Water Practice & Technology

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Water Practice & Technology Vol 18 No 1, 86 doi: 10.2166/wpt.2022.158

Water consumption and wastewater generation from small-scale crude palm oil extraction in Ghana

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ABSTRACT

Crude palm oil extraction is one of the sources of livelihood in Ghana's Central Region. However, the water use and wastewater generation associated with the industry have not been given adequate attention. This study assessed the water consumption and wastewater generation by small-scale crude palm oil extraction mills in the region. Twenty-five (25) mills were selected from four palm oil-processing local government areas in the region. An interview guide was used to obtain information about the operations of the mills and corroborated through structured observations. Water consumption and wastewater generation were measured using a graduated plastic bucket. Water for processing was found to be sourced from hand-dug wells (56%), treated piped water (20%), boreholes with handpumps (16%) and rivers (8%). Water was bought at US$1.93 (boreholes) and US$2.89 (piped water) per cubic metre. The recurrent cost of water was the same as that paid for domestic use. For a litre of palm oil produced, 0.760-2.391 litres of water were consumed and 68-82% returned as wastewater. Sixty-eight percent of the water was used for boiling. The distance to water source influenced the consumption, with higher water consumption recorded for mills with on-plot water sources. Higher recurrent costs of water did not necessarily lead to lower water consumption. There was no significant difference in the water consumption and wastewater production between the wet and dry processing methods. The small-scale palm oil processing industry requires attention to manage a potential competition between commercial and domestic water use in rural and small towns.

Key words: crude palm oil extraction, Ghana, small-scale industry, wastewater generation, water consumption

HIGHLIGHTS

- 1 L of crude palm oil produced could consume more than twice that volume of water.
- Wastewater return factor is 62–89%.
- Boiling of fruits consumes 68% of the water and generates 62% of the wastewater.
- 10 L of palm oil produced consumes the equivalent of one person's water demand in rural Ghana.
- Higher recurrent costs of water did not necessarily lead to lower water consumption.

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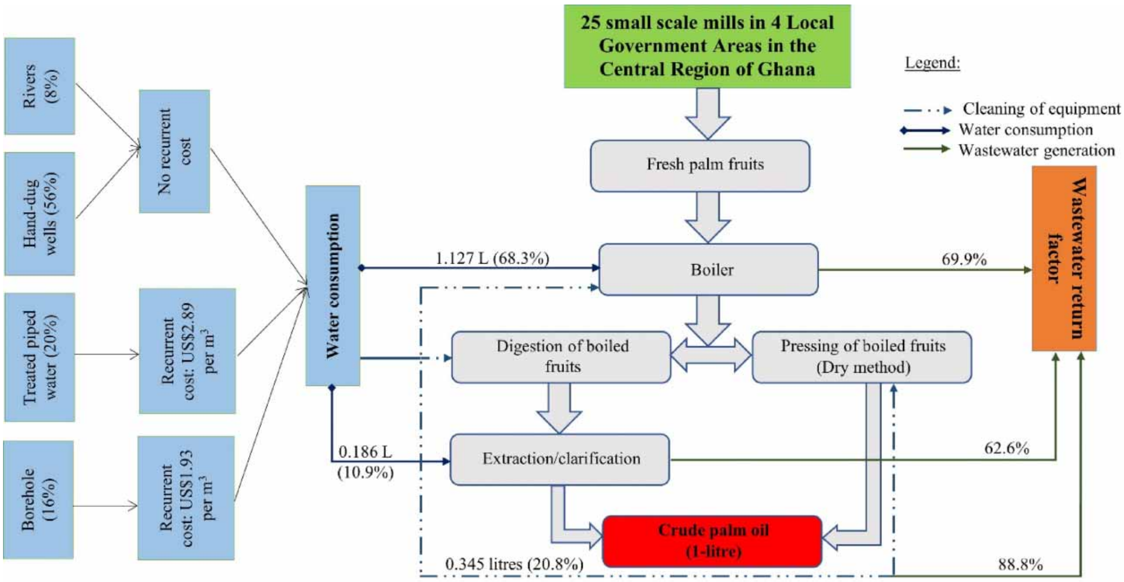
GRAPHICAL ABSTRACT



1. INTRODUCTION

Processing oil palm fruits into edible oil has traditionally been practised in Africa. The oil produced is an essential ingredient in much of the traditional West African cuisine. Palm oil is now an important domestic and industrial commodity worldwide. On the world commodity markets, palm oil is gaining increasing attention due to factors such as the high yields of oil palm as compared to other edible oil crops, high demand for domestic and industrial uses, use as biofuel (Angelucci 2013; Ratanaporn *et al.* 2017) and the need for cheaper sources of oleo chemicals (Inyan 2002). Even though palm oil processing is traced to West African origins, current production levels in the sub-region are significantly low. Recent data show that West Africa's palm oil output is around 2.54 million metric tonnes (MT), equivalent to about 3.5% of global production (USDA 2021). The major production centres have shifted to Southeast Asia, with Indonesia, Malaysia and Thailand as the world's leading producers (Index-Mundi 2020a). In West Africa, the main palm oil-producing countries are Nigeria, Ivory Coast, Ghana, Benin, Guinea, Liberia, Sierra Leone and Togo.

Ghana is ranked 13th in the world and third in West Africa in terms of production quantities (IndexMundi 2020b). As in many other West African countries, palm oil is the most important edible oil in Ghana. Palm oil and palm kernel represented 2% of the total agricultural production value of Ghana in 2010 (Angelucci 2013). From the analysis of palm oil production and consumption in Ghana between the years 2005 and 2010, Angelucci (2013) reported that the country produced a total of 120,000 T of palm oil. As of 2019, the country's crude palm oil production had increased to 375,000 T (IndexMundi 2020b). However, Ghana has an annual production deficit of about 30,000 T, which is estimated to reach 127,000 T by 2024 (Commodafrica 2018). Processing of oil palm is a major source of income and employment for many women in the rural areas of the forest agro-ecological zone of Ghana (Opoku & Asante 2008). Palm oil cultivation has a wide geographical coverage and is cultivated in 11 out of the 16 administrative regions of Ghana. The most suitable areas for oil palm cultivation are in the Central, Eastern and Western regions (Adjei-Nsiah *et al.* 2012).

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. Unlike in Southeast Asia where the processing of crude palm oil is entirely undertaken by agro-industries in high-technology well-equipped mills, palm oil processing in Ghana (like other West African countries) is undertaken by low-technology, mostly less-mechanized mills of varied levels of complexities (Poku 2002). These processing mills, according to their throughput and degree of complexity, may be classified into four categories, namely traditional, small-scale, medium-scale and large-scale mills. In terms of the level of complexity, traditional producers use methods that are basically manual and involve 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

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machines to a very varied combination of machines that cater to the various unit processes in the processing. In terms of throughput, small-scale processing units handle up to 2 T/h of fresh fruit bunches (FFB) (Poku 2002; MASDAR 2011). The medium-scale and large-scale mills have technologically up-to-date machinery, established by agro-industrial complexes for the production of palm oil (Hassan *et al.* 2016) with a production throughput of up to 60 T of FFB per hour. A detailed description of the various processing mills in Africa can be found in Poku (2002). Poku (2002)'s description of the small-scale oil palm process is applicable to the mills that were involved in this study.

Though small-scale producers are characterized by weak milling capacity (Kajisa *et al.* 1997; Uckert *et al.* 2015), they occupy a large share of the West African palm oil processing sector, accounting for up to 83% of palm oil production. (Hassan *et al.* 2016). Available data shows that there were more than 400 small-scale mills in Ghana as at 2002 (Poku 2002) producing 80% of the national palm oil production (Osei-Amponsah *et al.* 2012; Angelucci 2013). By 2015, they were employing over 2 million people mostly in rural areas (Yawson 2015). The informal, wide-spread nature and high contribution of small-scale mills to Ghana's palm oil production warrant attention and research. However, studies on the palm oil processing industry in Ghana have focused on processing technology, profitability, institutional analysis, quality of crude palm oil and gender roles (Osei-Amponsah *et al.* 2012; Tagoe *et al.* 2012; Adjei-Nsiah & Klerkx 2016). Research on water consumption and wastewater quantities, characteristics and treatment from small-scale palm oil-processing mills in Ghana is very limited.

In processing fresh palm fruits into crude palm oil, high quantities of fresh water are reported to be consumed (Hassan *et al.* 2004), generating high quantities of wastewater (Chavalparit *et al.* 2006). The water consumption and wastewater production quantities are dependent on the processing method and level of technology employed. For instance, to produce 1 T of crude palm oil, an estimated 5.0–7.5 T of water is consumed, out of which 50% returns as wastewater commonly called palm oil mill effluent (POME) (Ahmad *et al.* 2003). These estimates are reported for Malaysia and Indonesia where the palm oil extraction industry is dominated by large-scale industries employing more efficient processing techniques. The water consumption and wastewater production quantities could vary for small-scale palm oil processing mills which use less efficient methods (Poku 2002).

Data on the wastewater generation rates from these types of processing mills are required to inform the types and scales of technologies that may be developed or adopted to treat the POME resulting from their operations. For instance, the report of the masterplan study on the oil palm industry in Ghana recognized that large quantities of wastewater were produced during palm oil processing which requires appropriate treatment before discharge into the environment (MASDAR 2011). Raw POME is reported to contain oxygen-consuming minerals (BOD and COD), solid contents, nutrients and unrecovered fats and oils (Lam & Lee 2011) which could pollute the environment when disposed of without treatment. Ghana's small-scale palm oil processors have been cited for not adhering to any environmental protection practices (Poku 2002). However, data on the quantities of wastewater produced by small-scale palm oil processors are scarce in scientific literature.

Furthermore, the absence of data on water consumption by such an important industry could lead to an underestimation of the water demand of the most rural communities in which the mills are situated and, consequently, competition between palm oil processing and other water uses. It is worth noting that, the potable water supply to rural communities in Ghana is limited. About 68% of the rural population in Ghana used basic drinking water services and over 50% depended on public standpipes or boreholes in 2018 (GSS 2018).

This study was aimed at quantifying the water consumption and wastewater production from small-scale palm oil processing in the Central Region of Ghana. The outcome of this study provides insights into the proportion of rural water supply used by small-scale palm oil processors to inform future planning and design of rural water supply systems in such communities. In addition, the paper reports water consumption and wastewater production by the different unit operations within the production process and, hence, reveals which unit operations require more attention in the search for operational improvements to ensure water-use efficiency.

2. MATERIALS AND METHODS

2.1. Study setting

The study was conducted in the Central Region of Ghana. The Central Region is one of the 16 first-level government administrative units of Ghana. According to data from the 2021 Population and Housing Census, the region has a population of 2,859,821 inhabitants with around 42% living in rural areas (GSS 2021). The current

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population density is 291 inhabitants/km^2. The region is subdivided into 17 second-level administrative units classified as metropolitan, municipal or district assemblies. Based on the climate, the region is divided into three agro-ecological zones, namely coastal savanna, transitional and forest zones (MOFA 2020). The average temperature ranges between 24 and 34 °C with a relative humidity of 50–85%. The region is characterized by a bi-modal rainfall pattern with major and minor rainy seasons of March–July and September–November, respectively (Bessah *et al.* 2021). In terms of palm fruit production, the peak and lean seasons are, respectively, February–June and July–January (Osei-Amponsah *et al.* 2012). The average annual rainfall ranges from 800 mm in the Coastal Savanna to 1,500 mm in the forest zone. The main economic activities are agriculture, with 80% of the region's total land area considered cultivable (MOFA 2020). The major tree crops cultivated in the region are cocoa, oil palm, citrus and coconut. The region's land area for oil palm cultivation accounts for 16% of the total national area for oil production (MASDAR 2011).

Water supply to communities in the region is through piped water by the Ghana Water Company Limited (GWCL) or under the Community Water and Sanitation Agency (CWSA)'s small towns' piped water supply systems. The GWCL supplies water to urban and peri-urban areas while the CWSA supplies water to small towns (population of 5,000–50,000) and rural areas (population of less than 5,000). In communities without piped water supply (mostly in rural areas), inhabitants obtain their water mainly from boreholes fitted with pumps, hand-dug wells or untreated surface water. Available data show that rural and small-town water coverage in the region was 63.7% in 2014 (Antwi *et al.* 2015).

2.2. Selection of processing mills

Four MMDAs, namely Cape Coast Metropolitan Area (CCMA), Abura Aseibu Kwamankese District (AAKD), Twifo Hemang Lower Denkyira District (THLDD) and Mfantseman Municipality (MfM) were selected. The MMDAs were strategically selected to ensure agro-ecological balance. Thus, two (AAKD and THLDD) are in the forest zone and one each in the transition zone (MfM) and coastal savannah zone (CCMA). An initial list of 18 small-scale palm oil processing mills was obtained from the offices of the Business Advisory Centres (BAC) in the MMDAs. The snowball sampling method was used to identify additional seven processing mills for inclusion in the study. Preliminary visits were conducted to all the processing mills to obtain basic information about the mills. A review of the literature shows that both dry and wet methods of palm oil extraction are used by small-scale processing mills in Ghana (Poku 2002; Adjei-Nsiah *et al.* 2012; Osei-Amponsah *et al.* 2012). The method of palm oil extraction influences the quantity of water demand and wastewater generated. Through the preliminary visits, it was identified that six of the processing mills employed the dry extraction method while the remaining 19 mills use the wet extraction method. A map showing the study area and location of the selected small-scale processing mills is presented in Figure 1.

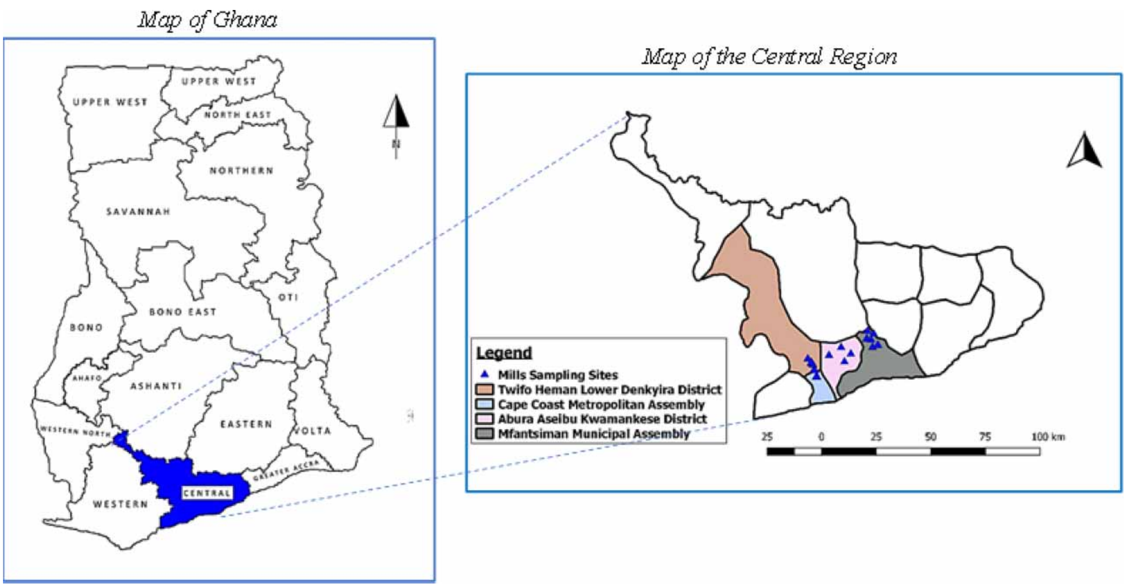

Figure 1 | Map of the study area and sampling location.

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2.3. Study design

The study was designed to:

- Qualitatively assess the processing techniques employed by the small-scale palm oil processing mills and to ascertain the stages where water is used and wastewater generated.
- Quantitatively measure the water usage and wastewater generation for each unit operation.

2.4. Data collection methods

Data for the study were collected through interviews, structured observations and field measurements. These data collection methods were applied to all the 25 small-scale palm oil-processing mills selected for this study.

2.4.1. In-depth interviews

An interview guide was designed and pre-tested (using eight small-scale palm oil processors in the Twifo Atti Morkwa District, Central Region of Ghana) for use in the study. For each of the processing mills, the manager and a worker were interviewed using the interview guide. Interviews were used to document the various stages where water was used, and wastewater generated. In addition, information on the sources, costs and distance of water from the processing mills were obtained.

2.4.2. Structured observation

The structured observation technique was employed to corroborate the information obtained from the mill operators through the interviews. Specifically, processing techniques, stages of water usage and wastewater generation, distance from the water source and sources of water were observed.

2.4.3. Field measurements

Field measurements were used to obtain the quantity of water used and wastewater generated for each processing cycle. To obtain the quantity of water and wastewater, the palm oil processing activities were followed right from the receipt of FFB to the final stage of palm oil processing. Graduated plastic tanks were provided to separately store fresh water and wastewater. The tank for water storage was filled and the processors were monitored to ensure they fetched water from only this tank. An 18-L graduated plastic bucket was used to fetch water from the tank thereby tracking the quantity of water used at different stages of the process. The volume of water used for each production cycle and the quantity of crude palm oil produced were recorded in a logbook.

As was done for water usage, wastewater generated was kept in different graduated storage tanks. Separate tanks were used to collect and measure the amount of wastewater from different processing activities (unit processes). For example, wastewater from the boilers was not mixed with the wastewater from the clarification tanks. After measuring the volume of wastewater generated, the processors were allowed to dispose of the wastewater using their existing management practices. This was observed and documented as the existing wastewater management practice employed by the mills. For each processing site, water consumption, the volume of oil produced and quantity of wastewater generated were measured for three production cycles in order to find an average and reduce accidental errors in measurement.

2.5. Data analysis

Data were analysed using Microsoft Excel. All data were tested for normality with Shapiro-Wilk test at a 95% significance level. Descriptive statistics of mean and standard deviations were recorded for the 25 processing mills and separately for dry and wet processing methods. Depending on the number of parameters tested, a t-test or one-way ANOVA test ($\alpha = 0.05$) was used to test for the statistical significance of differences.

3. RESULTS AND DISCUSSION

3.1. Processing operations, stages of water usage and wastewater production

Figure 2 is a flow chart showing the sequence of unit processes and operations employed by small-scale processing mills in the Central Region of Ghana, which included both wet and dry methods of extraction. The process flow diagram commonly used in major palm oil-producing countries in Asia (Figure 3) is included for comparison. The activities of small-scale mills differ from those large-scale industries in terms of the technology used and the sequence of the processes. At the small-scale mills studied, the processing of fresh fruits into crude palm oil involved receipt of FFB, quartering of FFB, storage of quartered FFB, stripping of FFB, cleaning of fruits

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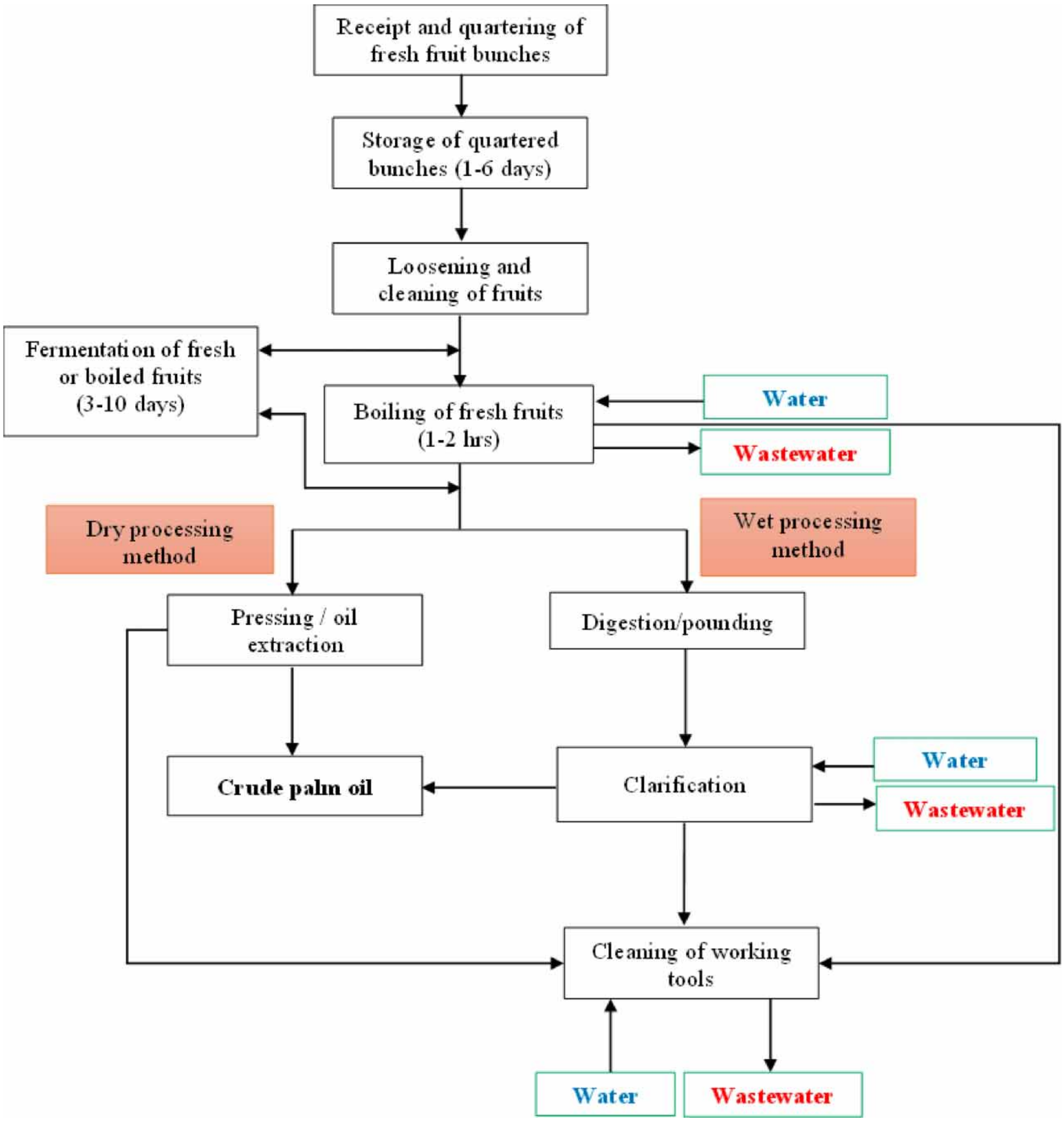

Figure 2 | Process flow chart for small-scale palm oil extraction in Central Region, Ghana.

(to remove spikelets and dirt), storage of fruits, boiling of fresh fruits, fermentation of fruits (optional), digestion of boiled fruits, extraction of oil/pressing, clarification (optional) and cleaning of working tools.

The processing practices of small-scale palm oil producers in parts of Ghana and Nigeria have been studied and reported in the scientific literature (Taiwo *et al.* 2000; Adjei-Nsiah *et al.* 2012; Osei-Amponsah *et al.* 2012). There were no significant differences between the unit processes reported in the literature and those employed by processors in the current study area. However, other optional operations such as fermentation of fresh or boiled fruits were observed among the studied mills. Also, as reported by Adjei-Nsiah *et al.* (2012) and Osei-Amponsah *et al.* (2012), the only mechanized operations that were observed were the digestion of boiled fruits and pressing of the digested fruits to extract the oil.

Both wet and dry methods of extraction were employed among small-scale processing mills in the Central Region of Ghana. Six of the processing mills studied used the dry method of processing, with the remaining19 using the wet method. In the dry method, oil is squeezed out of the boiled fruits using mechanical presses but in the wet method, water is added to the macerated fruits to make a slurry, which is kept on low heat to leach out the oil as reported by Kandiah *et al.* (2006) and Poku (2002).

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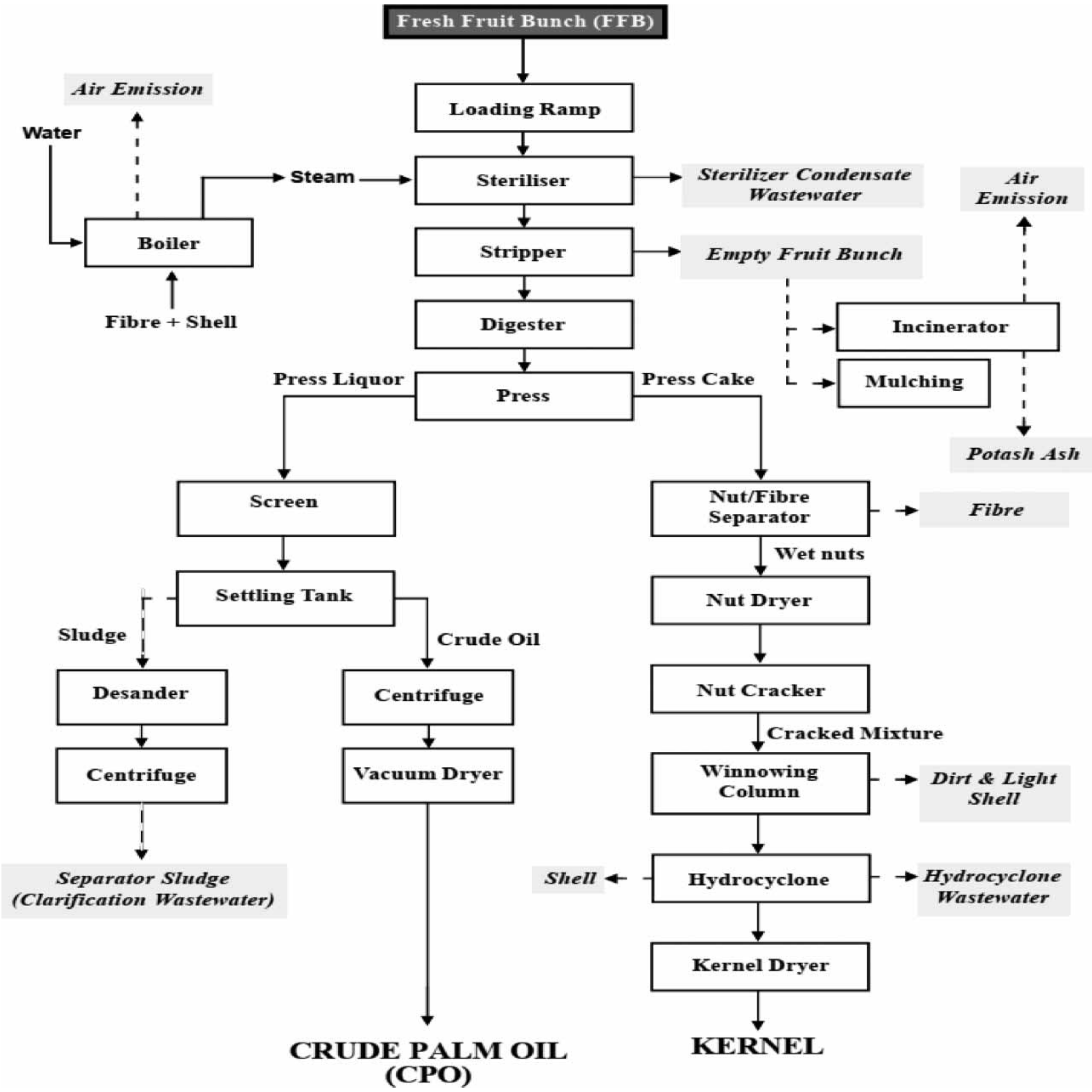

Figure 3 | Process flow chart for conventional palm oil production in Asia. *Source:* Department of Environment (1999).

The unit processes that required fresh water were boiling fresh fruits, clarification (in the case of the wet method), and cleaning of working tools. The three unit operations that require the use of freshwater are the ones that generate wastewater. Storage of the quartered bunches leads to a reduction in the moisture content of the fruits (Osei-Amponsah *et al.* 2012). Among the small-scale processing mills assessed, there were disparities in the level and stage of fruit storage. FFB were stored for 1–6 days and boiled fruits for 1–3 days (for wet method) and 3–10 days (for dry method) before digestion (wet method) or pressing (dry method). The length of storage of fruits, whether fresh or boiled, influences the moisture content of the fruits and ultimately the quantity of water consumption and wastewater generation.

3.2. Source, location and cost of water for palm oil processing

3.2.1. Sources of water

The sources of water were rivers/streams, hand-dug wells, mechanized boreholes and treated piped water from public standpipes. The proportion of mills using water from each of the sources is shown in Table 1.

The sources of water used by the processing mills largely reflect the sources of drinking water available to inhabitants in the study area. The latest available statistics on the specific types of water sources in the four MMDAs estimate 15.2–32.9% for public standpipes/taps, 0.8–50% for boreholes/tube wells/hand-dug wells fitted with a handpump, 0–1.7% for unprotected wells and 0.1–15.6% for rivers/streams (GSS 2013). In terms

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Table 1 | Sources of water for small-scale palm oil processing

Water source	Frequency (*N*)	Percentage (%)	WHO/UNICEF Classification[a]
Treated piped water	5	20	Basic
Borehole with handpump	4	16	Basic
Hand-dug well (Protected)	11	44	Basic
Hand-dug well (Unprotected)	3	12	Unimproved
River/stream	2	8	Surface water
Total	25	100	

[a]Based on WHO/UNICEF definition under SDG 6.1 (WHO and UNICEF 2017).

of the WHO/UNICEF classification, the proportion of the water sources used by the mills that may be classified as 'basic' (80%) favourably compares with the regional and national averages of 88.4 and 79.4%, respectively (GSS 2018).

Most small-scale palm oil processing mills are sited in villages and small towns where the piped water supply may not be available. In villages, boreholes and hand-dug wells fitted with handpumps serve as the major sources of water for the inhabitants (Armah 2014). Water from boreholes fitted with handpumps is available to users at a fee, mostly charged per 18-L bucket of water. However, to eliminate the need to always pay for water or travel long distances to access water for their operations, small-scale processing mills construct hand-dug wells at their premises. This accounted for the high dependence on hand-dug wells (56%). The masterplan study on the oil palm industry in Ghana (MASDAR 2011) observed a similar source of water used by small-scale palm oil processing mills.

3.2.2. Location of water sources

Table 2 summarises the results of the location of water sources relative to the site for the oil processing operations. Nearly half of the processing centres had their water sources, mostly hand-dug wells, on their premises while about one-third accessed water at locations within 100 m from their premises. The rest had access to water between 100 and 200 m from their premises. The locations of the water sources made it possible for those who do not have access on their premises to obtain water in less than 30 min as expected of a basic level of service.

Table 2 | Location of water sources relative to small-scale palm oil processing centres

Location of water source	Frequency (*N*)	Percentage (%)
On premises	12	48
<100 m	8	32
100–200 m	5	20
Total	25	100

3.2.3. Cost of water for processing

Even though the cost of water typically incorporates recovery of capital costs, manpower and other operational costs, this study captured the recurrent costs incurred by the mills for a number of reasons. Firstly, most study participants, especially the majority that relied on hand-dug wells, which were mostly constructed by their own manpower, had no data on the initial investments. Secondly, for those who purchased water from vendors, the price is based on the recovery of operational costs to ensure the maintenance and sustainability of the facilities as per Ghana's rural water supply policy (CWSA 2010b). Initial investment costs are mostly financed by the government with the support of development partners and a token (about 5% of the total cost) demanded from the beneficiary community as a measure to elicit their commitment to maintaining the facilities. Thirdly, it was assumed that the recurrent cost which depends on how much water is withdrawn is the variable that could most likely influence water usage or conservation practices among the palm oil processors as a measure to minimize operational costs.

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The above considerations led to the identification of three categories of recurrent water costs. The first category, comprising the majority of the mills (16 mills out of 25), reported no recurrent water costs. They did not pay directly for water due to their dependence on hand-dug wells mostly owned by the processing mills or freely available in the neighbourhood. This group also included those who fetched water from rivers and streams. For the second and third categories of mills that paid for water, the cost depended on the source. Water from boreholes fitted with handpumps was sold for 20 Ghana pesewas per 18-L bucket which, at the time, was the equivalent of 1.93 USD per cubic metre. This was used by 4 out of the 25 mills. The remaining five mills used treated piped water from public standpipes sold for 30 Ghana pesewas per 18-L bucket or 2.89 USD per cubic metre.

The price of water paid by the small-scale processing mills in the study area was the same as the price paid by householders who fetched water for domestic use. This price is similar to that reported across small towns in Ghana (Kumasi 2018). But the prices are about 2–3 times that charged at the time for urban and peri-urban domestic water (1.02 USD per cubic metre) by the GWCL (PURC 2020). It is also higher (about 1.2–1.8 times) than that of the GWCL's commercial rate. This could be attributed to the differences in institutional framework and economies of scale. Rural water supply systems are decentralized schemes of small sizes with high maintenance and operating cost per unit volume of water supplied, which must be recovered by the water tariffs. The urban water systems, on the other hand, are of larger sizes that benefit from economies of scale. For industrial use, it was expected that the price of water should be relatively higher than that of domestic use to reduce competition and encourage water-use efficiency and recycling by the industries. However, it can be deduced from the comparison with urban water cost that the cost of water in rural areas and small towns is expensive for both industrial and domestic consumption. Thus, applying the traditional principle of charging a higher rate for commercial consumption would make the water even more expensive for commercial consumers and, potentially, threaten the profitability of their business. Even though this study did not investigate the proportion of the production cost that is accounted for by water usage, the practice of making water available to the mills at the same price as domestic usage could be an incentive to increase the profitability of the industry and thereby boost rural enterprises to improve livelihoods and control rural–urban migration among the youth.

3.3. Water consumption

3.3.1. Water consumption rates

The results of the water consumption for small-scale palm oil processing are summarized in Table 3. The results are presented as quantity (in litres) of water used per litre of crude palm oil produced.

The test for normality using the Shapiro-Wilk test at 5% significance level showed that all the data were normally distributed.

The small-scale palm oil mills in this study consume 0.760–2.391 L (mean = 1.658 L, SD = 0.446) of water in extracting 1 L of crude palm oil. Using crude palm oil density of 879 kg/m^3 (determined at the laboratory), the quantity of water used by small-scale processor translates into 0.86–2.72 T (mean = 1.88) for a tonne of crude palm oil produced. A similar small-scale/cottage industry in Ghana is the shear butter production industry. It is estimated that to process 1 T of shea butter in the Northern and Upper West Regions of Ghana, 4.8–5.9 T of water is required (Jasaw *et al.* 2015). In Malaysia, Ahmad *et al.* (2003) reported water consumption of 5.0–7.5 T for a tonne of crude palm oil extracted. The quantity of water used by the small-scale mills for processing palm oil is lower than water used for shear butter processing in Ghana and palm oil production in Malaysia. The water consumption rate reported for Malaysia is 2.8–5.8-fold higher than what was recorded in this study. The wide differences could be attributed to the different processing technologies employed. As previously mentioned, small-scale mills use manual methods with few mechanized unit processes as opposed to large-scale mills which predominantly employ fully mechanized methods of palm fruits processing.

In estimating water demand for small towns in Ghana, the CWSA design guidelines specify a per capita water consumption of 20 L/capita/day for standpipes (CWSA 2010a). The water consumption per litre of oil extracted by the small-scale mills is about 4–12% of the daily per capita water demand from public standpipes in small towns and rural areas in Ghana. Thus, every 10-L production of palm oil could consume the equivalent of one person's water demand. Unfortunately, this study did not generate data on the average daily production rate as the water consumption was estimated for production cycles. The potentially high-water usage by the small-scale palm-oil processing mills as compared to the domestic consumption necessitates the factoring of this

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Table 3 | Overview of water consumption by dry and wet processing methods

	Water consumption per litre of crude palm oil produced (L)			
Unit operation	**All mills ($N = 25$)**	**Mills using dry method ($N = 6$)**	**Mills using wet method ($N = 19$)**	***t*-statistic (*p*-value)**
Boiling				
Min	0.640	0.640	0.719	1.165 (0.256)
Max	1.739	1.739	1.293	
Mean (SD)	1.127 (0.243)	1.227 (0.408)	1.095 (0.168)	
% of total	68.3	75.3	66.1	
Clarification				
Min	0.000	–	0.096	
Max	0.375	–	0.375	
Mean (SD)	0.186 (0.132)	–	0.245 (0.090)	
% of total	10.9	–	14.2	
Cleaning of equipment				
Min.	0.120	0.120	0.120	0.853 (0.403)
Max	0.792	0.720	0.792	
Mean (SD)	0.345 (0.185)	0.402 (0.240)	0.327 (0.168)	
% of total	20.8	24.7	19.7	
Total (all unit operations in a production cycle)				
Min	0.760	0.760	0.966	– 0.182 (0.857)
Max	2.391	2.391	2.313	
Mean (SD)	1.658 (0.446)	1.629 (0.643)	1.668 (0.387)	

SD, standard deviation; NB, the dry method does not involve clarification.

informal cottage industry in the design of rural and small towns' water supply systems in communities where the industry is prevalent.

3.3.2. Water consumption rates per unit operation

To better appreciate the differences in water consumption reported in this study and that of literature, it is important to analyse the contribution of different unit processes to the total water consumption. The unit operation demanding the highest quantity of water was boiling (68.3%) followed by cleaning of working tools and equipment (20.8%) and finally clarification (10.9%). The wide variation (50–80%) in the quantity of water for boiling could be a result of the absence of a standard practice for determining water requirements among the different small-scale mills. Different processors use water quantities based on the quantity of fruits to be processed and the experience of the processor. The manual and tedious nature of the clarification process used by the small-scale mills may have contributed to its limited usage and consequently less amount of water usage for that unit operation.

3.3.3. Influence of operational factors on water consumption

The influence of the proximity of mills to a water source and the recurrent cost of water on the mean water consumption is presented in Table 4. The mean water consumption increased when the source was nearer as reported by WEDC (2017). The processing mills that obtained their water from the remotest water source of 100–200 m consumed less water (mean = 1.041, SD = 0.162).

The distance to the water source significantly influenced water consumption. The differences in the mean water consumption among the various distances were statistically significant at 1% level. On-premises water sources encouraged higher water usage as also reported by Overbo *et al.* (2016).

The recurrent cost of water influenced the mean water consumption, but the pattern was not consistent. Surprisingly, the processing mills that paid more for water (2.89 USD per cubic metre) rather consumed a higher quantity of water (1.825 L per litre of oil extracted) than those mills that had no recurrent cost (1.731 L per litre of oil extracted). In obtaining water from boreholes with hand pumps and hand-dug wells, much more

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Table 4 | Influence of operational factors on water consumption

Classification of mills	*N*	Quantity of water used per litre of crude palm oil produced (L) Mean (SD)	*F*/*t*-statistic (*p*-value)
Proximity of mills to water source			
On premises	12	1.887 (0.352)	*F* = 13.705 (0.000)*
<100 m	8	1.678 (0.285)	
Between 100 m and 200 m	5	1.041 (0.162)	
Total	25		
Recurrent cost of water			
No recurrent cost	16	1.731 (0.453)	*F* = 4.945 (0.017)**
1.93 USD per cubic metre	4	1.112 (0.047)	
2.89 USD per cubic metre	5	1.825 (0.131)	
Total	25		

SD, standard deviation; USD, United States Dollar; N, number in sample; 1 USD = GH¢ 5.77.
*Significant at 1% level.
**Significant at 2% level.

human effort is needed as compared to piped water sources and this may have encouraged water-use efficiency among those who depended on their own hand-dug wells. The differences in the mean water consumption among the various price categories were significant at a 2% level. A *post hoc* test revealed statistically insignificant differences in the mean consumption between the mills with no recurrent cost and those that paid 1.93 USD per cubic metre.

3.4. Wastewater generation

3.4.1. Wastewater generation rates

The wastewater generation rates for the different unit processes and different processing methods are presented in Table 5. For each litre of crude palm oil produced, 0.568–1.888 L (mean = 1.246, SD = 0.357) of wastewater is generated. The densities of the crude palm oil and wastewater were determined in the laboratory to be 879 and 1,036 kg/m^3, respectively. Using the densities, the quantity of wastewater produced by the small-scale processing activities is equivalent to 0.67–2.23 T (mean = 1.49) for a tonne of crude palm oil produced.

However, the literature reports that for each tonne of crude palm oil extracted, 2.5–3.8 T of wastewater is produced (Ho *et al.* 1984; Ahmad *et al.* 2003; O-Thong *et al.* 2012). The wastewater production quantities by the small-scale mills in Ghana are about 27–59% of the wastewater production quantities reported in the literature for large-scale mills. This may be attributed to the quantity of water used for processing, pre-processing practices such as fruits drying, processing techniques and number of unit processes that generate wastewater. At the large-scale mills, the largest proportion of wastewater originates from clarification condensate (Prasertsan & Prasertsan 1996; Department of Environment 1999; Nasution *et al.* 2018a) as opposed to boiling by the small-scale mills in Ghana. In the small-scale mills, fresh fruits were boiled for up to 4 h in metal tanks and covered with jute sacks as has also been reported by Osei-Amponsah *et al.* (2012) with much of the vapour evaporating into the air. This consequently reduces the quantity of wastewater produced. More so, storage of fresh fruits and drying of boiled fruits reduced the moisture content and consequently the quantity of wastewater produced.

3.4.2. Wastewater generation rates per unit operation

In terms of contribution from individual unit processes, the unit processes generating the highest quantity of wastewater was boiling (62.3%) followed by cleaning of working tools and equipment (25.2%) and clarification (12.5%). In terms of unit processes and percentage proportions, the average results obtained in this study differ from those obtained in Malaysia, Indonesia and Thailand. In Malaysia (Department of Environment 1999) and Indonesia (Nasution *et al.* 2018b), the wastewater generation for different unit processes are in the order: clarification (60%), sterilization (36%) and hydrocyclone (4%). But in Thailand, the proportion for clarification was relatively higher (clarification-75%, sterilization-17%, hydrocyclone-8%) (Prasertsan & Prasertsan 1996). The

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Table 5 | Overview of wastewater generation rates

Unit operation	Wastewater produced per litre of crude palm oil produced (litres) All mills ($N = 25$)	Mills using dry method ($N = 6$)	Mills using wet method ($N = 19$)	t-statistic (*p*-value)
Boiling				
Min	0.454	0.454	0.481	1.070 (0.296)
Max	1.200	1.200	0.935	
Mean (SD)	0.786 (0.173)	0.852 (0.288)	0.765 (0.123)	
% of total	62.3	69.6	60.1	
Clarification				
Min	0.000	–	0.084	
Max	0.334	–	0.334	
Mean (SD)	0.151 (0.108)	–	0.198 (0.075)	
% of total	12.5	–	16.2	
Cleaning of equipment				
Min.	0.087	0.114	0.087	1.008 (0.324)
Max	0.752	0.662	0.752	
Mean (SD)	0.310 (0.176)	0.373 (0.220)	0.290 (0.162)	
% of total	25.2	30.4	23.7	
Total (all unit operations in a production cycle)				
Min	0.568	0.568	0.672	– 0.166 (0.870)
Max	1.888	1.807	1.888	
Mean (SD)	1.246 (0.357)	1.224 (0.501)	1.253 (0.317)	

SD, standard deviation; NB, the dry method does not involve clarification.

differences in our results (small-scale mills) and that obtained from the literature could be due to the differences in the level of technology used. At the large-scale mills FFB are sterilized before stripping (Hassan *et al.* 2004), allowing the empty fruit bunches to absorb and retain some of the water (see Figure 3) as opposed to stripping before boiling practised by the small-scale mills in this study. The high amount of wastewater from boiling at the small-scale mills as against clarification condensate at the large-scale mills could lead to differences in the characteristics of the wastewater (POME) produced by these industries.

3.4.3. Wastewater return factor

The wastewater return factor for all the processing mills and different unit processes is presented in Table 6. The mean wastewater return factor for all the mills is 74.9% (SD = 4.8%).

In Malaysia, Ahmad *et al.* (2003) reported that more than 50% of water used in the extraction process returns as wastewater. Assessment of the wet process in Thailand revealed that 50–79% of the water used in palm oil extraction returns as wastewater (Chavalparit *et al.* 2006). Similarly, 72–75% of water used by small-scale mills returns as wastewater in Nigeria (Ohimain & Izah 2013). It could be observed that the wastewater return factors obtained for this study are generally comparable to those reported by the other researchers. In the palm oil processing industry, the wastewater return factor is based on characteristics of the processing method (small-scale, medium-scale or high-scale), and the extraction system employed. The potentially high organic loads of POME (Lam & Lee 2011) bring to the fore, the need to explore environmentally friendly and appropriate technologies for wastewater treatment and reuse in the palm oil industry. It is therefore necessary to assess the quality of wastewater produced by the small-scale mills.

3.5. Variation of water consumption and wastewater generation with processing method

The mean water consumption, wastewater generation and wastewater return factor were marginally higher for the wet processing method than the dry method (refer to Tables 3–5) but a test of significance reveals that the differences in the mean water consumption ($p = 0.143$–0.839) and wastewater generation ($p = 0.143$–0.839) rates between the dry and wet methods are not statistically significant ($p > 0.05$). The differences were not greater

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Table 6 | Comparison of wastewater return factors from dry and wet production methods

Unit operation	All mills ($N = 25$)	Mills using dry method ($N = 6$)	Mills using wet method ($N = 19$)	t-statistic (*p*-value)
Boiling				
Water used (L)	1.127	1.227	1.095	– 0.249 (0.806)
WW produced (L)	0.786	0.852	0.765	
Mean WW return factor (SD)	69.9% (6.2%)	69.3% (4.1%)	70.1% (6.8%)	
Clarification				
Water used (L)	0.186	–	0.245	
WW produced (L)	0.151	–	0.198	
Mean WW return factor (SD)	62.6% (37.4%)	–	82.3% (12.2%)	
Cleaning of equipment				
Water used (L)	0.345	0.240	0.347	2.069 (0.216)
WW produced (L)	0.310	0.373	0.290	
Mean WW return factor (SD)	88.8% (10.2%)	93.3% (2.1%)	87.4% (11.3%)	
Total (all unit operations in a production cycle)				
Water used (L)	1.658	1.629	1.668	– 0.088 (0.930)
WW produced (L)	1.246	1.224	1.253	
Mean WW return factor (SD)	74.9% (4.8%)	74.7% (3.6%)	74.9% (5.2%)	

Note: Water used and WW produced are for a litre of crude palm oil produced.
WW, wastewater.

than 4%. Even though literature (Poku 2002) reports higher water usage and wastewater production by the processing mills using the wet method, the findings from this study do not support such reports. In terms of individual unit operations, only clarification distinguished between the two methods of extraction as the dry method involved no clarification and, hence, no water consumption or wastewater generation from that unit operation.

The major water-consuming and wastewater-producing unit process of boiling is common to both processing methods. In spite of the involvement of clarification in the wet extraction method, the contribution of clarification to the mean water consumption and wastewater generation rates was just about 16% of the total. This explains why the water consumption and wastewater production between the two processing methods were not significantly different. The wastewater return factor for the dry method (mean = 74.7, SD = 3.6) and wet method (mean = 76.5, SD = 2.7) are within the range of values reported in the literature (Chavalparit *et al.* 2006; Ohimain & Izah 2013). It may be inferred from the results that the processing method (either dry or wet) did not influence the water consumption and wastewater production.

3.6. Implications of findings for policy and practice

3.6.1. Implications for tariff policy

The Government of Ghana is seeking to increase palm oil production to meet domestic needs and for export. Consequently, more water will be required, which will generate more wastewater. There is the need for a policy intervention to encourage water-use efficiency among the small-scale palm oil mills. On paper, the Ghana Small Towns Operation and Maintenance Guidelines (CWSA 2010b) provides that the unit rate of tariff for small-scale commercial entities in rural areas and small towns shall be 140–150% of the normal tariff for public standpipe (domestic) customers. However, this study found no distinction between the price of water for domestic and industrial uses since they all obtain from public standpoints. This arrangement may be good for encouraging water-dependent rural enterprises to create jobs for rural dwellers as a social intervention. Indeed, it may be argued from the comparison with urban water tariffs that the rate being paid by the millers is already high. In other words, it is rather the rural consumers that are paying higher charges due to economies of scale. Even though commercial and industrial use of water attract higher tariffs, all other factors being equal, the application of that policy in this context may not be helpful. On the contrary, the CWSA should device an implementation arrangement that would rather enforce its policy of domestic consumers paying lower by

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reducing the cost of water for domestic consumption. Furthermore, there is the need for strategies to protect domestic consumers from undue competition from industrial users without necessarily compromising the availability of water for rural enterprises.

3.6.2. Implications for technology selection

Around 70% of the total water consumption is used for boiling. At the small-scale mills, fruits are submerged in water, covered with jute sacks over open fire as has also been observed in other parts of Ghana (Osei-Amponsah *et al.* 2012). This practice requires unnecessarily high amount of water and much of the water is lost due to evaporation. On the contrary, large-scale processing industries use steam sterilization (Mba *et al.* 2015). Thus, a shift from the current method of boiling to steam sterilization could significantly reduce the amount of water used for boiling. Consequently, this could reduce the total quantity of wastewater generated. In Asia where palm fruits are sterilized, 17–36% of the wastewater originates from sterilization (Prasertsan & Prasertsan 1996; Department of Environment 1999; Nasution *et al.* 2018b) compared to 42–80% from the boiling method practised by the small-scale mills in Ghana. It may be inferred that the water consumption and wastewater production from boiling could be reduced by over 50% upon implementation of this intervention. The statistically similar water usage and wastewater production characteristics for wet and dry processing methods imply that similar capacities of wastewater treatment technology could be selected for the small-scale processing mills employing either wet or dry methods.

3.6.3. Implications for further research

This study focused on the Central Region of Ghana. Additional studies on water consumption for small-scale production are needed in other palm oil production regions of Ghana to generate national-level data. A comprehensive data on the sources of water and quantities required for palm oil processing would provide useful inputs into future designs of small towns water supply projects in palm oil processing communities in Ghana. There is also the need to develop an appropriate technology for treating the wastewater generated. This should be preceded by the characterization of the content of the wastewater. There is also the need for further research on what policy interventions may be adopted to protect domestic water users from paying high tariffs and also from undue competition from commercial and industrial users.

4. CONCLUSIONS

This study was aimed at assessing the water usage and wastewater return factors by small-scale palm oil processing mills in Central Region of Ghana. The unit processes that consumed fresh water and generated wastewater were boiling of fresh fruits, extraction of oil (optional) and cleaning of working tools. Water for processing was sourced from protected hand-dug wells, piped water from public standpipes, boreholes with handpumps, unprotected hand-dug wells and rivers/streams. The proportion of water sources used by the mills reflects the water sources available to the inhabitants in the study communities. Eighty percent of the water sources were from the basic service level as per the definition of the Joint Monitoring Programme (JMP) of the WHO and UNICEF. The price of water ranged between 1.93 and 2.89 USD per cubic metre. The distance to the water source influenced the consumption rate with higher water consumption being associated with processing mills with on-plot water sources. The price of water paid by the processing mills was the same as the price paid by householders who fetched water for domestic use. The higher cost of water did not lead to lower water consumption. For a litre of crude palm oil produced, 0.760–2.391 L of water was used, representing about 4–12% of the per capita water demand of the rural communities, and generated 0.568–1.888 L of POME. In terms of wastewater return factors, 75% of the water used in the extraction industry returned as wastewater. Boiling fresh fruit as a unit operation consumed the greatest quantity of water (68.3%) and generated the highest quantity of wastewater (62.3%). The quantity of water used for boiling could potentially be reduced by using steam sterilizers instead of the current boilers which require that the fruits are submerged in water. Steam sterilization will reduce the amount of water lost due to evaporation and use about 50% of the water required by boilers. The processing method (either dry or wet) did not influence water consumption and wastewater production. There is a need to develop a national policy to manage the potential competition between domestic and industrial water uses in the communities where small-scale palm oil processing is prevalent. Further research is needed for characterizing and finding appropriate wastewater treatment technologies for use by the small-scale palm oil industry.

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ACKNOWLEDGEMENTS

The authors acknowledge the support of the following persons during the data collection exercise: Emmanuel Arthur, Ibrahim Adjei and Richard Mensah (past students of Cape Coast Technical University, Ghana).

FUNDING

No funds, grants, or other support were received.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 7 July 2022; accepted in revised form 2 December 2022. Available online 13 December 2022

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