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Effect of Hydrocarbon Contaminated Irrigation Water On Some Selected Soil Physical and Chemical Properties of Sudan Savannah Alfisols

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ABSTRACT: *Due to fresh water scarcity challenges around the world, high increase in the demand for agricultural irrigation water from different sources including hydrocarbon contaminated wastewater increases. However, these wastewaters can alter soil physical and chemical properties. The aim of this study is to evaluate the impact of the hydrocarbon contaminated irrigation water on some selected soil physical and chemical properties from three phases of Sharada industrial area, Kano, Nigeria. Soil and water samples were collected from three different phases of the industrial area and analyzed using standard laboratory procedures. The hydrocarbon irrigation water quality analyses indicated that the hydrocarbon concentration in all phases was low and below irrigation reuse standard. However, the major irrigation water quality parameters; chemical oxygen demand (COD), biochemical oxygen demand (BOD), nitrate nitrogen (NO_3-N), hydrogen carbonate (HCO_3), ammonium-nitrogen (NH_4-N), potassium (K), chlorine (Cl) and orthophosphate phosphorus (PO_4-P) in all phases were all high and above irrigation reuse standard in comparison to other parameters that were compliant to standard according to literature. Pertaining the impact of the hydrocarbon irrigation water on soil properties, results revealed that soil texture was sandy loam and loamy sand, pH was neutral while bulk density (BD), electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), cation exchange capacity (CEC) and phosphorus (P) were increased and higher compared with control soils. However, they are low in terms of concentration when compared with literature rating standard except P. Moreover, Ca, Mg, CEC and P of the soils showed significant variation statistically ($P<0.05$) in comparison to the remaining soil properties that recorded no significant statistical difference ($P>0.05$) in all phases and control soils after irrigation with the hydrocarbon wastewater. Overall, the research indicated that, the hydrocarbon wastewater was not fit for irrigation and has impacted relatively on some physical and chemical soil properties. Hence, all industries in Sharada should be directed by authorities to avoid direct discharge of their effluents without thorough quality investigation. In addition, farmers should also be educated to periodically monitor and assess the irrigation water quality of the effluents prior to application as well as incorporation of organic and inorganic amendments in the irrigated soils to uplift the concentration of the soil properties with concomitant improvement in soil fertility and quality of the study area.*

KEYWORDS: irrigation; water quality; soil quality; hydrocarbon; organic carbon

INTRODUCTION

Wastewater released from industries contain large quantity of organic and inorganic pollutants including petroleum hydrocarbons, and are all deposited on soil directly, or indirectly in watercourses from where the farmers use them as source of irrigation water and irrigate the soils (Sani et al., 2021). Hydrocarbon wastewater is found associated with conventional contaminants (CC); biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), turbidity, nitrogen compounds, toxic metals such as Cd, Cr, Ni and Pb, and faecal coliforms, and when discharged to water bodies cause deleterious effects on the different components of the water environment including fisheries, thus making the water unsuitable for drinking, irrigation agriculture and aquatic life (Albaldawi et al., 2014; Sani, 2015; Ruhuoma and Lucky, 2016). Comparably, if released into the soil environment degrade soil quality leading to problems of crop growth and total yield reduction (Sani, 2015).

Hydrocarbons, get into the environment by human related activities like refinery pipelines rupture, underground storage tanks leakages or accidental spills and industrial wastewater discharge points. Subsequently, they drain into gutters, water drains and open vacant plots, farm lands, run off and lastly to receiving water courses where they are admixed with other types of wastewaters and farmers use it as a source of their irrigation water (Sani et al., 2020, 2021).

Irrigation recycling of urban wastewaters such as hydrocarbon contaminated ones as a marginal quality water for agricultural production has been a disposal mechanism for centuries in developed nations such as America (Pedro et al., 2010), United Kingdom and Europe (Almukhtar et al., 2018), and lately in Asian and African countries (Qadir et al., 2007; Pedero et al., 2010) particularly in arid and semi-arid regions (Qadir et al., 2007; Sani et al., 2020). This is because of the understanding that the wastewaters are rich in essential nutrients for agricultural crops production. Furthermore, they can protect the environment from direct waste water pollution and save farmers economic cost of buying inorganic fertilizers in addition to improving fresh water sources exploitation (Bichai et al., 2012; Sani et al., 2020, 2021).

However, depending on the degree of hydrocarbon concentration in the wastewater, the applied hydrocarbons to the soil via the irrigation water can be detrimental or beneficial to soil quality in terms of fertility, productivity and yield of crops grown on the affected soils because their high or low concentration could alter the soil properties (Almuktar et al., 2014; Almuktar et al., 2018; Sani et al., 2020). These altered properties are the basis for determining soil's long-term sustainable use and profitable agriculture. For instance, after hydrocarbon wastewater irrigation, Almuktar et al. (2014) reported high concentration of some soil nutrients and essential elements in their experimental soils with apparent negative impact on crops agronomic parameters and the harvested yield. Nevertheless, in contrast, Almuktar and Scholz (2016) in the relevant experiment, reported best yield of fruits of vegetables in terms of their dimensions and fresh weights after irrigation with hydrocarbon wastewater. The authors attributed that to induced reduction of nitrogen concentration in the soil media within the permissible limit by the degrading hydrocarbon organisms. Furthermore, changes in soil

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physical properties such as reduction in aggregate stability, porosity and hydraulic conductivity, increased bulk density (Devatha et al., 2019) leading to poor texture and structure with subsequent increase in erosion by water and wind leading to soil quality degradation (Nieber et al., 2011) have been reported. Similarly, variation in chemical soil properties including soil salinity, electrical conductivity (EC), organic matter (OM) contents, exchangeable cations, cation exchange capacity (CEC), nitrogen (N) contents, phosphorus (P) concentration, micronutrients and pH (Almuktar et al., 2018) were also reported in soils irrigated with hydrocarbon contaminated irrigation water.

Due to high use of petroleum as a main source of energy as a result of rapid industrialization, population growth, and complete inattention for environmental health (Sani et al., 2015), pollution of soil and water environments with petroleum hydrocarbons is becoming a pervasive problem particularly in oil producing countries. The release of these hydrocarbons into soil bodies via hydrocarbon contaminated irrigation water usually causes soil quality deterioration with resultant negative effects on the crops grown on the affected soils. Subsequently, upon consumption of the affected crops, the hydrocarbons enter the consumer's food web where they exert their carcinogenic, neurotoxic, teratogenic and mutagenic effects (Al-Muktar et al., 2018; Sani et al., 2020). In addition, they are naturally persistent and have the ability to spread into soil and cause diseases like tumour growth, poor reproduction, poor development, poor immunity and excess risk of lung cancer (Abdel-shafy and Mansour, 2016) when ingested through crops grown on the soils affected with them. Hence, bio-accumulation and bio-concentration characteristics of hydrocarbons in soil made them a topic of concern globally (Haritash and Kaushik, 2009).

Hydrocarbon exemplars include diesel oil, volatile organic compounds (VOCs), total petroleum hydrocarbons (TPH), polyaromatic hydrocarbons (PAH), total aliphatics (TAP), benzene, toluene, ethylene and xylene (BTEX) and other compounds, which are usually harmful, mutagenic and carcinogenic (Tang *et al*., 2010; Sani, 2015) and may cause serious environmental problems to the ecosystem and have adverse effects to human health, even in low concentrations (Guittonny-Philppe *et al*., 2015).

In the BTEX, benzene is a human carcinogen which promotes myeloid leukemia (Mathur and Balomajumder, 2013) and a major pollution problem in soil and underground water. Moreover, it is considered the most problematic petroleum hydrocarbon because of its high toxicity and water solubility (Johnson et al., 2003). One of the most common sources for benzene contaminants of soil and groundwater is spills involving the release of petroleum products such as gasoline, diesel fuel, lubricating and heating oil from leaking oil tanks that drain into water ways and mix with wastewater released from industries and domestic sources to become irrigation water. From this irrigation water, benzene, very soluble enter the soil and underground water system and cause serious pollution problems (Scholz, 2010).

In this research, benzene in the irrigation water is studied as a model hydrocarbon compound to assess its impact on soil physical and chemical properties of Savanah Alfisols when applied from industrial wastewater as irrigation amendment. This is imperative considering the negative and health implication of the hydrocarbon to soil and crop quality due to its bio-accumulation and bio-concentration effect on the people and animals upon consumption of the crops grown on the soils irrigated with this type of wastewater. Moreover, the research will provide useful information to agricultural, petrochemical and environmental authorities in evaluating and understanding long term impacts of hydrocarbon wastewater from industrial sources particularly on irrigation of agricultural soil and its properties. In turn, this will help in developing an effective recommendation for soil best use application and choice of suitable crops or countermeasures to avoid any potential harmful effects.

.Many works were carried out and published on water quality of sharada industrial wastewater (Danazumi and Bichi, 2010; Amoo et al., 2018; Sani et al., 2020) while some focused on the impact of the industrial wastewater on soil quality (Sani et al., 2021, 2022). However, none of the authors assessed the impact of the hydrocarbon in the irrigation water on soil physical and chemical properties of the area. Therefore, the aim of the study is to be achieved via the following objectives;
1-To determine the irrigation water quality of benzene as a model hydrocarbon and other water quality parameters in the irrigation wastewater;

2-To assess the impact of the hydrocarbon in the irrigation water on some soil physical and chemical properties

MATERIALS AND METHODS

Study Area Description

The research was conducted at Sharada industrial area of Kano metropolis, Kano state, Nigeria. The area covered about 600 Km^2 and located between longitude 8º and 9ºE and latitude 10º and 12ºN in the Semi-arid ecological Savannah zone of the country. The climate of the research area is tropical wet and dry type, with dry and wet season months in between November to May and June to October respectively (Nuruddeen et al., 2016; Sani et al., 2021).The mean temperature is 26º C with the maximum value of 39º C occurring in the month of April/May and the lowest of 14º C in December (Nuruddeen et al., 2016; Sani et al., 2021). The industries in Sharada are located in three phases; phases I, II and III respectively. However, the different types of industries ranging from oil and gas, textiles and tanneries, plastic industries among others are arranged in no order. The wastewater released from the outlet of these industries composed of hydrocarbon and other conventional pollutants that drain into gutters, admixed with little component of domestic wastewater and empty into a receiving watercourse, where the local farmers use the water to irrigate their soil (Sani et al., 2021).

Sampling Procedure

The soil and water samples were collected from Sharada area using auger, core samplers, polythene bags, 550ml plastic bottles, cooler and ice block. Three samples from ten replications of soil and water samples were collected from three phases of the area; phases l, II and III respectively beside control using simple random sampling technique. The three composite soil samples collected were dug from 0-30cm depth and inserted inside polythene bags while the water samples into plastic bottles before subsequent analyses. Before the water sampling, plastic bottles were washed well and rinsed with the sample water. The collected water samples were put inside the cooler which contains ice block to inhibit the activities of microorganisms.

Laboratory Analyses

Soil and water pH and EC were determined using pH and conductivity meters respectively, soil Cation Exchange Capacity (CEC) was evaluated using neutral pH_7 in NH_4OAC saturation method as described by Anderson and Ingram (1993), Organic Carbon was assessed by the dichromate oxidation method as detailed by Nelson and Sommers (1982) while Mechanical Analysis was by standard hydrometer method as outlined by Gee and Bauder (1986). Total Phosphorus was determined by acid digestion as described by Murphy and Relay (1962), Total Nitrogen content was evaluated using the micro-Kjeldhal technique as described by Bremner (1982) while The exchangeable bases of Na and K were estimated using the flame photometer; Mg and Ca were measured using atomic absorption spectrophotometer**.** Water quality sampling and analyses were carried out according to American Public Health Association (APHA, 2005) unless stated otherwise.

Hydrocarbon Determination

Benzene hydrocarbon was determined by gas chromatography and flame ionization method (Exova Health Sciences (Hillington park, Glasgow, UK) according to their own accredited "Hydrocarbons in waste waters (with Aliphatic/Aromatic Splitting) Method" (Exova Health Sciences, 2014), which is accredited to the British Standard (BS) method BS EN ISO IEC 17025 by the United Kingdom Accreditation Service and compatible with the International Organization for Standardization (ISO) standards (e.g., ISO17025), BS method BS DD 220 1994, and American Standard methods (United States Environmental Protection Agency (USEPA) Method 3510C and USEPA SW846 Method 8015).

Statistical Analysis

To assess the impact level of the hydrocarbon on the soil properties in different phases and their corresponding differences, data mean values of the concentration in each phase were subjected to analysis of variance (ANOVA) using SPSS Statistical package. The treatment means were separated using Duncan Multiple Range Test (DMRT) at 5% level of probability.

RESULTS AND DISCUSSION

Irrigation Water Quality

The hydrocarbon wastewater used for irrigation of the soil of the study area was generated from wastewater treatment outlets of the Sharada industries. The released water from the three phases empty into a concrete open watercourse, where the local farmers of the research area use it for their soil irrigation. For comparison, the uncontaminated water are designated as fresh water while the soils that receive no hydrocarbon wastewater are designated as fresh water irrigated soils and as control. Benzene as a model hydrocarbon (Figure 1 and Table 1) recorded the highest values in phase I, followed by phase II and phase III, while no values were detected in the fresh water (Table 1). In terms of irrigation water quality standard, no permissible limit was set for benzene in crop irrigation because of no sufficient data available on the adverse effects of benzene in irrigation water (Narendar, 2007). However, considering it a member of BTEX and TPH organic compounds, 300ug/l and 5000ug/l would be set as the limit for wastewater quality standard (Grontimiji, 2015) and EPA (2005) respectively by environmental agencies, while 1000ug/l was set for irrigation reuse (Al-Isawi et al, 2016) for TPH, and in any case, all the

Table 1: Overall mean values of the Hydrocarbon wastewater and Fresh water used for Irrigation in the Industrial area

Parameters	Phase I	Phase II	Phase III	Fresh water
Benzene (ug/l)	9.471	9.204	8.568	nd
COD (mg/l)	299.75	274.68	262.15	5.40
BOD (mg/l)	170.37	187.58	171.27	4.30
pH (-)	6.46	6.52	6.53	7.10
EC(dS/m)	1.03	1.19	1.02	0.03
Mg (mg/l)	5.09	6.16	3.03	0.07
Ca (mg/l)	46.55	64.41	26.94	0.04
HCO_3 (me/l)	488.00	305.00	305.00	2.34
K (mg/l)	6.69	5.29	3.35	0.07
Na (mg/l)	7.95	8.92	3.17	1.01
Cl (me/l)	177.50	159.75	124.25	1.02
TDS (mg/l)	632.00	966.17	611.83	3.40
NO_3-N (mg/l)	151.14	418.93	199.87	0.20
NH_4-N (mg/l)	553.41	143.74	1758.90	0.30
PO_4-P (mg/l)	169.58	34.30	44.71	0.04

Note, COD, chemical oxygen demand, BOD, biochemical oxygen demand, EC, electrical conductivity, Mg, magnesium, Ca, calcium, HCO_3, hydrogen carbonate, K, potassium, Na, sodium, Cl, chlorine, TDS, total dissolved solids, NO3-N, nitrate nitrogen, NH4-N, ammonia-nitrogen, PO4-P, orthophosphate phosphorus and nd, not detected.

recorded values achieved compliance. Furthermore, the range of values of benzene in the irrigation water of this study (8.6-9.5ug/l) is comparable to what is obtained in the literature of between <10-100ug/l (Sani, 2015; Fayemiwo et al., 2017; Sani et al., 2020).

COD, BOD, NO_3-N, HCO_3, NH_4-N, K, Cl and PO_4-P in all phases were all above irrigation reuse standard according to regulatory agencies (Almuktar et al., 2018; Sani et al, 2021) in comparison to other parameters that were compliant (Almuktar et al, 2018) including fresh water sources (Table 1).Considering the aforementioned hydrocarbon contaminated irrigation water characteristics, the irrigation water quality is predominantly poor because most of the major discharge and irrigation water quality parameters are above the permissible allowable limit of both discharge and irrigation reuse (Sani et al., 2020).

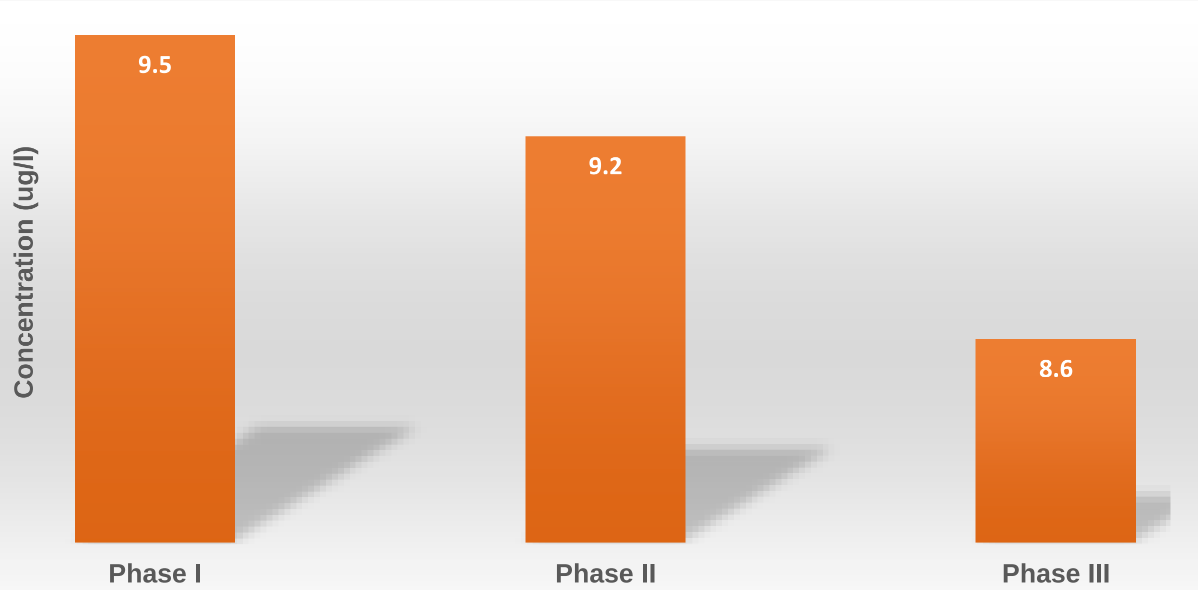

Figure 1: Hydrocarbon concentration in the irrigation water of different industrial phases

Effect of hydrocarbon on some selected soil physical properties

Soil Texture

The relative quantities of sand, silt and clay form a soil texture. Texture is a basic soil property which influences other characteristics such as water holding capacity, root growth and development, and nutrient dynamics in soil. The amounts and sizes of different particles should, provide proper balance between the macro and micro pores for easy air and water movement, in soil and holding water as well. These physical properties have direct effects on the dynamic and fates of any element in soil (Scherr et al., 2007; Abdel-Moghny, 2012).

The soil texture analysis of this research was shown in Table 2. The results showed slight variability in the soil textural classes through particle size distribution of soil samples from soils irrigated with hydrocarbon irrigation water and fresh water. The distribution of the soil particles indicated that Sharada phase I, II and III soils treated with hydrocarbon irrigation water recorded values of sand 77%, silt 18% and clay 5%; sand 78%, silt 18% and clay 4% and sand 83%, silt 13% and clay 4% respectively. That of fresh water treated soils recorded values of sand 92%, silt 2% and clay 8% in that order. Moreover, no statistical significant (P>0.05) difference (Table 2) was recorded in the distribution of the sand, silt and clay fractions across all soils both irrigated with hydrocarbon irrigation water and fresh water indicating that hydrocarbon in the irrigation water has not affected the soil texture of the study area. This could be attributed to the fact that the soils are sandy loam and loamy sand with little proportion of silt and clay components. Clayey soils are more plastic and sticky, have swelling and shrinkage ability, and the presence of hydrocarbon in them will make the soils more sticky, binding and clogging, and vice-versa with sandy soils. So, this makes the mobilization of the contaminants easier in the course textured soils (Abdel-Moghny, 2012) compared to the clayey soils. Generally, coarser particles (sand) when admixed with the fine clays and silt, build pore spaces with different shapes and sizes, then provide various routes and fates for the contaminants like hydrocarbons (Lee and Charles, 2002). Moreover, considering the loamy sand and sandy loam texture of the current study soils, the hydrocarbon contaminants in the irrigation water could not restrict vertical water and nutrients movement in the soil when in contact, since the clay content that stick and bind them in the soil matrix is little. In contrast, sand proportion allows normal roots penetration to absorb the nutrients in the water medium (Siddiqui and Adams 2002). However, the reverse will be the case if the texture is clayey due to the hydrocarbon's buoyancy effects with soil aggregates, ability to compact soil layers, limit root growth and adversely affect properties related to water and air movement in the soil around plant roots (Gurska et al., 2009) confirming the current study textural class data.

Soil Bulk Density

Soil bulk density (BD) is a physical indicator of soil compaction and soil health that affects water infiltration and permeability, rooting depth or restrictions, soil porosity, plant nutrients availability, and soil microorganisms' activity, which in turn influence key soil processes and productivity (Edenborn and Zenone, 2007).

Location	**Sand %**	**Silt %**	**Clay%**	**Textural class**	**BD (g/cm3)**
Sharada phase I	77	18	5	Loamy sand	1.66 ^{NS}
Sharada phase II	78	14	8	Sandy loam	1.60 ^{NS}
Sharada phase III	83	13	4	Loamy sand	1.52 ^{NS}
Fresh water/Control	90	2	8	Sandy loam	1.50^{NS}

Table 2: Impact of hydrocarbon wastewater Irrigation on some selected Soil Physical Properties in Sharada Industrial Area

Note; NS, no significant difference, BD, bulk density, Means having the same letters in the same column are statistically similar and the means are separated using DMRT at 5% level of confidence

The effects of the hydrocarbon irrigation water on soils BD in different phases was depicted in Table 2. According to the table, the values of BD were in decreasing trend, highest in phase I followed by phase II, phase III and lastly fresh water irrigated soils with no statistical significant difference observed between the soils (P>0.05). Although, no significant variation observed, the recorded BD values were all within the range of values that do not restrict crop root movement and growth in the soil which will reduce the crop's ability to explore the growing environment that will subsequently affect the yield productivity (Yiferu et al., 2018). This indicates that the hydrocarbon irrigation water applied in all soils did not negatively affect the BD of the soil, hence, no threat to crop growth. The plausible reason behind the recorded highest BD values in the hydrocarbon phase I irrigated soils in comparison to other soils could be attributed to high amount of hydrocarbon compounds in the hydrocarbon irrigation water that when applied to the phase I soils as irrigation amendment might have reduced the soil macro pores to meso and micro pores leading to the high recorded BD values. Niebir et al. (2011) reported that hydrocarbon-contaminants increase soil BD and an increasing soil BD implies a decrease in macro pores and an increase in meso and micro pores and the resultant changes has an impact on soils hydraulic conductivity. Furthermore total dissolved solids (TDS) found in the wastewater (Table 1) could be another reason for the higher recorded BD values, because it was reported that TDS from applied irrigation wastewater clog soil pores, increase BD leading to soil layers compaction, limit root growth with resultant negative impact on properties related to water and air movement in soil around plant roots (Gurska et al., 2009). However, this is contrary to the BD data of the current study, because the BD values of the current study do not clog soil pores and restrict root growth considering the assertion of Yiferu et al.(2018). The plausible reason for this could be attributed to lower values of BD obtained in the current research in comparison to the reported literature high BD values.

Effect of hydrocarbon on some selected soil chemical properties

Soil pH

pH is an important parameter essential for determining the availability and solubility of many soil nutrients, fate of soil itself and many pollutants including hydrocarbons, their breakdown and possible movement through the soil

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The result of soil pH in the soils irrigated with hydrocarbon irrigation water and fresh water was presented in Table 3. The soil pH range was between 7.20 and 7.42 in all the three phases and control. The result also indicated that no statistical significant difference was recorded (P>0.05) between the soils and H^+ concentrations. Depending on the pH concentration (acidic or basic) in the hydrocarbon irrigation water, application of the water on soils raises or lowers the soil`s pH. For example, Hu et al.(2006) and Wang et al. (2009, 2010) have reported that hydrocarbon contaminants in irrigation water raised the soil`s pH but depressed its hydrolytic acidity, total exchangeable bases (EB) and cation exchange capacity (CEC) in their irrigation experiment, indicating high concentration of hydrocarbon contaminants in the applied irrigation water. Furthermore, it has been expounded that acidic pH has implications on nutrient availability in the hydrocarbon-polluted soils and vice-versa with basic pH because such pH may affect the solubility of minerals such as aluminium and manganese and binding ability of the hydrocarbon contaminants to the soil which are toxic to many plants. Nitrogen fixation and decomposition activities are also known to be hindered in strongly acidic soils (Wang et al., 2010). However, in the case of the current experiment, the recorded pH values could be considered neutral according to the ratings of Msanya (2012), indicating no negative impact of the hydrocarbon contaminants on the soil pH from the hydrocarbon irrigation water and the possible reason for that could be ascribed to low amount of hydrocarbon contaminants and dissolved salts in hydrocarbon irrigation water (Figure 1 and Table 1).

Comparison of Electrical Conductivity

Electrical conductivity (EC) is a soil salinity indicator (Bauder et al., 2011). The EC findings of both hydrocarbon and fresh water irrigated soils were presented in Table 3. The results showed that the mean EC values of all hydrocarbon and fresh water irrigated soils recorded were statistically ($P>0.05$) similar (Table 3). Despite no recorded statistical variation, phases I and III recorded the highest values compared to phase II and control irrigated soils. The possible reason behind this high recorded EC values could be attributed to high amount of solid particles from the hydrocarbon compounds of the irrigation water of the former phases compared to the latter phases. And when applied as irrigation amendment to the soils increased the concentration of the EC values observed (Maradi et al., 2013). Increase in soil EC takes place through moisture-filled pores between combination of soil particles and the added hydrocarbon compounds from hydrocarbon irrigation water, leading to increase in concentration of electrolytes (salts) in the soil water (Seifi, Alimardani and Sharifi, 2010). However, all the EC values in both hydrocarbon and control irrigated soils complied with recommended threshold values of 0-4dS/m in soils (FAO, 1993). This indicates that no threat of hydrocarbon contaminants on the soil salinity which could hinder infiltration and water permeability, and overall growth and productivity of grown crops (Bauder at al., 2011; Sani et al., 2021). The possible reason for this could be due to low hydrocarbon concentration in the irrigation water which is not sufficient enough to trigger the EC values above 4dS/m. Harris et al. (2004) reported lower EC values in their experimental soils after irrigating them with petroleum hydrocarbon contaminated irrigation water confirming data of the current study.

Comparison of the Exchangeable Bases (Ca, Mg, K and Na)

The result of exchangeable bases was also shown in Table 3. Findings indicated that the concentration of Ca and Mg was stable and in increasing order under hydrocarbon irrigated soils while fresh water irrigated soils recorded the lowest values. There was a significant difference in Ca and Mg concentration statistically ($P<0.05$) in all phases and fresh water irrigated soils (Table 3). In contrast, the concentrations of K and Na were unstable and variable with no trend of increasing or decreasing order (Table 3), and recorded no statistical significant difference between ($P>0.05$) all the irrigated soils. In all cases, hydrocarbon irrigated soils contained high amount of exchangeable bases compared to fresh water irrigated soils indicating the impact of hydrocarbon on the bases. The plausible reason for this could be attributed to accumulation of exchangeable bases in the soil induced by the hydrocarbon compounds in the irrigation water. Many publications have reported that soil contamination with hydrocarbons was associated with the accumulation of exchangeable bases such as $Ca^{2+,}$ Na^{+}, and a reduction in exchangeable acidity and effective cation exchange capacity as a result of the hydrocarbon compounds application to the soil (Agbodi et al., 2007;Wang et al., 2013).

The concentration of all the exchangeable bases in the soils of the current experiment according to the literature rating (Esu, 1991) is low. This implies that the hydrocarbon concentration has not impacted negatively on the soil exchangeable bases because of their low concentration in the irrigation water and as a result, even after being applied to the soil as irrigation amendment, the combined effect of hydrocarbon compounds and the exchangeable bases in the soil will not cause soil water permeability and infiltration difficulty (Bauder et al., 2011; Sani et al., 2020), because their combination were not sufficient enough to cause any change in the concentration of the exchangeable bases, hence, a threat free to crop growth and development. Similar results have been reported elsewhere (Sani et al., 2021).

Comparison of Organic Carbon

The result of soil organic carbon (SOC) concentration was depicted in Table 3 with concentration in a decreasing trend. Highest values were recorded in phase I followed by phases II and III irrigated with hydrocarbon irrigation water and the least in fresh water irrigated soils. However, no significant statistical (P>0.05) difference observed between the soils and the irrigation water (Table 3).

In wastewater irrigation, COD and BOD are the major sources of organic carbon accumulation in soils. However, when their concentration was above permissible allowable limit in the irrigation water, they can lead to SOC toxicity and soil quality degradation, and can negatively affect the growth of the crops grown in the soil (Sani et al., 2021). Wang et al(2009,2013) reported that petroleum hydrocarbons contain traces of nitrogen (N), phosphorus (P) and organic carbon (OC), and when applied to soil via hydrocarbon irrigation water, they attach themselves to soil surface and increase their concentration. However, according to Table 1, the COD and BOD concentrations of the industrial hydrocarbon irrigation water were high and above discharge and irrigation reuse limit of 0-146mg/l (Radeideh et al., 2009) and 0-30mg/l (USEPA, 2004) respectively. In contrast, the hydrocarbon concentration in the irrigation water (Figure 1 and Table 1) was comparatively low in comparison to up to100 ug/l reported in literature (Fameyiwo et al., 2017). Nevertheless, the concentration of the OC (0.39-0.59%) from the soil being irrigated with the hydrocarbon irrigation water was low (Esu, 1991). This implies no apparent impact of both BOD, COD and hydrocarbon compounds on the concentration of the OC in the irrigated soil. This is surprising considering the combined BOD, COD and hydrocarbon compounds concentration in the applied hydrocarbon irrigation water. However, the possible reason for this recorded low OC concentration in the irrigated soil could be attributed to high prevalent temperature of the tropical regions. The temperature rapidly decomposes and mineralizes organic materials (Sharu et aI., 2013) which could have degraded the already accumulated OC in the soil into low concentration.

Comparison of Total Nitrogen

According to Table 3, the concentration of total nitrogen (TN) was in decreasing order with phase I recording the highest values in comparison to other phases and FW treated soils, and statistically, no significant differences were recorded (P>0.05) between them.

In irrigation wastewater, ammonium and nitrate nitrogen are the major sources of TN, and when applied inform of irrigation amendment to soil in appropriate concentration, increase TN content within the crops requirement. However, in contrast, if the concentration is above irrigation allowable limit, they lead to soil nitrogen toxicity, soil acidification and exerts harmful effects to the crops grown in the affected soils (Sani et al., 2020). According to Esu (1991), TN concentration of the current study is low in both hydrocarbon irrigated and control soils (Table 3). Nonetheless, the TN concentration is high and above both discharge and irrigation reuse limit (Sani et al., 2020) in the irrigation water sources (NO_3-N and NH_4-N) (Table 1) which is very suprising considering the recorded TN contents of the irrigated soils (Table 3). Furthermore, the result indicates that the applied hydrocarbon has not affected the nitrogen concentration of the soils despite literature has documented that hydrocarbon irrigation water contains nitrogen compounds in them, and when applied as irrigation amendment to agricultural soils increases the soils nitrogen contents (Wang et al., 2009, 2013).

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Table 3: Impact of hydrocarbon wastewater Irrigation on some selected Soil Chemical Properties in Sharada Industrial Area

Industrial phases					
Soil parameters	**Units**	**I**	**II**	**III**	**Control soils**
pH	(-)	7.47^{NS}	7.20^{NS}	7.22^{NS}	7.20^{NS}
Electrical Conductivity (EC)	dS/m	0.24^{NS}	0.20^{NS}	0.24^{NS}	0.12^{NS}
Calcium (Ca)	mg/kg	1.62^{b}	2.52^{ab}	3.69^{a}	0.49^{c}
Magnesium (Mg)	mg/kg	1.01^{b}	1.73^{a}	1.91^{a}	0.92^{b}
Potassium (K)	mg/kg	0.63^{NS}	0.67^{NS}	0.61^{NS}	0.21^{NS}
Sodium (Na)	mg/kg	0.46^{NS}	0.30^{NS}	0.12^{NS}	0.09^{NS}
Organic Carbon (OC)	(%)	0.59^{NS}	0.43^{NS}	0.39^{NS}	0.25^{NS}
Total Nitrogen (TN)	(%)	0.43^{NS}	0.29^{NS}	0.27^{NS}	0.22^{NS}
Cation Exchange Capacity (CEC)	cmol/kg	9.09^{a}	3.89^{b}	3.62^{c}	2.22^{d}
Phosphorus (P)	mg/kg	32.56^{a}	22.74^{c}	27.7^{b}	14.4^{d}

Note; NS, no significant difference and means having the same letters in the same column are statistically similar, Means are separated using DMRT at 5% level of confidence

However, the possible explanation behind these recorded low values of TN in the soil could be attributed probably due to consumption of the already accumulated nitrogen compounds in the soils by hydrocarbon degrading soil microorganisms as their source of energy (Scholz, 2010). This nitrogen utilization by the hydrocarbon degrading microbes must have led to the observed lower concentration in the hydrocarbon irrigated soils.

Concerning the statistical variation, although no significant difference recorded (P>0.05) between the irrigated soils in different phases and control soils, Table 3 indicated that phase I recorded the highest values of TN. This could be attributed to confluence of high human and animal faces (Nuruddeen et al., 2016), and excess nitrogenous compounds in the phase I hydrocarbon irrigation water from domestic and agricultural sources (Sani et al., 2020) around the area compared to other phases. Consequently, raising the TN concentration in hydrocarbon irrigated phase I soils.

Comparison of Cation Exchange Capacity

Cation exchange capacity (CEC) is an interfacial process during which a cation on a clay surface is replaced by another cation (Lehmann et al., 2005). Moreover, the capacity of soil particles to retain cations is measured by the CEC.

The variability in CEC concentration of the soils irrigated with hydrocarbon irrigation water and fresh water is presented in Table 3. The result indicated that highest CEC values were recorded in phase I compared to other phases with significant difference (P<0.05) statistically. However, despite these significant differences in the concentration of CEC observed, all the recorded values were low according to literature (Esu, 1991). Generally, the low CEC values observed across all the phases could be attributed to depression effect by the applied hydrocarbon contaminants in the soil via the irrigation water (Gong et al, 2008). The hydrocarbon contaminants bind with the soil inorganic and organic matter fractions, reducing the CEC concentration, thus making them unavailable to crops utilization (Hu et al., 2006). On the other hand, the plausible reason for the highest CEC concentration observed in phase I irrigated soils (Table 3) could be due to high amount of OC, TN and P from their sources (COD and BOD, NO_3-N and NH_4-N and PO_4-P) in phase I hydrocarbon irrigation water. Consequently, application of the water to the soils raised the CEC values in comparison to other irrigated soils. This is because the latter applied nutrients are responsible for retaining the exchangeable cations (Lickaz and Penny, 2001) hence, if they are in high concentration in the irrigation water, they rise the CEC concentration and vice-versa.

Comparison of Phosphorus

The concentration of soil phosphorus (P) irrigated with hydrocarbon irrigation water and fresh water was depicted in Table 3.The result indicated that P concentration was higher in phase I irrigated soils followed by phase III, phase II and control soils with significant statistical variation (P<0.05) (Table 3). This implies that the hydrocarbon irrigation water has impacted on the P contents of the soils. However, even with the significant statistical difference recorded, all the P concentrations recorded were high according to the rating of Esu (1991). The possible reason for this high concentration of P in the irrigated soils could be probably due to P concentration in the hydrocarbon irrigation water. Many studies revealed that hydrocarbon wastewater contains certain amounts of P in them (Wang et al., 2009, 2013), and when applied to the soils raises the P contents in the irrigated soils. On the other hand, the possible reason for the highest concentration of P in phase I soils compared to other soils could be attributed probably to the reason stated above (Wang et al., 2009, 2013) in the phase I irrigation water..

CONCLUSION

The aim of the current study was to assess the variability of chemical and physical characteristics of Sandy loam soils after long-term irrigation with hydrocarbon wastewater. Findings indicated that the hydrocarbon concentration in all phases was low and below irrigation reuse standard in the irrigation water. However, the major irrigation water quality parameters; COD, BOD, NO_3-N, HCO_3, NH_4-N, K, Cl and PO_4-P in all phases were all above irrigation reuse standard in comparison to other parameters that were compliant. Furthermore, the impact of the applied hydrocarbon irrigation water on the study area soils revealed that soil texture was loamy sand and sandy loam while soil parameters; OC, TN, CEC, P and Exchangeable bases increased in concentration compared with control. However, the soil EC was low and variable, pH was neutral, whereas BD values decreased in concentration along the phases and higher than control after long-term irrigation with hydrocarbon irrigation water. Overall, the study indicated that Sharada industrial hydrocarbon irrigation water can be used as an alternative source of irrigation water only following both discharge and irrigation reuse quality evaluation. Moreover, organic and inorganic amendments should be added to the soils to help and improve fertility and quality of soil properties of the study area.

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