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IMPACT OF PETROLEUM CONTAMINATION ON SOIL AND PASTORAL VEGETATION IN SOUTH SUDAN RANGE-LANDS: A CASE STUDY OF PALOUGE OIL FIELD AS A STEP TOWARD NATURAL REHABITALIZATION

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ABSTRACT: Petroleum contamination in oil-producing regions of South Sudan, especially inside and surrounding Palouge oil field, has resulted in severe degradation of natural range lands represented by soil and vegetation. This study traces the magnitude of degradation in soil physical and chemical properties, beside, identifying native range species and their resilience to petroleum contamination. Commonly, petroleum contamination has been shown to significantly alter soil chemical and physical properties in oil-producing regions of South Sudan. These alterations are represented by a decrease in pH value, reflecting an oxidation to hydrocarbon, an elevation in electrical conductivity, indicating an increased salinity, an increase in total carbon (%) coupled with a decrease in total nitrogen (%), which results in an increase in C: N ratio. Also, bulk density was increased because of compaction and loss of porosity. These alterations resulted in a significant reduction of soil water-holding capacity. The overall result of pH value decline and the increase in salinity and bulk density is inappropriate conditions for native and /or cultivated plant species. At the Palouge site, *Sorghum bicolor* and *Sorghum vulgare* showed the highest percentage cover in uncontaminated and contaminated plots (21.2 and 20.6% *vs.* 17.3 and 17.6% for the first and the second species in uncontaminated and contaminated plots, respectively). Also, the only graminous species that showed significant reduction in percentage cover with contamination were *Hyparrhenia rufa*, *Zea mays*, and *Festuca rubra*. Frequency (%) of graminous species was generally significantly reduced in contaminated plots, except for *Oryza longistaminate* and *Sorghum vulgare*. The forbs species' percentage cover was significantly favored with contamination for *Gossypium barbadense* and *Medicago sativa* (6.1 and 15.2% under contamination *vs.* 2.9 and 6.9% under uncontaminated conditions for the first and the second species, respectively). Plant cover was dominated by graminous species (90.2 *vs.* 73.9 for uncontaminated and contaminated plots, respectively). Native pastoral species showed variable levels of resilience with elite species such as *Tihonia diversifolia*, Sorghum *sp*, *Medicago sativa*, and *Gossypium barbadense*, proposing well qualifications as well-qualified phytoremediators. Proposed plans for soil restoration, environmental monitoring, and phytoremediation in oil-contaminated ranges of South Sudan are essential for long-term pasture rehabilitation.

Key words: South Sudan, Petroleum contamination, native pastoral species, resilience to petroleum contamination.

INTRODUCTION

Among the most significant environmental issues in regions of oil exploration and production is petroleum contamination. Among the richest oil reserves in sub-Saharan Africa, South Sudan has experienced expanding petroleum contamination, especially in the Palouge oil field. Many studies have illustrated the impact of petroleum spills on the environment, especially agriculture and biodiversity (UNEP, 2011; Ayuba *et al.*, 2019; and Okello *et al.*, 2021).

Soil physical and chemical properties are altered by complex organic compounds introduced by crude oil. Such compounds can disrupt soil structure, plant development, and

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ecosystem structure (Abdulrahman *et al*., 2018; Babalola *et al*., 2019). Studies in Niger Delta and Mexico Gulf, had postulated the impact of petroleum contamination on soil characters including reduced fertility and bad plant development (Ogbuehi *et al*., 2019, and Nduka *et al*., 2010).

Soil pH indicates nutrient availability and microbial activity. The value of soil pH is mostly reduced with petroleum contamination, because of its acidic nature. The major result of lower nutrient availability is reduced plant growth and lower yield (Nwoye *et al*., 2017). Soil microbial communities and soil structure are maintained by organic carbon content. This role is disturbed in case of contamination. Hydrocarbons in petroleum are complex organic molecules. Those molecules can reduce the organic matter decomposing microbes, ending with soil carbon depletion (Pang *et al*., 2018).

Nitrogen availability can be reduced by the effect of petroleum hydrocarbons under contamination. That affects reduce plant growth and microbial activity. The most affected microbes are nitrogen-fixing bacteria. That former bacterium is responsible for replenishing the nitrogen level in the soil (Kang *et al*., 2020, and Thavamani *et al*., 2017). This alteration to the nitrogen level can affect the types of plant species in contaminated sites, depending on the nitrogen level required for growth. The overall result of that is limited plant productivity and loss of biodiversity (Kang *et al*., 2020).

In South Sudan, regions like Palouge have experienced severe environmental degradation because of petroleum activities. Petroleum contamination disturbed soil texture, causing an increase in soil compaction and a reduction in soil porosity. The consequence of that is poor water infiltration and drainage, leading to waterlogging. Bad physical soil properties, along with chemical degradation, allow for a selective nature of soil to plant species (Mudu and Ajak, 2019).

By nature, many native plant species in South Sudan exhibit tolerance to conditions correlated with soil contamination with petroleum. Example species are *Sorghum arundinaceum*, *Oryza longistaminate*, and *Tithonia diversifolia*. Such species are proposed as potential phytoremediators, since they tolerate and degrade certain contaminants (Opolot and Wani, 2019).

Depending on the sever level of petroleum contamination in South Sudan, it’s essential to trace soil characteristics and plant cover alterations as a means for using plant species for phytoremediators (Juma *et al*., 2020).

The main objectives of this recent study are to reach a comprehensive understanding of the challenges posed by petroleum contamination in South Sudan soil and plant cover, with special focus on Palouge region.

MATERIALS AND METHODS

Among the objectives of this recent study was to identify plant species in the Palouge region, South Sudan, especially Palouge power plant DPOC (10.45057, 32.47559), Paloch (10.46987, 32.47922), and Zero village (10.50853, 32.50627), which represent plant species that grow on unrefined hydrocarbon-contaminated soils. In the meantime, vegetation on contaminated soil was compared to that on adjacent uncontaminated soil. The effect of contamination on soil, cover bare ground percentage, litter, and bare ground was also examined.

Study site

In September 2022, vegetation and soils were sampled at 12 sites in each of Palouge power plant DPOC (10.45057, 32.47559), *Paloch* (10.46987, 32.47922), and Zero Village (10.50853, 32.50627). The common climate is tropical, characterized by a rainy season from May to October. Mean annual precipitation is (750-1.000 mm) and mean annual temperature is (30- 37 °C). Soil is alluvial in origin, mainly clay (heavy clay). Habitats covering the sampled areas were wetlands in common. Because of differences among sites in the period of exposure to contamination with unrefined petroleum hydrocarbons, the exact age of the spill was not always known; hence, contamination age was given categories, i.e., 20-30, or 30-40 years. None of the contaminated plots had been grazed by cattle. The intensity and duration of grazing at the uncontaminated sites were not known.

Soil and vegetation sampling

At each of the studied sites, two 200 m^2 plots were established, one on contaminated and the other on uncontaminated soil. The minimum distance between the two plots was 20 m. The level of contamination was visually linked to the nature of the soil edge and vegetation disturbance. Four randomly positioned 5×5 m sub-plots, separated by a minimum of 5 m, were established within both the contaminated and uncontaminated plots. Soil samples were collected from the upper 0 to 15cm depth with a hand shovel from the center of each subplot, mixed in a plastic bucket. The soil samples were stored, two days of collection in a refrigerator at 5°C. Soil samples were dried in the open air and then passed through a 5mm sieve before analysis, which occurred within three months of collection. The four soil samples from each plot were analyzed for carbon percentage, nitrogen percentage (Rayan *et.al*, 2001). Petroleum hydrocarbons in a one-gram sample from each subplot were extracted by Soxhlet apparatus using acetone as solvent (Suhwab *et al*., 1999). The remaining soil from the four subplots was mixed to form composite samples. Two replicates of that composite were analyzed for texture (Gee and Bauder, 1986), pH (Mclean, 1982), and electrical conductivity (EC) using a 1:1 soil solution ratio (Khodades, 1982).

Absolute ground cover of plant species less than one meter in height, canopy cover of plant species taller than one meter, and ground cover of litter and bare soil were visually estimated in randomly locked 1×1 meter quadrates per subplot (20 quadrates/plot) using Braun – Blanquet cover classes (Mueller-Dombosis and Ellenberg, 1974). Barbour et al. (1987) chose a 1 × 1 meter quadrate size to minimize the perimeter-to-area ratio while allowing easy observation of the entire quadrate.

The percentage cover and frequency of each plant species were identified and recorded. Dominant plant species were classified into graminoids (grasses) and forbs (non-grass herbaceous plants).

Percentage cover: the percentage of ground area covered by each plant species within the quadrate.

Frequency (%): the percentage of quadrates in which each species was present.

Botanical surveys (Opolot, 2019) for native plant species were used to list plant species in the Paloch area. These species were assessed regarding tolerance to contamination and potential for phytoremediation.

Data was compiled in comparative tables to clarify the difference between uncontaminated and contaminated soil conditions.

Data analysis

Student's t–test for soil characteristics, and percentage cover between uncontaminated and contaminated subplots were performed. Also, t–test between contaminated and uncontaminated plots was performed for percentage cover and frequency of principal species (Snedcor and Cochran, 1967).

RESULTS AND DISCUSSION

Table 1 illustrates the sampling site, habitat, soil subgroup, type of contamination, and duration of contamination (years). Data illustrated that the study area was between flat and wetland native prairies, while soil sub-groups were mostly loamy clay (Palouge Power Plant, Poloch, and Zero Village). While Sandy loam type represented half the samples in Palouge Power Plant, and only a quarter sampled plots in the Zero Village site. Heavy clay soil existed only at the Paloch site, representing half the tested samples. The contamination type was mostly a result of buried flare pits, besides surface spills in Palouge Power Plant and Paloch sites. The duration of contamination in the tested sites was a minimum of 25 years up to a maximum of 35 years.

Table 1: Sampling site, habitat, soil-sub group, type of contamination, duration of contamination.

Site	Sample	Habitate	Soil sub-group	Type of contamination	Duration of contamination
Palouge Power Plant Dpoc	1	Native prairie flat	Loamy clay	Surface spill	20-30
	2	Native prairie flat	Loamy clay	Surface spill	20-30
	3	Native prairie flat	Sandy loam	Buried flare pit	20-30
	4	Native prairie wetland	Sandy loam	Buried flare pit	20-30
Paloch	1	Native prairie wetland	Heavy clay	Surface spill	20-30
	2	Native prairie flat	Heavy clay	Surface spill	20-30
	3	Native prairie flat	Loamy clay	Buried flare pit	30-40
	4	Native prairie wetland	Loamy clay	Buried flare pit	30-40
Zero village	1	Native prairie wetland	Loamy clay	Buried flare pit	30-40
	2	Native prairie wetland	Loamy clay	Buried flare pit	30-40
	3	Native prairie wetland	Loamy clay	Buried flare pit	30-40
	4	Native prairie wetland	Sandy loam	Buried flare pit	30-40

Soil characters

Data in Table 2 summarizes soil chemical and physical properties of 10-15cm depth samples at the uncontaminated (u) and contaminated (c) plots sampled in the study area of South Sudan. Soil pH values were significantly reduced in contaminated plots relative to adjacent uncontaminated plots. This might be due to hydrocarbons oxidation (Ogbuenhi *et al.*, 2019 and UNEP, 2011), which might be explained as hydrocarbons breakdown. The values of electric conductivity indicated that contamination with hydrocarbons had led to an elevation in soil salinity, indicated by a significantly higher value of electrical conductivity. This elevation in salinity might be due to an accumulation of hydrocarbon residues (UNEP, 2011; Adebayo *et al*., 2018). Also, soil total carbon (%) showed a significant increase in contaminated plots of each of the three studied sites. This might be due to the role of organic petroleum constituents (Nduka *et al.*, 2010). Meanwhile, total nitrogen (%) was decreased in contaminated plots. This decrease was significant in ten out of the twelve samples studied. That reduction in total nitrogen might be due to nitrogen depletion due to microbial suppression (Ayuba *et al.,* 2019). Alterations in total carbon (%) and total nitrogen (%) resulted in an elevation of significant magnitude in most studied samples in carbon/nitrogen ratio (C: N ratio). Contaminated soil samples of the three studied sites showed hydrocarbon content ranged between 422 and 644 (mg/g), indicating an accumulation of hydrocarbons. Bulk density (g/cm^3) was significantly increased with hydrocarbon contamination. This might be due to soil compaction from reduced porosity and loss of structure (Ayuba *et al*., 2019). Water-holding capacity (%) was significantly reduced by more than 50% due to hydrocarbon contamination. This might be due to pore blockage by oil (Ogbuehi *et al*., 2019).

Commonly, petroleum contamination has been shown to significantly alter soil chemical and physical properties in oil-producing regions of South Sudan. These alterations were represented by a decrease in pH value, reflecting an oxidation to hydrocarbon, an elevation in electrical conductivity indicating an increased salinity, an increase in total carbon (%) coupled with a decrease in total nitrogen (%), which results in an increase in C: N ratio. Also, bulk density was increased because of compaction and loss of porosity. The latter resulted in a significant reduction of soil water-holding capacity. The overall result of pH value decline and the increase in salinity and bulk density is inappropriate conditions for native and /or cultivated plant species. A consequence of such conditions is the reduction in microbial biomass, which might affect soil health and reduce natural remediation activities (Odokuma and Dickson, 2003).

Table (2a): Soil chemical and physical properties for 10-15 (cm) depth samples at the uncontaminated and contaminated plots sampled in South Sudan.

Site	Sample	pH		Electrical Conductivity (us/cm)		Total Carbon (%)		Total Nitrogen (%)	
		u	c	u	c	u	c	u	c
Palouge Power Plant Dpoc	1	7.3	6.2*	230	980*	18.2	21.6*	0.07	0.03*
	2	7.5	6.1*	260	870*	19.2	22.1*	0.06	0.03*
	3	7.6	6.4*	250	920*	18.7	22.2*	0.08	0.04*
	4	8.2	6.8*	270	1050*	19.1	21.9*	0.09	0.05*
Paloch	1	7.4	5.9*	310	850*	17.7	20.6*	0.10	0.08
	2	7.9	6.3*	330	820*	18.4	21.2*	0.07	0.04*
	3	8.2	6.1*	320	930*	19.6	22.3*	0.08	0.03*
	4	7.7	6.4*	340	870*	17.8	20.9*	0.06	0.04
Zero Village	1	8.2	6.8*	280	840*	17.6	20.1*	0.07	0.03*
	2	7.5	6.3*	310	960*	17.2	19.4*	0.09	0.05*
	3	7.4	6.4*	290	1100*	16.9	19.4*	0.11	0.06*
	4	7.7	6.3*	320	1200*	17.6	20.8*	0.12	0.07*

Table (2b): Soil chemical and physical properties for 10-15 (cm) depth samples at the uncontaminated and contaminated plots sampled in South Sudan.

Site	Sample	C: N Ratio		Total petroleum Hydrocarbon (mg/g)	Bulk density (g/cm^3)		Water holding capacity (%)	
		u	c		u	c	u	c
Palouge Power Plant Dpoc	1	12.2	26.3*	544	1.28	1.73*	36*	14
	2	12.3	23.4*	506	1.26	1.67*	34*	12
	3	14.2	39.2*	480	1.36	1.66*	41*	21
	4	17.3	21.2*	519	1.37	1.74*	43*	22
Paloch	1	17.5	25.1*	612	1.32	1.68*	37*	15
	2	19.7	23.4*	532	1.34	1.64*	43*	23
	3	17.2	19.70	631	1.28	1.72*	42*	21
	4	19.40	21.1	644	1.26	1.62*	35*	16
Zero Village	1	15.60	26.50*	384	1.42	1.68*	37*	14
	2	13.40	24.2*	425	1.35	1.74*	40*	22
	3	20.3	39.4*	409	1.34	1.76*	48*	24
	4	19.7	36.2*	516	1.40	1.80*	46*	23

u: uncontaminated soil plot.
c: contaminated soil plot.
*: significantly higher than the adjacent plot at the 0.05 level using the t-test.

Vegetation cover and frequency in uncontaminated vs. contaminated plots

Table 3 shows the frequency and percentage cover of plant species found on uncontaminated (u) and contaminated (c) plots based on 20 quadrates/plot at the Palouge power plant site. Data representing percentage cover and frequency showed that gramineous species represented the majority of plant cover relative to forbs (77.5 *vs*. 21.7%, and 68.9 *vs*. 26.7% in uncontaminated and contaminated plots, respectively). The highest cover percentages were those of *Sorghum sp*. in uncontaminated (18.4 and 19.3% for *S. bicolor* and *S. vulgure*, respectively) and contaminated plots (16.9 and 17.4% for *S. bicolor* and *S. vulgare*, respectively). Also, the most under-frequented species were *S. arundinaceum* (32%) with minor disturbance under contamination (26%), *Hyparrhenia rufa* (37%) and frequency reduction to 32% with contamination, and *Sorghum bicolor* with frequency of 32%. The percentage cover of all plant covers graminous species showed an insignificant change with contamination, except for *Hyparrheniarufa*. Meanwhile, the frequency of species in both uncontaminated and contaminated plots had significantly reduced with contamination, except for *Sorghum arundinaceum*, *Oryza longistanminate*, *Hyparrhenia rufa*, and *Sorghum bicolor*. Forbs' species showed variable cover (%) and frequency in uncontaminated and contaminated plots. *Medicago sativa* showed the highest percentage cover among forb species (9.4 *vs*. 16.7% for uncontaminated and contaminated plots, respectively). Whereas, *Vicia faba* showed the least percentage cover (2.4 *vs*. 0.8 in uncontaminated and contaminated plots, respectively). All forb species showed a frequency (%) reduction in contaminated plots. Paradoxanly, *Gossypium barbadense* and *Medicago sativa* showed significantly higher percentage cover in contaminated plots (6.8 and 16.7% vs. 4.7 and 9.4% for the former and the latter, respectively).

Table 3: Percentage cover and frequency of plant species found on uncontaminated (u) and contaminated (c) plots based on 20 quadrates/plots at Palouge power plant site.

Plant species	Cover %		Frequency %	
	u	c	u	c
Sorghum arundinaceum	9.6	8.4	32	26
Oryza longistaminate	5.9	4.1	27	21
Tithoni adiversifolia	8.6	7.2	29	19
Hyparrhenia rufa	8.2*	5.4	37	32
Sorghum bicolor	18.4	16.9	32	26
Sorghum vulgare	19.3	17.4	29	18
Zea mays	5.1	4.1	28	21
Cynodon dactylon	4.9	3.8	16	11
Festuca rubra	2.6	1.6	14	6
Total graminoids	**77.5**	**68.9**		
Gossypium barbadense	4.7	6.8*	42	21
Glycine max	5.2*	2.4	19	11
Medicago sativa	9.4	16.7*	43	29
Vicia faba	2.4*	0.8	21	12
Total forbs	**21.7**	**26.7***		

u: uncontaminated soil plot.
c: contaminated soil plot.
*: significantly higher than the adjacent plot at the 0.05 level using the t-test.

At the Paloch site (Table 4), *Sorghum bicolor* and *Sorghum vulgare* showed the highest percentage cover in uncontaminated and contaminated plots (21.2 and 20.6% *vs.* 17.3 and 17.6% for the first and the second species in uncontaminated and contaminated plots, respectively). Also, the only graminous species that showed significant reduction in percentage cover with contamination were *Hyparrhenia rufa*, *Zea mays*, and *Festuca rubra*. Frequency (%) of graminous species was generally significantly reduced in contaminated plots, except for *Oryza longistaminate* and *Sorghum vulgare*. Forbs's species percentage cover was significantly favored with contamination for *Gossypium barbadense* and *Medicago sativa* (6.1 and 15.2% under contamination *vs.* 2.9 and 6.9% under uncontaminated conditions for the first and the second species, respectively). Plant cover was dominated by graminous species (90.2 *vs.* 73.9 for uncontaminated and contaminated plots, respectively).

Table 4: Percentage cover and frequency of plant species found on uncontaminated (u) and contaminated (c) plots based on 20 quadrates/plots on the Paloch site.

Plant species	**Cover %**		**Frequency %**	
	u	**c**	**U**	**c**
Sorghum arundinaceum	8.4	7.2	43*	30
Oryza longistaminate	6.2	4.3	31	26
Tithonia diversifolia	11.1	8.4	42*	31
Hyparrhenia rufa	7.3*	5.7	46*	34
Sorghum bicolor	21.2	17.3	51*	32
Sorghum vulgare	20.6	17.6	31	29
Zea mays	6.4*	4.9	24*	16
Cynodon dactylon	6.2	7.3	16*	8
Festuca rubra	2.8*	0.9	19*	9
Total graminoids	**90.2**	**73.6**		
Gossypium barbadense	2.9	6.1*	31*	18
Glycine max	3.2*	1.6	18*	9
Medicago sativa	6.9	15.2*	44*	28
Vicia faba	0.9	0.7	19*	7
Total forbs	**13.9**	**23.6**		

u: uncontaminated soil plot.
c: contaminated soil plot.
*: significantly higher than the adjacent plot at the 0.05 level using the t-test.

In Zero Village Site (Table 5), most graminous species showed percentage cover significantly similar for uncontaminated and contaminated plots, except for *Zea mays* and *Festuca rubra*. Although the frequency percentage was significantly decreased in contaminated plots, except for *Cynodon dactylon*. The highest cover (%) was presented by *S. bicolor* and *S. vulgare* under any of the uncontaminated or contaminated plots (14.6 and 21.4% *vs.* 18.2 and 18.9% for the first and the second species, respectively). Forbs' species cover (%) was significantly varied between uncontaminated and contaminated plots. Significantly higher cover (%) in contaminated plots was presented by each of *Gossypium barbadense* (6.7 *vs.* 4.2% for uncontaminated plots) and *Medicago sativa* (16.2 *vs.* 8.2% for uncontaminated and contaminated plots). The frequency (%) of all species was significantly reduced in contaminated plots.

Table 5: Frequency and percentage cover of plant species found on uncontaminated (u) and contaminated (c) plots based on 20 quadrates/plots on the zero-village site.

Plant species	Cover %		Frequency %	
	u	c	U	c
Sorghum arundinaceum	9.2	8.6	28*	22
Oryza longistaminate	6.3	4.2	24*	19
Tithonia diversifolia	9.4	7.8	27*	17
Hyparrhenia rufa	5.9	5.1	37*	28
Sorghum bicolor	19.6	18.2	31*	26
Sorghum vulgare	21.4	18.9	27*	19
Zea mays	4.9*	5.4	21*	16
Cynodon dactylon	5.4	5.2	12	11
Festuca rubra	2.4*	1.2	16*	9
Total graminoids	**84.5**	**74.6**		
Gossypium barbadense	4.2	6.7*	31*	18
Glycine max	4.9*	2.1	14*	6
Medicago sativa	8.2	16.2*	37*	27
Vicia faba	2.2*	0.9	18*	11
Total forbs	**19.5**	**25.9**		

u: uncontaminated soil plot.
c: contaminated soil plot.
*: significantly higher than the adjacent plot at the 0.05 level using the t-test.

Overall, the three studied sites of South Sudan (Table 6), cover (%) of *S. arundinaceum*, *Hyparrhina rufa*, *S. bicolor*, *S. vulgare*, and *Cynodon dactylon* had insignificantly changed between uncontaminated and contaminated plots. Meanwhile, *Oryza longistaminate*, *Tithonia diversifolia*, *Zea mays*, and *Festucarubra* presented significantly lower cover (%) in contaminated plots. All graminous species showed significantly similar frequency (%) in uncontaminated and contaminated plots, except for *S. vulgare*, *Cynodon dactylon*, and *Festuca rubra*, who's showed significantly lower frequency (%). Graminoid species represented 84.0% of plant cover in uncontaminated plots *vs.* 73.7% in contaminated plots. Among forb species, *Medicage sativa* enjoyed the highest cover (%) (7.3 *vs.* 14.4% for uncontaminated and contaminated plots, respectively). *Gossypium barbadense* showed a similar pattern with higher cover % in contaminated plots (5.3 *vs.* 3.0 % for contaminated and uncontaminated plots, respectively). *Medicago sativa* presented the least significant reduction in frequency % among forb species (34 *vs.* 28 (%) for uncontaminated and contaminated plots).

Table 6: Percentage cover and frequency of plant species found on uncontaminated (u) and contaminated (c) plots based on 20 quadrates/plots as an average over the three studied sites.

Plant species	Cover %		Frequency %	
	U	c	u	c
Sorghum arundinaceum	7.4	6.8	0.31	0.26
Oryza longistaminate	5.4*	3.7	0.24	0.22
Tithonia diversifolia	10.2*	8.9	0.31	0.32
Hyparrhenia rufa	6.7	5.9	0.32	0.30
Sorghum bicolor	20.8	18.9	0.34	0.30
Sorghum vulgare	20.3	17.4	0.28*	0.22
Zea mays	5.5*	4.0	0.18	0.14
Cynodon dactylon	5.1	5.7	0.12*	0.06
Festuca rubra	2.6	0.4	0.18*	0.01
Total graminoids	**84.0**	**73.7**		
Gossypium barbadense	3.0	5.3	0.27*	0.16
Glycine max	3.9*	1.1	0.12*	0.02
Medicago sativa	7.3	14.4*	0.34*	0.28
Vicia faba	1.2*	0.8	0.12*	0.08
Total forbs	**15.4**	**21.6***		

u: uncontaminated soil plot.
c: contaminated soil plot.
*: significantly higher than the adjacent plot at the 0.05 level using the t-test.

Table 7) showed vegetation percentage, litter cover, and bare ground percentage in the three studied sites. Data showed that vegetation represented the highest percentage of test quadrates in uncontaminated plots (50.8, 51.75, and 65.23 % for Palouge Power Plant, Palouge, and Zero Village, respectively). Meanwhile, bare ground represented the highest percentage of test quadrates in contaminated plots. (46.24, 54.67, and 52.40 % for Palouge Power Plant, Paloch, and Zero Village, respectively). Also, contamination reduced previous growth residues (litter cover) to about one quarter that existed in uncontaminated plots (9.82 *vs.* 38.33, 11.99 *vs.* 40.09, and 7.77 *vs.* 29.61 % for contaminated and uncontaminated plots of the three studied sites, respectively).

Plant species that represented responsible component of plant cover in Palouge sites, had marked as a tolerant to hydrocarbon contaminated soil (*Sorghum sp.* (Opolot and Wani, 2019)) or an effective in phytoremediation (*Oryza longistaminata* (Opolot and Wani 2019)) or a high biomass producer used in remediation (*Hyparrhenia rufa* (Opolot and Wani, 2019)) or fast growing, aid in soil remediation (*Tithonia diversifolia* (Opolot and Wani, 2019)) or capable of hydrocarbon uptake (*Gossypium barbadense* (Opolot and Wani, 2019)). In affected sites like South Sudan toxic effects of oil contaminants affect germination rate, nutrient uptake, and overall plant resilience, resulting in different components of plant cover and frequency of species, depending on the phytoremediation potential of species (Opolot and Wani, 2019).

Oil contamination in the range lands of South Sudan, especially the Palouge region, has caused drastic soil degradation. The major symptoms of those degradations are increased salinity, low level of fertility, accumulation of hydrocarbons, and loss of ground-cover density. These marks of deterioration lower the range lands sustainability for growing crops, grazing, wildlife, and ecosystem services. This situation highlights the need for urgent phytoremediation and sustainable managerial pathways, such as breeding phytoremediation and resilient plant species.

Table 7: Vegetation percentage, litter cover, and base ground on uncontaminated and contaminated plots at three field sites in South Sudan.

Cover %							
Site	**Plot**	**Vegetation**		**Litter cover**		**Base ground**	
		u	**c**	**u**	**c**	**u**	**c**
Palouge Power Plant	1	51.51	44.26	34.29	7.18	14.20	48.56
	2	50.89	43.48	34.77	11.26	14.43	45.26
	3	48.63	40.72	41.09	7.36	10.28	51.92
	4	52.18	47.31	43.17	13.48	4.65	39.21
	Mean	**50.80***	**43.94**	**38.33***	**9.82**	**10.89**	**46.24***
Paloch	1	56.21	34.60	36.21	18.05	7.58	47.35
	2	49.43	32.40	37.92	5.94	12.65	61.66
	3	46.98	30.17	40.67	12.09	12.35	57.74
	4	54.36	36.18	45.56	11.89	0.08	51.93
	Mean	**51.75***	**33.34**	**40.09***	**11.99**	**8.17**	**54.67***
Zero Village	1	72.11	43.21	26.38	12.39	1.51	44.40
	2	68.26	39.68	24.12	6.63	7.62	53.69
	3	56.18	36.18	39.74	0.78	4.08	63.04
	4	64.36	40.26	28.21	11.27	7.43	48.47
	Mean	**65.23***	**39.83**	**29.61***	**7.77**	**5.16**	**52.40***

u: uncontaminated soil plot.
c: contaminated soil plot.
*: significantly higher than the adjacent plot at the 0.05 level using the t-test.

Conclusion

Petroleum contamination in South Sudan oil fields, particularly in Palouge, had a significant impact on soil physical and chemical characteristics. Native pastoral species showed variable levels of resilience with elite species such as *Tihonia diversifolia*, Sorghum *sp*, *Medicago sativa*, and *Gossypium barbadense*, proposing well qualifications as well-qualified phytoremediators. Proposed plans for soil restoration, environmental monitoring, and phytoremediation in oil-contaminated ranges of South Sudan are essential for long-term pasture rehabilitation.

Future Research needs

Future research on the rehabilitation of the studied range lands of *Palouge* (South Sudan) by petroleum contamination must target phytoremediation using native and new plant species known to have good resilience and biomass superiority, besides the potential to maintain soil physical and biological characteristics.

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تأثير التلوث بالبترول علي التربة و الأنواع الرعوية في جنوب السودان . دراسة حالة بمنطقة حقل بترول " بيلوش" كخطوة نحو اعادة التأهيل الطبيعي للمراعي

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الملخص العربي

التلوث البترولى في المناطق المنتجة للبترول في جنوب السودان خاصة في المناطق الداخلية والمحيطة بحقل بترول "بيلوش" نتج عنها تدهور شديد لاراضي المراعي الطبيعية متمثلاً بكل من التربة والغطاء النباتي. أجريت هذه الدراسة لتتبع مستوي التدهور في صفات التربة الفيزيائية والكيماوية، بالاضافة لتمييز الأنواع الرعوية البرية وقدرتها علي تحمل التلوث بالبترول , وقد ظهر بصفة عامة ان التلوث بالبترول يؤدي الي تدهور معنوي في صفات التربة الكيماوية والطبيعية في مناطق إنتاج البترول بجنوب السودان. وقد تمثل هذا التدهور بتناقص قيم رقم الأس الهيدروجيني بما يعكس اكسدة للهيدروكربونات، بالاضافة الي ذيادة درجة التوصيل الكهربي بما يعبر عن زيادة درجة الملوحة ، كما صاحب هذا التدهور زيادة في نسبة الكربون الكلي بالتربة يصاحبه تناقص فى محتوى التربه من النيتروجين، وقد ادى ذلك الى زياده نسبه الكربون النتروجين . ايضا فقدت زادت قيم الكثافه الظاهريه للتربه بسبب زياده الانضغاط وفقد المساميه . وقد نتج عن السابق نقص معنوى في قدره التربه على الاحتفاظ بالماء . ويعتبر كل من النقص فى درجه الاس الهيدروجيني وزياده مستوى الملوحه والكثافه الظاهريه ظروف غير مناسبه للانواع النباتيه البريه والمنزرعه فى المنطقه.

وقد اظهرت معاينه موقع " بيلوش " ان الانواع *Sorghum vulgare, Sorghum bicolor*,مثلت اعلى نسبه من الغطاء النباتى فى كل من المنطق الملوثه والغير ملوثه (٢١,٢ و ٢٠,٦ % فى مقابل ١٧,٣ و ١٧,٦ % من الغطاء النباتى للنوع الاول والثانى فى المواقع الغير ملوثه والملوثه على الترتيب) ايضا، فان الانواع النباتيه النجيليه التى تناقص نسب وجودهما فى المواقع الملوثه *festuca rubra, Zea mays, hyparrhenia rufa* , وقد تناقص معدل تكرار وجود الانواع النجيليه (%) معنوياً فى المناطق الملوثه فيماعدا الانواع *Sorghum vulgare ,Oryza longstaminate* , نسبه الانواع عرضه الاوراق من القطاع النباتى تزايدت معنويا مع الظروف التلوث وذلك للانواع *Medicago sativa ,Gossypium barbadense* , (٦,١ و ١٥,١ % تحت ظروف التلوث فى مقابل ٢,٩ و٦,٩ % تحت ظروف عدم التلوث النوع الاول والثانى على الترتيب) تغلب على الغطاء النباتى الانواع النجيليه (٩٠,٢ فى مقابل ٧٣,٩ فى المناطق الغير ملوثه والملوثه على الترتيب) . وقد اظهرت انواع الرعويه البريه درجات مختلفه من التحمل مع التفوق لبعض الانواع مثل *Sorghum sp, Tihonia diversifolia ,Gossypium barbadense, Medicago sativa* بما يؤهلها جيدا لتصبح من عناصر المعالجه النباتيه للتلوث , واقتراح الخطط لاستعاده خصائص التربه ، ودراسه التغيرات البيئيه واتمام المعالجه النباتيه للمراعى الملوثه بالبترول فى جنوب السودان ضروريه لاعاده التاهيل طويل الامد للمراعى.