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Investigation of Palm Oil Mill Effluent Pollution Impact on Groundwater Quality and Agricultural Soils

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Authors' contributions

This work was carried out in collaboration among all authors. Author SAN designed the study, wrote the protocol, literature searches, analyses of study and wrote first draft of the manuscript. Author SOU did the statistical analysis. Authors SAN and IJU read and approved the final manuscript.

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ABSTRACT

A field study was conducted to investigate palm oil mill effluent (POME) pollution impact on ground water quality and agricultural soils. Raw POME and two water samples were also collected from the downstream and upstream locations away from the effluent discharge point using 1 litre capacity container. This was found less than 100 m from the mill. Soil samples from the POME dumpsite as well as non-POME soil were collected. Temperature, pH, electrical conductivity (EC), salinity, total hardness, turbidity, sulphate, COD, BOD_5, total dissolved solids (TDS), total suspended solids (TSS), dissolved oxygen, total alkalinity and percentage saturation for water samples were determined. pH, water holding capacity, total organic carbon (TOC), total organic matter (TOM), total nitrogen, available phosphorus, exchangeable cations: K, Na, Ca, Mg and cation exchange capacity for soil. Data obtained from the study were subjected to statistical analyses of variance (ANOVA). Significant variations exist in most of the physicochemical variables among the sampled parameters. Data for water samples were also compared with world health organization and Nigerian standard for drinking water quality. Most of these parameters indicated pollution but were

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below the standard limits for consumption. pH, EC, total hardness, turbidity, sulpahte, COD, BOD5, TDS, TSS, dissolved oxygen, total alkalinity, % saturation were all significant difference from each other. Soil pH, EC, TOC, total nitrogen, available P, TOM, Ca and exchangeable acidity were also all significant difference from each other. It is concluded that a strong move towards quality and environmental management through ecological improvement and cleaner technology approach within manufacturing industries in Nigeria is implemented.

Keywords: Pome; composition; impact; water quality; agricultural soil.

1. INTRODUCTION

The palm oil industry is one of the major agro based enterprise in Nigeria especially in the southern part where palm oil trees are found both in the wild and plantations [1]. Palm oil processing is carried out using large amounts of water in mills where oil is extracted from the palm fruits. During the extraction process, over 50% of the water results in effluents. It is estimated that for every 1 tonne of palm oil produced, 5 to 7.5 tonnes of water end up as effluent [2,3,4,5]. Raw POME consisting of complex vegetative matter that is thick, brownish colloidal mixture of water, oil and fine suspended solids. It is hot and have a very high Biochemical Oxygen Demand which is non-toxic as no chemicals are added to the extraction process [6,7], and also acidic with a pH of about 4.5 as it contains organic acids in complex forms that are suitable to be used as carbon source [8]. These brownish and colloidal suspensions of POME have high concentration of organic matter, chemical oxygen demand (COD) (51,000 mg/L), oil and grease (4,000 mg/L), high volumes of total solids (40,000 mg/L), and biological oxygen demand (BOD) (25,000 mg/L) [9]. The component of raw POME has been described to be a colloidal suspension initiating from mixture of sterilizer condensate, separator sludge and hydro cyclone wastewater in a ratio of 9:15:1 respectively [10]. Nevertheless, it holds considerable amounts of plants nutrients such as magnesium, nitrogen, calcium and potassium [11,12]. Toxic metals such as lead (Pb) can also be found in POME [11], but their concentrations are generally below sub-lethal levels (> 17.5 µg/g) [13]. Additional heavy metals present in POME are iron, cadmium, chromium and copper. The raw treated POME has a high content of degradable organic matter, which is due in part to the existence of unrecovered palm oil [14].

Untreated POME holds high quantities of protein, fatty acids, carbohydrates etc. [15,16], which has the affinity of changing environmental parameters particularly BOD, dissolved oxygen (DO), carbon to nitrogen ratio (C/N) and COD level [4]. This highly polluting POME can contaminant nearby streams and rivers due to oxygen depletion, land use and other related effects [17,18,4,14,6,19]. Discharged POME on aquatic ecosystem turns the water brown, smelly and slimy [18], which may kill fishes and other aquatic organisms and deny the human inhabitant of such area assesses to safe water for domestic uses [20]. Thus, while enjoying a most profitable commodity, palm oil, the opposing environmental impact from the palm oil industry cannot be overlooked. Large and medium scale mills produce numerous volumes of POME from the processing lines, like sterilizers, clarifying centrifuges and hydrocyclones. However, small-scale processors generate minimal effluents because majority of the wastewater are reused.

Most of the POME produced by small scale traditional operators in southern Nigeria undergo no treatment and are generally discharged in the surrounding environment. This POME could foul streams, rivers or surrounding land [4], either as point or non-point source of pollution. Rivers and streams water consequently turns brown, smelly and slimy. Often fish and other aquatic organisms get killed and local people are denied the availability of local water sources for domestic uses and fishing [21]. The aim of this study was to investigate POME pollution impact on quality of receiving surface water and agricultural soils in Abak Usung Idim, Abak Local Government area of Akwa Ibom State, Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

Ekaidem Multipurpose Cooperative Mill is located in Abak Local Government Area, Akwa Ibom State, Nigeria. It is located within the fresh water swamp forest between longitude 4° 5’ 0’’ and 5° 3’ 0’’ East and latitude 7° 4’ 5’’ and 8° 0’ 0’’ North. Rainfall ranges from 2000-3000 mm per annum, temperature are generally high all year

round ranging between 26 ℃ – 28 ℃. Fig. 1 shows the map of the study area and map of Nigeria showing Abak.

2.2 Samples and Sampling Techniques

A visual inspection of the sampling sites was conducted and the differences between the sites in terms of vegetation, presence of constitution, soil colour, odour, etc. was observed and noted Plate 1 shows POME dumpsite. 1 litre capacity container was used to collect the POME for laboratory analyses. Two water samples were also collected (5 meters) upstream which serve as a control and (5 meters) downstream from the point of contamination of the river. The water samples were collected at the surface with 1 litre capacity containers rinsed several times with the water to be collected. Composite soil samples were collected at a depth of 15 cm from the POME dump sites and from a non-effluent soil about 100 metres away which served as control. Each sample was labelled immediately after collection and taken to laboratory for chemical analysis.

2.3 Determination of Physico-chemical Parameters and Heavy Metals of POME

Table 1 shows the methods of analysis of different parameters of POME sample.

2.4 Water Samples Analysis

The water samples were preserved in the refrigerator until analyses were conducted. Total alkalinity and hardness were determined by titrimetric method. Conductivity and salinity was determined using conductivity meter. Total suspended solid was determined by filtration and dried at $103 \pm 2^{\circ}C$. Total dissolved solid was determined by electrical conductivity measurement. Temperature was determined using mercury filled Celsius thermometer. Oxidation-Reduction potential and pH was determined by potentiometric measurement according to method No.4500HB. BOD was determined by a five-day dissolved oxygen measurement according to method No. 5210. Chemical oxygen demand was determined by closed reflux titrimetric method according to method No. 5220C. Sulphate was determined by turbidimetric method according to method No. 4500E. Dissolved oxygen was determined by membrane electrode method according to method No. 4500-OG. Turbidity was determined by Nephelometric method according to method No. 2130B. All analyses were carried out according to [22].

2.5 Determination of Soil Properties

The collected soil samples were air-dried for five (5) days to halt all microbial activities in the soil. The air-dried samples were sieved using a 2 mm sieve mesh size to remove debris and stones. The air-dried and sieved samples were used to examine for various parameters. The following parameters were analyzed; particle size distribution, soil pH, water holding capacity, total organic carbon, total organic matter, total nitrogen, available phosphorus, exchangeable cations: K, Na, Ca, Mg and cation exchange capacity.

Fig. 1. Map of Abak

Table 1. Methods of analysis of different parameters of POME sample

Parameters	Instrument used to identify the parameters
pH	Electronic pH meter
DO (mg/l)	DO meter
COD (mg/l)	Open reflux method
BOD (mg/l)	Winkler's method
Cadmium (mg/l)	Absorption Spectrophotometer
Chromium (mg/l)	Absorption Spectrophotometer

Fig. 2. Map of Nigeria Showing Abak

Plate 1. Palm oil mill effluent dumpsite

Soil pH was measured out by the potentiometric method as described by [23]. A glass electrode Testronic digital pH meter (Model 511) was used for the measurement. Water holding capacity was carried out by the Core method described by [24]. Organic carbon measurement was carried out by the method of [25]. Soil organic carbon was determined by the Wakley and Black procedure according to [26]; soil organic matter was estimated as organic carbon multiplied by 2.724. Total nitrogen assay was carried out by the Kjeldahl method as described by [26]. Available phosphorus was determined by the method described by [27,28].

Exchangeable cations determination was carried out with about 100 ml of concentrated ammonium acetate added to a 10 g measurement of air-dried soil and shaken for 30 min. The preparation was then filtered and taken to the flame analyzer for reading. Calcium, Sodium and Potassium were read on the flame photometer. Readings for Magnesium was obtained from further titration with sodium EDTA as flame photometers cannot be used. Cation exchange capacity was determined by the summation of the cubic centimeter (cm^3) values of the exchangeable cations of each sample determined above.

For available Phosphorus Determination, 2 g of air-dried soil was weighed and dispensed in 20 ml of (0.025N HC1 + 0.03N NH4F) solution, shaken for 5 minutes and then filtered. After filtration, 3 ml of the preparation was put into test tube, 3 ml of (0.87N HC1, 0.38N ammonium molybdate, 0.05% H_3BO_3) solution and 5 drops of (2.5 g of 1-amino 2- tetraoxosulphsate (vi) acid, 5.0 g NA_2SO_3, 146 g $Na_2S_2O_5$) solution were sequentially added to the preparation. A colorimeter (at wave length of 660 nm) was then used to take readings.

Exchangeable Acidity Determination: 5 g of air-dried soil was weighed into 250 ml of conical flask and about 50 ml of Potassium Chloride was added. The preparation was stirred for 1 hr and then filtered. Another 50 ml of KCl was added and shaken for 1 hr and was also filtered into 100 ml volumetric flask to mark up to 1 M KCl using a pipette, about 50 ml of the filtered preparation was dispensed into a 250 ml conical flask. Using phenolphthalein indicator, the preparation was titrated with 0.01M NaOH into a pinkish end point. One or two drops of 0.01MHCI was added to the pinkish end point to bring it back to colourless, then 10 ml of NaF was added to regenerate the faded colour, titration was done again with HCl until it was colourless, titration was done again with 0.01M HCl until it was colourless. The first value was a combination of Aluminum and hydrogen but the second value is hydrogen; the second value was subtracted from the first.

3. RESULTS AND DISCUSSIONS

3.1 Physico-Chemical Characteristics of POME

The results of physico-chemical characteristics of POME sample are presented in Table 2.

Table 2. Physico-chemical characteristics and heavy metal concentrations of the POME sample

Details	Pome
pH	5.56
DO (mg/l)	3.27
COD (mg/l)	1572.105
BOD_5 (mg/l)	290.635
Cadmium (mg/l)	0.0174
Chromium (mg/l)	1.5523

Values are Means of Triplicate

The pH of the POME sample determined was 5.56. The value of pH recorded in this study is however more acidic than the [29] guideline value (pH 6 – 9) for effluent from vegetable oil processing. The acidic nature of POME maybe as a result of organic acids found in fresh fruit. The dissolved oxygen in the effluent of mill was 3.27 mg/l. Dissolved oxygen concentration indicate whether aerobic or anaerobic conditions exist in surface/groundwater, and therefore provide useful information to assess the potential for biodegradation or biotransformation of chemical of potential concern. Manjare et al. [30] reported that the dissolved oxygen of raw POME is 1.250 mg/l. The relatively high DO reported in this study may be due to the high temperature and duration of bright sunlight, which influenced the percentage of soluble gases (O_2 & CO_2) in the effluent [31]. DO is an important parameter in POME quality assessment and reflects the physical and biological processes prevailing in the POME.

The COD value of the POME was 1572.105 mg/l. The value of COD recorded in this study was far higher than the [29] guideline value of 250 mg/l for effluent from vegetable oil processing. The biological oxygen demand (BOD_5) of the POME sample determined was 290.635 mg/l. The BOD value recorded in this study was also higher than the [29] guideline value of 50 mg/l for vegetable oil processing effluents. The concentration of heavy metals in the POME sample recorded (0.0174 mg/l) for Cd and (1.5523 mg/l) Cr. [32] reported 0.001 mg/l for Cd and 0.01 mg/l for Cr in POME. The variations observed were probably due to various factors such as trace metal contents of the crops, contamination from the engine during digestion process [33]. The degree of hardness of the water used in processing might affect the dissolution of heavy metals [34].

3.2 Water Analyses

The results of analysis of variance (ANOVA) and comparison of the sample parameters with [35] and [36] are presented in Table 3.

The temperature of water samples (upstream and downstream) recorded 28 and 28.4 ℃ which was found outside the range of world health organization [35] standard 25 ℃ for domestic water, hence indicating the presence of foreign bodies such as active micro-organisms. They were insignificantly different from each other. The permissible limit for pH in drinking water is 6.5 - 8.5 according to Nigerian Standard for Drinking Water Quality [36] and World Health Organization [35]. The pH of the water samples

recorded 4.74 and 4.62. They were insignificantly different from each other (P<0.05). The acidic pH is mainly due to the contamination of water by POME. The dissolved oxygen recorded 2.72 at the downstream while 4.4 at the upstream (control), being significantly different (P<0.05) from each other. Dissolved oxygen values were found outside the range for drinking water quality standard (2 mg/l) when compared with world health organization [35] which indicated that the river was unsafe for consumption. DO is an important parameter in POME quality assessment and reflects the physical and biological processes prevailing in the palm oil mill effluent, it indicates the amount of pollution in water bodies [30]. The total alkalinity, COD, BOD5 and TDS were all generally higher at downstream than the upstream. They were all significantly different from each other. This result also comes to an agreement with the general perspective on the water bodies which are naturally mineralized, probably due to the influence of the underlying rock. On the other hand, further study may be required on the composition of the rocks to understand the role of such influence. The electrical conductivity, total hardness, turbidity, sulphate and percentage saturation were also all generally higher at the downstream than the upstream (control), and they were significantly different from each other. The electrical conductivity, turbidity and sulphate were within world health organization (WHO) standard for drinking water standard.

3.3 Soil Analyses

Table 4 shows Chemical Properties Constituent of Soils at the Two Experimental Sites (Site A and Control B).

PH is very important on the decomposition of mineral rock into essential elements that plants can use. The pH of non-effluent dumpsite was acidic while that of effluent dumpsite was alkaline, and it was significantly different (P< 0.05) from each other. Batjes [37] Reported that when raw palm oil mill effluent is discharged the pH is acidic but seems to gradually increase to alkaline as biodegradation takes place. Considering the depth of collected soil sample, which contained already degrading palm oil mill effluent and the dumping of palm oil mill effluent, was irregular, which could have been responsible for the pH of 9.27. The non-POME soil studied in this research was at variance with this norm but reasons for this could not be easily ascertained apart from nature. The organic carbon and total nitrogen contents of the effluent and non-POME soil samples showed a significance difference (P < 0.05). The higher organic carbon value for the POME can be related to the constituents of raw and untreated palm oil mill effluent. It is possible that a slow decomposition of organic matter in POME under water-saturated conditions, particularly when mean soil temperatures are low [38] contributed significantly to the higher organic carbon of the palm oil mill effluent soil.

Table 3. Analysis of variance (ANOVA) and comparison of chemical constituent of water samples at the two experimental sites (Upstream and Downstream) with WHO (2011) and NSDWQ (2)

Samples	Mean±SD		NSDWQ2015	WHO 2011
	Downstream	Upstream		
TEMP	28.40±0.20	28±0.21	NS	25
p H	4.62±0.05	4.74±0.07	6.5 - 8.5	6.5 - 8.5
EC	248.67±3.5*	14.63±0.10*	1000	1000
Salinity	0.01±0E-7*	0.00±0E-7*	-	-
T. Hardness	685.67±26.6	6.78±0.69*	150	-
Turbidity	9.54±0.4*	2.01±0.08*	5	-
Sulphate	3.48±0.51*	0.02±0.00*	100	100
COD	13.95±1.0*	7.85±0.32*	-	< 10
BOD5	8.84±0.88*	4.68±0.49*	-	0.8 -5
TDS	121.47±1.1*	7.55±0.54*	500	-
TSS	1019.00±4.6*	8861.00±8.19*		3
DO	2.72±0.30*	4.40±0.08*	NS	2
T. Alkalinity	264.30±12.9*	50.10±0.08*		200
% Saturation	5.65±0.32*	41.80±0.66*		

Nigerian Standard for Drinking water quality (NSDWQ); Values are Means and Standard Deviation of Triplicate. Values with Asterisk (∗) Significant difference (p = 0.05). Downstream Contaminated Site, Upstream Control Site

Table 4. Chemical properties constituent of soils (0 to 15 cm) at the two experimental sites (Site A and Control B)

Samples	Mean±SD	
	Contaminated Site A	Control Site B
p H	9.27±0.1	6.98±0.09
EC	900.00±35.4*	100.00±35.4*
Organic Carbon	38.22±0.1*	8.74±0.1*
T. Nitrogen	2.96±0.1*	8.64±0.07*
Available Phosphorus	224.97±0.1*	95.27±0.1*
Organic Matter	65.89±0.1*	14.90±0.1*
Ca	2.50±0.1*	1.17±0E-7*
K	0.38±0.9*	1.71±0.1*
Mg	0.21±0.1*	0.14±0.1*
Exch. Acid	0.25±0.0*	1.50±0.1*
CEC	3.42±0.1*	3.73±0.14*
WHO (%)	40.26±3.5*	46.13±3.5*

Values are Means and Standard Deviation of Triplicate. Values with Asterisk (∗) Significant different (p = 0.05)

The organic matter of a soil is usually determined and reported as a measure of the organic carbon concentration in the soil as reported by Deiana et al. [39]. Organic matter content strongly affects the soil fertility by increasing the availability of plant nutrients, improving the soil structure and the water holding capacity and also acting as an accumulation phase for toxic, heavy metals in the soil environment [40,41]. For this reason, the recycling of organic wastes through their application to the soil can be an important promising practice for agricultural activities. The organic matter content recorded at the palm oil mill effluent dumpsite was higher than the control site. Organic matter may form natural chelates aiding in maintaining iron in a soluble form. High organic matter contents provides more available boron to plants, but decrease copper availability due to strong bonding of copper to organic matter and may tie up manganese into unavailable organic complexes [41].

The mean exchangeable cations considered alongside with cation exchange capacity were higher at the palm oil mill effluent dumpsite than the control site. They were all generally insignificantly different from one other. The results showed enrichment of the soils in phosphorus, sodium, potassium, nitrogen, calcium and magnesium due to the application of palm oil mill effluent. The palm oil mill effluent soil was observed to be richer in phosphorus than the non-POME effluent soil. In fact, there was a significant different ($P < 0.05$) in phosphorus values of the palm oil mill effluent dumpsite over that of non-POME. This may be due to the gradual biodegradation of palm oil mill effluent, which leads to a delayed effect on the soil. Electrical conductivity recorded the higher value at site while the control site recorded a lower value. The electrical conductivity of the effluent dumpsite was significantly different ($P<0.05$) from the non-effluent dumpsite. An increase in EC may be due to the high amount of soluble salts present in palm oil mill effluent and to the presence of NO_3-N and P in soil. The water holding capacity was higher at the control site than the dumpsite and they were insignificance from each other. The reason for this was not far-fetched when comparing the site to the control site (non-POME).

The palm oil mill effluent site was observed to be bare without vegetation whiles the non-palm oil mill effluent site was grown with weeds. Due to the oil-palm effluent discharge noticeable in dump site the color of the soil was dark brown, damp and odiferous while that of the non-palm oil mill effluent site was observed to be brown, dry and free of odour. The palm oil mill effluent site was also covered with debris from the processing mill while that of the non-palm oil mill effluent site is filled with debris from leaves as it is for typical natural environments.

4. CONCLUSIONS

Results from this study revealed that the physico-chemical properties of soil at the palm oil mill effluent dump site were altered. Since POME has been shown to be alkaline in nature, it is advisable that it undergoes some form of treatment or decomposition before being discharged into soil environment taking into cognizance the physico-chemical properties of the soil in the area so as to avoid the initial harsh

effects of POME on soil. The state of the soil in that environment will determine the best treatment for the effluent to be dumped on it. It is concluded that proper use and safe disposal of POME in the land environment could lead to improved soil fertility. Environmental pollution considerations in small-scale palm oil milling need better attention as this segment of industry require higher importance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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