The Impacts Of The Oil Industry Development On The Soil Pollution, A Case Study Fula And Jake Oil Fields In Western Kordofan State, Sudan

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Abstract:
Over the decades, the oil industry's development has had significant impacts on the natural environment, including soil. This study aims to investigate the impact of the development of the oil industry on soil pollution in the Fula and Jake oil fields in West Kordofan, Sudan. To achieve this goal, the study used the results of laboratory tests conducted on soil samples, as well as the observation method, in addition to secondary data and studies related to soil pollution. The results of the study showed the presence of concentrations of hydrocarbons (TPH) with a total of 3044.72 tons of contaminated soil in the Fula field and a total of 15139.72 tons of contaminated soil in the Jake field, exceeding the recommended limit. Concentrations of heavy metals (Cd, Cr, Cu, Fe, Ni, Pb, and Zn) were also observed in soil samples in the Fula and Jake oil fields. These concentrations exceeded what is recommended by the World Health Organization, the Sudanese authorities, and the US Environmental Protection Agency, which indicates a risk to human health if this contaminated soil interacts with groundwater or surface water during the rainy season. The study recommended the necessity of activating government oversight of oil companies and conducting studies to detect any pollution or health risks that threaten the environment and negatively affect the health of animals, plants, and humans.

Keywords: Oil industry, Soil pollution, Hydrocarbons, Heavy metals, Western Kordofan, Sudan.

1.Introduction:

The oil industry poses a major economic and environmental challenge, which is to balance economic development and social welfare for the population on the one hand and preserving the natural environment from the effects of the oil industry on the other. In recent years, there have been increasing calls to completely abandon fossil fuels and move towards green energy to preserve the natural environment and ensure more sustainable economic growth(Kareem, 2016). However, achieving this goal is still out of reach in light of the increasing reliance on oil versus other types of renewable energy such as solar energy, hydropower, and others. Statistics indicate that the world needs an estimated 103 million barrels daily to continue industrial and economic growth (Mekkiyah *et al.*, 2023), which adds more oil waste to the environment and negatively affects the main elements of soil, air, and water.

Soil is one of the most polluted elements of the natural environment. On the other hand, its pollution is also the most dangerous due to its continuous interaction with other natural elements such as water and air, and this is where the danger lies. The FAO Global Symposium on Soil Pollution held in 2018 indicates that soil pollution has a direct impact on food security, and soil pollution facilitates and accelerates other degradation processes and loss of biodiversity(Soil, 2018).

Hydrocarbons and heavy metals are among the most common oil pollutants. Many studies have shown that hydrocarbons and heavy metals affect soil by increasing its density and reducing its values, thus making it unsuitable for agriculture and causing serious damage to the ecosystem. In addition, oil pollution increases soil viscosity, increases the movement of water and food at night, increases the percentage of oxygen in the soil, and affects the percentage of moisture in the soil and its chemical properties(Okafor, 2023).

Heavy metals found in crude oil consist of metals with relatively high density and atomic weight, such as iron, nickel, zinc, copper, and cadmium. Some of these metals are highly toxic and pose a risk to human and animal health, while hydrocarbons are known to consist of complex chemical compounds of carbon and hydrogen atoms that originate in crude oil. The World Health Organization and some national bodies have set certain standards that determine the maximum permissible level for the presence of these pollutants in the soil(Ogunlana, Korode and Ajibade, 2021).

There are standards set by the World Health Organization (WHO) and the US Environmental Protection Agency (EPA) for the maximum permissible level of heavy metals in soil (mg/kg). Cadmium = 0.003. Standard cadmium level = 1 mg/kg; Standard iron level = 0.3 ppm; Copper = 62 mg/kg; Zinc = 290 mg/kg; Chromium = 160 mg/kg; Nickel = 130 mg/kg;

Standard lead level = 45 mg/kg; Nickel = 37 mg/kg(Ahmed *et al.*, 2021). These standards have been adopted by the Sudanese government.

There are some studies indicate that increasing heavy metals and hydrocarbons above the recommended level may require longer time, high financial costs, and large areas to clean the soil, in addition to the type of technology used in treatment. The properties and type of soil in terms of alkalinity and acidity may also play a role(Akpokodje, Juwah and Uguru, 2022),(Akpokodje, Juwah and Uguru, 2022).

The soils in the study area are almost homogeneous from Jake to Fula; like many parts of western Sudan, the dominant soil type is the Qoz soil, a deep, well-drained sandy soil with a red/brown color (due to the presence of ferric oxide), fine texture, and small, uniform grain size. The soil lacks any significant development in the soil profile (endosoil). In addition to the dominant Qoz soil, there are several other types, but they are always confined to one location (see Figure 1). Around the Jake and Fula oil fields, there are about three different soil compositions that extend over small areas (no more than 2 km in length). At km 115 of Jake, the soil changes to clay at the top (about 1.5 m deep) and sandy silt at the bottom; this change appears to be part of the Wadi El Ghala sedimentary deposits, as the waters of this wadi cover a vast area during the flood season(Jalal and Ganawa, 2021).

Soil properties that pertain to land use and soil suitability include, but are not limited to soil erodibility, fertility, and moisture contents. Soil erodibility is a measure of the properties that make up a soil’s capacity to withstand erosion. These include soil structure and grain sizes, soil permeability, soil texture, particle density, organic matter and chemical contents, shear strength and cohesiveness, infiltration capacity and surface roughness and stoniness(Yagoub, Suliman and Adam, 2018).

Since the soil in most areas of the study area is described as fragile and susceptible to degradation, the presence of heavy metals and hydrocarbons due to the oil industry may accelerate the degradation process. This study attempts to reveal the impact of the oil industry on the soil condition in the study area through laboratory tests of soil samples and the extent of their content of heavy metals and hydrocarbons, and whether they are compatible with the standards recommended by the World Health Organization, the government and the US Environmental Protection Agency and do not pose a risk to the soil ecosystem.

2.Materials and Methods:

1.2 Study Aera:

Fula Field: Fula oil field is in the Maglad sedimentary basin in the southern part of Sudan, about 600 km southwest of Khartoum and 50 km south of the city of Fula. The field includes the central oil plant in the central region, which is characterized by a relative elevation of 550 meters above sea level. The central oil plant in Fula was designed with a capacity of 40,000 barrels per day and receives crude oil from 8 oil wells that are collected, in addition to flow lines for 5 heavy oil wells, and flow lines for 4 light oil wells. The facility was commissioned in November 2003(Ministry of Oil and Energy, 2023).

Jake Oil Field: Located within the so-called Maglad Sedimentary Basin, which covers an area of 120,000 square kilometers and extends to the state of South Sudan, Jake Field is about 48 km northwest of the Fula Oil Field, and the area is 510 meters above sea level. The field reached its maximum production in 2020, with Jake's total cumulative oil production reaching 50,883,276 barrels per day, while total gas production reached 53,685,039 standard cubic feet, and total water production reached 88,780,999 standard barrels. Details of the performance of Jake Oil Field wells show that out of 36 available wells, 15 are pumping, 4 are flowing normally, 11 are closed due to problems at the bottom of the well, 2 are low-potential wells, and 4 are no-potential wells(Ali, Murshed and Papyrakis, 2023)**.**

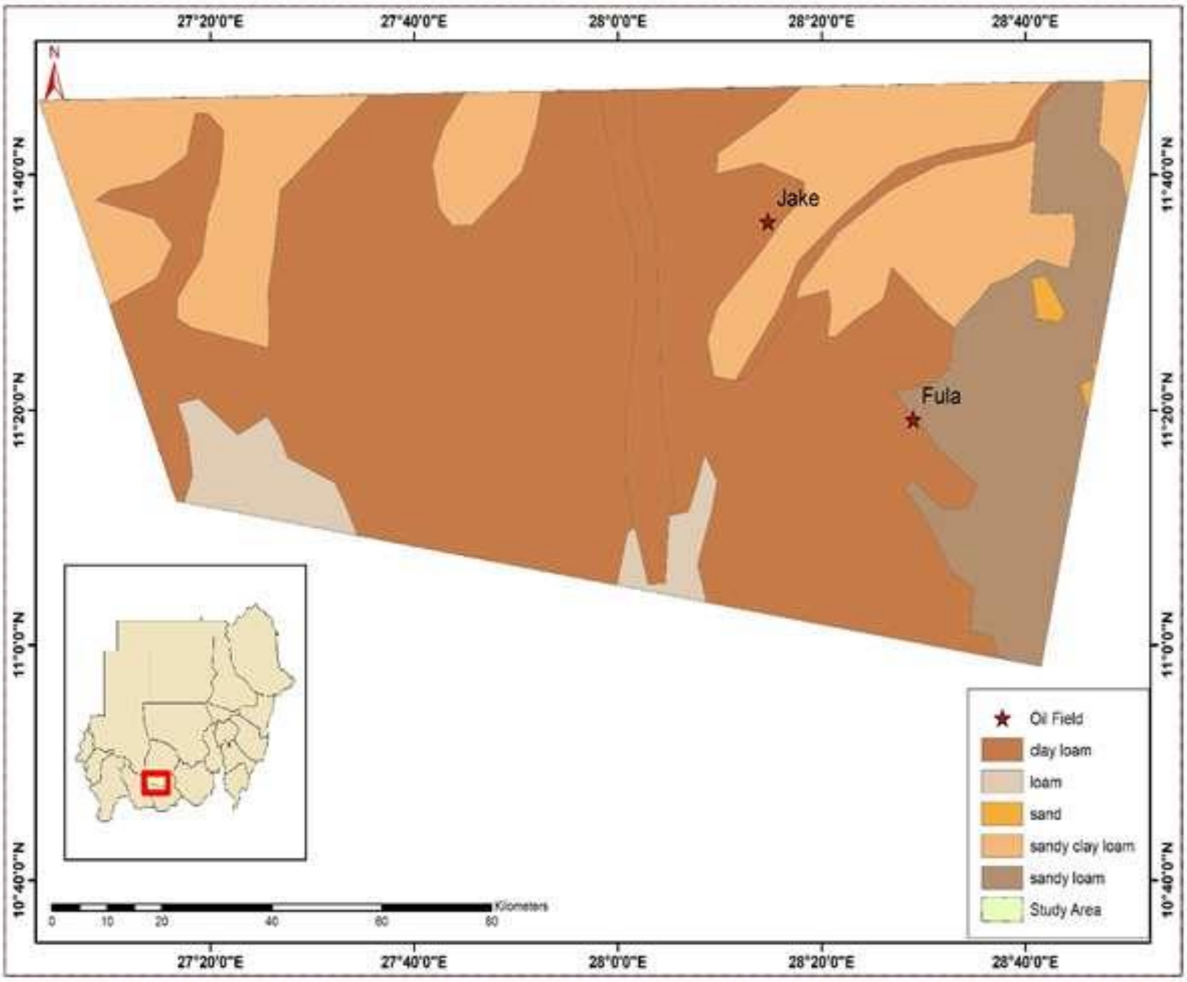
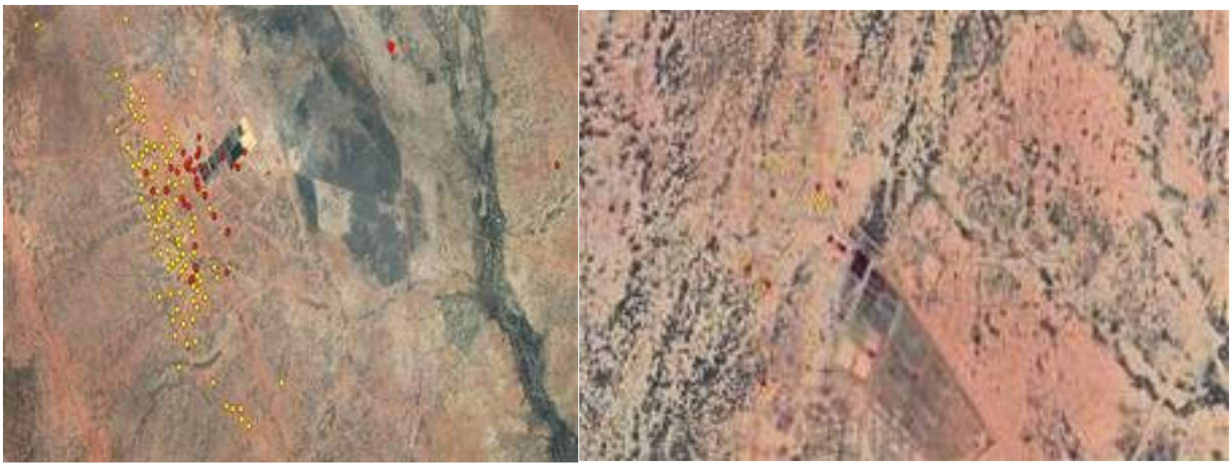


Figure 1. Map of study area and soil distribution.

2.2 Data Collation:

Soil sample: The soil sampling program was implemented by visiting the target sites. The core sites were extracted from previous environmental impact assessment studies provided by the oil company Petro-Energy responsible for the site. Satellite imagery analysis was also reviewed using GIS. The sites visited included the base camp, Field Processing Facility (FPF), evaporation ponds, biological treatment ponds, burrow pits, wellheads, OGMs, waste storage areas, an external site point in each oil field, wadi crossings, and a representative of each soil series in the target areas. At each of the selected sites, the coordinates of the sample sites were recorded against a serial number, and representative soil samples were taken at depths of 0–30, 30-60, and occasionally 60–90 cm. These samples, after being described in the field in a standard format, were stored in labeled plastic bags.



Fula oil field site *Jake oil field site*

Figure 2. ***On January 4th, 2023***, Site visiting and sample distribution in the oil fields.

3.2 Laboratory analysis and methods: After collecting the samples from the oil fields, the samples were sent to the laboratories of the University of Khartoum for analysis. In the laboratory, each soil sample was air dried at room temperature and sieved through a 2 mm sieve. Th e samples were kept in plastic bags for later analysis according to international procedures. The soil samples were divided into three parts for soil paste and extracts for chemical analysis according to Sparks (2007) and particle size distribution using the hydrometer method to separate silt from clay and was carried out according to (Klute, 1986). Total organic carbon was analyzed according to (Sparks, 2007). Hydrocarbons were formulated according to EPA, 418.1 (1990); heavy metals were formulated according to ICP/AAS (1990) and AOAC (1990).

3.Results and Dissuasion:

3.1. Fula oil field:

3.1.1. Pollution by Hydrocarbons:

Laboratory analysis indicates that total petroleum hydrocarbons (TPH) in the Fula field are above the standard levels setby the Sudanese government, the World Health Organization and the US Environmental Protection Agency (*See Table 1*). Soil contamination in the Fula oil field is shown in Central Processing Falu (CPF), Fula North (FN) 36 660653/1252033; CPF 660578/125228 – 660723/1251986 – 660654/1252206 – 660973/1252367; Wellhead 5 660567/1251553; Wellhead 108 660601/1251468; Wellhead 107 660723/1251424; Chemical Bangas 660908/1251794; Wellhead FN 166 660950/1251705; Wellhead FN28 660275/1251996; Wellhead 664630/1259363; Wellhead 5664620/1259363; FNE 664701/1259423; FNE 664735/1259396; Fula Northeast FNE 664778/1259349; OGM 660855/1250892; Wellhead 23 660881/1250546; Wellhead H-11 523074/1279330 and Power Station 522163/1282129. The total contaminated soil is 3044.72 tons.

The impact of chemicals that negatively affect the properties of the surface soil include hydrocarbons, organic pollutants, heavy metals, changes in soil pH, as well as various changes in the nutrient status of the soil ecosystem. This occurs when crude oil enters the environment due to spills or leaks. Hydrocarbons have an acute impact on the soil and a chronic effect if they reach groundwater(Qaiser *et al.*, 2019). People and plants will be negatively affected when crude oil and other associated pollutants reach groundwater(Sari, Trihadiningrum and Ni'matuzahroh, 2018). Spills must be addressed immediately and managed in the preliminary stages. Oil spills can be contained and treated more easily if handled properly. Groundwater contamination will have a long-term impact and will be exceedingly difficult to treat, and complete removal of pollutants can be expensive. Surface water runoff during the rainy season and groundwater and stream flows can discharge large amounts of these toxic hydrocarbons and pollutants into lowlands where water accumulates. Of more concern is that the study area contains natural pastures with vast areas that are preferred by herders during the rainy season for their livestock, which increases the level of threats facing humans and animals in the area.

3.1.2 Pollution by Soil heavy metals: Heavy metals accumulations from any source, such as oil spills, crude oil leaks, and toxic chemicals, pose a widespread and long-term health risk to local populations if they reach groundwater and may affect plants. Soil samples taken from the Fola field were analyzed for heavy metals and the results revealed that the contamination was above the Sudanese government and the US Environmental Protection Agency standards (see Table 2). It is worth noting that the soil pH of the study area is slightly alkaline to alkaline, so there may not be a significant threat of soil contamination at the levels detected by the analysis because these heavy metals come out of solution (sediment) at this alkaline pH. Chemical impacts that negatively affect the properties of the topsoil as well as groundwater quality include the introduction of hydrocarbons, organic contaminants, and heavy metals into the soil and groundwater, changes in soil pH, and changes in the nutrient status of the topsoil.

Type of Analysis: Total petroleum hydrocarbon (TPH)
Date of sampling: 04/01/2023 Date of submission:05/03/2023
Location: Coordinates: N(X): E(Y): Number of Samples: 48 Sample

No	Facility	X	Y	PHC (O/G) (mg/kg)	Remarks
S1	CPF	660760	1252106	0.00	Inside CPF the texture is SCL (landfill) no pollution
S2	CPF	660670	1252013	0.00	South well FN 36 not polluted
S3/1	CPF FN36	660653	1252033	1200	Polluted soils (2 samples) 2*2*3.14*0.6*1.2 = **9.04 ton**
S3/2	CPF FN36	660653	1252033	340	

S3	CPF FN36	660675	1252031	0.00	No soil pollution
S4/1	CPF	660578	1252228	194	Polluted soil 300*0.9*1.2 = **324** ton
S4/2	CPF	660578	1252228	240	
S5	CPF	660723	1251986	230	Polluted soil and collection of Bangas 4*0.3*1.2 = 1.**44 ton**
S6	CPF	660912	1252168	0.00	Collection of Ammonia Cylinders. No pollution
S7/1	CPF	660654	1252206	350	Polluted soil 20*5*0.9*1.2 = **108 ton** (2 soil samples)
S7/2				350	
S7	CPF	660972	1252260	0.00	Water leakage from boilers. No pollution
S8/1/2	CPF	660973	1252367	362	Poll. landfill 10*2*0.6*1.2 = 14.4 + 80*0.6*1.2 = 57.6 **(72 ton)**
S8				362	Poll. landfill 80*0.3*1.2 = 28.8 **ton**
S9	CPF	660971	1252445	0.00	No soil pollution
S10/1	Burrow pit	667056	1239338	0.00	Airport Bridge (3 soil samples) no pollution
S10/2	Burrow pit	667056	1239338	0.00	Airport Bridge (3 soil samples) no pollution
S10/3	Burrow pit	667056	1239338	0.00	Airport Bridge (3 soil samples) no pollution
S11/1	Burrow pit	667410	1242061	0.00	2 soil samples no pollution
S11/2	Burrow pit	667410	1242061	0.00	
S12	Landfill	-----	----	0.00	Not polluted
S13/1	W. H. 5	660567	1251553	374	Working soil polluted 15*4*0.6*1.2 = **43.2 ton** (2 soil samples)
S13/2				374	
S14/1	W. H. 108	660601	1251468	380	Working polluted 2*2*3.14*0.6*1.2 = **9.04 ton** (2 soil samples)
S14/2				374	
S15	W. H. 107	660723	1251424	373	Not working polluted 6*6*3.14*0.6*1.2 = **81.4 ton**
S16	Site exterior	660863	1251957	0.00	The soil of the project area (not sampled) not polluted
S17	Site exterior	660902	1251825	0.00	The soil of the project area (not sampled) not polluted
S17	Chem./Bangas	660908	1251794	362	Soil polluted 50*50*0.6*1.2 = **1800 ton**
S18	W. H. FN166	660950	1251705	255	Working soil polluted 6*6*3.14*0.3*1.2 = **40.7 ton**
S19	Site exterior	660425	1251940	0.00	The soil of the project area (not sampled) not polluted
S20	W. H. FN28	660275	1251996	244	Working soil polluted 7*7*3.14*0.6*1.2 = **110.8 ton**
S21/1	W. H.	664630	1259384	332	Working soil polluted 8*35*0.6*1.2 = **201.6 ton**
S21/2				332	
S22	W. H.	664620	1259363	254	Similar to S21 soil polluted, 100*.6*1.2 = **72 ton**
S23	Chem. Injection	664622	1259397	0.00	Not polluted (not sampled)
S24	Gardud soil	664628	1259443	0.00	Not polluted (not sampled)

S25	FNE OGM	664652	1259443	0.00	Landfill not polluted (not sampled)
S26/1	FNE	664701	1259423	355	Pollution around the Oil tank 80*0.6*1.2 = **57.6 ton** (2 samples)
S26/2				355	
S27	FNE	664735	1259396	480	Pollution around the Oil tank 80*0.6*1.2 = **57.6 ton** (2 samples)
S28	FNE	664778	1259349	230	Polluted (1 sample) 20*0.6*1.2 = **14.4 ton**
S29	OGM	660855	1250892	224	Polluted 4*0.6*1.2 = **2.9 ton**
S30	W. H. 23	660881	1250546	130	Not working polluted 3*3*3.14*0.3*1.2 = **10.2 ton**
S31	B-Basecamp	665119	1237905	0.00	Landfill and odour from the warehouse (Not polluted).
S32	B-Basecamp	665421	123851	0.00	Not polluted
S33	B-Basecamp	665425	1237958	0.00	Not polluted
S34	B-Basecamp	665137	1237509	0.00	Not polluted
Total				3044.72	

Note the red color indicates contaminated soil.

Table 1. The Total Petroleum hydrocarbon (TPH) Fula Oilfield

Type of Analysis: Heavy metals
Date of sampling: 04/01/2023 Date of submission:05/03/2023
Location: Coordinates: N(X): E(Y): Number of Samples: 48 Sample

No	Facility	X	Y	Fe	Pb	Zn	Cr	Cu	Ni	Cd
				mg/kg soil						
S1	CPF	660760	1252106	44.7	0.02	0.002	0.0	0.001	0.00	0.003
S2	CPF	660670	1252013	42.5	0.02	0.002	0.0	0.001	0.00	0.003
S3/1	CPF FN36	660653	1252033	44.2	0.02	0.002	0.0	0.001	0.00	0.003
S3/2	CPF FN36	660653	1252033	44.2	0.02	0.002	0.0	0.001	0.00	0.003
S3	CPF FN36	660675	1252031	42.5	0.02	0.002	0.0	0.001	0.00	0.003
S4/1	CPF	660578	1252228	33.1	21.3	2.4	**1.3**	2.4	**0.9***	**0.5***
S4/2	CPF	660578	1252228	33.1	21.3	2.4	**1.3**	2.4	**0.9***	**0.5***
S5	CPF	660723	1251986	234.5	23.2	1.7	**0.9**	1.6	**0.6***	**0.8**
S6	CPF	660912	1252168	56.3	0.01	0.0	0.0	0.0	0.00	0.001
S7/1	CPF	660654	1252206	66.3	0.01	0.0	0.0	0.0	0.00	0.002
S7/2				66.3	0.01	0.0	0.0	0.0	0.00	0.002
S7	CPF	660972	1252260	66.3	0.01	0.0	0.0	0.0	0.00	0.002
S8/1/2	CPF	660973	1252367	876.3	0.01	1.4	**0.8**	0.0	0.00	**0.87**

S8	CPF			876.3	0.01	1.4	0.8	0.0	0.00	0.87
S9	CPF	660971	1252445	654.5	0.01	2.4	2.4	0.0	0.00	0.60
S10/1	Burrow pit	667056	1239338	44.2	0.01	1.6	0.0	0.0	0.00	0.23
S10/2	Burrow pit	667056	1239338	44.2	0.01	1.6	0.0	0.0	0.00	0.23
S10/3	Burrow pit	667056	1239338	44.2	0.01	1.6	0.0	0.0	0.00	0.23
S11/1	Burrow pit	667410	1242061	54.2	0.01	0.0	0.0	0.0	0.00	0.0
S11/2	Burrow pit	667410	1242061	42.5	0.02	0.002	0.0	0.001	0.00	0.00
S12	Landfill	-----	----	778.3	0.01	2.7	1.3	5.7	0.00	0.22
S13/1	W. H. 5	660567	1251553	43.2	0.01	0.0	0.0	0.0	1.1	0.20
S13/2				43.2	0.01	0.0	0.0	0.0	1.21	0.10
S14/1	W. H. 108	660601	1251468	53.4	0.01	0.0	0.0	0.0	0.1.1	0.21
S14/2				43.2	0.01	0.0	0.0	0.0	1,1	0.24
S15	W. H. 107	660723	1251424	876.5	4.6	5.4	1.3	2.5	5.7*	0.78
S16	Site exterior	660863	1251957	34.2	0.02	0.0	0.0	0.0	0.00	0.0
S17	Site exterior	660902	1251825	45.6	0.03	0.0	0.0	0.0	0.00	0.0
S17	Chem.Banga	660908	1251794	44.6	0.02	0.0	0.0	0.0	1.2	0.45
S18	W. H. FN166	660950	1251705	36.1	0.04	0.0	0.0	0.0	1.3	0.43
S19	Site exterior	660425	1251940	34.6	0.04	0.0	0.0	0.0	0.00	0.0
S20	W. H. FN28	660275	1251996	34.3	0.04	0.0	0.0	0.0	1.4	0.84
S21/1	W. H.	664630	1259384	44.3	0.01	0.0	0.0	0.0	1.4	0.83
S21/2				44.3	0.01	0.0	0.0	0.0	1.3	0.84
S22	W. H.	664620	1259363	32.8	0.02	0.0	0.0	0.0	1.4	0.89
S23	Chem. Injection	664622	1259397	36.7	0.0	0.0	0.0	0.0	0.0	0.0
S24	Gardud soil	664628	1259443	37.2	0.0	0.0	0.0	0.0	0.0	0.0
S25	FNE OGM	664652	1259443	36.2	0.0	0.0	0.0	0.0	0.0	0.0
S26/1	FNE	664701	1259423	41.2	3.3	-	-	-	1.0	0.89
S26/2				41.2	3.3	-	-	-	0.99	0.87
S27	FNE	664735	1259396	521.4	27.4	1.6	32.1	9.5	1.0*	3.4
S28	FNE	664778	1259349	876.5	4.6	5.4	1.3	2.5	0.6	3.4
S29	OGM	660855	1250892	34.2	0.02	0.0	0.0	0.0	0.5	3.5
S30	W. H. 23	660881	1250546	45.6	0.03	0.0	0.0	0.0	0.7	3.5
S105	B-Basecamp	665119	1237905	35.5	0.023	0.000	0.00	0.0	0.00	0.002

S106	B-Basecamp	665421	123851	33.3	0.025	0.000	0.00	0.0	0.00	0.003
S107	B-Basecamp	665425	1237958	36.6	0.024	0.000	0.00	0.0	0.00	0.002
S108	B-Basecamp	665137	1237509	34.8	0.023	0.000	0.00	0.0	0.00	0.003

WHO (mg/kg) Cd = 0.003. Sudanese (mg/kg) Cd= 0.003; EPA USA Standard Guidelines 1991; Cd standard level = 1 mg/kg; Fe standard level = 0.3 ppm; Cu = 62 mg/kg; Zn = 290 mg/kg; Cr = 160 mg/kg; Ni = 130 mg/kg; Pb standard level = 45 mg/kg; Ni = 37 mg/kg

Note the red color indicates contaminated soil.

Table 2. Heavy metals analysis of Fula Oilfield.

3.2 Jake oil field:

3.2.1 Pollution by Hydrocarbons: Laboratory analysis results of the soil of the Jake field showed that it is mainly composed of Entisols, Aridisols and Alfisols with sandy loam and sandy loam texture and occasionally clay in the valleys and streams. The soil fertility in the Jake areas is low in organic matter content and therefore low in microorganisms and water permeability is good to high in most places and the soil suffers from nitrogen and phosphorus deficiency, organic and inorganic fertilizers are needed to improve the soil in case of agriculture.

The total petroleum hydrocarbons (TPH) are more than the standard levels set by the Sudanese, WHO, and USA EPA in the contaminated areas, including W. H. JS72 635669/1283118; W. H. JS24 635829/1283814; Oil spills J59, JS17 634952/1282432; Surface contamination 635678/1282689; chemical injections 635585/1282741;W. JS32 pollution 634757/1282541; polluted soil JE1 637750/1292736; polluted soil 637801/1292774 W. Jake Center 2 635593/1289613. The total contaminated soil is approximately 15139.72 tons (See Table 3).

Based on the above, soil contaminated with total petroleum hydrocarbons negatively affects the physical, chemical, and biological properties of the soil and the quality of surface and groundwater. Hydrocarbons can also cause changes in soil pH as well as in the nutritional status of the soil. All this happens when crude oil enters the soil through spills or leaks (Sivkov, 2020)(Al-Sanad, H. A., Ismail, W. K. W., & Eid, 2018). These pollutants can have both acute and chronic effects if they reach the surface and groundwater, so such contamination must be addressed and managed immediately after it occurs. Oil spills can be contained and treated more easily if they are handled properly. Groundwater contamination will have a long-term impact, and remediation will be exceedingly difficult and expensive. Surface water discharge, rainy season runoff, and possibly groundwater runoff can discharge large amounts of these toxic hydrocarbon pollutants into waterways.

3.2.2 Pollution by Soil heavy metals: Soil samples taken from the Jake field showed that heavy metals copper, nickel, cadmium, zinc, iron, chromium, and lead, resulting from oil spills and crude oil leaks in the soil, pose a wide-ranging health risk to humans and animals in the long term if they reach surface water and groundwater, as confirmed by(Ogunlana, Korode and Ajibade, 2021). The results revealed that the contamination is greater than the standard set by the Environmental Protection Agency and the Sudanese government (See Table 4). Although the soil alkalinity in the study area is alkaline, which helps in the release of heavy metals, the risk of contamination remains.

Type of Analysis: Total petroleum hydrocarbon (TPH)
Date of sampling: 04/01/2023 Date of submission:05/03/2023
Location: Coordinates: N(X): E(Y): Number of Samples: 20 Sample

No	Facility	X	Y	PHC (O/G)	
S35	Wadi Al-Ghala	640632	1277850	0.00	Desert tree, Sunt, Talih, Arad, Kukul, Sahab, Tabaldi, Aradaib Kadak
S36	Jake Basecamp	636001	1281962	0.00	Landfill SCL (1 sample)
S37	Ret. pond	636124	1282414	0.00	Reeds (1 sample)
S38	J. Forest area	636442	1281803	0.00	Forest area irrigated from the treated water (1 sample)
S39	W. H. JS72	635669	1283118	246	Polluted 4*4*3.14*0.6*1.2 = 36.2 ton

S40	Jake OGM2	635461	1283088	0.00	Not polluted (not sampled)
S41	W. H. JS24	635 829	1283814	235	Polluted 2*2*3.14*0.6*1.2 = 9.04 ton (1 sample)
S42	L. OGM3	635006	1283044	0.00	Not polluted (1 sample)
S43	O. spill JS9, JS17	634952	1282432	274	Poll 2*2*3.14*0.6*1.2 = 9.04 ton + 10000*0.05*1.2 = 600 ton (609.04 ton)
S44	F. storage tank	635723	1282676	0.00	Not polluted (not sampled)
S45	Surface contam.	635678	1282689	282	Surface pollution, Mustaba 3*20*0.02*1.2 = 1.44 ton
S46	Chem. Injection	635585	1282741	254	Polluted 3*20*0.6*1.2 = 43.2 ton
S47	W. JS32 Poll.	634757	1282541	243	Landfill from Well 9, 85*2*50*1.2 = 10,200 ton (3 samples)
S48/1	Polluted soil	635751	1283903	212	Landfill 30*30*2*1.2 = 2160 ton (2 samples)
S48/2				281	
S49	Well JE1	637750	1292736	280	Oil spill 6*15*0.6*1.2 = 64.8 ton
S50	Poll. soil JE1	637801	1292774	218	Transported polluted soil 72*15*1.5*1.2 = 1944 ton
S51	W Jake Centre2	635593	1289613	220	Colored soil (Gardud soil) 100*.6*1.2 = 72 ton
S52	W. H. JS03	634909	1281760	0.00	Rig cleaning the well pit 3*4*4 filled with crude oil
S85	Fula basecamp	664995	1237988	0.00	Not polluted (1 sample)
Total					**15,139.72**

Note the red color indicates contaminated soil.

Table 3. Soil samples Jake oilfield Total petroleum Hydrocarbon (TPH).

Type of Analysis: Heavy metals
Date of sampling: 04/01/2023 Date of submission:05/03/2023
Location: Coordinates: N(X): E(Y): Number of Samples: 20 Sample

No	Facility	X	Y	Fe	Pb	Zn	Cr	Cu	Ni	Cd
				mg/kg soil						
S31	Wadi Al-Ghala	640632	1277850							
S32	Jake Basecamp	636001	1281962	42.6	0.02	0.0	0.0	0.0	0.00	0.0
S33	Ret. pond	636124	1282414	41.6	0.02	0.0	0.0	0.0	0.00	0.0
S34	J. Forest area	636442	1281803	43.6	0.02	0.0	0.0	0.0	0.00	0.0
S35	W. H. JS72	635669	1283118	40.6	0.02	0.0	0.0	0.0	0.00	0.0
S36	Jake OGM2	635461	1283088	----	----	----	----	----	----	----
S37	W. H. JS24	635829	1283814	40.6	0.02	0.0	0.0	0.0	0.00	0.0
S38	L. OGM3	635006	1283044	----	----	----	----	----	----	----
S39	O. spill JS9, JS17	634952	1282432	34.6	0.02	0.0	0.0	0.0	0.00	0.0
S40	F. storage tank	635723	1282676	----	----	----	----	----	----	----
S41	Surface contam.	635678	1282689	34.3	0.02	0.0	0.0	0.0	0.00	0.0
S42	Chem. Injection	635585	1282741	42.2	0.02	0.0	0.0	0.0	1.1	0.1
S43	W. JS32 Poll.	634757	1282541	43.1	0.02	0.0	0.0	0.0	0.9	0.0
S44/1	Polluted soil	635751	1283903	39.9	0.02	0.0	0.0	0.0	1.1	0.4
S44/2										
S45	Well JE1	637750	1292736	40.2	0.02	0.0	0.0	0.0	1.5	0.5
S46	Poll. soil JE1	637801	1292774	38.8	0.02	0.0	0.0	0.0	1.0	0.1
S47	W Jake Centre2	635593	1289613	42.2	0.02	0.0	0.0	0.0	1.4	0.1
S48	W. H. JS03	634909	1281760	41.0	0.02	0.0	0.0	0.0	1.2	0.2
S49	Fula basecamp	664995	1237988	44.6	0.02	0.0	0.0	0.0	0.00	0.0

WHO (mg/kg) Cd = 0.003. Sudanese (mg/kg) Cd= 0.003; EPA USA Standard Guidelines 1991; Cd standard level = 1 mg/kg; Fe standard level = 0.3 ppm; Cu = 62 mg/kg; Zn = 290 mg/kg; Cr = 160 mg/kg; Ni = 130 mg/kg; Pb standard level = 45 mg/kg; Ni = 37 mg/kg

Table 4. Soil samples Jake oilfield Heavy metals.

4.Conclusion:

After conducting laboratory tests on the soil in the study area, it was found that the heavy metals and hydrocarbons resulting from crude oil were above the recommendations of the World Health Organization, the Sudanese government and the US Environmental Protection Agency in both the Jake and Fula fields. This can cause significant damage to the soil ecosystem in several ways. The chemical and physical properties of the soil begin to change gradually, and then its fertility decreases. The danger of oil pollutants to the soil is not limited to fertility and the ability to grow plants, but extends to mixing rainwater with the polluted soil, and thus this fresh water becomes polluted and unfit for humans and animals in the study area. The results of this study will provide a good reference for oil companies in Sudan, draw attention to the impact of the oil industry on the soil, and can contribute to raising awareness of the danger of pollution. This requires intensive efforts to maintain the safety of the soil using advanced technology in treating waste and oil spills.

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