Chapter

Small-Scale Palm Oil Production in Ghana: Practices, Environmental Problems and Potential Mitigating Measures

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Abstract

The environmental impact of small-scale palm oil processing mills in Ghana has come under serious questioning, especially the disposal of wastewater generated from their operations. This chapter describes the small-scale palm oil production operations in Ghana to highlight the associated environmental problems arising from the disposal of wastewater and other waste by-products. The chapter further discusses the effluent discharge permitting arrangements and possible modifications to the production practices and policy interventions that could improve their environmental compliance and encourage resource recovery. The data in this chapter was obtained from a survey of selected small-scale palm oil processing mills in Ghana, laboratory analysis of wastewater samples from processing mills and review of related literature. Wastewater generated from the processing activities is currently disposed of without any form of treatment. The characteristics of wastewater indicate the need for treatment before disposal. Treatment technologies that could achieve resource recovery (such as biogas, compost, earthworm biomass) and fit into the framework of circular economy should be explored.

Keywords: Ghana, environmental impacts, palm oil production, palm oil mill wastewater, small-scale processing mills

1. Introduction

1.1 Background information

Palm oil is largely produced in Asia, Africa, and Latin America. However, the origin is traced to the tropical rain forest and equatorial region of Africa. Whereas oil palm is traced to Africa, 2019 data suggests that palm oil production as a

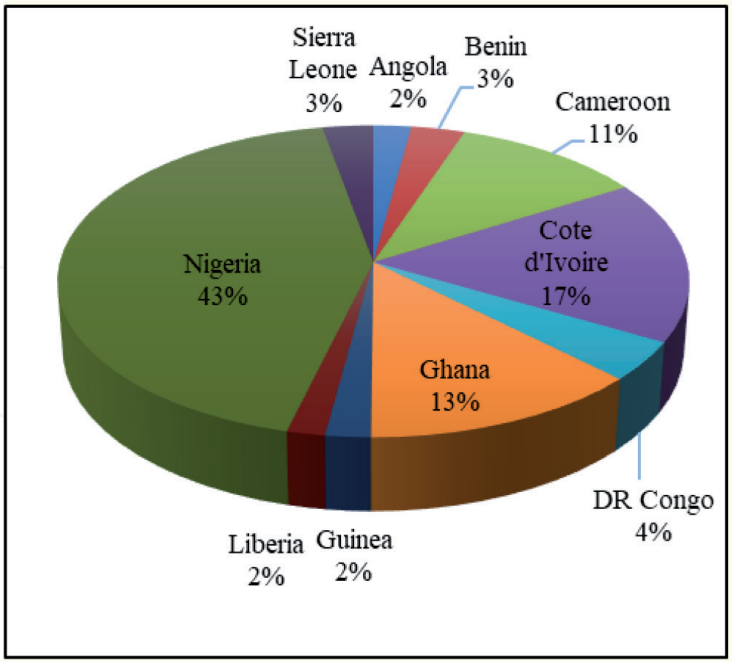

Figure 1.
Proportion of palm oil production in Africa, 2019. Data from FAOSTAT [1].

percentage of the global output was only about 3% for West Africa and 4% for Africa [1]. The major palm oil production countries in Africa are Nigeria (43%), Cote d'lvoire (17%), Ghana (13%) and Cameroon (11%). **Figure 1** shows the proportion of Africa's 2019 palm oil production by country. This does not include countries with less than 2% output.

Palm oil is the most important edible oil in Ghana and in the West Africa region. Palm oil and palm kernel represented 2% of total agricultural production value of Ghana in 2010 [2]. The processing of oil palm is a major source of income and employment to many women in the rural areas of the forest agroecological zone [3]. By 2015, the palm oil production sector was employing over 2 million people mostly in rural areas [4]. Crude palm oil, particularly those produced by the small-scale industry of Ghana, is used as vegetable oil in many local cuisines. Data from the 2008 Ghana Demographic and Health Survey shows that one out of every two households (54%) in the country and four out of five (80%) households in the Central Region used palm oil in food preparation [5]. From analysis of palm oil production and consumption in Ghana between the year 2005 and 2010, Angelucci [2] reported that the country produced a total of 120,000 tonnes of palm oil. As at 2021, the country's crude palm oil production had increased to 375,000 tonnes [6], doubling the production in a decade. The trend of palm oil production in Ghana from 2000 to 2021 is presented in **Figure 2**. However, Ghana has an annual production deficit of about 30,000 tonnes which is estimated to reach 127,000 tonnes by 2024 [7].

Suitable conditions for oil palm cultivation exist in the wetter southern part [8] in the rainforest and semi-deciduous forest zones. Based on the agro-ecological zones, palm oil has a wide national geographical coverage as it is cultivated in nine (9) out of the sixteen (16) first level administrative regions of Ghana. The most suitable areas for oil palm cultivation are said to be the Ahafo, Ashanti, Bono, Bono East, Central, Eastern, Oti, Western, and Western North Regions [8].

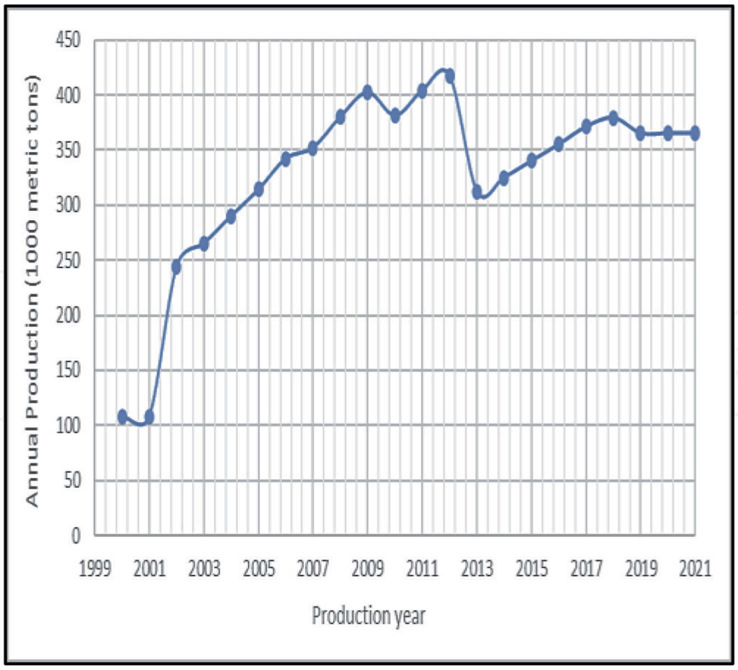

Figure 2.
Annual crude palm oil production of Ghana, 2000-2021. Data from IndexMundi [6]

1.2 Overview of imports and exports of palm oil in Ghana

Ghana is a net importer of crude palm oil even though the country exports crude palm oil to other neighboring West African countries such as Senegal, Benin, Burkina Faso, Nigeria, and Niger [9]. There has been a steady increase in exports and imports of crude palm oil, but the trend is not consistent. **Figure 3** shows the trend of trade value of palm oil imports and exports for Ghana from 2005 to 2019.

Imports of crude palm oil reached 119,821 MT with a trade value of US$ 57.2million (**Figure 3**) in 2019. Countries from where Ghana imports palm oil are mainly Malaysia, Indonesia, Cote d'lvoire, Liberia, Singapore and Togo [9]. On the other hand, exports for 2019 was significantly lower with only 15,392 MT with a trade value of US$ 11.1million, about one-fifth of the import value. For most of the years, imports were higher than exports except for 2012 and 2013 when crude palm oil exports far exceeded (31–69 times) the imports. Within the past one-half decades (i.e., 2005–2019), there has been substantial imports of crude palm oil to meet domestic and industrial needs. From 2005 to 2019, Ghana imported about 1.1 million metric tonnes of crude palm oil with a trade value of about US$ 1.2billion. However, export quantity (in MT) within the same period was only about 18% of the total imports.

1.3 Palm oil processing characteristics

Palm oil is processed from fresh fruits using various techniques that differ in the level of mechanization and interconnecting material transfer mechanisms. The scale of operations also differs at the level of processing. Palm oil processing in Ghana (like other West African countries) is undertaken by four (4) distinct groups of actors [10]. These actors, according to their throughput and degree of complexity, are traditional, small-scale,

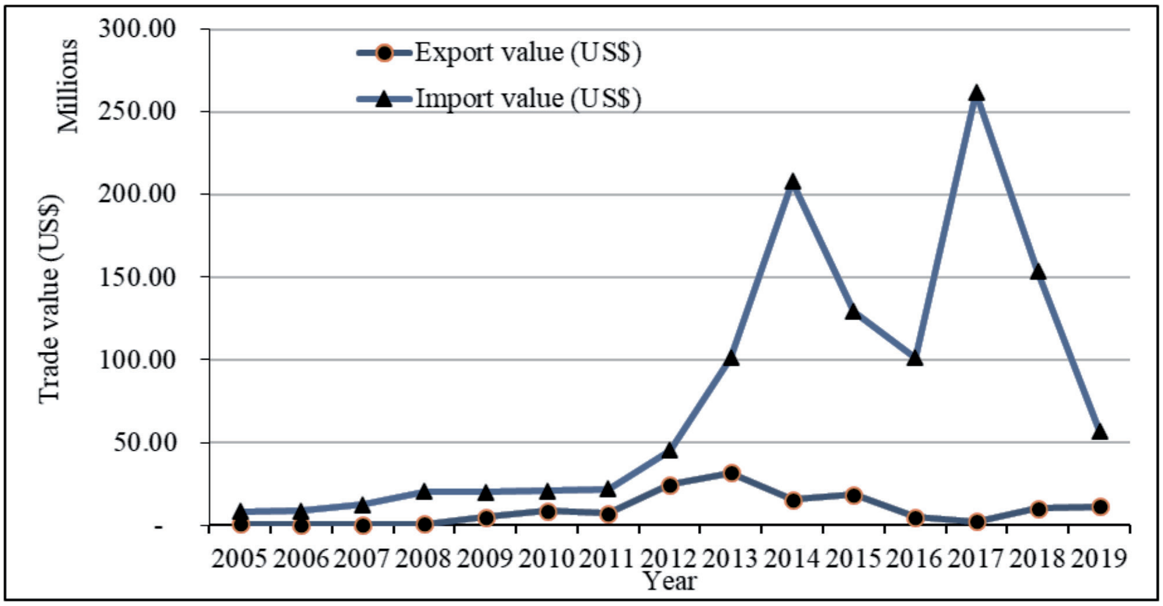

Figure 3.
Trade value of export and import of crude palm oils, Ghana (2005–2019).

medium-scale and large-scale mills. In terms of the level of complexity, the traditional producers use methods which are basically manual with the use of rudimentary tools. The small-scale producers use a variety of low-efficiency machinery ranging from simple hand presses and other stand-alone machines to a very varied combination of machines which cater for the various unit processes in the production cycle. In terms of throughput, small-scale processing units handle up to 2 tonnes per hour of fresh fruit bunches (FFB) [10, 11]. The medium-scale and large-scale mills have technologically up-to-date machinery, established by agro-industrial complexes for the production of palm oil [12] with production throughput of up to 60 tonnes of FFB per hour. Characteristics of the different palm oil mills in Ghana is summarized in **Table 1**.

Though small-scale producers are characterized by weak milling capacity and low quality crude palm oil produced [13, 14] they occupy a greater share of the palm oil processing industry. Available data shows that there were more than 1200 small-scale mills in Ghana [11] producing 60–80% of the national palm oil production [2, 15]. By 2015, the small-scale industry was employing over 2 million people [4] mostly in rural areas.

2. The problem and contribution of the chapter

There are reports of the discharge of raw palm oil mill wastewater into the environment [15, 16]. The Master Plan study on the Palm Oil Industry in Ghana revealed that the activities of small-scale palm oil processers do not comply with environmental regulations [11]. The limited data on the characteristics of wastewater produced by small-scale mills in Ghana casts shadow on the level of environmental damage caused by this important subsector of the economy. This, in turn, obscures the possible technical and policy interventions that may be proffered to mitigate the environmental impacts of the industry. The informal and wide-spread

Characteristic	Large-scale Mills	Medium-scale Mills	Small-scale Mills	Artisanal Mills
Annual Production (FFB in tonnes)	70,000 – 140,000	15,000 – 30,000	2000–5000	2–70
Oil Extraction Rates (%)	16–23	12–15	12–13	8–10
Material Handling	Fully mechanized system in sequential processing steps	Semi mechanized system with few manual interventions	Semi mechanized system with more manual interventions	Manual process
Technology	Intermediate	Intermediate	Low	Very low
Labour	High skilled artisans and labour	Mix of skilled and unskilled labour	Mainly unskilled labour	Laborious and unskilled.
Environment	Compliant with EPA regulations and members of RSPO	Non-compliant with EPA	Non-compliant with EPA	Non-compliant with EPA

Source: MASDAR [11].

Table 1.
Scale of palm oil processing mills in Ghana and their characteristics.

nature and high contribution of small-scale mills to Ghana's palm oil production warrant attention and research.

This chapter describes the small-scale palm oil production operations in Ghana to highlight the associated environmental problems arising from the disposal of wastewater and other waste by-products. The chapter further discusses the effluent discharge permitting arrangements and possible modifications to the production practices and policy interventions that could improve their environmental compliance and encourage resource recovery.

3. Chapter methods

3.1 The study area and selection of production mills

The study was conducted in the Central Region of Ghana, which is one of the sixteen (16) first-level government administrative units of Ghana. There is only one functional large-scale palm oil processing plant in the Central Region. This affords small-scale mills the opportunity for greater access to oil palm for processing. Twenty-five (25) small-scale processing mills were selected from four (4) palm oil processing Metropolitan, Municipal and District Assemblies (MMDA) namely Cape Coast Metropolitan Area (CCMA), Abura Aseibu Kwamankese District (AAKD), Twifo Hemang Lower Denkyira District (THLDD) and Mfantseman Municipality (MfM) all in the Central region of Ghana. The MMDAs were strategically selected to ensure agro-ecological balance (forest zone, transition zone, and coastal savanna zone). A map showing the study area and location of the selected small-scale processing mills is presented in **Figure 4**.

3.2 Data collection methods

Data for this chapter was collected through interviews, structured observations, and review of relevant literature. An interview guide was designed and pre-tested (using eight small-scale palm oil processers in the Twifo Atti Morkwa District, Central Region of Ghana) for use in the study. For each of the processing mills, the manager/mill operator and a worker/processer were interviewed using the interview guide. The structured observation technique was employed to corroborate the information obtained from the mill operators through the interviews.

3.3 Wastewater characterization

Wastewater samples were collected from four (4) small-scale palm oil processing mills from Abura Aseibu Kwamankese District in the Central Region of Ghana. Samples were taken from each of the processing mills during the lean palm oil production season (August 2019) and peak production season (March 2020). For each of the processing mills and in each season, samples of wastewater were collected separately from boiling and clarification tanks. Samples were collected in opaque plastic containers and labeled appropriately before transport to the Environmental Quality Engineering laboratory of the Cape Coast Technical University, Ghana for analysis.

The following parameters were measured: pH, total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total nitrogen, phosphorus, potassium and oil and grease. The pH measurements were performed using Portable pH-meters XS Series. The solids content was determined using the gravimetric method. Fats and oils were determined using the Soxhlet extraction method. All the remaining parameters were analyzed using Hanna multiparameter photometer (HI83399) and associated reagents. Analysis was carried out according to Standard analytical methods

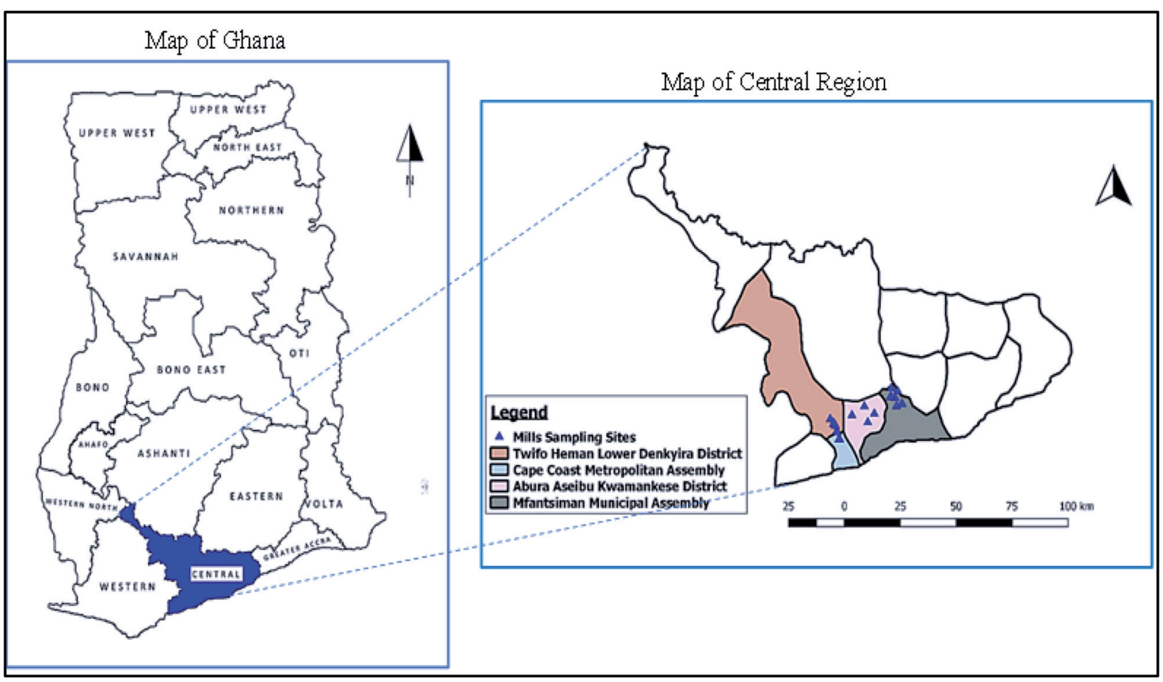

Figure 4.
Map of the study area and sampling location.

prescribed by Standard Methods for Examination of Water and Wastewater [17]. All analysis was performed in triplicates and the mean value taken.

3.4 Assessment of processing practices and wastewater management

The processing practices for palm oil production and wastewater management practices employed by the processing mills were obtained through the interviews and structured observation. Moreover, reasons for the wastewater management practices at the processing mills were ascertained through the interviews.

4. Results and discussion

4.1 Palm oil production processes in Ghana

The production processes used in the study area generally reflect what is employed in other parts of Ghana. The processing of fresh palm fruits into crude palm oil involves receipt of fresh fruit bunches, splitting, storage, stripping, fermentation, boiling, digestion/pressing and clarification. The only mechanized operations are digestion and/or pressing of boiled fruits as noted by other authors [15, 18]. However, fermentation of fresh or boiled fruits is an optional activity which is used depending on the expected grade (food or soap) of the crude palm oil produced. **Table 2** describes the production processes employed by the small-scale processing mills in the Central Region of Ghana. The corresponding process flow diagram is shown in **Figure 5**.

4.2 Environmental regulations for palm oil processing mills in Ghana

4.2.1 Environmental permitting

Palm oil processing mills (small-, medium- and large-scale) are required under Regulation 1 of the Ghana Environmental Assessment Regulations, 1999 (LI 1652) to register with and obtain environmental permit from the Ghana Environmental Protection Agency (EPA) prior to the commencement of the undertaking. In addition, existing undertakings, where EPA considers to have or is likely to have adverse effect on the environment or public health, are required to register with and obtain environmental permit in respect of the undertaking. Similarly, the Environmental Protection Agency Act, 1994 (Act 490) authorizes the EPA "to issue environmental permits and pollution abatement notices for controlling the volume, types, constituents and effects of waste discharges, emissions, deposits or any other source of pollutants and of substances which are hazardous or potentially dangerous to the quality of the environment or a segment of the environment."

The Ghana EPA is therefore legally mandated to regulate and enforce all environmental laws and regulations. But, the small-scale processing mills belong to the informal sector where compliance to legal requirements has been noted to be relatively weak [19, 20]. The economic activities (in law and practice) of small-scale mills are not or insufficiently covered by formal arrangements including registration and regulation [20]. This is confirmed by Gyamfi [21] that 70% of respondents from small-scale mills in Ashanti, Eastern, Central and Western regions of Ghana were

Unit operation	Processing practices
Receipt of fresh fruit bunches	The fresh fruit bunches are brought to the mills in baskets or in small trucks. Harvesting, postharvest transportation and handling of fresh fruit bunches at the small-scale mills lead to much of the fruits been bruised [10].
Splitting of bunches	The FFBs are divided into small parts (splitting /quartering) using cutlass or ax. The aim is to obtain smaller sizes for easy handling during stripping. This activity is mostly performed by men. Splitting or quartering is done on the bare ground which leads to fruit bruises.
Storage	The quartered/split bunches are stored on the bare floor with or without covering for up to 6 days. A storage duration of 3-7 days have been reported in other areas [15, 18, 22, 23]. Materials mostly used for covering are palm fronds, jute bags or plastic sheets. The aim of this activity is to allow enough time for the tissue holding the fruit and bunches together to wilt and facilitate loosening of the fruits from the bunches. However, storage allows the formation of free fatty acids (FFA) which affects the quality of the crude palm oil produced. To some extent, storage also reduces the moisture content of the fruits [18].
Stripping/ loosening	The fruits are manually separated from the bunches using sticks, blunt side of cutlasses or handpicking. The stripping equipment used further leads to fruit bruising. The waste product from this operation is fresh empty fruit bunches (FFB).
Fermentation (optional)	The loosened fresh fruits are heaped in baskets for 3–10 days (used in the study area) or 1–4 weeks as reported by others [15, 18] to allow fermentation to take place. The duration of storage depends on the end-use of the crude palm oil (food-grade or soap-grade). For food-grade oils, fermentation period does not exceed 1 week [19]. On the other hand, for soap-grade oil, the boiled fruits are fermented for 2–5 days to reduce the moisture content before pressing [24].
Boiling	The fermented or unfermented fruits are submerged in water in metal drums or cooking pots and boiled over open fires. The fires are set and maintained by using firewood, dried coconut branches, dried empty palm fruit bunches and palm pressed fiber. The use of waste car tires to set the fire has been reported in other areas [15]. During boiling, the fruits are covered with jute bags or palm fronds to minimize heat loss. Boiling takes 1–2 hours. The objectives of fruit boiling, according to Poku [10] are to: • Deactivate the enzymes responsible for free fatty acid (FFA) build-up • Soften and prepare the fruit mesocarp for digestion • Detach kernels from the shells and to prevent the kernels from breaking during pressing The fire produces smoke which could affect the health of processers. In addition, processers are exposed to heat during manual scooping and transfer of fruits to the digester. The waste product from boiling is boiler wastewater, smoke and ash.
Digestion	This is one of the mechanized operations. The boiled fruits are manually scooped and conveyed into a mechanical digester. The digestion process breaks the exocarp and oil-bearing mesocarp to enhance oil extraction. This operation is undertaken while the boiled fruits are still hot in order to reduce the viscosity of the oil [10]. The most common mechanical digesters in use are horizontal and vertical digesters [23].
Oil extraction and clarification	Extraction of oil is accomplished using mechanical presses. The process separates the oil from the mash. Depending on the required quality of the oil, two methods of oil extraction exist, i.e., 'dry' and 'wet'. The dry method uses mechanical presses to squeeze out the oil. The oil produced from the dry method is mostly soap-grade. In the wet method, the boiled fruits are squeezed to produce a mixture of oil, cell debris, fibrous materials, and water. Hot water is added, and the mixture is then kept on fire under low heat for 1–2 hours for the oil to flow to the surface. The clear oil is skimmed manually from the surface into a storage tank. Food-grade oil is produced from the wet method. The waste products are pressed cake which comprises of palm pressed fiber, palm kernels and clarification wastewater.

Table 2.
Description of small-scale palm oil production processes in Ghana.

either not aware of or did not know how to comply with national environmental laws and regulations.

4.2.2 Effluent standards for palm oil mill industry in Ghana

Wastewater produced by the palm oil processing mills are required to be treated to meet the Ghana Environmental Protection – Requirements for Effluent Discharge (GS 1212:2019) Standard [25] promulgated by the Ghana Standards Authority. The Standard specifies the requirements for sector specific effluent quality and gives guidelines for discharge of effluents into the environment. **Table 3** shows the effluent discharge standard for oil and fat processing which includes the palm oil industry.

4.3 Characteristics of wastewater from Central Region of Ghana

4.3.1 Composite characteristics of palm oil mill wastewater

The composite characteristics of wastewater from the small-scale palm oil processing in Central Region of Ghana are summarized in **Table 4** compared with the Ghana effluent discharge standard, characteristics of palm oil mill wastewater from small-scale processing mill in Nigeria and a large-scale mill in Malaysia. The wastewater contained solids, oxygen-consuming compounds, nutrients (nitrogen, phosphorus and potassium) and oil and grease. Around 13–22% of the total solids and 20–23% of suspended solids were in the form of oil and grease.

The COD:BOD_5 was 2.1–3.1 (mean = 2.5) indicating the presence of slowly biodegradable organic matter as noted by Henze, van Loosdrecht [26]. This may be attributed largely to the unrecovered fats and oils in the wastewater as noted by

Parameter	Unit	Standard
Color	TCU	300
Temperature	°C	≤3 above Ambient
pH	—	6–9
TDS	mg/L	1000
TSS	mg/L	50
BOD_5	mg/L	50
COD	mg/L	250
Oil and grease	mg/L	10
Pesticides, Total	mg/L	0.5
Phosphorus, Total	mg/L	2
Coliforms, Total	MPN/100 ml	400

Oil and fat processing industry includes oil and palm, shear butter, peanuts, coconut oil, palm kernel, etc. Source: GSA [25].

Table 3.
Effluent standard for oil and fat processing industry in Ghana.

Parameter	Central Region, Ghana	Iwuagwu and Ugwuanyi [27]	Wood, Pillai [28]	Ghana effluent discharge standard
pH	4.61–4.74	3.9	—	6–9
TS	2569-5327	76,000	29,600-55,400	
TDS	211–551	32,000	15,500-59,000	1000
TSS	2070-5106	44,000	14,100-26,400	50
BOD_5	16,172-27,888	—	17,000-26,700	50
COD	50,391-60,544	114,800	42,900-88,250	250
Total Nitrogen	160–373	420	500–800	—
Phosphorus	43–90	—	94–131	—
Potassium	126–191	—	1281-1928	2
Oil and grease	321–792	—	4400-8000	10

All values are in mg/l except pH.
TS-total solids; TDS-total dissolved solids; TSS-total suspended solids.
Figures in bold are outside the Ghana effluent discharge limits.

Table 4.
Characteristics of palm oil mill wastewater from small-scale mills in the Central Region of Ghana and literature.

Cisterna-Osorio and Arancibia-Avila [29]. It has been reported that, slowly biodegradable COD constitutes 45% of the total COD of raw palm oil mill wastewater with only about 20% being readily biodegradable due to the free fatty acids [30]. Low pH of wastewater from palm oil processing is also due to the organic acids formed during fermentation of the palm fruits [31]. The acidity of palm oil and, by extension, the palm oil mill wastewater have been reported to be affected by the extraction procedure, presence of microorganisms and the genotype of the palm tree [32]. Suspended solids in the wastewater consists of carbohydrates with oil and other organic and inorganic solids [28]. Most of these solid constituents could serve as nutrient sources for microorganisms.

4.3.2 Seasonal characteristics of palm oil mill wastewater

The wastewater characteristics varied with production season (see **Table 5**). The characteristics of wastewater produced during the peak season were generally higher than the lean season except for pH and solids (total and suspended). Irrespective of the production season, the wastewater was characterized by slowly biodegradable organic matter ($COD:BOD_5$ = 2.5–2.6).

Boiling and clarification time during the lean season are mostly greater than the peak season due to lower processing cycles. A longer clarification time corresponds to greater oil extraction rate, higher evaporation, lower moisture content and higher solids in the wastewater. This reflects the higher concentration of solids in wastewater produced during the lean season as compared to the peak season. The differences in the mean pH, TDS and total nitrogen were significant at 1% level. Potassium concentration in the peak season was significantly higher than the lean season at 3% level. The seasonal variation for TS, TSS, BOD_5, COD, Phosphorus and oil & grease were statistically insignificant. It could be deduced from the results that similar organic and solid loading rates may be used for designing treatment system to handle wastewater for both the peak and lean seasons.

Parameter	Mean (SD)		Seasonal differences [a] (*p*-value)
	Peak season	Lean season	
pH	4.17 (0.23)	4.65 (0.05)	−0.48 (*0.000*)**
TS	3419 (1381)	3976 (1397)	−557 (*0.436*)
TDS	1107 (431)	358 (158)	749 (*0.001*)**
TSS	2313 (962)	3618 (1551)	−1305 (*0.066*)
BOD_5	23,803 (3766)	21,877 (4728)	1926 (*0.384*)
COD	58,948 (5370)	56,357 (3441)	2591 (*0.273*)
Total nitrogen	377 (40)	246 (86)	131 (*0.003*)**
Phosphorus	60 (16)	49 (24)	11 (*0.325*)
Potassium	188 (28)	156 (24)	32 (*0.026*)*
Oil and grease	628 (389)	527 (198)	101 (*0.527*)

All values are in mg/l except pH.[a]Peak season minus lean season.
**Significant at 3% level.*
***Significant at 1% level.*
Source: Authors.

Table 5.
Seasonal characteristics of palm oil mill wastewater.

4.3.3 Characteristics of different wastewater streams

The characteristics of the wastewater from boiling and clarification sampled during the peak and lean production seasons are presented in **Table 6**. For both production seasons, the pH, TDS, BOD_5 and COD of the wastewater from boiling were higher than for clarification. For the remaining parameters (TS, TSS, oil & grease, total nitrogen, phosphorus and potassium) the clarification wastewater was higher than the wastewater from boiling. Apart from BOD_5 and COD, the trend of the results was consistent with the characteristics of individual wastewater streams reported in Malaysia.

The COD:BOD_5 was 2.3–2.4 for wastewater from boiling and 2.6–3.1 for wastewater from clarification. The biodegradability of the wastewater from boiling would be better than the wastewater from clarification. The higher COD:BOD_5 for wastewater from clarification compared to boiling may be attributed to the higher fat and oil content of the wastewater from clarification. The differences in the mean concentration of parameters between boiling and clarification were statistically significant at 1–2% level.

4.4 Wastewater management practices and potential environmental impacts

4.4.1 Wastewater management practices in the Central Region of Ghana

Assessment of the twenty-five (25) small-scale processing mills revealed that none of the mills had a wastewater treatment facility. Consequently, untreated wastewater generated from the extraction processes were discharged on the land or through drains to nearby bushes (**Figure 6**).

Parameter	Peak season			Lean season		
	Mean (SD)		p-value	Mean (SD)		p-value
	Boiling	Clarification		Boiling	Clarification	
pH	4.36 (0.08)	3.98 (0.13)	*0.054*	4.67 (0.05)	4.62 (0.01)	*0.125*
TS	2130 (82)	4708 (81)	*0.000***	2670 (68)	5282 (40)	*0.000***
TDS	1420 (55)	503 (113)	*0.001***	2168 (84)	214 (4.8)	*0.002***
TSS	710 (27)	4205 (179)	*0.000***	502 (54)	5068 (36)	*0.000***
BOD_5	26,672 (3050)	20,935 (1358)	*0.026**	26,196 (1211)	17,559 (971)	*0.000***
COD	63,503 (2867)	54,392 (1932)	*0.003***	59,141 (1297)	53,572 (2295)	*0.008***
Total nitrogen	362 (3.1)	393 (55)	*0.339*	170 (7.1)	321 (44)	*0.006***
Phosphorus	29 (8.1)	69 (12)	*0.003***	46 (2.2)	73 (11)	*0.018**
Potassium	163 (5.4)	214 (7.1)	*0.000***	136 (12)	175 (13)	*0.005***
Oil and grease	276 (19)	980 (147)	*0.003***	358 (35)	695 (119)	*0.006***

*All values are in mg/l except pH.*Significant at 5% level.*
***Significant at 1% level.*
Source: Authors.

Table 6.
Characteristics of wastewater from boiling and clarification for peak and lean production seasons.

Similar environmentally unfriendly wastewater disposal practices by small scale mills have been reported in Nigeria [16]. Contrary to other observations [15], none of the mills assessed in this study disposed their wastewater directly into streams or rivers. Nevertheless, in all the mills assessed, the areas where wastewater was disposed had lost their vegetation. This confirms observations in Africa by Poku [10] that the bushes near the small-scale mills where wastewater is disposed die slowly. Moreover, a very strong stench characterizes the processing mills possibly due to the decomposing wastewater.

4.4.2 Reasons for current wastewater management practices in Central Region, Ghana

The reasons ascribed by the processing mills for disposal of untreated wastewater in the natural environment are presented in **Figure 7**.

All the operators of the processing mills are aware of the legal requirement to treat the wastewater generated by their activities. However, majority (48%) of the operators blamed the absence of treatment system on their limited technical capacity on wastewater management. Others (36%) do not have the financial resources to construct and manage a treatment facility. Finally, few processing mills took advantage of limited enforcement of environmental regulations by the relevant Government

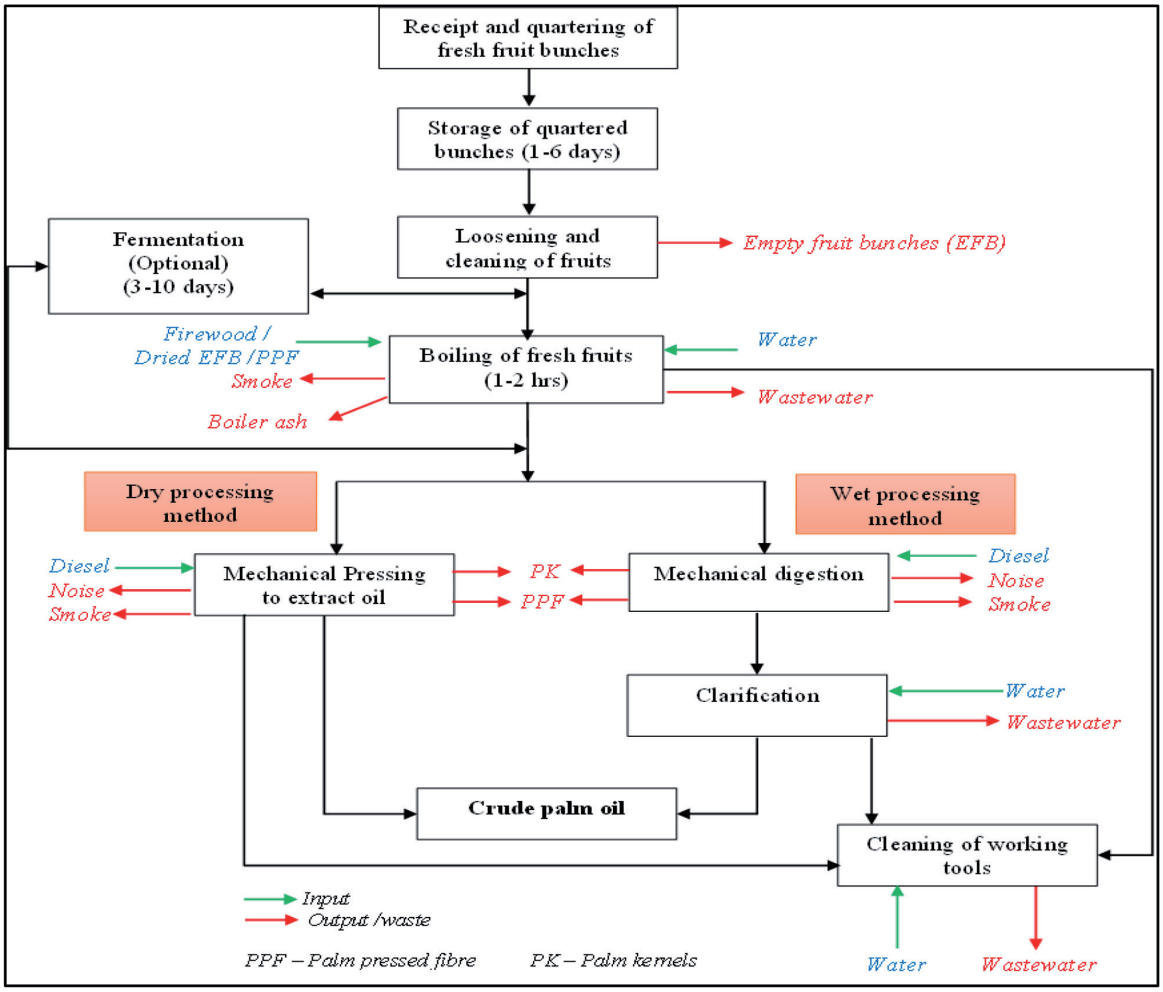

Figure 5.
Process flow diagram for palm oil processing at small-scale level. Source: Authors.

Figure 6.
Wastewater disposal practices at small-scale palm oil processing mills in the Central Region of Ghana (source: Authors).

Agency (Ghana Environmental Protection Agency) to dispose of their wastewater without treatment. Comparatively, a study conducted by Gyamfi [21] revealed that 70% of respondents from small-scale mills in Ashanti, Eastern, Central and Western

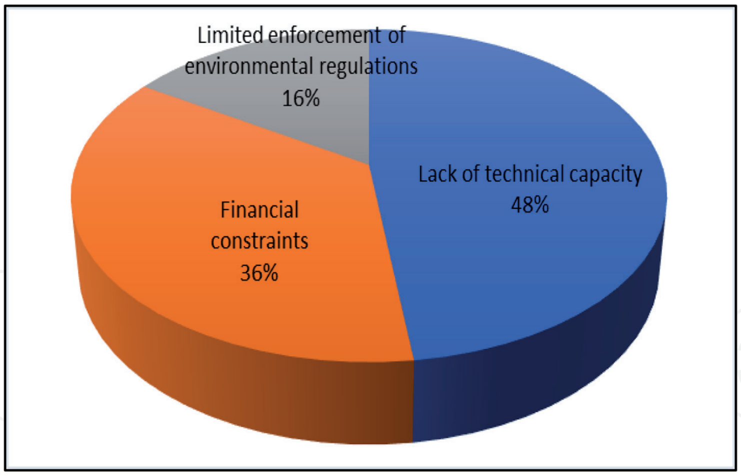

Figure 7.
Reasons for absence of wastewater treatment facilities at small-scale processing mills in the Central Region of Ghana. (source: Authors).

regions of Ghana were either not aware or did not know how to comply with national environmental laws and regulations. The economic activities (in law or practice) of small-scale mills are not or insufficiently covered by formal arrangements including registration and regulation [20].

4.4.3 Potential environmental impacts of current wastewater management practices

The concentrations of most of the parameters were over 2-order of magnitude higher than the limits set by Ghana Standards Authority (see **Table 4**). Palm-oil extraction wastewater disposed on land could be washed into surface water bodies by runoff. When washed into water bodies, the high organic content of the wastewater could deplete the oxygen content of the receiving water bodies [33, 34] and affect the life of their aquatic organisms [35]. Using a per capita BOD loading of 54 gBOD/day [36], the population equivalent (PE) of the small-scale industry is about 200 inhabitants. Excessive fats and oils may form scum [37] on the surface of waterbodies further depriving the water body of dissolved oxygen.

Moreover, the untreated wastewater pollutes the air through odor production as reported by Ahmad and Ghufran [38] and Loh, Lai [39]. Aside the odor, the degradation of the wastewater could generate biogas with over 60% methane content [39, 40]. Methane gas is considered one of the potent greenhouse gases and contributes 25 times to global warming compared to CO_2 [41]. The current practice of disposing raw wastewater into the natural environment by small-scale processing mills is negatively affecting the environment.

4.5 Other palm-oil extraction waste products and their management in Ghana

4.5.1 Solid waste

The categories of solid waste generated at the processing mills are empty fruit bunches (EFB), palm pressed fiber, palm kernel (PK), and ash from boiler furnaces. The high moisture content of EFBs prevents their immediate use as solid fuel. At most of the small-scale mills, the EFB are heaped and left to undergo decomposition. Some small-scale mills dry and use EFBs and palm press fibers as solid fuel for boiling the palm fruits as reported also by Gyamfi [21]. At the small-scale mills, palm kernels are mostly sold to palm kernel processors which are used to produce palm kernel oils.

4.5.2 Smoke

Smoke is generated from the boiling activities or open burning of EFBs. The smoke hangs over the mills causing discomfort to mill workers as noted by MASDAR [11]. The community members who reside close to the mills are also affected by the smoke. The smoke is mostly generated within the breathing zone of the mill workers which could potentially affect the health of the mill workers. In the study area, small-scale mills do not have in place measures and appropriate technology to control or manage smoke produced from their activities. In Elele, Nigeria, Ohimain and Izah [42] measured elevated concentrations of carbon monoxide, sulfur dioxide, nitrogen dioxide, volatile organic compounds, and suspended particulate matter at small-scale palm oil processing mills with most of the parameters above the Nigerian Ambient Air Quality standards. Diesel exhaust fumes from digesters contribute significantly to combustion-derived particulate matter air pollution [42].

4.5.3 Noise pollution

Mechanical digesters used by the mills produce noise. There is no technology in place to control the noise generated by the machinery used for processing. Application of noise-reduction technologies at small-scale processing mills in other study areas has not been reported in scientific literature. Moreover, the level of noise produced by the mechanical equipment used by small-scale mills in Ghana has not been investigated. In Nigeria, noise levels generated at small-scale mills were within permissible limits of 90 dB [43]. At the large mills in Ghana (such as Twifo Oil Palm Plantation), noise is minimized by installation of silencers to exhaust and rubber-lining ducts and cyclones within the plant controlling noise levels.

4.5.4 Odor nuisance

The odor at the small-scale processing mills studied is associated with rotten fruits, decomposing EFB and POME. Unpleasant odor pervades the mills and downwind of the POME and EFB disposal sites.

5. Implications of findings for policy and practice

The characteristics of the different wastewater streams and the current waste management practices at the small-scale mills in Ghana suggest the need to adopt appropriate and sustainable management practices.

5.1 Enforcement of environmental regulations

Wastewater is currently disposed on the bare ground without any form of treatment. Considering the characteristics and wastewater disposal practices, particular attention should be paid to the small-scale processing mills which dominate the palm oil production sector. In terms of policy, Regulation 1 of the Environmental Assessment Regulations, 1999 (LI 1652) [44] requires specific undertakings including oil and fats processing to register with and obtain environmental permit from the Ghana EPA prior to the commencement of the undertaking. In addition, existing undertakings, where EPA considers to have or is likely to have adverse effect on the environment or public health, are required to register with and obtain environmental permit in respect of the undertaking. Therefore, palm oil processing mills (including small-scale mills) are required to register with and obtain an environmental permit. However, small-scale processing mills belong to the informal sector where compliance to legal requirements is relatively weaker [19, 20]. The Ghana EPA, which is responsible for ensuring environmental compliance in Ghana, should extend enforcement of the Ghana Environmental Protection Requirements for Effluent Discharge to the small-scale (cottage) industries to ensure compliance. The government of Ghana, acting through the relevant agencies and the Artisanal Palm Oil Millers and Outgrowers Association, should provide technical support on sustainable waste management to the small-scale processing mills.

5.2 Selection of appropriate management solutions

Many technologies have been tested and applied to successfully treat palm oil mill wastewater mostly in Asia. Detailed description of different treatment methods can be found in the works by Liew, Kassim [45], Iskandar, Baharum [46] and Ohimain and Izah [47]. However, the selection of management solutions particularly for resource constrained environments such as what pertains in small towns and villages in Ghana where small-scale mills are located, must follow the principle of 'appropriate' technology. More importantly, the solution selected must lead to the recovery of valuable resources for beneficial use in the production process following the principles of circular economy.

5.2.1 Biogas production

The high BOD and appreciable concentration of nutrients (total nitrogen, phosphorus and potassium) and solids suggest the presence of considerable amount of organics which could serve as nutrients for microbial community in anaerobic digesters. Quah and Gillies [48] reported that anaerobic digestion of $1m^3$ of POME could generate $28m^3$ of biogas with 65% methane content. For small-scale palm oil mills in Ghana, the wastewater generated from the processing of one liter of crude palm oil could produce about 16–53 liters of biogas with 10.4–34.4 liters of methane content. Implementation of technologies to generate green energy would reduce the dependence on smoke-producing fuel wood which affects the health of the mill workers. Moreover, tapping the biogas for beneficial use would reduce the release of greenhouse gases into the environment.

5.2.2 Solid fuel production

Conversion of agricultural waste products into solid fuel has attracted attention and research. Empty fruit bunches, palm pressed fiber and sludge from palm oil mill wastewater are potential products for use as fuel. As has already been mentioned, limited quantities of EFB are dried and used as fuel by the small-scale mills. The suspended solids which contain solids and oils could be dried and used as solid fuel in the processing operations. The presence of unrecovered oil in palm pressed fiber is reported to enhance their combustibility and use in starting fires at the palm oil processing mills [49]. The potential of drying palm oil mill sludge and empty fruit bunch fiber for use as solid fuel has been reported by Awere, Bonoli [50]. Research must be directed at exploring different ways of converting the solid waste products into solid fuel which could be utilized in the production process or sold out to other industries.

5.2.3 Co-composting

Composting is the decomposition of organic residues into manure using a consortium of microorganisms (bacteria, actinomycetes and fungi) in a controlled environment. The high organic solids and appreciable nutrients content of POME [33, 47, 51] makes them potential substrates for compost production. In composting, wet substrates such as POME, low moisture bulking agents are required [52, 53]. POME may therefore be co-composted with bulking agents such empty palm fruit bunches and sawdust. Co-composting of POME with empty fruit bunches or saw dust has shown considerable success both at the laboratory and field scale. At a field-scale, Baharuddin, Wakisaka [54] co-composted partially treated POME from anaerobic pond with shredded empty fruit bunches (ratio of 1:3) over a 60-day period. The characteristics of the final compost showed considerable amounts of nutrients (carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and iron), trace amounts of manganese, zinc, and copper but very low levels of heavy metals. In a related study, palm oil mill sludge was co-composted with sawdust (1.86:1) over a 90-day period [55]. Through a pot experiment, the compost improved the growth of pseudostems of Cymbopogon citratus cultivated in a sandy soil.

Co-composting of POME significantly reduces the emission of greenhouse gases due to the aerobic decomposition process employed [56, 57]. The favorable climatic conditions of Ghana could enhance the compost production. The filtrate from the composting station could be assessed for their potential as liquid fertilizer.

5.2.4 Vermi-composting

An alternative to the conventional composting is vermi-composting which uses earthworms. Vermi-composting has been found to exhibit a higher rate of organic degradation and produce nutrient-rich compost with finer texture [58]. The composting period could be 50% of the time required by conventional composting systems. Composting of POME using earthworms has shown a great potential. Syirat, Ibrahim [59] used epigeic earthworms (Eudrillus eugeniae) to decompose POME sludge in a closed system within 60 days. They obtained a compost of high nutrient content compared with compost produced from EFB-POME sludge and mesocarp fiber-POME sludge. Similarly, Rupani, Embrandiri [60] used Lumbricus rubellus for vermi-composting POME-palm pressed fiber (1:1) over 30 days. The resulting compost showed significant improvement in nitrogen, phosphorus, and potassium content with 75% vermi-compost extract enhancing germination of mung bean. In another study, various compositions of empty fruit bunches and POME solid were vermi-composted using Eisenia fetida earthworms for 84 days [61]. In their study, a significant increase in total Kjeldhal nitrogen (0.4–1.7 mg/kg), total phosphorus (0.2–1.4 mg/kg) and total potassium (0.06–0.5 mg/kg) was recorded for all vermi-compost with the highest increase recorded for 1:1 EFB-POME solid combination. Vermi-composting produces two (2) important end products: manure/compost and earthworm biomass. The latter could be processed into protein source and sold to poultry and fish farmers [62].

6. Conclusion

The mean characteristics of wastewater produced during the peak season were generally higher than the lean season except for pH and solids (total and suspended). Irrespective of the production season, the wastewater was characterized by slowly biodegradable organic matter (COD: BOD_5 = 2.5–2.6). Wastewater from clarification had higher solids and nutrient content but lower oxygen-consuming compounds compared with wastewater from boiling. The current practice of disposing raw wastewater into the natural environment by the small-scale processing mills is negatively affecting the environment. Based on the characteristics of the wastewater and the tropical climatic conditions in Ghana, appropriate technologies that generate beneficial by-products such as biogas, compost or solid fuel must be explored. Enforcement of environmental regulations by the Ghana EPA should be extended to the small-scale (cottage) industries to ensure adoption of appropriate wastewater management technologies. Additional studies are needed in other palm oil production regions of Ghana to generate national-level data. This will guide the development of a compendium of wastewater treatment technologies applicable to small-scale processing mills in Ghana.

Conflict of interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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