Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 9, Issue, 12, pp.63070-63075, December, 2017

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

HYDROCARBONS IN CRUDE-OIL PRODUCTION SITES OF THE SUDD-REGION SOUTH-SUDAN: IMPLICATION ON SOIL FERTILITY AND PLANT SPECIES RISK

[1,2,*] Jane Alexander Ruley, [2]Alice Amonding, [2]Tumuhairwe, J. B., [2]Basamba, T. and [3]Oryem-Origa, H.

[1]Department of Agricultural Sciences, CNRES, University of Juba, P.O. Box 82, Juba, Jubek State, South-Sudan
[2]Department of Agricultural Production, Makerere University (MAK), P.O. Box 7062, Kampala, Uganda
[3]Department of Natural Sciences, Makerere University (MAK), P.O. Box 7062, Kampala, Uganda

ARTICLE INFO

Article History:
Received 10th September, 2017
Received in revised form
11th October, 2017
Accepted 16th November, 2017
Published online 31st December, 2017

Key words:
Contaminant,
Crude-oil,
Hydrocarbons,
Soil fertility,
Plant species,
Sudd Wetland.

ABSTRACT

Crude oil activities lead to soil contamination with hydrocarbons, this drastically affects normal functioning of the soil and result in nutritional constraints; thus, negatively affect plant growth, and low productivity. These studies were objectively incepted to determine the effects of crude oil on soil properties and spatial distribution of plant species in oil production sites in South-Sudan. Soil samples were taken at two depths of 0-30cm and 30-60cm within 1m^2 quadrats located at different distances of 0-1km (drilled-land); 5km (Cultivated land) and 50km (natural-land). The soil samples were analyzed for Total petroleum hydrocarbons (TPHs) and physicochemical properties; also herbaceous plant species were counted and identified within the same quadrats. Results showed that surface and subsurface soils in the drilled lands were highly contaminated with TPHs. Locations 5Km away from the drilled wells were also contaminated with hydrocarbons when compared to the critical limits of Sudan of 5000mg kg^{-1} soil and the Canada-Wide Standard of 5600mg kg^{-1} soil for petroleum hydrocarbons. Similarly, all the soil chemical properties analyzed deteriorated with increasing TPHs concentration. Therefore, land use change from natural to oil exploration without proper management leads to reduction in soil fertility, rendering the soil unsuitable for agricultural productivity purposes. Concentrations of hydrocarbon contaminants call for urgent need for remedial treatments as a strategy to rejuvenate soils of the Sudd region. In drilled lands the dominant plant species were, *Sorghum arundinaceum*, *Oryza longistaminata*, *Hyparrhenia rufa*, *Nicotiana tabacum*, *Gossypium barbadense* and *Abelmoschus ficulneus*. The abundance of such plant species in the crude oil drilled lands support the assertion that, they are tolerant to hydrocarbons. However, these plant species need testing for their ability and efficiency to accelerate hydrocarbon degradation, thereafter be used as phyto-remediators to eliminate the threat to soil fertility and plant diversity in the world's biggest wetlands, the Sudd in South-Sudan.

Citation: Jane Alexander Ruley, Alice Amonding, Tumuhairwe, J. B., Basamba, T. and Oryem-Origa, H. 2017. "Hydrocarbons in crude-oil production sites of the Sudd-region South-Sudan: Implication on soil fertility and plant species risk", *International Journal of Current Research*, 9, (12), 63070-63075.

INTRODUCTION

The exploration and extraction of crude oil has become a soil contamination problem of great importance in oil producing countries worldwide (Kadafa, 2012; Wang *et al.*, 2013). During various crude oil industrial activities, waste water and oily sludge are produced and oil spills end up in soil ecosystems as the final sink (Berger and Schwarzbauer, 2016; Shapiro *et al.*, 2016). Crude oil is a complex mixture of Petroleum Hydrocarbons (PHCs) (CCME, 2001; Rivas *et al.*, 2014) and in general, PHCs have a direct contamination effect on soils. Hydrophobicity has been determined as a critical property controlling PHCs behavior in the soil (Morales-Bautista, *et al.*, 2016; Umeh *et al.*, 2017). Soil hydrophobic properties can be defined as the difficulty of soil to absorb, turn into moisture or have soil water repellence properties and negatively affects soil properties (Adams *et al.*, 2008; Vogelmann *et al.*, 2013). The presence of PHCs in the soil environment overtime, apart from causing human health problems (Liu *et al.*, 2016), releases chemical components that undergo various changes and transformations within the soil, thereby modifying the physical, chemical and biological properties of the soil (Wang *et al.*, 2013). This impairs soil processes such as nutrient cycling and infiltration, consequently making the soil more susceptible to surface runoff. The overall effect is the disruption of the normal

*Corresponding author: [1,2] Jane Alexander Ruley,
[1]Department of Agricultural Sciences, CNRES, University of Juba, P.O. Box 82, Juba, Jubek State, South-Sudan
[2]Department of Agricultural Production, Makerere University (MAK), P.O. Box 7062, Kampala, Uganda

functioning of the soil (Shukry *et al*., 20013). Furthermore, Bakke et al. (2013) and Pal *et al*. (2016) reported that waste water from crude oil extraction causes alteration of both physical and chemical properties of the soil, which is followed by soil deterioration, thus inhibiting plant growth and microbial activities. Such disruption leads to reduction in agricultural productivity (Shirdam *et al*., 2008), hence negative effects on the livelihoods of the local communities within and around oil contaminated sites, particularly small-scale farmers (Fallet, 2010; Ofuoku *et al*., 2014). Sudd is the world's largest wetland and makes up to approximately 5% of the Republic of South-Sudan (648,000 Km^2) (Ramsar Convention, 2010; Sosnowski *et al*., 2016). The Sudd ecosystems are fragile and are under threat from oil exploration and extraction activities since the 1980s (Rueskamp *et al*., 2014; Mager *et al*., 2016; Pragst *et al*., 2017). Some reports have indicated high salt content in the water, dying of livestock, reduction in vegetation cover and uncommon diseases among the local communities around the crude oil extraction sites (Fallet, 2010; Tutdel, 2010; Rueskamp *et al*., 2014; Pragst *et al*., 2017). The Sudd ecosystems are of vast socio-economic, cultural and biological importance locally, national and internationally. For this reason, it was designated as a Ramsar site in 2006 (Ramsar Convention, 2010), which makes it essential for nature conservation. Besides its biodiversity importance, the Sudd region is geologically rich in oil, with production estimated at 198,000/290,000 barrels of crude oil per day in 2013, after decline from its peak in 2011 at around 298,000/489,000 barrels per day as reported by De Waal (2014). Despite the obvious importance of the Sudd Region, very little information is available on the management of the region under various crude oil activities. Baseline studies on ecological processes that determine the existence of the wetland are equally limited. Therefore, understanding the ecological context of the Sudd region is a pre-requisite for establishment of a long term and efficient oil waste management strategy. Soil fertility is a fundamental index in determining agricultural productivity (Gelaw *et al*., 2015). This is due to its helpful role in ecosystem maintenance, integrating the diverse functions including nutrient supply which is necessary for promoting plant production (Sanginga and Woomer, 2009). However, many studies continue to note declining soil fertility in Sub Saharan Africa which has been mainly attributed to human activities.

It has been documented that under a stressful environment, numerous morphological and physiological changes occur to plants (Parida and Das, 2005; Nawaz *et al*., 2010); these are caused by the direct and indirect effects of stress. Furthermore, the intrinsic responses of plants can influence the chances of their nutritional quality and productivity, hence putting plant production in an unsustainable path (Shapiro *et al*., 2016). To date, little information is available on the effect of crude oil exploration and extraction activities on plant species and soil fertility status in the Sudd wetlands of South-Sudan which is the third oil producing country in Sub-Saharan Africa after Nigeria and Angola (Patey, 2010). Risk assessment on soil fertility status in the Sudd oil production sites were therefore necessary in order to determine how far contaminants migrated from their point of source and measure PHCs concentrations at different distances outward from the oil drilled wells. Such information would provide an impetus to the effective oil activities management strategy. Hence, the inception of this study which was undertaken in the major crude oil production sites with the objectives to examine the severity of hydrocarbons on soil fertility status and distribution plant species in the Sudd region of South Sudan.

MATERIALS AND METHODS

Study area

The major oilfields in the Greater Sudd region of South Sudan were discovered by the American multinational oil company Chevron in the 1970s. Since then, South Sudan's Sudd region history of crude oil exploration and extraction has been marred by wars and conflict. This history partly explains why such oil fields and their environmental impacts were less studied. The Sudd is thus a suitable site for the risk assessment of PHCs contamination in soil and plant species. This research was conducted in two states, namely, Upper Nile and Unity where crude oil is drilled. These two states are the main sites for crude oil extraction activities in the Greater Sudd-region of South-Sudan (Tutdel, 2010;Pragst *et al*., 2017; Mager *et al*., 2016). Located within Latitudes 6^0 30'- 9^0 30' North, and Longitudes 30^0 10'- 31^0 45' East, with an elevation of 320 m above sea level. The concentration of total petroleum hydrocarbons in the Sudd region and its effect on soil properties and plant species were assessed from two years abandoned drilled oil wells in June 2016.

Study design

Determination of present plant species and soil sampling points were based on the systematic line transect sampling method using Quadrats. Plant species were identified, counted and recorded from 72 quadrats of 1 m^2 (6 drilled oil wells x 4 transects each x 3 distances (0, 0.5 &1km) outward from drilled wells) from contaminated land. Similarly, plant species were counted from cultivated land (5km away from each drilled oil wells) and natural land (50km away from drilled oil wells), each from 72 quadrats (6 plots x 4subplots x 3 quadrats). Soil samples were also taken from each of the quadrats where plant species were counted; therefore, in total, 144 soil samples (6 drilled oil wells x 4 transects each x 3 intervals (0, 0.5 and 1km) outward from drilled oil well x 2 soil depths within quadrat (0-30 and 30-60cm)) were taken from each of the three land use types of: oil drilled well, cultivated land and natural land. The 144 soil samples from natural land were kept differently, while the 288 soil samples from contaminated land and cultivated land were wrapped in aluminum foils, well labeled and placed in zip lock bags. They were carried in a cooler to the laboratory and stored in a refrigerator at -4 ^{0}C for further treatment and analysis.

Laboratory soil analyses

The physicochemical properties (Soil texture, pH, Soil Organic Matter, Total Nitrogen, Available Phosphorus, Calcium, Magnesium, Potassium, Sodium, Cation exchangeable capacity) were analyzed using standard laboratory procedures as outlined by Okalebo *et al*. (2002) and the total petroleum hydrocarbon levels in the sampled soils from the six locations were analyzed according to the Canadian Council of Ministers of the Environment (CCME), "Reference Method for the Canada-Wide Standard for Petroleum Hydrocarbons in soil - Tier 1 method" (CCME, 2001). This method defines four PHC fractions based on boiling point of n-alkanes as follows: F1: Fraction 1 of petroleum hydrocarbons which contain C6-C10, F2: Fraction 2 of petroleum hydrocarbons which contain C10-

C16; F3: Fraction 3 of petroleum hydrocarbons which contain C16-C34; and F4: Fraction 4 of petroleum hydrocarbons which contain C34-C50; in addition to BTEX (benzene, toluene, ethylbenzene and xylene).

Statistical data analysis

Data for petroleum hydrocarbons, physico-chemical properties of the soil across the three land use types were subjected to Analysis of Variance (ANOVA) by Genstat statistical computer package to generate treatment means using Fisher's Least Significant Difference (LSD) test at 5 % probability level, while the plant species were subjected to diversity index.

RESULTS AND DISCUSSION

Petroleum Hydrocarbons concentrations in the soil across land use types. Results of the TPHs across different land uses and soil depths are shown in Table 1. Concentrations of total petroleum hydrocarbons (TPHs) across the different land uses were significantly different ($P \leq 0.05$), with highest value (45097 mgkg^{-1}) under crude oil drilled land followed by 7002 mgkg^{-1} at the cultivated land (a distance of 5 km away from the oil drilled wells). Total petroleum hydrocarbons were not detected in the soil samples taken from natural land (at distance of 50 km from the drilled wells). Petroleum hydrocarbon concentrations for BTEX (benzene, toluene, ethylbenzene and xylene) plus fraction F1 and fractions F2 to F4 were undetected under the natural land and very high in the drilled land both in the surface and subsurface soil, while concentrations of volatile PHCs (BTEX and F1) and F4 in the cultivated land were below the critical levels according to CCME for fine textured farm surface soil (260 mgkg^{-1}soil) and subsoil (760 mgkg^{-1}soil) but high in F2 (1566 mgkg^{-1}soil) and F3 (2982 mgkg^{-1}soil) PHCs fractions in surface soil.

Response of soil physicochemical properties to land use types

Soils in the study area are predominantly fine textured, with high clay content and range between 50.9 % and 62.7% (Table 2). Crude oil contaminated land was quite acidic compared to the cultivated and natural land (pH - water 4.5, 5.5 and 6.7, respectively). Soil chemical properties are among the most important factors that determine the availability of nutrients in soil. The chemical properties of the analyzed soil from crude oil drilled, cultivated and natural lands are presented in Table 2. Chemical properties of the soil under crude oil drilled activities exhibited alteration, with very low values in all analyzed parameters. According to the classification of soil chemical parameters as per the ranges or critical values for tropical soils suggested by Okalebo *et al*. (2002), the soil nutrients of the Sudd region are very low in drilled, low in cultivated land and medium to high in the natural land in all the analyzed parameters.

Effect of land use type on plant species

To determine which plant species were more common in contaminated land, plant species proportions on all the land use types were quantitatively analyzed (Table 3). In addition, the Shannon and Simpson indices were used to measure plant diversity of the sampled species. These indices provide information about the dominant species. Results showed that some species were absent in the contaminated land.

Out of the 23 herbaceous plant species found in uncontaminated lands, only six herbaceous plant species were found to exist in crude oil contaminated land. The *Sorghum arundinaceum*, *Oryza longistaminata*, *Hyparrhenia rufa*, *Nicotiana tabacum*, *Gossypium barbadense* and *Abelmoschus ficulneus* were the six herbaceous plant species found to be common in both contaminated and uncontaminated lands Table 3. According to the plant diversity indices used in this study, the natural and cultivated land are more diverse compared to the oil drilled land. This study indicates that soils as far as 5 km away from oil drilled wells are contaminated with petroleum hydrocarbons; with the highest concentrations of TPHs generally observed in the top soil layers (0-30 cm); this could be attributed to high clay content which ensures retention of high petroleum hydrocarbons in surface soils (Brady and Weil, 1999). High concentrations of total petroleum hydrocarbons in soil samples were the causative agents for decreased levels of soil chemical properties, thereby indicating high nutrient deficiencies in crude oil drilled lands as well as the cultivated land. Variation in chemical properties across the different land uses (oil-drilled, cultivated land and natural land) could be due to the hydrophobic properties of crude oil in the soil which deprives the soil of water retention properties; and result into death of soil microorganisms and limitation of water infiltration in crude oil-contaminated land. Similar results of the effect of crude oil on soil properties have been reported from previous studies conducted in Nigeria (Kadafa, 2012; Gighi *et al*., 2012), China (Wang *et al*., 2013; Wang *et al*., 2017 and Liu *et al*., 2016) and Mexico (Morales-Bautista *et al*., 2016). Generally, the presence of crude oil activities in the study area led to high petroleum hydrocarbon concentrations, which directly lowered the plant species count (Osuji *et al*., 2004), or indirectly limited the availability of nutrients. Bakke *et al*. (2013) and Pal *et al*. (2016) reported that waste water from crude oil extraction caused alteration of both physical and chemical properties of soil, which was followed by soil degradation, thus inhibiting plant growth and microbial activities. Such disruption leads to reduction in plant species in contaminated lands. Furthermore, the observed reduction in species number in contaminated land concur with studies of Boutin and carpenter (2017) in Alberta, Canada; Omodanisi *et al*. (2011) and Osuji *et al*. (2004) in Nigeria, who also observed reductions in plant species numbers and diversity in oil contaminated sites.

Conclusion and recommendations

This study revealed that soils from oil drilled land as well as from locations 5 km (cultivated land) away from oil wells in the Sudd region are highly contaminated with petroleum hydrocarbons. The soil samples from the oil drilled land gave the highest concentrations of TPHs (45097 mgkg-1 of soil). Both oil drilled and cultivated lands had concentrations of TPHs far much higher than the critical value of 5000 mgkg^{-1} soil given by the Sudan guideline for petroleum hydrocarbons. This can pose a toxic to ecosystem through air, soil and water, thus leading to toxic reactions along the food chain which can be a serious threat to human health. The results also indicate that all the soil chemical properties analyzed in the study were altered negatively by crude oil contaminants, negatively impacting on the soil fertility status. The general conditions in the crude oil extraction lands of the Sudd region imply low soil fertility, leading to the reduction in number of plant species, with only six herbaceous plant species identified to exist in the crude oil-contaminated soils.

Table 1. Effects of land use and soil depth on the concentration of petroleum hydrocarbons

Parameters $mgkg^{-1}$ soil	Land use type Soil depth (cm)	Drilled (0-1 km)	Cultivated (5 km)	Natural (50km)	LSD (0.05)	SEM	Critical value[a]
TPHs	0-30	45097	7002	0	2320.9	834.9	5600
	30-60	32088	2420	0			10000
BETX+F_1	0-30	373.2	181	0	55.13	19.8	260
	30-60	804.2	284	0			750
F_2	0-30	10540	1566	0	595.1	214.1	800
	30-60	6954	675	0			2300
F_3	0-30	20782	2982	0	1196.7	430.5	900
	30-60	14118	1017	0			3500
F_4	0-30	13403	2274	0	577.6	207.8	5600
	30-60	10212	445	0			10000

LSD = least significant difference; SEM = standard error of mean; Critical value[a] according to Canada-Wide Standard for Petroleum Hydrocarbons in soil - Tier 1 method" (CCME, 2001); BTEX = benzene, toluene, ethylbenzene and xylenes; F = fraction of carbon number, n= number, C= carbon F_1 = nC6 to nC10; F_2= >nC10 to nC16; F_3= >nC16 to nC34; and F_4>nC34 to 50; Mean of 72 samples

Table 2. Effects of land use and depth on physiochemical soil properties

Soil property	Soil depth (cm)	Land use types: Drilled	Cultivated	Natural	LSD (0.05)	SEM	Critical value[a]
Sand (%)	0-30	29.15	26.38	24.23	0.64	0.23	–
	30-60	28.26	25.63	23.24			
Clay (%)	0-30	50.90	57.66	61.29	1.38	0.50	–
	30-60	52.84	60.26	62.74			
Silt (%)	0-30	19.95	15.95	14.47	0.78	0.28	–
	30-60	18.91	14.10	14.02			
STC	0-30	Clay	Clay	Clay	–	–	–
	30-60	Clay	Clay	Clay			
pH (H_2O)	0-30	4.54	5.48	6.71	0.13	0.05	5.5
	30-60	4.93	5.91	6.86			
TN (%)	0-30	0.09	0.15	0.27	0.03	0.01	0.2
	30-60	0.10	0.09	0.15			
Aval P (mg/kg)	0-30	10.07	11.92	15.64	0.29	0.10	15
	30-60	5.85	8.86	8.77			
SOM (%)	0-30	1.91	3.78	5.01	0.18	0.06	3
	30-60	1.01	2.31	2.80			
CEC (cmol(+)/kg)	0-30	9.77	19.22	28.61	0.43	0.16	25
	30-60	5.18	10.24	16.14			
K (cmol(+)/kg)	0-30	0.50	1.46	1.69	0.04	0.01	0.5
	30-60	0.28	0.94	0.95			
Na (cmol(+)/kg)	0-30	1.86	1.61	0.63	0.04	0.11	<1.0
	30-60	0.97	0.79	0.19			
Mg (cmol(+)/kg)	0-30	0.37	0.53	1.25	0.04	0.01	0.6
	30-60	0.17	0.30	0.39			
Ca (cmol(+)/kg)	0-30	4.12	7.95	9.92	0.21	0.08	10
	30-60	2.55	4.30	5.87			

LUT= Land Use Type; Km=distance in kilometers from the drilled oil well; LSD = Least Significant Difference; SEM = Standard Error of Mean; STC=Soil Texture Class; TN =Total Nitrogen, Aval P = Available phosphorus; SOM=Soil Organic Matter; CEC=Cations Exchangeable Capacity; P=Potassium; Na=Sodium; Mg=Magnesium, Ca=calcium; means of 72 soil samples; Critical values[a] according to Okalebo et al. (2002) for most crops in East Africa

Table 3. Proportions (p_i) of plant species and their diversity indices

Plants: Scientific names	Common names	Plant species p_i across land use types: Drilled	Cultivated	Natural
Abelmoschus ficulneus	Wild okra	0.180	0.091	0.005
Capsicum frutescens	Pepper	____	0.015	____
Corchorus olitorius	Kodora/ Jews mallow	____	0.053	____
Vigna unguiculata	Cow pea	____	0.034	____
Desmodium motorium	_____________	____	____	0.025
Echinochloa spp.	Barnyard grass	____	____	0.061
Eleusine coracana	Finger millet	____	0.060	____
Arachis hypogaea	Groundnuts	____	0.020	____
Gossypium barbadense	Roko/Kidney cotton	0.037	0.064	0.011
Hyparrhenia rufa	Thatching grass	0.376	0.134	0.234
Nicotiana tabacum	Tobacco	0.039	0.059	0.004
Oryza longistaminata	Wild rice	0.193	0.103	0.168
Phragmites spp.	Reeds (El-boush)	____	____	0.102
Cucurbita maxima	Pumpkin	____	0.009	____
Cyperus spp.	Sedges	____	____	0.029
Sesamum indicum	Sesame	____	0.011	____
Setaria italica	______________	____	____	0.107
Sorghum arundinaceum	Wild Sudan grass	0.174	0.094	0.095
Sorghum bicolour(L) Moench	Dura	____	0.161	____
Sporobolus spp.	Abu balila	____	____	0.030
Striga hermonthica	Striga (witch weed)	____	0.055	0.074
Saccharum officinarum L.	Sugarcane	____	0.009	____
Tithonia diversifolia	False sunflower	____	0.011	0.057
Total number of individuals species		534	1569	225 6
Shannon diversity index (H)= $-\Sigma\ p_i \ln p_i$		1.555	2.555	2.257
Simpson diversity index (D)= $1/\ \Sigma\ p_i^2$		4.112	10.989	7.788

In= Natural logarithm

Therefore, land use change from natural to oil drilling, without proper management, aggravates reduction in soil fertility which render the soil unsuitable for agricultural productivity, consequently threatening the livelihoods of the surrounding population. There is need for remedial treatment as a strategy to rejuvenate the soils of the Sudd region. Also, there is need to test these plant species for their ability to accelerate hydrocarbons degradation.

Acknowledgements

This study was funded by NORAD through the Sudd project (NORHED Project No. SSD-13/0021) being implemented at University of Juba. The author also acknowledges the support of the Ministry of petroleum and Gas, Sudanese Petroleum Corporation, Petroleum laboratories, for analysis of the soil samples and Prof. Dr. Philip Wani Marchelo–d'Ragga of the University of Juba for reading the manuscript and rendering useful suggestions.

REFERENCES

Adams, R.H., Osorio, F.G. and Cruz, J.Z. 2008. Water repellency in oil contaminated sandy and clayey soils. *International Journal of Environmental Science and Technology,* 5(4), 445-454.

Bakke, T., Klungsøyr, J. and Sanni, S. 2013. Environmental impacts of produced water and drilling waste discharges from the Norwegian offshore petroleum industry. *Marine Environmental Research*, 92: 154-169.

Berger, M. and Schwarzbauer, J. 2016. Historical Deposition of Riverine Contamination on Terrestrial Floodplains as Revealed by Organic Indicators from an Industrial Point Source. *Water, Air, and Soil Pollution*, 227(1): 20.

Boutin, C. and Carpenter, D.J. 2017. Assessment of wetland/ upland vegetation communities and evaluation of soil-plant contamination by polycyclic aromatic hydrocarbons and trace metals in regions near oil sands mining in Alberta. *Science of The Total Environment*, 576: 829-839.

Brady, N.C. and Weil, R.R. 1999. The Nature and Properties of Soils., 12 Edition, Prentice Hall, Upper Saddle River, New Jersey.

CCME Canadian Council of Ministers of the Environment 2001. Backgrounder - Petroleum Hydrocarbons in Soil-Canada-Wide Standard 2pp. Available at: http://www. ccme.ca/assets B/pdf / phc_backgrounder_e.pdf. Last visited: March 29, 2016.

De Waal, A. 2014. When Kleptocracy becomes insolvent: Brute causes of the civil war in South Sudan. *African Affairs*, 113(452): 347-369.

Fallet, M. G. 2010. The impact of the Oil industry on local Communities in South Sudan (Master's thesis). Department of International Environment and Development Studies, Noragric. Norwegian University of Life Sciences.

Gelaw, A.M., Singh, B.R. and Lal, R. 2015. Soil quality indices for evaluating smallholder agricultural land uses in northern Ethiopia. *Sustainability*, 7(3): 2322-2337.

Gighi, J.G., Tanee F.B.G. and Albert E, 2012. Post-impact soil assessments of crude oil spill sitein Kpean community in Khana LGA (Ogoni) of Rivers State, *Nigeria Journal of Science*, 2: 109-120.

Kadafa, A.A. 2012. Environmental impacts of oil exploration and exploitation in the Niger Delta of Nigeria. *Global Journal of Science Frontier Research Environment and Earth Science*, 12(3): 19-28.

Liu, G., Niu, J., Guo, W., An, X. and Zhao, L. 2016. Ecological and health risk-based characterization of agricultural soils contaminated with polycyclic aromatic hydrocarbons in the vicinity of a chemical plant in China. *Chemosphere*, 163: 461-470.

Mager, A., Wirkus, L. and Schoepfer, E. 2016. Impact Assessment of Oil Exploitation in South Sudan using Multi-Temporal Landsat Imagery. *Photogrammetrie-Fernerkundung-Geoinformation*, (4): 211-223.

Morales-Bautista, C. M., Adams, R. H., Hernández-Barajas, J.R., Lobato-García, C.E. and Torres-Torres, J.G. 2016. Characterization of fresh and weathered petroleum for potential impacts to soil fertility. *International Journal of Environmental Science and Technology*, 13(11): 2689-2696.

Nawaz, K., Hussain, K., Majeed, A., Khan, F., Afghan, S. and Ali, K. 2010. Fatality of salt stress to plants:Morphological, physiological and biochemical aspects. *African Journal of Biotechnolog*y, 9:34.

Ofuoku, A.O.U., Emuh, F.N. and Ezeonu, O. 2014. Social impact assessment of crude oil pollution on small scale farmers in oil producing communities of the central agricultural zone of Delta State, Nigeria. *Asian Journal of Agriculture and Rural Development*, 4(3): 233.

Okalebo, J.R., Gathua, K.W. and Woomer, P.L. 2002. Laboratory Methods of Soil and Plant Analysis: A Working Mannual. TSBF-KARI, SSEA, SACRED Africa, Nairobi, 128p.

Omodanisi, E.O., Salami, A.T. and Oke, S.O. 2011. The effect of oil pipeline vandalization on the Mangrove Vegetation: A case study. *Int. J. Ecol. Dev*., 19: S11.

Osuji, L.C., Adesiyan, S.O. and Obute, G.C. 2004. Post□Impact Assessment of Oil Pollution in Agbada West Plain of Niger Delta, Nigeria: Field Reconnaissance and Total Extractable Hydrocarbon Content. *Chemistry and Biodiversity*, 1(10): 1569-1578

Pal, S., Banat, F., Almansoori, A. and Abu Haija, M. 2016. Review of technologies for biotreatment of refinery wastewaters: progress, challenges and future opportunities. *Environmental Technology Reviews*, 5 (1): 12-38.

Parida, A.K. and Das, A.B. 2005. Salt tolerance and salinity effects on plants: A review. *Ecotoxicology and environmental safety*, 60 (3): 324-349.

Patey Luka A. 2010. Crude days ahead? Oil and the resource curse in Sudan. *African Affairs*, 109 (437): 617-639.

Pragst, F., Stieglitz, K., Runge, H., Runow, K.D., Quig, D., Osborne, R. and Ariki, J. 2017. High concentrations of lead and barium in hair of the rural population caused by water pollution in the Thar Jath oilfields in South Sudan. *Forensic Science International*, 274: 99-106.

Ramsar Convention Secretariat, 2010. The Ramsar Strategic Plan 2009-2015: Goals, strategies and expectations for the Ramsar Convention's implementation for the period 2009 to 2015. Ramser handbooks for the wise use of wetlands 4th edition, vol. 21. Ramsar Convention Secretariat, Gland Switzerland.

Rivas, G., Cordova, J., Granadillo, F., Marzin, R., Solari, B. and Zacarias, L. 2014. "Hydrocarbon composition" U.S. Patent No. 8,815,765. Washington, DC: U.S. Patent and Trademark Office.

Rueskamp, H., Ariki, H., Stieglitz, K. and Treskatis, C. 2014. Effect of oil exploration and production of salinity in Oil fields, Southern Sudan. Zbl. Geol. Paläont. Teil I, Jg. Heft 1: 95–115.

Sanginga, N. and Woomer, P.L. (Eds.). 2009. Integrated soil fertility management in Africa: principles, practices, and developmental process. CIAT.

Shapiro, K., Khanna, S. and Ustin, S.L. 2016. Vegetation Impact and Recovery from Oil-Induced Stress on Three Ecologically Distinct Wetland Sites in the Gulf of Mexico. *Journal of MarineScience and Engineering*, 4(2): 33.

Shirdam, R., Zand, A.D., Bidhendi, G.N. and Mehrdadi, N. 2008. Phytoremediation of hydrocarbon-contaminated soils with emphasis on the effect of petroleum hydrocarbons on the growth of plant species, *Phytoprotection*, 89: 21–29.

Shukry, W.M., Al-Hawas, G.H.S., Al-Moaikal, R.M.S. and El-Bendary, M.A. 2013. Effect of petroleum crude oil on mineral nutrient elements, soil properties and bacterial biomass of the rhizosphere of jojoba. *British Journal of Environment and Climate Change*, 3(1): 103.

Sosnowski, A., Ghoneim, E., Burke, J.J., Hines, E. and Halls, J. 2016. Remote regions, remote data: A spatial investigation of precipitation, dynamic land covers, and conflict in the Sudd wetland of South Sudan. *Applied Geography*, 69, 51-64.

Tutdel, I.Y. 2010. Falling between the Cracks? Prospects for Environmental Litigation Arising from Oil Production in Southern Sudan. The South Africa. Institute of Inter. Affairs. occasional paper number 61.

Umeh, A.C., Duan, L., Naidu, R. and Semple, K.T. 2017. Residual hydrophobic organic contaminants in soil: Are they a barrier to risk-based approaches for managing contaminated land? *Environment International*, 98; 18-34.

Vogelmann, E.S., Reichert, J.M., Prevedello, J., Awe, G.O. and Mataix-Solera, J. 2013. Can occurrence of soil hydrophobicity promote the increase of aggregates stability? *Catena*, 110:24-31.

Wang, J., Zhang, X., Ling, W., Liu, R., Liu, J., Kang, F. and Gao, Y. 2017. Contamination and health risk assessment of PAHs in soils and crops in industrial areas of the Yangtze River Delta region, China. *Chemosphere*, 168: 976-987.

Wang, Y., Feng, J., Lin, Q., Lyu, X., Wang, X. and Wang, G. 2013. Effects of crude oil contamination on soil physical and chemical properties in Momoge wetland of China. *Chinese Geographical Science*, 23(6): 708-715.

****