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Evaluation of the Health Status in a Post Remediated Crude Oil Contaminated Soil Using a Suitable Soil Quality Index (SQI)

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Abstract The soil quality (healthy) status of a post remediated crude oil contaminated soil have been determined experimentally. This study is aimed at determining the health status (soil quality) in the post bioremediated crude oil polluted soilusing a suitable soil quality index (SQI) for the purpose of evaluating the use of TPH level as the only criterion for assessing health status (soil quality) hydrocarbon remediated sites. The proposed suitable Soil Quality Index incorporates 19 important properties/parameters of soils. Results presented using the suitable index was based on the score accumulated from parameters that have been analyzed. A post oil spill analysis from the soil sample showed that the TPH concentration dropped from 4105 mg/kg at the start of the treatment to 37 mg/kg about six weeks after application of the various RENA techniques which is below TPH maximum level of 50 mg/kg compliance baseline limit set for petroleum industries in Nigeria indicating a site that is suitable for agricultural activities. However, SQI calculated in this study is 13indicating that the studied soil has significantly lower than that of a good soil or healthy soil of SQI of 26. Therefore the use of TPH as the parameter to determine the level of restoration of crude oil contaminated site should be reviewed as it is deficient in assessing itshealth status (soil quality).

Keywords Soil quality, post remediated soil, total petroleum hydrocarbon, Soil Quality Index, crude oil

1. Introduction

The soil, like air and water, is an integral component of our environment and together with water constitutes the most important natural resource. 95% of our food comes from the soil one way or another as it provides support to plants; soil is home of diverse microorganisms such as bacteria, yeast cells and fungi and it helps in the decomposition and mineralization of organic matter and regeneration of nutrients. The wise use of this vital resource is essential for sustainable development and feeding the growing world population. However, in the past decades, hydrocarbon - polluted soils are widespread across the globe due to increase in the demand for petroleum as an energy source. Petroleum (crude oil) and its product enter the soil via crude oil pipe leakages, oil tank ruptures, pipeline vandalization and indiscriminate disposal of refinery products [1] leading to changes in soil properties [2].

Soils polluted with petroleum hydrocarbon are low in fertility and hence, do not support adequate crop growth and development [3]. Crude oil polluted is unproductive in agricultural terms. For soil to perform its function in both the production of food and fiber and global ecosystems it must be healthy. Soil health, or quality, can be broadly defined as the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health [4]. Soil quality can be conceptualized as a three-legged stool, the function and balance of which requires an integration of three major components — sustained biological productivity, environmental quality, and plant and animal health [5]. Defining soil quality is a complex functional concept and cannot be measured directly in the field or laboratory but can only be inferred from soil characteristics, a range of soil parameters or indicators has been identified to estimate soil quality. Thus, a mathematical or statistical framework was put forward in early 1990s to estimate soil quality index (SQI) ([5-6]. Of the soil quality indices developed, the Amacher *et al*., 2007 index that that integrates 19 soil physical and chemical properties measured in into a single number have been used to monitor changes in forest and agricultural soil properties with time (Table 1).The individual index values for all the mineral soil properties measured and summed to give a total SQI:

$$\text{Total SQI} = \Sigma \text{ individual soil property index values}$$

The maximum value of the total SQI is 26 while the minimum is -2 if all 19 soil properties are measured.

The total SQI is then expressed as a percentage of the maximum possible value of the total SQI for the soil properties that are measured:

$$\text{SQI, \%} = (\text{total SQI / maximum possible total SQI for properties measured}) \times 100$$

Solutions to reversing unproductive soil to productive soil are very important. In today's era of heightened environmental awareness and good stewardship of limited natural resources effort to clean up contaminated sites involve series of remedial techniques or approaches ranging from conventional physicochemical techniques and natural attenuation to phytoremediation (the most emerging biotechnology approach).A post oil spill total petroleum hydrocarbon (TPH) analysis from the soil is required as part of monitoring and remediation programme and TPH maximum level of 50mg/kg compliance baseline limit set for petroleum industries in Nigeria [7]. Therefore this study is aimed at determining the health status (soil quality) in the postbioremediated crude oil polluted soils using soil quality index (SQI) for the purpose of evaluating the suitability of using TPH level as the only criterion for assessing health status (soil quality) hydrocarbon remediated sites.

Table 1: Soil Quality Index [8]

S/No	Parameters/ Units	Level	Interpretation	Index
1.	Bulk density (g/cm^3)	> 1.5	Possible adverse effects	0
		< 1.5	Adverse effects unlikely	1
2.	Coarse fragments	> 50	Possible adverse effects	0
		<50	Adverse effects unlikely	1
3.	Soil pH	< 3.0	Severely acid – almost no plants can grow in this environment	-1
		3.01 to 4.0	Strongly acid – only the most acid tolerant plants can grow in this pH range and then only if organic matter levels are high enough to mitigate high levels of extractable Al and other metals	0
		4.01 to 5.5	Moderately acid – growth of acid intolerant plants is affected depending on levels of extractable Al, Mn, and other metals	1
		5.51 to 6.8	Slightly acid – optimum for many plant species, particularly moreacid tolerant species	2
		6.81 to 7.2	Near neutral – optimum for many plant species except those that prefer acid soils	2
		7.21 to 7.5	Slightly alkaline – optimum for many plant species except those that prefer acid soils, possible deficiencies of available P and some metals (for example, Zn)	1
		7.51 to 8.5	Moderately alkaline – preferred by plants adapted to this pHrange, possible P and metal deficiencies	1

		> 8.5	Strongly alkaline – preferred by plants adapted to this pH range, possible B and other oxyanion toxicities	0
4.	Total organic carbon in mineral soils (percent)	>5	High – excellent buildup of organic C with all associated benefits	2
		1 to 5	Moderate – adequate levels	1
		<1	Low – could indicate possible loss of organic C from erosion orother processes, particularly in temperate or colder areas	0
5.	Total nitrogen in mineral soils (percent)	>0.2	High – excellent reserve of nitrogen	2
		0.1 to 0.5	Moderate – adequate levels	1
		<0.1	Low – could indicate loss of organic N	0
6.	Exchangeable Na percentage (exchangeable Na/ECEC x 100)	>15	High – sodic soil with associated problems	0
		<15	Adverse effects unlikely	1
7.	K (mg/kg)	>500	High – excellent reserve	2
		100 to 500	Moderate – adequate levels for most plants	2
		<100	Low – possible deficiencies	0
8.	Mg (mg/kg)	> 500	High – excellent reserve	2
		50 to 500	Moderate – adequate levels for most plants	1
		< 50	Low – possible deficiencies	0
9.	Ca (mg/kg)	> 1000	High – excellent reserve, probably calcareous soil	2
		101 to 1000	Moderate – adequate levels for most plants	1
		10 to 100	Low – possible deficiencies	0
		< 10	Very low – severe Ca depletion, adverse effects more likely	- 1
10	Al (mg/kg)	> 100	High – adverse effects more likely	0
		11 to 100	Moderate – only Al sensitive plants likely to be affected	1
		1 to 10	Low – adverse effects unlikely	2
		< 1	Very low – probably an alkaline soil	2
11	Mn (mg/kg)	> 100	High – possible adverse effects to Mn sensitive plants	0
		11 to 100	Moderate – adverse effects or deficiencies less likely	1
		1 to 10	Low - adverse effects unlikely, possible deficiencies	1
		< 1	Very low – deficiencies more likely	0
12	Fe (mg/kg)	> 10	High – effects unknown	1
		0.1 to 10	Moderate – effects unknown	1
		< 0.1	Low – possible deficiencies, possibly calcareous soil	0
13	Ni (mg/kg)	> 5	High – possible toxicity to Ni sensitive plants, may indicate serpentine soils, mining areas, or industrial sources of Ni	0
		0.1 to 5	Moderate – effects unknown	1
		< 0.1	Low – adverse effects highly unlikely	1
14	Cu (mg/kg)	> 1	High – possible toxicity to Cu sensitive plants, may indicate mining areas or industrial sources of Cu	0
		0.1 to 1	Moderate – effects unknown, but adverse effects unlikely	1
		< 0.1	Low – possible deficiencies in organic, calcareous, or sandy soils	0

15	Zn (mg/kg)	> 10	High – possible toxicity to Zn sensitive plants, may indicate mining areas or industrial sources of Zn	0
		1 to 10	Moderate – effects unknown, but adverse effects unlikely	1
		< 1	Low – possible deficiencies in calcareous or sandy soils	0
16	Cd (mg/kg)	> 0.5	High – possible adverse effects	0
		0.1 to 0.5	Moderate – effects unknown, but adverse effects less likely	1
		< 0.1	Low – adverse effects unlikely	1
17	Pb (mg/kg)	> 1	High – adverse effects more likely, may indicate mining areas or industrial sources of Pb	0
		0.1 to 1	Moderate – effects unknown, but adverse effects less likely	1
		< 0.1	Low – adverse effects unlikely	1
18	S (mg/kg)	> 100	High – may indicate gypsum soils, atmospheric deposition, mining areas, or industrial sources	0
		1 to 100	Moderate – adverse effects unlikely	1
		< 1	Low – possible deficiencies in some soils	0
19	P (mg/kg)	> 30	High – excellent reserve of available P in slightly acidic toalkaline soils, possible adverse effects to water quality fromerosion of high P soils	1
		10 to 30	Moderate – adequate levels for plant growth	1
		< 10	Low – P deficiencies likely	0

2. Materials and Methods

2.1. Study Site Description

A ten-inch (10") kwale-Irri pipeline that transport crude oil from Irri field to Kwale gas recycling plant was vandalized at a point within Ofagbe community axis thus releasing appreciable quantity of crude oil (120 barrels) into the surrounding environment [9]. Sub section 2.11.3 of Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) states that "any operator or owner of a facility that is responsible for a spill that results in impact of the environment shall be required to monitor the impacted environment alongside the restoration activities [7]. Consequently the impacted was cleaned-up and thereafter remediated using the Remediation by enhanced natural attenuation(RENA) method.

The following RENA techniques were employed to treat the contaminated soil.

Spiking of Test Soils: The soils were spiked with water uniformly to soften the soil and to allow the water penetrate the soil matrix.

Initial Tilling: The soils were tilled in a week after they were spiked, that is mixing the soil and breaking the lumps. This was done using shovel, composite samples were collected and sent to the laboratory for physiochemical and microbial evaluation.

Secondary Tilling: The soils were tilled and homogenized a week after the initial tilling. The lumps were broken to very fine particles with as hovel and a rake. The essence of the tilling and homogenization was to uniformly distribute the petroleum contaminants and break up the soil lumps to fine particles thereby increasing the surface area. The composite samples were taken for analysis.

Windrow Construction: Windrows/ridges were constructed after the secondary tilling of the test site. The ridges measured about 50 cm high and 10 cm wide. The windrows are made to achieve better aeration and optimize the efficiency of the attenuated processes in action, which exposes the microorganisms to oxygen, and aids in the biodegradation process of the petroleum hydrocarbon. Soil samples were taken for analysis

Breaking down of Windrows: The windrows were broken down after standing for between 3 and 4 weeks, after construction. Soil samples were taken for analysis.

Addition of Water: Water was added to the sandy soil to enhance the biodegradation of the petroleum hydrocarbons by the microorganisms when it penetrates the soil.

Addition of Biosolve Surfactant: Biosolve surfactant application was done manually by sprinkling the surfactant over the contaminated area. The process enhances the biodegradation of the petroleum hydrocarbon

*Outcome of the Bioremediation:*The TPH concentration dropped 4105mg/kg at the start of the treatment to 37 mg/kg about six weeks after application of the various RENA techniques, which is below TPH maximum level of 50mg/kg compliance baseline limit set for petroleum industries in Nigeria [7,9].

2.2. Experimental procedure

For the purpose of the study, three (3) random soil samples were obtained from the post remediated site within the depth of 0– 30cm depths under no-tillage (NT)practices and composited to make representative sample. Soil samples were collected using the hand auger. Samples for physico-chemical analysis were collected into coded plastic bags and were taken to the laboratory for analysis.

At the laboratory samples were analysed for the 19 parameters as required by soil quality index. Bulk density (BD) was determined using the dry weight method. The pH of the soil samples was determined in 1:2 soil:water ratio slurry using a Thermo-scientific Orion Star Series pH Meter. Concentrations of soil total organic C and total N were determined using an Elemental analyzer (Vario Max, Elemental Americas, Inc., Germany) by the dry combustion method (900°C) after grinding subsamples to 0.25 mm. Heavy metals (Mn, Fe, Ni, Cu, Zn, Cd, and Pb) in the soil samples were determined using ATI Unicam Atomic Absorption Spectrophotometer, Model 939. The sample digestion/preparation procedure followed is described in ASTM D5198/D3974.Exchangeable cations (Na, K, Mg and Ca) in the soil samples were determined using ATI Unicam Atomic Absorption Spectrophotometer (AAS), Model 939. The samples were prepared according to the procedure described in the ASTM D5198. Aluminium content of the soil sample was determined by air-acetylene flame atomic absorption spectrometry.The amount of phosphorus was determined by Spectrophotometric method in which the ammonium phosphomolybdate complex, which was formed first, was reduced by ascorbic acid in presence of antimony to give a distinct blue colour which was measured at 880nm. Sulphur was analyzed by adding excess barium chloride to precipitate barium sulfate which be then determined by turbidimetry method and was measured at 420nm. All methods of analysis are consistent with international standards [7, 10-11].

3. Results and Discussion

Results of the physico-chemical analysis of the soil sample using the Soil Quality Index of 19 parameters [8] are as presented in Table 2.

Table 2: Soil Quality Index and Interpretation of Study Site

S/No	Parameters	Obtained values	Soil Quality Index(SQI) of Study Site	Interpretation
1	Bulk density(g/cm^3)	1.34 g/cm^3	1	Adverse effects unlikely
2	Coarse fragments	37	1	Adverse effects unlikely
3	Soil pH	5.9	2	Slightly acid – optimum for many plant species, particularly moreacid tolerant species
4	Total organic carbon inmineral soils (percent)	4.7	1	Moderate – adequate levels
5	Total nitrogen in mineralsoils (percent)	0.06	0	Low – could indicate loss of organic N
6	Exchangeable Napercentage (exchangeable	12.8	1	Adverse effects unlikely

	Na/ECEC x 100)			
7	K (mg/kg)	29.1	0	Low – possible deficiencies
8	Mg (mg/kg)	31.8	0	Low – possible deficiencies
9	Ca (mg/kg)	16.3	0	Low – possible deficiencies
10	Al (mg/kg)	4.7	2	Low – adverse effects unlikely
11	Mn (mg/kg)	0.71	0	Very low – deficiencies more likely
12	Fe (mg/kg)	37.4	1	High – effects unknown
13	Ni (mg/kg)	0.24	1	Low – adverse effects highly unlikely
14	Cu (mg/kg)	0.83	1	Moderate – effects unknown, but adverse effects unlikely
15	Zn (mg/kg)	0.18	0	Low – possible deficiencies in calcareous or sandy soils
16	Cd (mg/kg)	0.07	1	Low – adverse effects unlikel
17	Pb (mg/kg)	0.05	1	Low – adverse effects unlikely
18	S (mg/kg)	0.80	0	Low – possible deficiencies in some soils
19	P (mg/kg)	2.60	0	Low – P deficiencies likely
∑SQI			13	

Soil bulk density may indicate soil compaction but is dependenton many soil factors including particle size distribution, soil organic matter content,and coarse fragment content. Generally, bulk density increases with increasingsand and rock content and decreases with increasing organic matter content. Bulk density gives a good indication of the suitability for root growth and soil permeability and is vitally important for the soil-plant-atmosphere system [12-13]. A mineral soil with goodphysical properties has 50 percent solids and 50 percentpore space occupying a given volume of space. At optimal water content, half the pore space is filled with water. Such a soil will have a bulk density of 1.33 g/cm^3 [14].

The soil sample in the remediated site has a bulk density value of 1.34g/cm^3 indicative of a site that is suitable for plant growth. In general, roots grow well in soils with bulk densities of up to 1.4 g/cm^3 and rootpenetration begins to decline significantly at bulk densities above 1.7 g/cm^3 [15-16].

Soils with a coarse fragment content of > 50 percent have a greater probability of adverse effects from infiltration rates that are too high, water storage capacity that is too low, more difficult root penetration, and greater difficulty in seed germination and seedling growth. High coarse fragment contents have been shown to limit forest soil productivity [17].

The soil sample in the remediated site has a coarse fragment content of 37 percent.

pH is a measure of acidity and alkalinity. It is one of the most significant measurements of the chemical properties of a soil. Although many plant species are adapted to acidic or alkaline soils, vegetation diversity tends to decline at strongly acid (pH<4) or strongly alkaline (pH>8.5) pH levels. pH is also an indicator of plant nutrient availability, mineral solubility and micro-organism activity. For example, the availability of many plant nutrients (e.g. P), non-essential elements (e.g. Al, Cd, Pb), and essential trace elements (e.g. Mn, Fe, Cu, Zn) is strongly dependent on soil pH [18]. Generally, metal cations (for example, Mn, Fe, Ni, Cu, Zn, Cd, Pb) become more available as pH decreases, while oxyanions (for example, SO_4) become more available at alkaline pH levels. Only the most acid- or alkaline-tolerant plant species can survive at the very acidic or alkaline ends of the pH scale. Knowledge of the soil condition and the crop are important in managing soil pH for the best crop performance. Obtained pH in the study area is 5.9 indicating a slightly acidic soil suitable for the growth of some plants.

Organic matter (carbon and nitrogen) is a key component of soils because of its influence on soil physical and chemical properties and soil biota [19]. Soils with total organic carbon (TOC) and total N contents of less than 1 percent and 0.1 percent, respectively, are at a greater risk of decline if soil erosion and/or other disturbances that accelerate organic matter loss continue to result in a net loss of soil organic matter, particularly in areas where nearby undisturbed, native soils are found to have higher levels of TOC and total N [19]. TOC is expressed as percent C per 100 g of soil and in this study TOC value of 4.7% was obtained.Nitrogen level in the soil sample is low with a value of 0.06% and this may have resulted from the sandy nature of soil.

Exchangeable sodium percentage (ESP) is computed by dividing the exchangeable Na concentration (cmolc/kg) by the effective cation exchange capacity (ECEC) (cmolc/kg) multipliedby 100 (Na^+/{(Na)/(Ca + Mg + K + Na)} x 100). Soils with an ESP of > 15 percent are classified as sodic or saline/sodic soils depending on the salt content of the soils as measured by the electrical conductivity of a saturated soil extract [20]. The soil sample obtained at the study site contains 12.8% of exchangeable sodium and this dominates the exchange complex. A soil is considered sodic when the Exchangeable Sodium Percentage (ESP) is 6% or greater.

Potassium (K) is an essential nutrient for plant growth. Because large amounts are absorbed from the root zone in the production of most agronomic crops, it is classified as a macronutrient. Potassium is associated with movement of water, nutrients, and carbohydrates in plant tissue. If K is deficient or not supplied in adequate amounts, growth is stunted and yields are reduced. The total K content of soils frequently exceeds 20,000 ppm (parts per million). In the study site low quantity of K is avaialble (29.1 mg/kg) therefore the need for K in a fertilizer program is recommended.

Magnesium is a component of several primary and secondary minerals in the soil, which are essentially insoluble, for agricultural considerations. These materials are the original sources of the soluble or available forms of Mg. Magnesium is also present in relatively soluble forms, and is found in ionic form (Mg^{++}) adhered to the soil colloidal complex. The ionic form is considered to be available to crops. Magnesium is essential for many plant functions especially in chlorophyll formation. Soil sample obtained from the study site contain magnesium level of 31.8mg/kg which is considered low. Plants growing in soils with very low levels of exchangeable K and Mg (< 100 and 50 mg/kg, respectively) have a greater probability ofexhibiting deficiency symptoms than plants growing in soils with higher levels of these elements.

Calcium is considered a secondary plant nutrient. Only nitrogen and potassium are required in larger amounts by plants. Every plant needs calcium to grow and once fixed, calcium is not mobile in the plant. It is an important constituent of cell walls and can only be supplied in the xylem sap. Thus, if the plant runs out of a supply of calcium, it cannot remobilize calcium from older tissues. Without adequate amounts of calcium, plants experience a variety of problems. Calcium level in the study soil sample is 16.3mg/kg.

Aluminum is not an essential element for plants. It can be harmful to plants. High exchangeable Al levels are deleterious to plant growth, but this can be mitigated somewhat by high organic matter levels (Hargrove andThomas, 1981). Excess soluble/available aluminum (Al^{+++}) is toxic to plants and causes multiple other problems such as; reduced availability of phosphorus (P), through the formation of Al-P compounds, reduced availability of sulfur (S), through the formation of Al-S compounds. Soil sample in the study site is 4.7mg/kg which is adequate for plant growth as it within the soil pH of between 5.5 and 6.0, soluble Al is not likely to be a significant problem [21].

Manganese (Mn) is essential for many plant functions. Some of them are: the assimilation of carbon dioxide in photosynthesis; aids in the synthesis of chlorophyll and in nitrate assimilation; activates fat forming enzymes; the formation of riboflavin, ascorbic acid, and carotene; and in electron transport during photosynthesis. High soil pH reduces Mn availability while low soil pH will increase availability, even to the point of toxicity. Level of Mn in the studied soil sample is 0.71 mg/kg.

Iron is essential for many plant functions. Some of them are: chlorophyll development and function; plays a role in energy transfer within the plant; a constituent of certain enzymes and proteins; in plant respiration and plant metabolism and involved in nitrogen fixation. Iron concentration in the soil sample is 37.4 mg/kg. Obtained value may be due to the natural component of the earth because the study area is within the Niger Delta area that is made up of the Benin Formation [22].

Nickel (Ni) is a heavy metal whose natural content in the soil can vary from very small proportions (< 5 mg kg^{-1}), which qualify it as a trace element, to excessively high concentrations (5000 mg kg^{-1}), found in the soils formed on ultrabasic igneous rocks [23]. Plants require Ni because the element acts as a urease activator, which breaks urea into carbonic gas and ammonia [24]. Nickel in the soil sample is 0.24 mg/kg.

Copper (Cu) is an essential nutrient for plant growth, but because only a small amount is needed, it is classified as a micronutrient. Copper is an important component of proteins found in the enzymes that regulate the rate of many biochemical reactions in plants. Soil sample in the study area contain 0.83mg/kg of copper and it is adequate for optimum crop yields [24].

Zinc (Zn) is an essential nutrient required in some fertilizer programs for crop production. While some soils are capable of supplying adequate amounts for crop production, addition of zinc fertilizers is needed for others. In study site Zn had value of 0.18mg/kg.

Cadmium, a rare but widely dispersed element, is found naturally in the environment as cadmium ore (green ockite). Cadmium level in the soil sample is 0.02mg/kg which is lower than the range 0.1 to 1.8 mg kg^{-1}dry weight (DW) for rural soils, with a mean of 0.39 mg kg^{-1} in United Kindom [25].

Lead contamination is naturally present in all soils. It occurs generally in the range of 15 to 40 parts lead per million parts of soil (ppm), or 15 to 40 milligrams lead per kilogram of soil (mg/kg) [24]. Obtained lead level in the study site is 0.05 mg/kg which may be attributed to natural factors.

Sulphur (S) is essential for many plant functions. Some of them are; structural component of protein and peptides; active in the conversion of inorganic N into protein; a catalyst in chlorophyll production; promotes nodule formation in legumes; a structural component of various enzymes and a structural component of the compounds that give the characteristic odours and flavours to mustard, onion and garlic. The dominant form of S in soil is sulphate (SO_4^{2-}). Sulphate is highly mobile in most soils. High levelsof exchangeable sulphate would likely only be found in acid soils containingmetal oxide minerals that can sorb the sulphate, metal sulphides mineral areas. Sulphur level in the soil sample was 0.8mg/kg. Sulphur is leachable, plus sandy soils are typically low in organic matter, therefore these soils are often low in sulphur [18].

Plant roots absorb phosphorus from the soil solution in the form of Orthophosphates ($H_2PO_4^-$ and HPO_4^{2-}), and are the primary forms of phosphorus taken up by plants. Phosphorus is involved in many plant processes, including: energy transfer reactions; development of reproductive structures; crop maturity; root growth and protein synthesis. At the study site phosphorus level in the soil sample was 2.60mg/kg. The low level may have resulted from the presence of sandy soil. Generally, deficiency symptoms are not exhibited by plants growing in soils with P levels above 15 mg/kg [8].

3.2. Soil Quality Index

The SQI value obtained in this study is 13 for all 19 physical and chemical soil properties indicating an environment of decline soil quality. Amacher et al.,(2007) have reported that lower values of SQI numbers (<20)within a given area is an indication of the potential for an increased risk of soil-related health decline.However, maximum value of the total SQI for a healthy (good quality) soil is 26 while the minimum for poor soil is -2 if all 19 soil properties/parameters.

4. Conclusion

A post oil spill analysis from the soil sample showed that the TPH concentration dropped from 4105mg/kg at the start of the treatment to 37 mg/kg about six weeks after application of the various RENA techniques which is below TPH maximum level of 50mg/kg compliance baseline limit set for petroleum industries in Nigeria [7]. This indicates that the soil is suitable for agricultural activities. However, SQI calculated in this study is 13 which is less than 26 indicating an area of great potential for an increased risk of soil-related health decline.

Therefore the use of TPH as the parameter to determine the level of restoration of crude oil contaminated site should be reviewed as it is deficient in assessing the health status (soil quality).

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