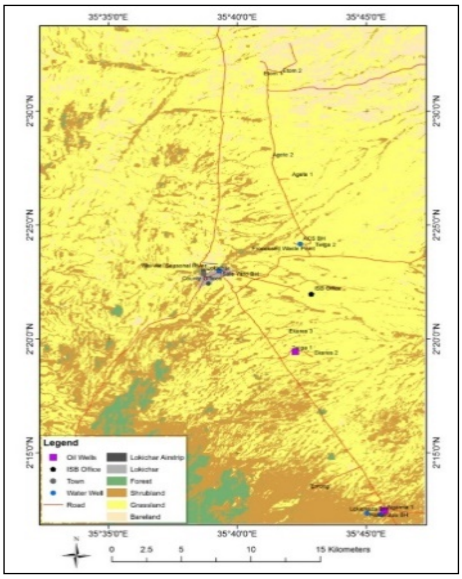
Land use	**Area in hectares: rainy season**	**Area in hectares: Dry season**
Forest	7,656.98	5,255.73
Shrubland	33,578.92	32,828.31
Grassland	71,933.61	65,824.56
Bareland	10,625.22	19,886.13
TOTAL	**123,794.84**	**123,794.84**

YEAR 2008

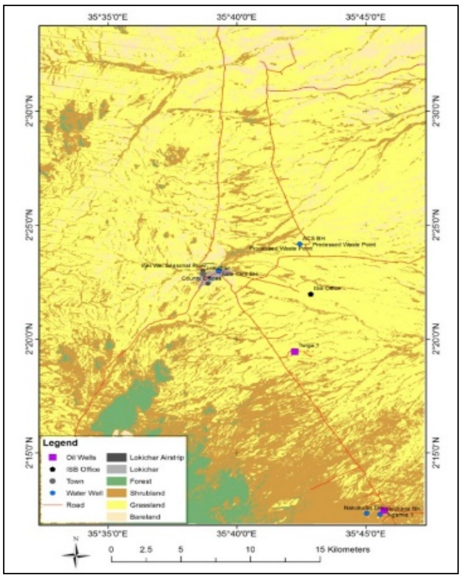
Landuse	**Area in hectares: rainy season**	**Area in hectares: Dry season**
Forest	5,648.49	4597.83
Shrubland	29,106.36	28,600.12
Grassland	80,007.40	73,212.80
Bareland	9,032.50	17,384.00
TOTAL	**123,794.84**	**123,794.84**

Tab. 1 Landuse/Landcover changes in hectares before the oil and gas exploration begun

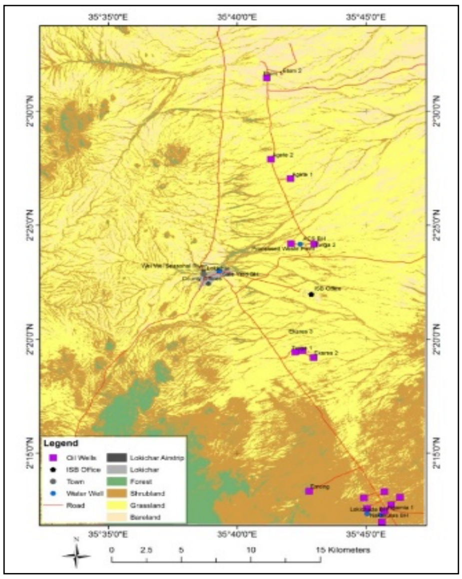
The oil and gas exploration developments had not begun and therefore the minimal changes on the land cover were as a result of climatic factors. Table 1 below shows a total of 12,3794.84 hectares of land within the study area and the extent of LU/LC changes across the years. The bareland increased by 41% from 10,625.22 hectares during the rainy season to 19,886.13 hectares for the dry season in year 2006 within the area of study. The other vegetation cover indicated a decline during the dry seasons in both 2006 and 2008/2009. The bareland decreased by 15 % between 2006 to 2008 for the rainy season and increased by 12% for the dry seasons. More than 60% of the vegetation cover in the study area consists of grassland, followed by shrubland at 25% in both rainy and dry seasons.



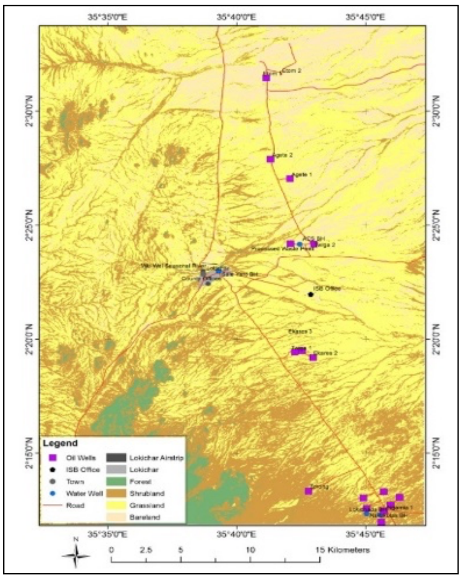
m1 Land use map dry season 2012



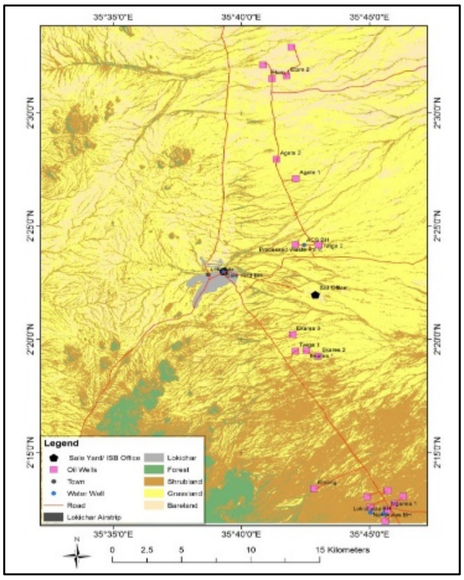
m2 Land use map rainy season 2012



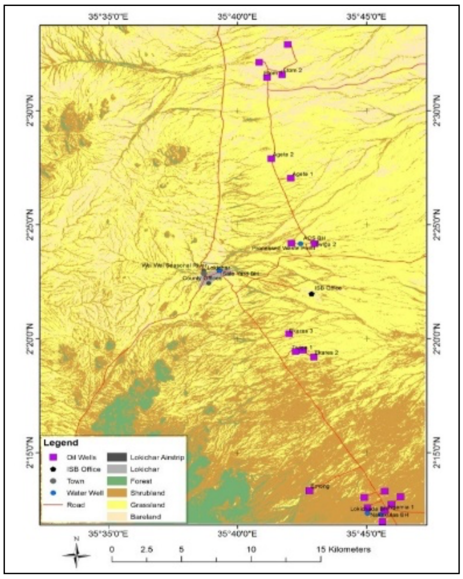
n1 Land use map dry season 2015



n2 Land use map rainy season 2015



o1 Land use map dry season 2017



o2 Land use map rainy season 2017

Fig. 3 Plate 1(k1;k2, l1;l2, m1;m2, n1;n2 &o1;o2):LU/LC maps for dry and rainy seasons of South Lokichar Basin: The maps shows the land use land cover maps from k1 to l2 for the area before oil and gas exploration commencement and maps from m1 to O2 for the area after commencement of oil and gas exploration developments. The various well pads are shown in purple. The access roads and the various vegetation cover are shown which are dry forest cover, shrubland, grassland and bareland (Source: Landsat 5TM & 8OLI/TIRS)

Plate 1 (*m*1 and *m*2, *n*1 and *n*2 and *o*1 and *o*2) (Fig. 3) shows the study area after the commencement of oil and gas exploration. Well pads and access roads which are increasing in number with each subsequent year from 2012 to 2017 are visible. The developments of well pads and access roads led to the decline of the dominant grass cover vegetation and shrubland since the bareland was increasing with each subsequent year since 2012 as shown in table 2 below. The Southern part of the study area had a dense riverine vegetation since the seasonal river Wei Wei shown in the study map passes through the area. Table 2 below shows extent in hectares of the various LU/LC changes of the study area from year 2012 to 2017.

Year 2012

Landuse	Area in hectares: Rainy season	Area in hectares: Dry season
Forest	5,922.09	4,908.42
Shrubland	36,450.75	28,639.39
Grassland	76,798.00	75,094.80
Bareland	8,224.00	12,452.20
Well pads	21.68	21.68
TOTAL	**123,794.84**	**123,794.84**

Year 2015

Landuse	Area in hectares: Rainy season	Area in hectares: Dry season
Forest	5,876.31	5,531.67
Shrubland	33,800.10	33,334.20
Grassland	67,271.80	66,820.40
Bareland	16,667.60	17,929.00
Well pads	273.00	273.00
Total	**123,794.84**	**123,794.84**

Year 2017		
Landuse	**Area in hectares: Rainy season**	**Area in hectares: Dry season**
Forest	5,691.56	3,641.40
Shrubland	35,357.44	34,045.10
Grassland	64,926.68	64,200.10
Bareland	17,640.10	21,729.20
Well pads	282.00	282.00
Total	**123,794.84**	**123,794.80**

Tab. 2 Land use/land cover changes in hectares after oil and gas exploration begun

From Tab.2, the vegetation cover during the rainy seasons declined from 5,922.09 hectares for the forest, 36,450.75 hectares for the shrubland and 76,798 hectares for the grassland in 2012 to 5,691.56 hectares for the forest, 35,357.44 hectares for the shrubland and 64,926.68 hectares for the grassland in 2017 respectively determined during the rainy seasons. Each land use area calculated for the rainy season in each year declined during the dry season indicating the negative impact of lack of adequate precipitation on vegetation cover. The bareland in 2012 increased by 51% in 2015, the variation between the size of the bare land during the rainy and dry season was 7% increase while in 2017 the bareland increased by 23% during the dry season.

The bareland increased from 8224 hectares during the rainy season and 12,452 hectares during the dry season in 2012 to 17,640.10 hectare and 21,729.20 hectares respectively in 2017, an increase of 114% and 74% for rainy and dry seasons respectively. The fact that the percentage increase of the bare land for the rainy seasons was higher than that of dry seasons between 2012 and 2017 demonstrates other factors apart from precipitation affected the vegetation. This is also evidenced by the fact that between 2006 and 2009 before the oil and gas exploration developments begun the bareland in the study area decreased by 15% for the rainy seasons and increased by only 12% for the dry seasons. The land acquired for well pads construction increased from a total of 21.680 hectares for all the well pads constructed in 2012 to 282 hectares in 2017 for the 11 well pads sampled within the study area. The area under the constructed access roads was integrated in the area under the bare land. This area seemed to increase as oil and gas exploration developments intensifies in the region. Exploratory drilling appraisal and developments oil wells are spread across South Lokichar Basin as shown in figure 1 of the study area map and this is causing fragmentation of the community grazing land when compounded with access roads, boom towns, oil transportation corridors such as pipelines, highways and trails.

4.1 Two sample t-test on area under vegetation cover pre and post commencement of oil and gas exploration in south Lokichar basin

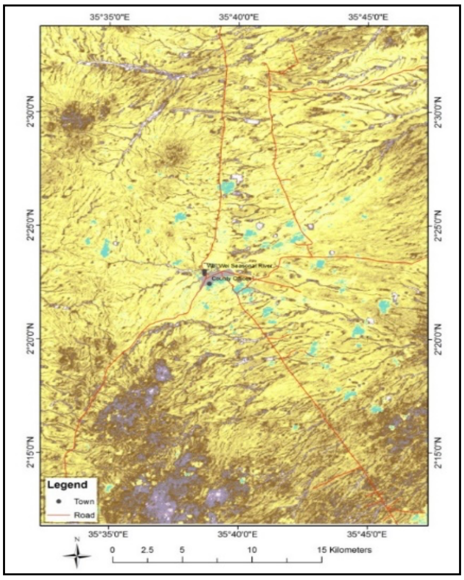
Table 2 shows that the area under vegetation cover had declined since the oil and gas exploration developments begun**.** Results of a two-sample t-test gave a mean difference between the size of the land covered by forest, grassland and shrubland before the oil and gas exploration begun and after of 1589. 12 hectares 6248 hectares and 7,274.21 hectares were recorded respectively with standard deviations of 937.69, 6,549.10 and 5,359.42 respectively.

The analysis had standard errors of the mean of 454.45 hectares, 7,221.57 hectares and 2,984.92 hectares respectively and 90% confidence intervals of -2,343.947-5,522.19, 66,590.73-54,104.72, -4,352.19 – 18,900.61 respectively. The obtained *t*-values were 3.4968, 0.8645 and 2.437 at, 1.199, 1.2225, 2.2363 respectively degrees of freedom and the statistical significance (2-tailed *p*-value) of the two sample t-test (Pr(|T| > |t|) under Ha: mean(diff) != 0), which were;0.0718, 0.07381 and 0.0609 respectively.

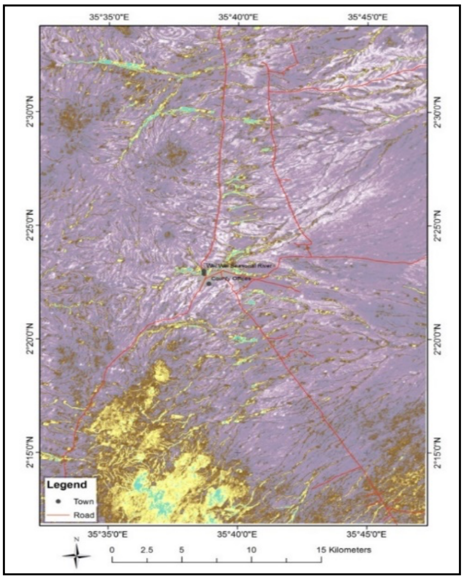
As the *p*-values were less than 0.1 (i.e., $p< 0.1$), the study concludes that there is a statistically significant difference between the area under vegetation cover before the oil and gas exploration developments begun and after. This is consistent with Osei *et al.* 2006 for a study done in Niger Delta.
The clearing of the vegetation in the study area had led to the decline of NDVI value.

4.2 Oil and gas exploration developments effect on normalized distribution vegetation index of the study area under changing climatic conditions

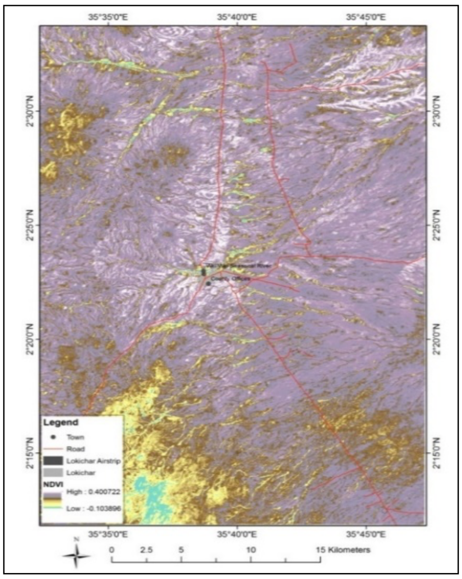
NDVI depicts the density of green vegetation on a patch of land. Decimation of the vegetation cover immensely lowers the NDVI. The study hypothesized that commencement of oil and gas exploration did not have a significant effect on the NDVI value of the study area. The study did an analysis of the NDVIs of the years 2006, 2008 and 2009 for the dry and rainy season, this was before the oil and gas exploration developments began in South Lokichar Basin. This was compared with the NDVIs of the study area after the commencement of oil and gas exploration developments for the years 2012, 2013, 2015 and 2017. The NDVIs were calculated and shown in the NDVI maps in plate 2 (f1;f2 g1;g2, h1;h2, i1;i2, j1;j2, k1;k2, l1;l2, m1;m2).



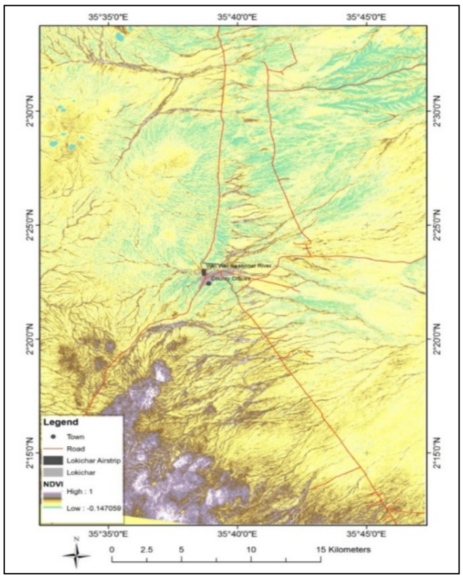
f1 dry season NDVI 2006



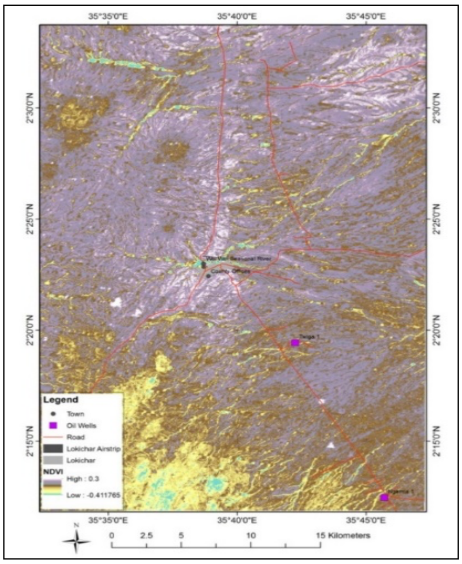
f2 rainy season NDVI 2006



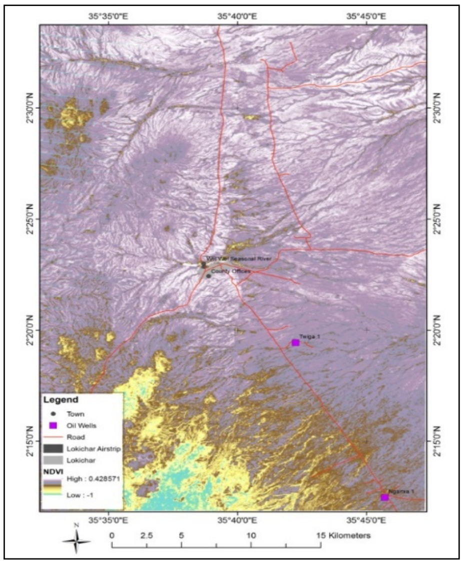
g1 dry season South Lokichar Basin NDVI 2009



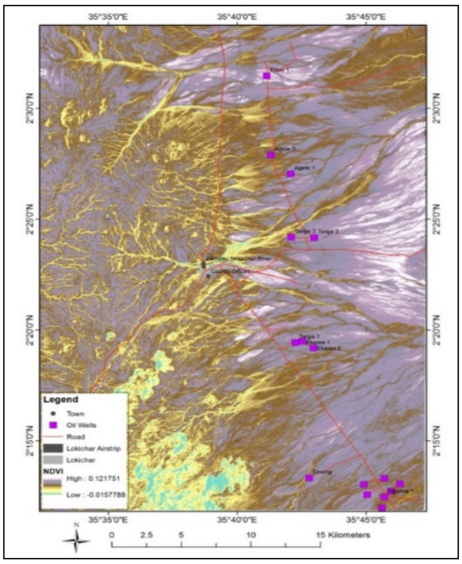
g2 rainy season NDVI 2008



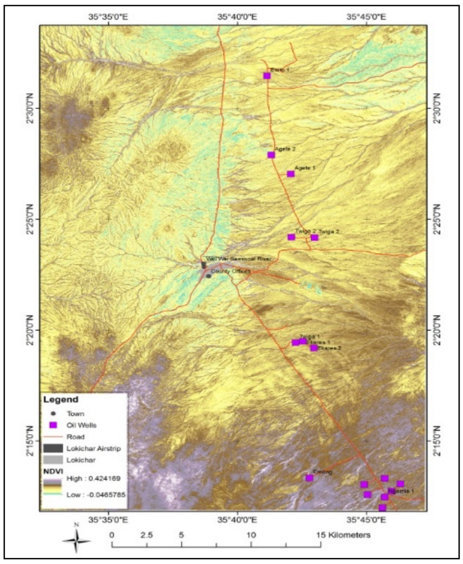
h1 dry season South Lokichar Basin NDVI 2012



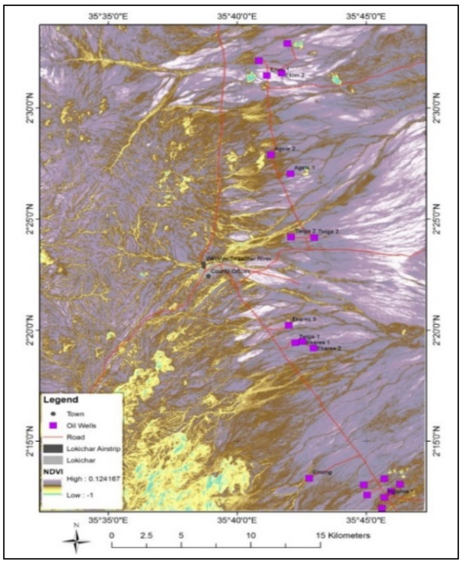
h2 rainy season South Lokichar Basin NDVI 2012



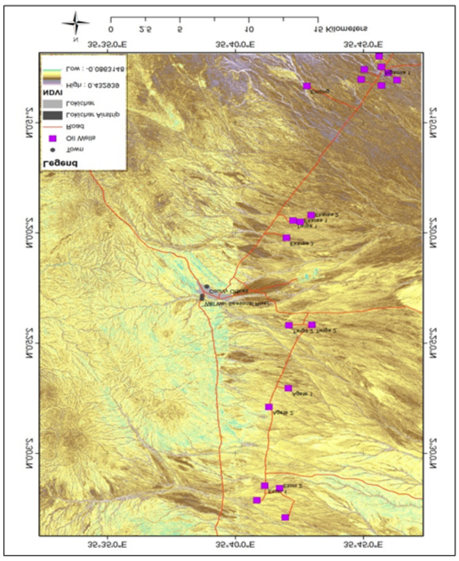
i1 dry season South Lokichar Basin NDVI 2015



i2 rainy season South Lokichar Basin NDVI 2015



j1 dry season South Lokichar Basin NDVI 2017



j2 rainy season South Lokichar Basin NDVI 2017

Fig.4 Plate 2 (f1;f2 g1;g2, h1;h2, i1;i2, j1;j2, k1;k2, l1;l2, m1;m2):Showing NDVI for dry and rainy seasons of South Lokichar Basin. The NDVI maps shows the high and low NDVI values for2006(f1;f2), 2009(g1), 2008(g2), 2012(h1;h2), 2015(i1;i2), 2017(j1;j2)(source:Landsat 5 and 8 imageries)

From plate 2 (f1 and f2) above the study established that the area high and low NDVI values were 1 and -0.12 respectively for the rainy seasons experienced between October-December. The dry season recorded NDVIs were 0.4107 and -0.138 and were determined between May-July as shown in Fig. 5.

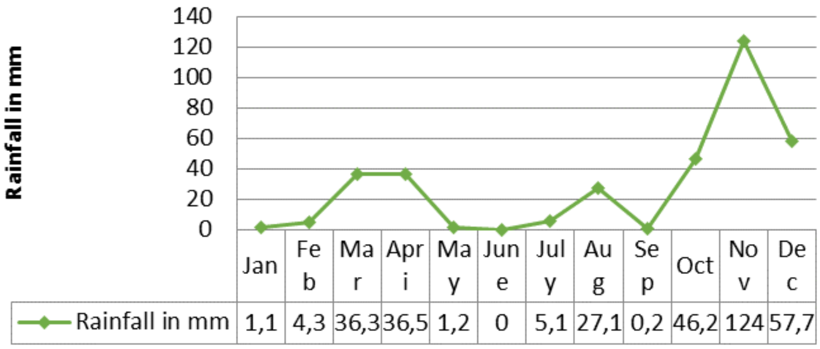


Fig.5 Rainfall received during the rainy and dry seasons for the year 2006 in South Lokichar Basin (Source: Republic of Kenya (RoK), 2017)

Plate 2(*g2*) had a high and low NDVI values of 1 and -0.147 respectively. These recordings were done during the rainy season experienced between September and November 2008 as shown in the rainfall data graph in Fig.6.

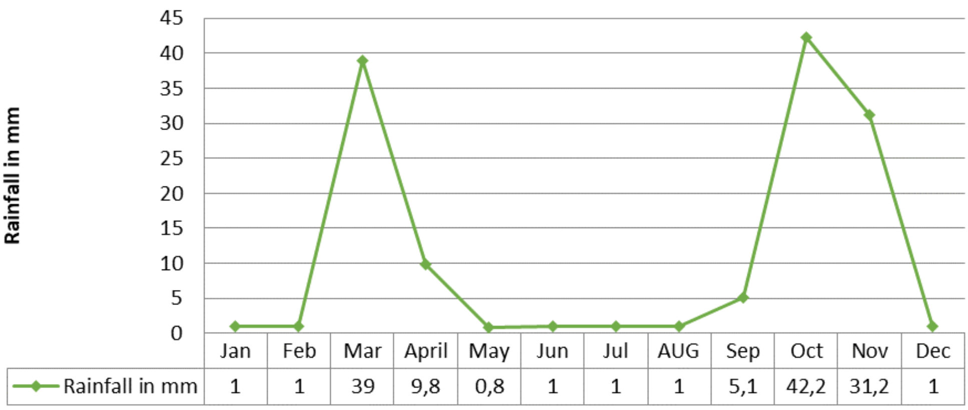


Fig.6 Rainfall received in September-November rainy season for the year 2008 in South Lokichar Basin (Source: RoK, 2017)

Though the year did not receive as much rainfall during the rainy season as compared to the years 2012, 2015 and 2017, the fact that there was no disturbance on the vegetation cover emanating from oil and gas exploration developments may have contributed to the high NDVI recorded. The NDVI of the study area for the dry season shown in *g*1 was less than the one in *g*2 for the rainy season since rainfall is a significant factor that affects the NDVI. The highest and the lowest NDVI values for the dry season between July and September shown in figure7 were 0.4007 and -0.1038 respectively.

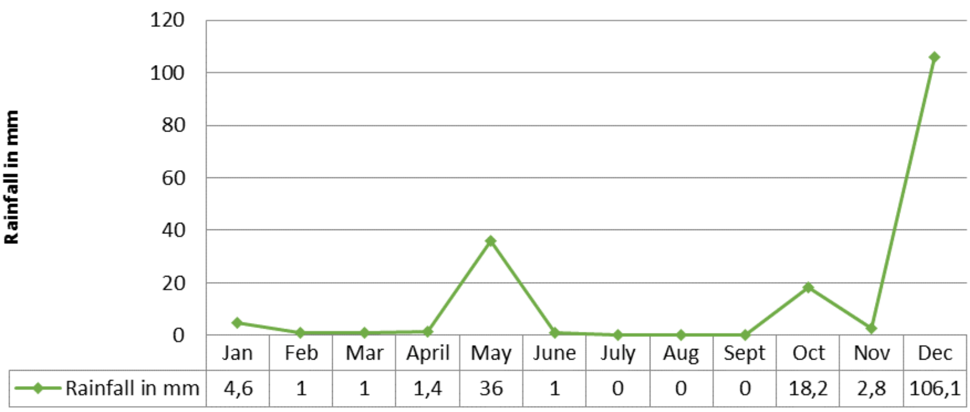


Fig.7 Rainfall received in June-September dry season for the year 2009 in South Lokichar Basin (Data Source: RoK 2017)

The NDVI of the study area in 2012 determined during the rainy season shown in figure 8 did indicate a slight variation when compared to the 2008 values for a similar season.

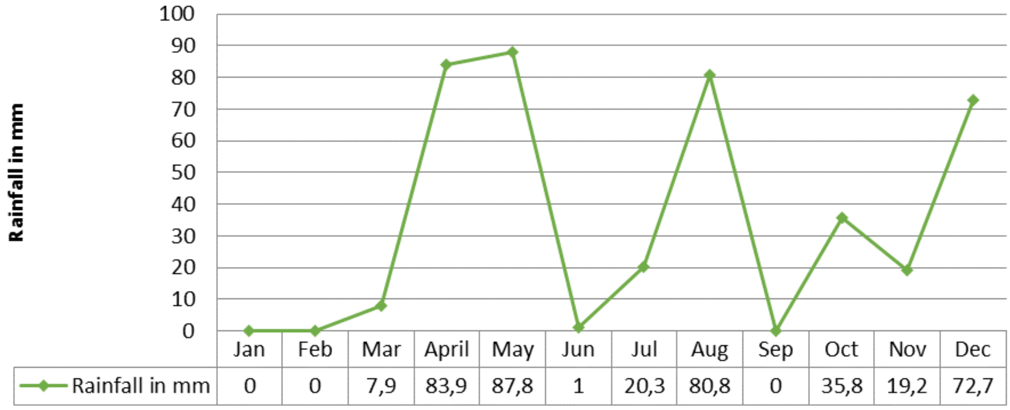


Fig.8 Rainfall received in March-May rainy season for the year 2012 in South Lokichar Basin. (Source: RoK, 2017)

The highest NDVI during the rainy season experienced between March and May was 0.4285, and the lowest was -1 as shown in plate 2 (h2). The NDVI of the study area for the dry season experienced between September and November 2013 as shown in figures 6 was slightly lower than that of the dry season in the year 2009. The highest value recorded was 0. 3, and the lowest was -0.4117 as shown in plate 2 (h1). The finding implies that in 2008 before the excavation and exploration developments began the area had some more vegetation cover as compared to 2012 under the same environmental condition. The rainy season of 2008 experienced more rainfall as shown in Fig. 5 than the amount of rainfall experienced in a similar season in 2012 shown in Fig. 8. Both dry seasons in 2009 and 2013 received less than 1 millimeters of rainfall indicating that the reduction in NDVI was as a result of an external factor rather than climatic conditions in the study area.

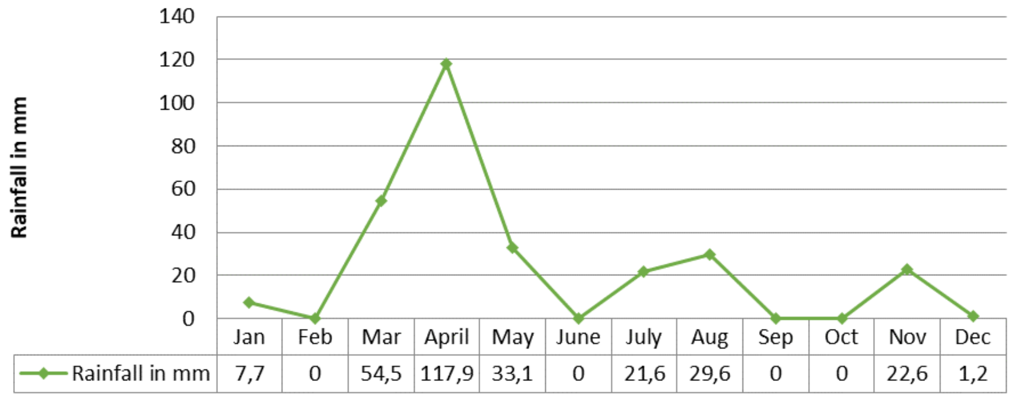


Fig.9 Rainfall received in September-November dry season for the year 2013 in South Lokichar Basin (Source:RoK, 2017)

The highest NDVI value of the study area for the rainy season experienced between March and May shown in Fig.10 for the year 2015 was 0.4241, and the lowest was -0.0455 as indicated in plate 2 (i2). The value was lower than the one for year 2012 for a similar season despite the fact that the amount of rainfall received in the two seasons was almost the same as shown in Fig. 8 and Fig. 10. The highest NDVI for the dry season determined between July and September of the year 2015 as shown in figure 109 was 0.124167, and the lowest was -1 shown in plate 2 (i1) which was slightly lower than the one recorded in the year 2012 in a similar season.

The study area recorded the lowest NDVI value in the year 2017. The highest NDVI value determined during the rainy season between August and October shown in figure 11 was 0.410939 and the lowest value was -0.0863 indicated in plate 2 (*j*1).

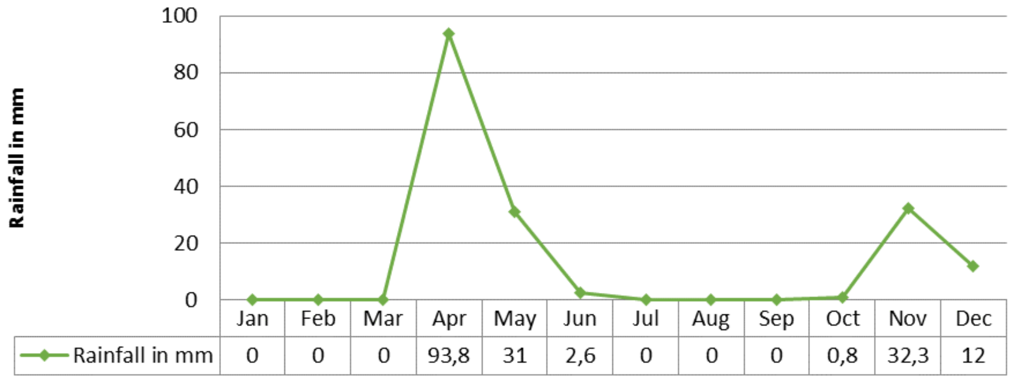


Fig. 10 Rainfall received in both March-May rainy season and July-September dry seasons for the year 2015 in South Lokichar Basin (Source:RoK, 2017)

The highest and lowest NDVI values for the dry season experienced between May and July shown in Fig. 11 was 0.12157 and 0.0157 as indicated in plate II(*j2*). These values were lower compared to the NDVI determined under similar environmental conditions in 2015.

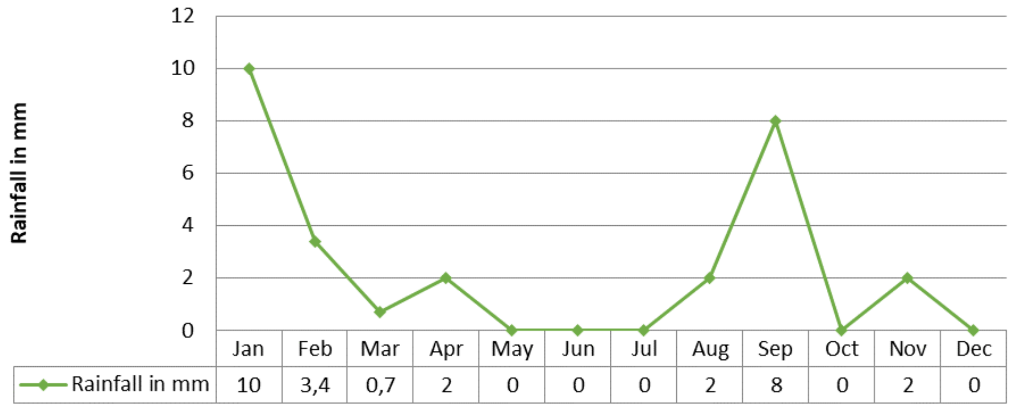


Fig. 11 Rainfall received in both August-October rainy season and May-July dry seasons for the year 2017 in South Lokichar Basin (Source: RoK, 2017)

The NDVI of the study area between 2006 and 2009 was constant in both dry and rainy seasons but started to decline from the year 2012 through 2017.

The study attributes the decline to the developments of the oil well pads and other infrustructures to aid in extraction and conveyance of crude oil such as access roads, pipelines, highways and trails in South Lokichar Basin. This is due to the fact that these developments in the study area affected the vegetation abundance hence the decline in NDVI. Climatic conditions and human activities leading to vegetation clearance may affect the NDVI of an area (Bagherzadeh et al., 2020). The fact that the NDVI declined in both dry and rainy seasons means that rainfall was not the only factor contributing to the reduction of NDVI. The variation in the amount of rainfall experienced during the rainy seasons was minimal indicating that rainfall had little significance on the NDVI value variations over the different year's rainy seasons. This means that declining vegetation cover and increasing bare land was the primary factor causing the decline in NDVI value.

The bare land as noted in table 1 increased by 117% from 2012 to 2017 from an area size of 8245 hectares to 17922 hectares. The study attributes the increased bareland to the developed well pads and access roads. This led to a significant change in NDVI of the study area.

4.3 Pearson linear correlation analysis for the trend of ndvi for the rainy season from 2006 to 2017 in the study area

The analysis in figure 11 indicated a very strong negative linear correlation with a Pearson correlation R-value of -0.86. This means that the NDVI was decreasing with time from 2006 to 2017. The NDVI declined due to the Land cover/land use change. As noted in the figure, the decline between 2006 and 2012 was quite minimal as compared to the decline of the NDVI between 2012 and 2017. This could be explained by the fact that there were little oil and gas exploration developments between 2006 and 2012 with only two well pads developed in 2012 and limited road infrastructures were constructed.

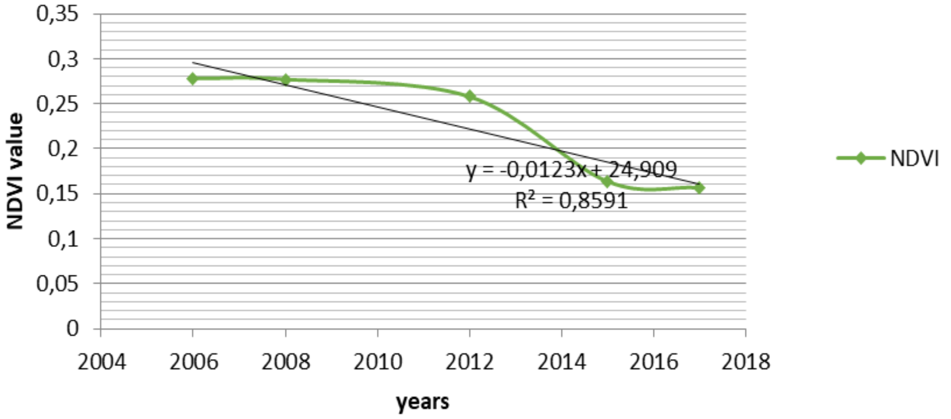


Fig. 12 Trend of average NDVI value for South Lokichar Basin for the rainy seasons (*Source:Landsat imageries 2006; 2008, 2013; 2015 & 2017*)

This is contrary to the period between 2012 and 2017, a period whereby most of the well pads and transport corridors such as access roads to the various well pads were developed.

The fact that all these NDVIs values were determined during the rainy seasons across the years, affirms this study assertion that, another factor could have contributed to the declining NDVIs value and this could only be the clearing of vegetation due to excavation from oil and gas exploration developments.

Figure 13 shows the trend of the NDVI of the study area across the years determined during the dry season. It shows a strong negative linear correlation with an R- correlation factor of -0.97.

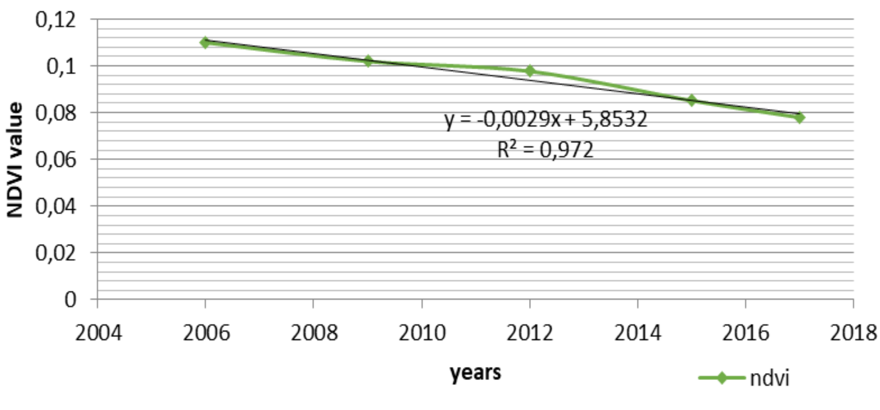


Fig.13 Trend of average NDVI value for the South Lokichar Basin for the dry seasons (*Source:Landsat imageries 2006; 2009, 2013; 2015, 2017)*

The fact that the NDVI values for the study area during the dry seasons were less than those recorded during the rainy seasons is a clear indication that rainfall influences the NDVI value. The NDVI values determined for the rainy seasons without any other external influence in the study area should have been the same since the area has homogenous vegetation. However as noted this was not the case as the NDVI value for the rainy season declined from 1 for high value and -0.147059 for lower value in 2006 to 0. 121751 for high value and -0.0157788 for lower value in 2017.

4.4 Results of paired t-test and simple linear regression analysis on significant change of ndvi value pre and post commencement of oil and gas exploration

Results of the paired t-test of the average NDVI value of the study area pre and post oil exploration gave a statistical significance (2-tailed) paired t-test had a calculated *p*-value of 0.0091. As the *p*-value was less than 0. 05 (i.e., *p*<. 05), the study concludes that there was a statistically significant difference on the NDVI value before and after oil and gas exploration developments began in South Lokichar Basin. The difference can be explained by decreased vegetation cover and increased bared land due to construction of well pads and access roads as evidenced by simple linear regression analysis of bare land area size and average NDVI across the years did show a strong linear regression relationship with R value of 0.953. The statistical regression coefficient signifance (2-tailed p-value) was -0.012 at 95% confidence interval as shown in Tab. 3. As the p value was < than 0.05 and the statistical significance was negative as shown in Tab. 3, the study concludes that increased bareland due to vegetation clearance as access roads and other oil and gas developments infrastructures led to a decline in NDVI value in the study area.

Coefficients

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**T**	**Sig.**
		B	Std. Error	Beta		
1	**(Constant)**	0.388	0.031		12.512	0.001
	land area	-1.286E-005	0.000	-0.953	-5.471	-0.012

Tab.3 Linear Regression Analysis in Determinng the Relationship Between Changing Bareland and NDVI of the Study Area

5 Conclusion

The findings of this study implies that, since rainfall was abundant across the years during the rainy seasons, then vegetation clearance that resulted from oil and gas exploration developments contributed immensely to the decline of the NDVI value across the years. Ground trothing and literature review established that in regard to the exploration well drilling, vertical well drilling was the technology that was being used in South Lokichar Basin despite its impacts on increased ecological footprints in areas where it has been used. In addition this study established that five dry wells had been encountered since exploration drilling began in 2012, and restoration was yet to be done by 2017.

This study has established that Land use land cover changes are taking place in South Lokichar Basin with increasing oil and gas exploration developments. As observed the area of study falls under Oil Block 13T which is one of the 9 oil blocks of Rift Tertiary Basin.

As much as the study focused on South Lokichar area of the Basin, the oil and gas developments work is going on across the entire Rift Tertiary Basin. The land use land cover changes noted in South Lokichar Basin, within Lokichar Ward is happening in other parts of the entire Rift Tertiary basin. Lokichar Ward was adopted as a case study area in this research. It is of interest to note that before oil and gas developments commencement in 2012, there was minimal variations on land use land cover changes in addition to minimal decline in biophysical index NDVI. The study attributes this minimal changes to limited oil and gas developments between 2006 and 2012 with only two well pads and few access roads having been developed. The decline in NDVI between 2012 and 2017 was higher and this could be explained by the fact that many well pads and access road infrastructures were developed within this period.

The fact that all these NDVIs values were determined during the rainy seasons across the years, and as observed there was minimal variation in average rainfall received, the study concludes that another factor was immensely contributing to the declining NDVI and in this case vegetation clearance due to oil and as gas developments of well pads and access roads. As oil and gas developments is projected to continue, a thorough understanding of the ecological and environmental concerns is crucial to the sustainability of the fragile grassland ecosystems. Proper measure needs to be taken to ensure sustainable management of the indigenous vegetation land cover such as adoption and implementation of sustainable drilling technologies and indigenous species restoration approaches. This is due to their ecological and socio-economic role especially that of supporting pastrolism, bearing in mind that this is the main economic activity in the region.

Acknowledgement

The study was financially supported by German Academic Exchange Service (DAAD) through an awardment of a PhD scholarship and National Research Fund of Kenya through fieldwork research grant. We appreciate the Executive Director, Friends of Lake Turkana Trust; Ikal Angelei for logistical support in the study area. We thank the two anonymous reviewers for constructive comments which helped to improve the quality of the manuscript.

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Image sources

Fig.1: Author 2020

Figs. 2-8: Author 2020 with data from Kenya meteorological Department

Figs. 9 and 10: Author 2020 Imageries from United State Geological Survey

Plate 1 and 2: Author 2020 Imageries from United State Geological Survey

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