REPORT D1.2

Baseline studies towards demonstration of water-smart solutions in Accra

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D1.2 – Public

Baseline studies towards demonstration of water-smart Solutions in Accra

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ABSTRACT

This document presents the outcome of activities undertaken for Task 1.2 (T1.2) of the WIDER UPTAKE Project. T1.2 is the reuse of wastewater for urban agriculture and production of biochar from wastewater sludge for fuel in Accra. The purpose of this report is to provide baseline information about the Accra demonstration sites for wastewater use in urban farming. In addition, the document provides better understanding of the wood fuel needs of selected SMEs in Accra while. Thus four studies were conducted to provide such baseline information: (i) A socioeconomic baseline was carried out of urban farmers in the city of Accra, including the demonstration sites for treated wastewater use; (ii) a baseline study to assess the quality of wastewater presently being used by farmers at the sites selected for demonstration (CSIR-Water Research Institute and CSIR-Animal Research Institute); (iii) baseline of 16 selected SMEs in Accra; and (iv) establish a baseline of the feedstock (faecal sludge), the laboratory-produced biochar.

KEYWORDS

Wastewater use, urban agriculture, Accra, biochar, water-smart solution

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Executive summary

Ghana's population has been growing rapidly since independence in 1957. This rapid growth has been accompanied by rapid urbanisation as well. Over the years, the country has moved from a more rural population to urban population. The current population of Ghana is estimated at 31.5 Million with growth rate of 2.12% (UN World Population Review 2021). With an urban population over 90%, the challenges in Accra deserve special attention taking into account the rapid expansion of the urban city. Yet, despite the increasing urbanisation in Ghana, there has not been a national discourse on water-smart use options for the nation and even for specific urban areas that face perennial water shortages.

Against this background, it is imperative for a roadmap for widespread implementation of water-smart symbiotic solutions for wastewater reuse and resource recovery in Ghana, hence, WIDER UPTAKE which will demonstrate the use of treated wastewater for urban farming and produce biochar from faecal sludge as replacement for wood-based charcoal. However, prior to the demonstration, four baseline studies were carried.

A socioeconomic baseline was carried out of urban farmers in the city of Accra, including the demonstration sites for treated wastewater use. A total of 214 farmers were interviewed for the study—most of them were males (99%)—and an average age of 40 years old. Most of the farmers had some level of formal education, albeit primary level of education. The farmers were mainly engaged in vegetable farming, with the popular types being lettuce and other leafy vegetables. The farmers indicated their openness to new farming methods, most of them used treated pipe-borne water to irrigate their crops (42%), although a sizeable number relied on streams (22%) and drains (13%) that are connected to drains as sources of water. The farmers indicated their preparedness to pay for treated wastewater, although they were not ready to pay as much as they already are paying for treated pipe-borne water. In terms of quantity of water used, the average farmer used 6680 litres per day. Most of the farmers did not own the land they farmed.

Alongside the socioeconomic baseline study, a baseline study was conducted to assess the quality of wastewater presently being used by farmers at the demonstration sites (CSIR-Water Research Institute and CSIR-Animal Research Institute), the quality of crops, and the soil characteristics. On this score, the study conducted physical-chemical, bacteriological, and parasitological analyses. Analyses of recalcitrant compounds and bacteriophages are outstanding due to capacity related challenges of institutions in Ghana that could conduct such analyses. Discussions are ongoing with partners in the Czech Republic to assist with these analyses. The available results, however, show that generally, the physical-chemical characteristics of wastewater, soil and vegetables sampled had levels below national recommended values. Except for chromium concentration in vegetables, the pH, biological oxygen demand (BOD), chemical oxygen demand (COD), both measures of organic matter in the water, and heavy metal values were within the FAO/WHO (United nations Food and Agriculture Organisation and World Health Organisation) standard values.

Since the Ghana case will produce biochar for use by small and medium size enterprises (SMEs), a baseline was conducted on 16 selected SMEs in Accra. Majority of the respondents/owners of the SMEs were females (89%) and on average had more female employees (4 females against 2 males). All SMEs interviewed did use wood-based charcoal, consuming over 10kg per week. The SMEs were willing to pay a little extra for environmentally friendly alternative (biochar) to the wood-based charcoal so far as such alternative was efficient, did not have any offensive smell, and was readily available.

To establish a baseline of the feedstock (faecal sludge), the laboratory-produced biochar, as well as other properties such as heavy metal content and calorific values, a fourth baseline study was conducted. This study showed that the sulphur content was high in the sludge as well as the carbonized form (biochar); heavy metals generally tended to be concentrated on carbonizing; and lead content was high as well. Furthermore, the sampled biochar was dense, which reduced heat diffusion through the sample leading to uncarbonized inner core. Hence, there is need to identify and apply appropriate measures to reduce the sulphur and lead contents.

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1 Introduction

1.1 Background

Ghana's population has been growing rapidly since independence in 1957. This rapid growth has been accompanied by rapid urbanisation as well. Over the years, the country has moved from a more rural population to urban population with more than half the population reported to be living in urban localities (GSS, 2014). This situation is consistent with expected rapid increase in urbanisation in sub-Sahara Africa (SSA), and indeed it has been projected that urban population of Ghana could reach 70% by 2050 (Tuholske et al., 2020, p. 420). Figure 1 below shows the trends in urbanisation in Ghana by region[1] for the last five census periods. The figure shows that Greater Accra has consistently been the most urbanised region in Ghana, reaching 90.5% in 2010.

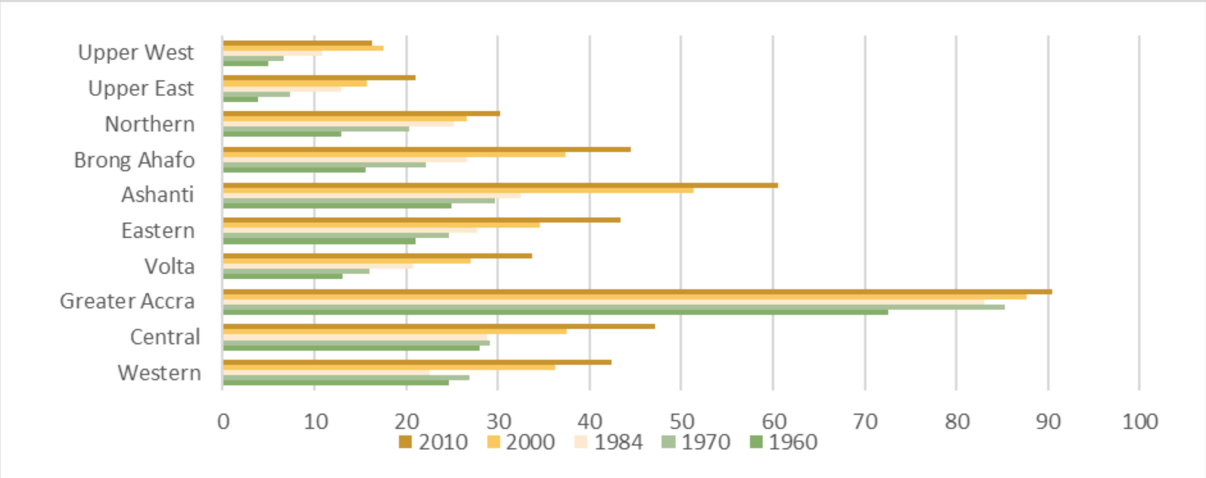

Figure 1: Trends in Urbanisation (1960-2010); Source: Constructed based on data from GSS (2014, p. 19)

With an urban population over 90%, the challenges in Accra deserve special attention taking into account the rapid expansion of the urban area since the 1990 with a serious backlog of services and infrastructure (UN Habitat, 2015). Moreover, the level of urbanisation has several ramifications: for example, the level of food and nutrition security, land availability for food production, extraction and use of freshwater, and the impact of urbanisation on environmental quality (such as pollution of water bodies) are some of the effects. Indeed, there is recognition that the size of health risks is a function of the quality and quantity of wastewater and the probability of human contact (Van Rooijen & Drechsel, 2008).

Yet, despite the increasing urbanisation in Ghana, there has not been a national discourse on water-smart use options for the nation and even for specific urban areas that face perennial water shortages. Meanwhile, as a form of livelihood option, there is urban farming in the major urban centres in Ghana with Accra (the capital city) being one. The urban farmers are located along major drains and streams in the city and extract raw water from the drains to irrigate their crops directly. Some have dug reservoirs that are used to store the extracted water before using to irrigate the crops (Figure 2).

[1] At the time of the last census, Ghana had ten regions, but in 2018, 6 more regions were carved out of existing regions. Greater Accra was not affected in anyway.

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Figure 2: Shallow Reservoir Holding and Raw Drain Water Being Extracted for Irrigation; Source: Authors

A study conducted by Fianko and Korankye (2020, pp. 140–141) concluded that:

> *Water samples used for informal irrigation in urban and peri-urban agriculture in Greater Accra Region of Ghana were found to contain significant levels of microbial load which is an indication of pollution. The average CPI [comprehensive pollution index] values 0.27 is an indication of moderate pollution of the irrigation water. About 42% of samples were found to be sodic waters, hence there should be a degree of restriction on use of water from this area for irrigation.*

The need for quality water for urban farming in Accra cannot be overemphasised.

Ghana's economy continues to rely on charcoal as an energy source—not only households, but small and medium enterprises (SMEs) as well. Yet, most of the charcoal produced comes from the ecologically fragile parts of Ghana, the Guinea Savanna and Forest Transitions ecological zones, where the wood for charcoal is collected mostly from natural standing trees (Obiri et al., 2014). In short, most of the local charcoal-making process in Ghana is not regulated and the source of the feedstock is not sustainable (Energy Commission, 2019). Hence, there is need to find alternatives to wood-based charcoal.

In view of the above there is recognition that the barriers to the implementation of water-smart solutions are not only technological but also of organizational, regulatory, social, and economic character. Against this background, the Ghana Case of the WIDER UPTAKE project will demonstrate innovative solutions for wastewater reuse and energy recovery in symbiosis with agricultural and manufacturing industries. In furtherance of this, Sewerage Systems Ghana Limited (SSGL) will make treated wastewater available for urban farmers in Accra. In addition, SSGL will produce biochar from sludge recovered from wastewater treatment for use as substitute for wood-based fuel and charcoal. The target is to supply SMEs in the city that are dependent on wood-based fuel.

However, before the case commences with the demonstration of the innovative solutions, a number of baseline studies have been conducted for the purposes of measuring changes in the safety and quality of crops due to the use of treated wastewater from the Mudor Treatment Plant (MTP) operated by SSGL and to obtain better understanding of the energy needs of SMEs in the study area. These baseline studies are also important to establish bases for comparison with demonstration outcomes in the long-term.

1.2 Objectives of the Report

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The overarching objective of this report is to present findings of four baseline studies conducted for the demonstration of the innovative solutions of circular economy in respect of wastewater treatment. Specifically, the report will present findings from:

1. A socioeconomic study of urban farmers in the city of Accra, including farmer at the demonstration sites
2. A baseline study of the quality and quantity of wastewater currently being used by urban famers in the demonstration sites
3. An assessment of wood-based fuel use among selected SMEs in Accra
4. Assessment of the feedstock for making biochar and laboratory produced biochar

1.3 Organization of Report

This report is organised into five chapters. The first chapter sets the background and introduces the overall content of the report. The second to sixth chapters present reports of four studies conducted as part of the overall baseline. Hence, Chapter Two presents findings of the socioeconomic baseline study of urban farmers. Chapter Three presents the baseline characteristics of water presently being used by urban farmer, the quality of the crops and soils. Chapter Four presents result of studies conducted on selected SMEs in Accra to assess the present wood-based fuel needs and their willingness to adopt biochar as an alternative. In Chapter Five, the study presents results of a study conducted to analyse the characteristics of the feedstock for making biochar (sludge) and the laboratory-produced biochar. Chapter Six presents overall conclusion of the report.

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2 Socioeconomic baseline of urban farmers in Accra

2.1 Introduction

It has been estimated that between 50-90% of vegetables consumed in Accra are produced with wastewater (Antwi-Agyei et. al., 2016); mainly on small-scale irrigated lands using wastewater from drains. The wastewater used by majority of the farmers are untreated, having the potential to contaminant the crops. Studies have shown the presence of E. coli in these vegetables (see Antwi-Agyei and Ensink, 2016;). As estimated by Obuobie et al. (2006), there are between 800-1000 small-scale vegetable farmers in the Accra metropolis, cultivating about 47ha in the rainy season and 116ha in the dry season.

Wastewater generation in Accra is estimated at 80000000L per day with vegetable farmers using up to 14% of the wastewater (Lydecker and Drechsel, 2010). Watering cans are used to collect wastewater from the drains, dugouts, and streams to irrigate the fields and with little or no protection to the body despite the wastewater being polluted with bacteria, fungal and faecal matter. In some instances, water pumping machines are connected into the drains to pump the water to the fields. Crops normally produced are vegetables which are sold to market women and food vendors, locally referred to as 'chop bar' operators. Some of these vegetables include onion, cabbage, lettuce, *amaranthus spp*, pepper, eggplant, and spring onion. The vegetables are grown throughout the year because of the availability of wastewater.

This chapter presents findings of the socioeconomic study of urban famers in selected sites of the capital city of Ghana, Accra. The chapter first presents a review of existing literature on urban agriculture in Ghana, discussing some benefits and harms related to the practice; next, the chapter presents the methods used in the data collection, which leads to the findings of the socioeconomic study. The chapter ends with some concluding remarks and recommendations.

2.2 Urban Agriculture and Wastewater Use in Ghana

Wastewater use for irrigated agriculture has been in existence for many years because of increasing scarcity of freshwater resources in inner-city areas. As a result, the use of treated wastewater is increasingly being promoted by governments and development practitioners in recent years due to the health implication of untreated wastewater for both producers and consumers (Becerra-Castro, et al., 2015). Wastewater reuse can have two effects (Becerra-Castro, et al., 2015; pp 1):

1. Soil productivity and fertility
2. Pose serious risks to the human and environmental health

However, sustainable use of wastewater should avert both effects. Literature suggest that wastewater can broadly be categorized into treated and untreated. Untreated wastewater is "sewage from household, municipal, and industrial sources" while treated wastewater is "wastewater that has gone through cleaning processes to improve its quality" (Rice et al., 2016; pp. 4). This report adopts these definitions.

Studies have been undertaken to analyse the importance of wastewater use in urban and peri-urban agriculture. For instance, Danso et al. (2002) examined wastewater use in informal irrigation in urban and peri-urban areas of Kumasi, Ghana (see also Cornish and Aidoo, 2000; Jaramillo and Restrepo, 2017). Wastewater reuse enables small-scale wastewater-irrigated vegetable producers in urban areas to achieve an annual income level of between US$400–800/ha. Some estimates have projected more than US$1,400/ha (Cornish et al., 2001). Recent data by Abdulai et al. (2017) suggest that small-scale wastewater-irrigated urban and peri-urban vegetable producers in Kumasi, Ghana can obtain a return on investment of about US$7, 818.06 per annum.

The significance of wastewater use for small-scale urban vegetable production is not only reflected in the livelihood support, income, employment generation and contribution to sanitation services but also opportunity to put to use small open places in urban areas which might otherwise be neglected by city authorities. Mostly,

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small-scale irrigation vegetable producers in urban areas make use of small lands to turn them into productive economic ventures using untreated wastewater, which mostly comes at no cost. The overall advantages of the activities of small-scale urban vegetable producers on urban areas cannot be overemphasized.

City dwellers often relied on these producers to get fresh vegetables for their homes. Because of the highly perishable nature of vegetables and the lack of effective transportation and refrigeration systems to transport fresh vegetables from rural to urban areas, most urban dwellers rely on small-scale urban vegetable growers, who rely on untreated wastewater to cultivate the vegetables (Nugent, 2000; Smith, 2002; Antwi-Agyei, 2015).

Of the many benefits of wastewater use, one noticeable benefit is that it reduces the pressure or demand for freshwater use in production (WHO, 1989). Agriculture production alone accounts for about 70% of the global freshwater usage (Katzenelson et al., 1976; World Bank (WB, 2020); however, the use of wastewater serves as sources of water for production thereby reducing global demand for freshwater. Wastewater reuse for irrigated agriculture can also help to promote circular economy by recovering nutrients from the treated wastewater and applying them to crops, through the process of fertigation. Consequently, wastewater reuse decreases the need for additional applications of inorganic fertilizer.

Notwithstanding benefits derived from wastewater reuse, there are challenges associated to its use. For instance, wastewater can lead to animal and crop contamination because contaminants from such water can find their way into plants and animals as a result of absorption from the soil or ingestion. Arimiyaw et al., (2020) assessed the health risk associated with urban vegetable farming with results showing high contamination levels of total *coliform, Escherichia coli and Enterococci aerogene*s bacteria in both samples of wastewater and vegetables collected in Kumasi contrary to farmers' perception that these vegetables were safe for consumption. This problem remains a major worry not only to health practitioners but also to policy makers and consumers as well. Due to health concerns, some consumers in urban areas do not eat vegetables because they believe irrigated urban vegetables production uses wastewater which is unhygienic (Nchanji and Bellwood-Howard, 2018). For this reason, some assemblies have instituted bylaws. As can be observed in the Accra Metropolitan Assembly bylaws, "No crops shall be watered or irrigated with the effluent from a drain from any premises or any surface water from a drain which is fed by water from a street drainage unless it is treated to an acceptable level" (AMA, 2017 pp. 160).

Fruits and vegetables that are likely to be consumed in their raw state are to be guided by these assembly bylaws. The use of wastewater in irrigating small-scale urban agriculture particularly vegetable production remains largely unregulated. Where there are regulation(s) they are unenforced since urban vegetable producers have no alternative to the untreated wastewater. Because of this city authorities appear helpless or unwilling to enforce the bylaws (Drechsel and Keraita, 2014).

2.3 Methodology

This section explains the processes and procedures the study adopted to obtain the data and the ensuing analysis. There was a study inception meeting to map out strategies to accomplish the goal and outcome of the study. This was followed by literature review to analyse existing literature related to the work to inform the project team on approaches available and what can be improved. Information from literature was relied upon to design the questionnaire. There was a two-day training for enumerators to ensure that they were well acquainted with what was required of each question. This was followed by pretesting of the questionnaire. This was to help enumerators foresee challenges that may rise. Results from the pretesting were relied upon to revise the questionnaire.

2.3.1 Data Collection

The study selected all the major wastewater-irrigated urban farming sites within the Accra Metropolis. Wastewater-irrigated urban farmers were purposively selected because they are the focus of the study and

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indeed, will be participating in the demonstration of the use of treated wastewater for farming. Depending on the population of farmers at a given site, a proportion of farmers were purposively selected. Table 1 shows the number of farmers selected for each site. Simple random sampling technique was used to select the farmers to be interviewed. This is to avoid bias and to ensure fair representation in the selection. The study encountered challenges with the questionnaire administration due to time schedule of farmers. In some instances, enumerators had to reschedule the time of interview at the convenience of the farmers. However, all randomly selected farmers were interviewed.

Table 1: Sites and Number of Farmers Interviewed

Sub-Metropolitan Area	Site name/area	Frequency	Percent
Ayawaso West	CSIR	38	17.8
	Dzorwulu	30	14.0
	Roman Ridge	37	12.6
	Legon	23	10.8
	Okponglo	9	4.2
Ayawaso Central	Plantpool	28	13.1
Ablekuma South	Korle-Bu	59	27.6
	Total	214	100.0

Source: Field survey, 2020

2.3.2 Data Analysis

After the data was obtained, it was cleaned and reviewed to ensure that questions were satisfactorily answered. In all, 214 farmers were interviewed. Stata 16 was used for the analysis and the results were presented in tables, bar, and pie charts. The interpretations and discussion are, thus, presented in what follows according to the observed statistics.

2.4 Results

2.4.1 Demographic, Gender and Socio-Economic Data

The study was conducted in seven urban farming sites in the Greater Accra Metropolitan Area of Ghana. Specifically, the study covered farmers in Ayawaso West, Ayawaso Central and Ablekuma Central Sub-Metropolitan Areas of Accra. Table 1, above, shows the distributions of the study sites in the sub-metropolitan areas.

2.4.1.1 Gender and Age Distributions

The demographic analysis of the respondents in this section focuses on the gender, age, education, and employment status of the respondents. In total 214 farmers were interviewed of which majority, 98.6% were male. The ages of the respondents varied, ranging from the youngest of 20 years to the oldest of 80 years. The average age of farmers interviewed was 40 years. The youngest and oldest farmers were both male. The results further show that all female farmers interviewed were between the ages of 46-55 years with a standard deviation of 4.6 years. Using the Seventh Ghana Living Standard Survey (GLSS7) age classification of youth as persons below 35 years, the study found that the majority of male respondents interviewed, 43.8%, fell in the youth group (Figure 3).

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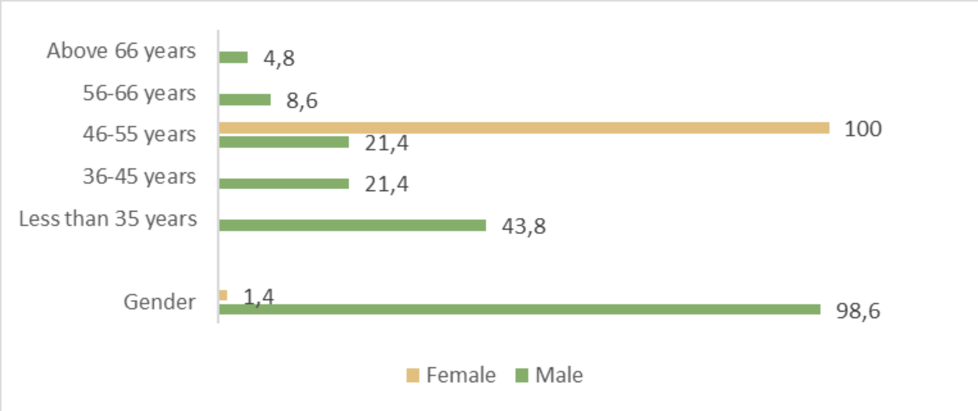

Figure 3: Age Categorisation and Gender of Respondents; Source: Field survey, 2020

2.4.1.2 Level of Education and Main Employment of Respondents

All three females interviewed had received formal education. They affirmed they individually had attained secondary education, middle school leavers and primary education, respectively. The highest percentage of male respondents had no form of formal education. Basic level of education was the highest level of formal education for 21% of male respondents and these respondents had a mean age of 40 years. The Middle School Leavers Certificate was revealed as the educational level with the highest mean age of 57 years. Less than 3% of the respondents had received tertiary education. Additionally, the results show that, the youthful group formed the highest proportion of respondents with some form of formal education. Only 18% of respondents had no formal education, and they were all males (Table 2).

Table 2: Level of education

What is your highest level of education?	Sex			Mean age
	Male	Female	Total	
Tertiary	5 (2.37)	0	5	40
Senior Secondary	14 (6.64)	1 (33.33)	15	35
Technical/vocational	4 (1.90)	0	4	52
MSLC	10 (4.74)	1 (33.33)	11	57
Junior Sec.	35 (16.59)	0	35	42
Primary	45 (21.33)	1 (33.33)	46	40
No education	81 (38.39)	0	81	38
Others (specify)	17 (8.06)	0	17	43
Total	211	3	214	40

Percent [%] in parenthesis; Source: Field survey, 2020

In examining the main employment of the farmers interviewed, since it is common that some farmers may be engaged in the activity only as a supplementary occupation, the study revealed that respondents were mostly (95%) vegetable farmers. A very small minority (2.3%) of the respondents specified "other types" of employment such as gardening and security service as their main source of employment (Table 3). A cross tabulation with the age groups of respondents showed that respondents above the age of 55 years were only vegetable farmers as their main occupation. Also, all of the three female respondents where vegetable farmers.

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Table 3: Main Occupation

Main occupation of respondent	Frequency	Percent
Vegetable farming	203	94.86
General crop production	4	1.87
Self-employed (non-farm enterprise)	2	0.93
Other type of employment (specify	5	2.34
Total	214	100.00

Source: Field survey, 2020

The study further showed that half of the farmers who were engaged in other specified occupations such as gardening as a main agricultural-related activity also engaged in secondary occupations for subsistence. The remaining half constituted 27% of farmers who were involved in the marketing of farm produce, 14% were involved in agro-processing, 8% in livestock rearing and the remaining 1% was into aggregator service provision.

2.4.2 Production activities

2.4.2.1Main Farm Produce and Farm-Related Activities

Most of the respondents were into vegetable production and at the time of the survey, the popular vegetable produced was identified by the farmers as lettuce (Figure 4). Further disaggregation of the data showed that lettuce farming as the main vegetable grown was dominant only at the Korle-Bu site (76.3%), Dzorwulu site (53.3%) and Roman Ridge site (51.3%). Farmers at the Plantpool and CSIR farming sites confirmed leafy vegetables (such as Amaranthus) as the most grown type of vegetable, while peppers (62%) remained the main vegetable grown by farmers of the Legon site.

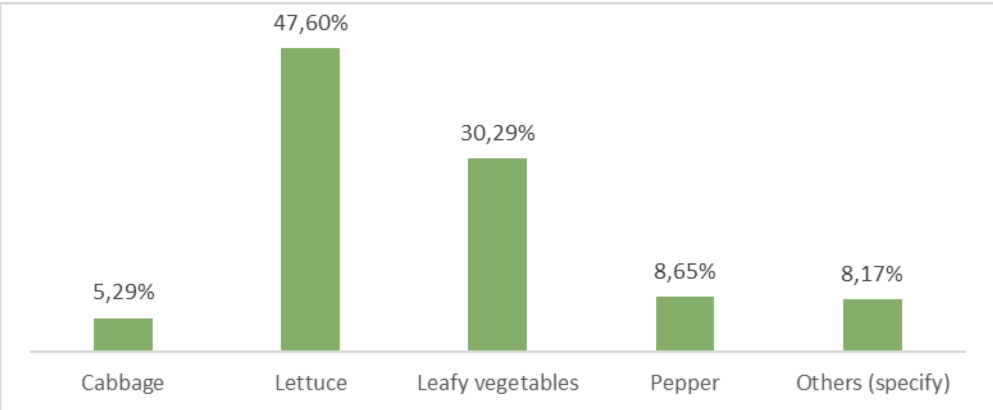

Figure 4: Type of Vegetables Mainly Produced; Source: Field survey, 2020

In terms of value addition to the farm produced, only 6% of all the respondents interviewed alluded to adding value to their produce and all these respondents were male farmers. The various forms of value addition farmers engaged in include grading and standardization (42%), packaging (33%) and vegetable processing (25%). A chi squared test of independence found no statistically significant relationship, $(\chi^2(18) = 169, p - value = 0.530)$, between the level of education of the respondents and the type of value addition farmers engaged in. Thus, the type of value addition practiced by a farmer did not depend on the level of education of the farmer.

However, majority of the farmers indicated their openness to applying new farming and marketing methods. Although 20% of the male farmers and one of the three female farmers opined that they were not open to new farming and marketing methods. Generally, the same proportion was evident among all age groups of farmers interviewed. Although, a cross tabulation of the level of education and farmer openness to new faming and marketing methods showed that the rate of non-openness to new farming proportionately increased with low levels of education (Table 4).

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After production, the majority (86%) of the farmers confirmed that they sold the farm produce at gate by selling whole beds. Other marketing strategies used by 12% of the respondents was packaging their farm produce for sale while the remaining 2% of processed their farm produce.

Table 4: Openness to New Farming/Marketing Methods

What is your highest level of education?	Are you opened to new farming and marketing methods?		
	Yes	No	Total
Tertiary	4	1	5
	(80.00)	(20.00)	(100.00)
Senior Secondary	11	4	15
	(73.33)	(26.67)	(100.00)
Technical/vocational	4	0	4
	(100.00)	(0.00)	(100.00)
MSLC	10	1	11
	(90.91)	(9.09)	(100.00)
Junior Sec.	27	7	34
	(79.41)	(20.59)	(100.00)
Primary	36	9	45
	(80.00)	(20.00)	(100.00)
No education	62	18	80
	(77.50)	(22.50)	(100.00)
Others (specify)	14	3	17
	(82.35)	(17.65)	(100.00)
Total	168	43	211
	(79.62)	(20.38)	(100.00)

Percent [%] in parenthesis; Source: Field survey, 2020

The land size represented by the total number of raised beds that were cultivated by the farmers was averaged at 47.9 beds (603.54 square metres)[2]. A farmer had as many as 270 beds (3402m^2) and as few as one bed. The majority of the farmers indicated that their land sizes had not changed from the previous year (2018/2019). Although a tenth of the respondents had experienced some changes (increase [4%] and a decrease [6%]) in the land sizes in the previous farming year. Hence, generally, farmers continued to farm on same pieces of land year in year out.

In terms of income obtained from urban farming in 2019, farmers recorded an average annual total revenue of Gh₵8,537.89 (USD1,472)[3]. Although a respondent confirmed a maximum total revenue of Gh₵55,000 (USD9,483) in 2019. The results showed that the expenditure of farmers on seeds was the highest at an average cost of Gh₵1527.98 (USD263). The results also showed that farmers spent more on inorganic fertilizer annually than organic fertilizer. Pesticides and weedicides were purchased at an annual average of Gh₵3,300 (USD569) and Gh₵1250 (USD215) respectively. Other expenditures included an average cost of Gh₵77.55 (USD13) for transporting inputs (for instance, organic fertilizers, fuel for powering spraying machines and fungicides). See Table 5.

[2] By estimation, an average bed is 12.6 square metres.
[3] Using exchange rate of Gh₵5.8 = USD1

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Table 5: Quantity and Costs of Inputs Per Annum

Variable	Obs	Quantity (Kg)				Costs (Gh ₵)			
		Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Seeds	202	194.693	432.262	0.2	3450	1527.98	2938.022	30	18000
Organic fertilizer	197	520.947	993.009	0	7500	264.861	316.565	0	2400
Inorganic fertilizer	171	117.168	293.803	0	3300	369.011	761.834	0	9188
Pesticides	202	22.246	106.622	0	1095	388.42	527.493	0	3300
Weedicides	170	11.762	80.092	0	1000	77.551	168.304	0	1250
Other (fungicide, cost of transportation, spraying machine, fuel)						243	155.02	90	400

Standard error in parenthesis; Source: Field survey, 2020

2.4.3 Water Use, knowledge, and farmer perception

2.4.3.1Source of Water for Urban Agriculture

Almost half of the farmers, forming the highest proportion (42%) indicated that a borehole/pipe borne water was the main source of water for farm production. However, in areas without access to borehole/pipe borne water such as CSIR, Korle-Bu and Roman Ridge farming sites, the stream were the main source of water farmers used for farm production. In total, 22% of the respondents indicated streams were the main source of water for production. Shallow wells or dugouts were mostly used in the Korle-Bu farming site. Also, approximately 13% of the respondents used drain water for production. This source of water for production was dominant in the Roman Ridge. It is important to point out that in the inner cities, most of the streams have been turned into drains, as such, the percentage of farmers using drains is much higher than the study would suggest. Rainfall was specified by only 4% of the farmers as their main source of water for production (Table 6).

Table 6: Main source of water for production

What is your main source of water for production/ irrigation?	Total	CSIR	Dzorwulu	Korle-Bu	Okponglo	Plantpool	Roman Ridge	Legon
Borehole/pipe borne	89 (41.98)		21 (70.00)		5 (55.56)	26 (92.86)		13 (59.09)
Shallow wells/dugout	40 (18.87)	2 (2.26)	1 (3.33)	24 (41.38)	4 (44.44)		8 (29.63)	
Stream	47 (22.17)	32 (84.21)	4 (13.33)	25 (43.10)		1 (3.57)	10 (37.04)	
Drains	27 (12.74)	4 (10.53)	4 (13.33)	9 (15.52)		1 (3.57)	9 (33.33)	
Other (specify) Rainfall	9 (4.25)							9 (40.91)
Total	212 (100.00)	38 (100.00)	38 (100.00)	58 (100.00)	9 (100.00)	28 (100.00)	27 (100.00)	22 (100.00)

Percent [%] in parenthesis; Source: Field survey, 2020

As shown in Figure 5, more than half of the respondents use manual water cans as the primary system for irrigation. Motorized (water pumping) machines were used by 29% of the farmers.

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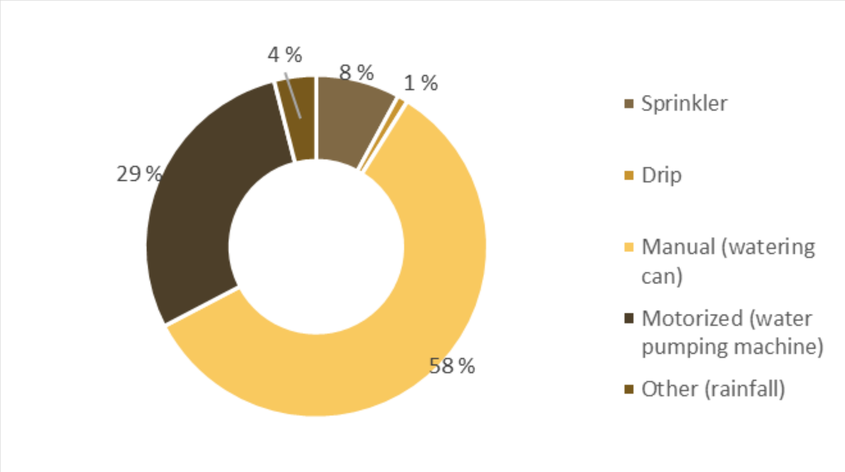

Figure 5: Type of Irrigation Practiced

A cross tabulation of the main source of water production and the systems of irrigation showed that the most dominant water source, borehole/pipe borne water, was used mostly with manual watering cans. Farmers who use streams as the main source of water also mainly used motorized (water pumping machine) for irrigation (Table 7).

Table 7: Main source of water for urban farming

What is your main source of water for production/irrigation?	Type of irrigation practiced					
	Sprinkler	Drip	Manual (watering can)	Motorized (water pumping machine)	Other (specify)	Total
Borehole/pipe borne	11	1	59	15	4	90
Shallow wells/dugout	1	0	34	5	0	40
Stream	3	0	16	28	0	47
Drains	2	0	17	9	0	28
Others (specify):	0	0	0	0	8	8
Total	17	1	126	57	12	213

Source: Field survey, 2020

The respondents further described their source of water for irrigation as generally good (62%). With less than a tenth observing their source of water as neutral. Also, less than 5% percent described their water source as bad. The respondents confirmed that two thirds of the time, their assessment of the quality of water used was through observation by sight.

2.4.3.2 Water Use on Urban Farms

When asked about the seasonal availability of water for urban farming, 69% of the farmers indicated that water was available for year-round production. For the remaining 31%, 5% indicated that they do not have access to water for at most once in a year. A greater section (68%) of the respondents mentioned that they do not have access to water for 8 months. While 15% and 12% of respondents without consistent annual water flow indicated than they lack access to water for 3 months and 6 months respectively in a year.

Due to the water availability, 43% of the respondents noted that they irrigated their farms once a day; 31% irrigate their plants twice a day; 18%; and 5% of the respondents irrigate their farm beds every two days and 3 days respectively while 4% of the respondents mentioned that they depend on the frequency of the rains in the

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rainy season. On average the respondents use approximately 605 watering cans (6050 litres[4]) per day. The highest recorded volume of water used by a farmer in a day was 4600 cans (46000 litres) while the lowest volume of water used by a farmer is 56 cans (560 litres) per day. Results also showed that, most farmers use 300 cans (3000 litres) of water per day.

2.4.3.3 Willingness to Use Treated Wastewater

2.4.3.3.1 Willingness to Pay for Treated Wastewater

The study conducted comparative expenditure analyses of the means of how much respective respondents are willing to pay for treated wastewater to be delivered for production and how much they presently paid for water to irrigate their crops. This was done using the t-test (one tailed and two tailed). The results (Table 8) showed that there was statistically significant difference between how much respondents were averagely willing to pay (Mean=Gh₵76.2) and how much respondents averagely currently paid (Mean=₵117.9) for water each month (at 5% significance level, t = -2.75 p =0.00). This implies that, willing respondents are not prepared to pay as much as they currently pay on water charges for treated wastewater.

Table 8: Paired t-test on willingness to pay for treated wastewater

Variable	Obs.	Mean (Standard Deviation)	t-value	Prob.
Maximum amount willing to pay for treated water	90	76.166	-2.75	0.007
Current amount being paid		117.889		

Source: Field survey, 2020

Regardless, the results show that, overall, 94% of respondents who are willing to pay would pay a fee for treated wastewater to be delivered for production. Respondents were willing to pay a fee as high as Gh₵1,200 and as low as Gh₵10 each per month. Averagely, respondents are willing to pay a fee of Gh₵115.42 each month for the treated wastewater.

2.4.3.3.2 Quantity of Treated Wastewater Farmers Require

The farmers also noted that their mean daily treated wastewater usage was 668 cans (6680 litres). The maximum and minimum daily requirement were 4600 cans (46000litres) and 25 cans (250 litres). A significant Paired t-test showed that the farmers expected to be supplied an average of 673.6 cans (6736 litres) of water each day. An increase of 100.4 cans (1040 litres) more of water compared to the current average quantity of primary water source (see Table 9).

Table 9: Paired t-test on quantity of treated wastewater required per day

Variable	Obs.	Mean (Standard Deviation)	t-value	Prob.
Quantity of treated wastewater required per day	191	673.6	3.8	0.000
Current quantity of primary source of water		573.2		

Source: Field survey, 2020

[4] 1 watering can is approximately 10 litres

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2.4.3.3.3 Desirable Characteristics of Treated Wastewater Farmers Desire

Respondents indicated that the main characteristics which would likely influence their acceptance and use of treated wastewater are the consistent availability of the treated wastewater (69%), absence of bacterial/pathogen (57%), nutrients availability (47%), level of Biological Oxygen Demand (BOD) (24%), level of Chemical Oxygen Demand (COD) (16%) and other factors (16%) such as customers liking the taste of crops grown with treated wastewater.

2.4.3.4Farmers' Awareness and Practice of Safety in Use of wastewater for Farming

Famers were asked about the common ailments among them. They identified diarrhoea, cholera, guinea worm, malaria, typhoid fever, and others such as intense body pains and aches as the main ailments they face while farming (Table 10).

Table 10: Frequency of diseases

Disease	Frequency				
	Once a fortnight	Once a month	Once a Year	Once a Year	Not in the last year
Diarrhoea				1 (1.22)	81 (98.78
Cholera	1 (1.18)	1 (1.18)	7 (8.24)	7 (8.24)	76 (89.41)
Guinea worm			3 (3.66)		79 (96.34)
Malaria	6 (4.41)	2 (1.47)	10 (7.35)	76 (55.88)	42 (30.88)
Typhoid fever		1 (119)	13 (15.48)		70 (83.33)
Other (body pains)		5 (9.62)	10 (19.23)	19 (36.54)	18 (34.62)

Source: Field survey, 2020

Although almost all, 99%, of the farmers maintained that none of their customers had ever complained of health-related problems as a result of consuming their produce. The two farmers forming the remaining 1% noted that in their opinion a consumer complained of health-related problems as a result of improper use of pesticides and weedicides.

The farmers also stated that with respect to the use of protective apparel, they generally used nose masks when applying pesticides and other chemicals. Majority of the farmers wear wellington boots while on the farm. While in total, only a third of respondent's wear goggles in their daily farm activities. Although majority of the third only wear goggles while applying pesticides (Figure 6).

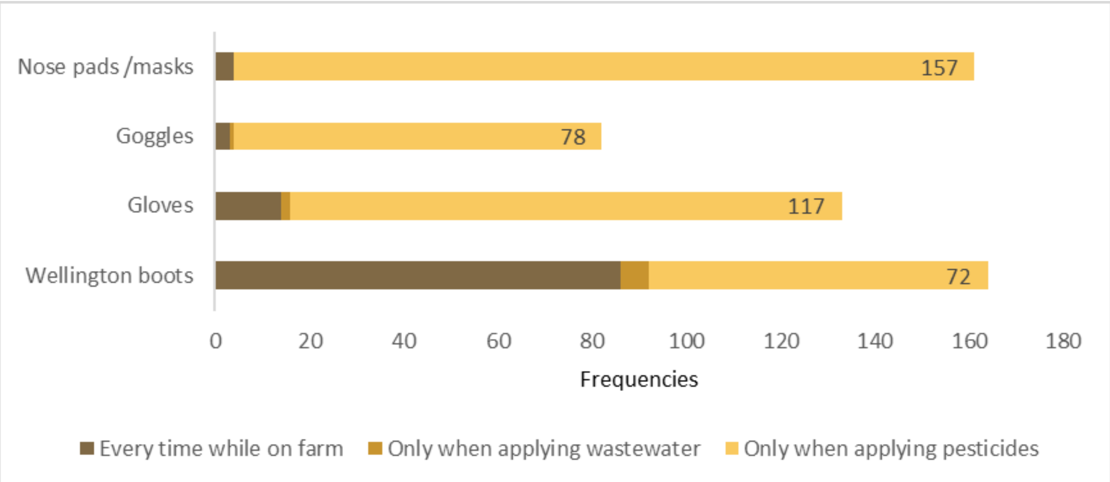

Figure 6: Use of protective gear; Source: Field survey, 2020

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Furthermore, less than a quarter of the farmers had put in place innovative or simple structures to minimize the exposure of, and ensure the safety of, farm attendants. This includes wooden planks as paths (8.9%), farm foot bridges (12.7%), and others (1.4%) such as covering boreholes and providing raincoats.

2.4.4 Access to Markets and Land Ownership

2.4.4.1 Market Opportunities

As can be observed in Table 11, a majority (93.9%) of the farmers sell their farm produce at the 'farm gate.' Not more than 4% (3.8%) of the produce are sold through open market and 0.5% and 1.4% are sold through supermarkets/shops and private sales, respectively. Sales at the farm gate could be a strategy by farmers to avoid the cost of transporting the produce to the markets, which can help reduce the cost of production and/marketing. The supermarkets being a smaller market could arise from the perception of poor quality of the vegetable as a result of the use of untreated wastewater. It may also be the inability of producers to meet the high demand of supermarkets. Despite complains of low prices at farm gate (Drechsel and Keraita, 2014), it is interesting to observe that most farmers still sell at the farm gate. But as stated earlier, this could be a strategy to reduce cost and social implication of open market sales. This may also maintain the freshness of the produces for traders and consumers.

Table 11: Main market outlet

Main market outlet used by the farmer.	Frequency	Percent
Farm gate	200	93.9
Open markets	8	3.8
Supermarkets/shops	1	0.5
Private sales	3	1.4
Others (specify)	1	0.5
Total	213	100

Source: Field survey, 2020

Table 12 shows that most (55.6%) of the farmers who sell their produce in open markets do so at Madina market. The second (22.2%) preferred place is the Dome market while Agbogbloshie market (11.1%) and Vegetable city (11.1%) are the other markets. These markets are located in parts of the city of Accra and some of the busiest market centres in the city. Even though Agbogbloshie is one of the busiest markets, it is least frequented by respondents because farmers may mostly compete with vegetables brought in from the hinterlands and which are mostly produced with better quality of water.

Table 12: Market area

Name of the markets produce are sold	Frequency	Percent
Agbogbloshie	1	11.1
Dome market	2	22.2
Madina market	5	55.6
Vegetable city	1	11.1
Total	9	100.0

Source: Field survey, 2020

There is local demand for the produce of urban farmers, as 93% of the farmers attest to that while 7% suggested otherwise (Figure 7). The fact that there is local demand for the produce is an opportunity for farmers to increase production and expand their market frontier (through group advertisement to implore supermarkets/shops to purchase the vegetables). It is an opportunity for youth employment and income generation.

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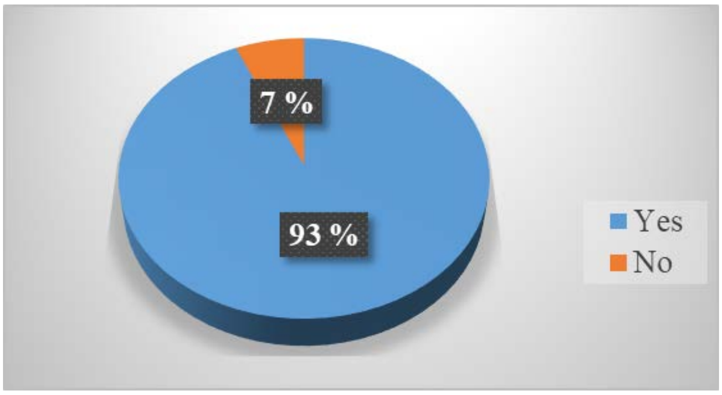

Figure 7: Local demand for produce; Source: Field survey, 2020

The study results show that there are ready markets for urban vegetable production in Accra using wastewater. Shown in Table 2-2.4.12 are the farming sites that farmers were interviewed. While there are market opportunities in all the areas, there appears to be more guaranteed market opportunities for farmers in the Legon site (95.7%). CSIR and Okponglo sites ranked second (81.6%) and third (77.8%) places respectively with better guaranteed market opportunities. The least was Roman Ridge site (59.3%). There appears to be better market opportunities in areas like Okponglo because of proximity to the Madina market (a popular market within the city) while at the same time it is closer to the University of Ghana with large student population (a potential market). A similar scenario can be described for the CSIR area. The implication is that siting of urban vegetable production must take into consideration the density of human population (as potential market) and busy economic activity environments (such as market infrastructure)

Table 13: Urban farming sites and market opportunities

Farming Site	Guaranteed Market for Produce		
	Yes	No	Total
CSIR	31 (81.6)	7 (18.4)	38 (100)
Dzorwulu	20 (66.7)	10 (33.3)	30 (100)
Korle-Bu	39 (68.4)	18 (31.6)	57 (100)
Legon	22 (95.6)	1 (4.4.)	23 (100)
Okponglo	7 (77.8)	2 (22.2)	9 (100)
Plantpool	18 (64.3)	10 (35.7)	28 (100)
Roman Ridge	16 (59.3)	11 (40.7)	27 (100)
Total	153 (72.2)	59 (27.8)	212 (100)

Percent [%] in parentheses (Source: Field survey, 2020)

2.4.4.2Land Ownership

Most of the farmers do not own the lands used for vegetable production. The study observed that most (71%) farmers do not have any contractual arrangement with the owners of the lands. It seems because most of these lands are public properties there have been no effort by empowered state authorities to initiate and/or enforce a contractual arrangement. Only 29% of farmers have contractual arrangements with landowners. Although, this study did stop short of establishing who own the lands that have contractual arrangements, it is anticipated that they may be lands owned by private citizens or quasi state institution.

It is interesting to note that for farmers that had contractual arrangements with landowners, many of them were with no formal education. Given that only 38% of farmers were with no formal education, it is surprising to note that none of the farmers with contractual arrangement had tertiary education. This may be due to the fewer numbers of farmers in the study with tertiary education.

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For those who had contracts, the contracts were verbal. That is, agreements between the landowner and the farmers on how much would be paid as rent for a year, which could be in kind (as in with harvested crops) or cash. The amount of rent was varied from period to period depending on the prevailing economic and living conditions of the moment. Contract were usually enforced with a sanction by the landowner (refusal to allow farmers to continue to use the land); the farmers on the other had no means of enforcing contracts. A farmer may be given an opportunity to vary the contract in disaster situation like outbreak of pest and diseases or fire.

2.5 Concluding Remarks

Urban agriculture remains an important source of livelihood for the youth in the capital city of Ghana, Accra. Besides, urban agriculture is an important source of vegetables for the inner-city dwellers. Thus, urban agriculture enhances the city's nutrition and food security status. However, the need to provide safe vegetables to consumers is important. Therefore, it is significant to note that urban farmers are willing to use treated wastewater for producing their crops.

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3 Baseline of water, soil, and crops quality

3.1 Introduction

Increasingly people are realizing the importance of eating more vegetables. Unfortunately, this currently comes with dangers that the public may not even be aware of as water used in irrigating vegetables may not be wholesome. Untreated wastewater discharged into drains may have high levels of contaminants that are injurious to human health. Heavy metals can pose a serious health hazard to consumers if accumulated in elevated concentrations above body requirements as described by Gupta and Gupta (1998). Over time, a prolonged ingestion of lead, cadmium, mercury and arsenic may lead to chronic toxicity (Inaba et al. 2005; Vázquez et al. 2015). Untreated wastewater or the so-called partially treated wastewater in drains usually have high levels of microbial contaminants due to open defaecation and poorly functioning treatment systems that empties into such drains. To ensure safety of consumers, monitoring of wastewater used for irrigation of crops, particularly those that are eaten raw, need to be conducted. Early detection of contaminants is critical to any health and safety measure.

3.1.1 Study objective

The objective of this study is to provide baseline data on the use of wastewater for urban farming at the demonstration sites for the Wider Uptake Project in Accra.

3.1.2 Scope of work

The study seeks to report on baseline assessment of the characteristics of wastewater used by urban farmers for vegetable irrigation in the study area, the quantity of wastewater used, the quality of the vegetables irrigated with untreated wastewater and any possible impact this may have on the soil in which the plants are grown.

Activities include:

- Sampling of the soil, wastewater, and vegetables at the CSIR-Water Research Institute (WRI) and CSIR-Animal Research Institute (ARI) project sites.
- Laboratory analyses of the soil, wastewater, and vegetables quality.
- Preparation of a report.

3.2 Materials and methods

3.2.1 Sampling for physical-chemical analysis

Wastewater, soil, and vegetable samples were taken at the WRI and ARI sites as shown in Figure 8. With regards to the vegetables, *Brassica oleracea* (cabbage) and Lactuca sativa (lettuce) were sampled at ARI while *Amaranthus* and *Hibiscus sabdariffa* (spinach) were sampled at WRI. Four (4) replicate samples of the soils and eight (8) replicates of the vegetables were taken at each site per season (rainy and dry seasons). Eight replicate samples of the wastewater were taken per season at each site using the Grab method. The samples were taken every other week between 09.00 hrs and 10.00hr GMT for the minor rainy season (August to November 2020) and the dry season (December 2020 to March 2021).

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Figure 8: Sampling of soil, wastewater, and vegetables; Source: Authors

3.2.2 Laboratory analyses of physical-chemical parameters

The physical-chemical analyses were carried out at the WRI Laboratories in Accra. The following parameters were determined:

Wastewater samples

- pH
- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Ammonia-Nitrogen (NH3 – N)
- Phosphate –Phosphorous (PO4 - P)
- Nitrate – Nitrogen (NO3 – N)
- Lead
- Cadmium
- Chromium
- Iron
- Zinc

Soil and vegetable samples

- Lead
- Cadmium
- Chromium
- Iron
- Zinc

All analyses were performed according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2012) and are briefly presented in Table 14.

Table 14: Analytical methods employed for physical-chemical analyses of wastewater

Parameter	Method employed
pH	Schott Gerate pH meter C G 818
Ammonia – nitrogen	Direct Nesslerization Method
Nitrate – nitrogen	Hydrazine Reduction Method
Phosphate – phosphorous	Stannous Chloride Method
Chemical Oxygen Demand	Potassium Dichromate Reflux Method
Biochemical Oxygen Demand	Dilution and Dissolved Oxygen Determination after Incubation at 20^{o}C for 5 days
Lead	Atomic Absorption Spectrophotometer
Cadmium	Atomic Absorption Spectrophotometer
Chromium	Atomic Absorption Spectrophotometer
Iron	Atomic Absorption Spectrophotometer
Zinc	Atomic Absorption Spectrophotometer

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3.2.3 Analyses of pesticides and recalcitrant organic compounds

Wastewater, soil, and vegetable samples taken for the analyses of pesticides were taken to the Ghana Standards Authority laboratory for analyses. Results are yet to be received.

Recalcitrant organic compounds were to be analysed at the laboratory of the Ghana Standards Authority. Unfortunately, the laboratory later informed CSIR that their standards have expired and that they would require some time to replace them. Currently the CSIR Project Team is discussing with Czech Technical University (UCT) about the possibility of their laboratory processing samples from Ghana for recalcitrant organic compounds under the WIDER UPTAKE Project.

3.2.4 Bacteriological and parasitological analyses

Sampling

Wastewater and vegetable samples (*Amaranthus* spp and *Hibiscus sabdariffa* at the WRI site and cabbage and lettuce at the ARI site) were collected for microbial and parasitological analyses as shown in Figure 8. Eight (8) replicate samples of vegetables and another eight (8) replicate samples of wastewater were taken from each of the two sites (WRI and ARI) during the minor rainy season (August to November 2020). Similarly, another set of eight (8) replicate samples of wastewater and eight (8) samples of vegetables were again collected for analyses during the dry season (December 2020 to March 2021). The wastewater samples were collected at the two sites using the Grab method. The samples were taken every other week between 09.00 hrs and 10.00hr GMT. Samples were analysed immediately upon arrival in the laboratory. All samples were collected using sampling techniques and protocols in accordance with the Standards methods for the examination of water and wastewater samples.

Laboratory analyses of wastewater and vegetable samples

Wastewater samples were collected into sterile 500ml sampling bottle and 1 litre clean bottles for the determination of the bacteria and intestinal parasites, respectively. Additionally, 100 g of each vegetable was used for the bacteria and intestinal parasites analyses. All analyses were carried out aseptically and this followed the standard methods as described in APHA (2012). The wastewater and vegetable samples were analysed for *E. coli, Salmonella sp, Faecal enterococcus sp (for WRI samples only), Faecal streptococcus (for ARI samples only), Vibrio sp* and intestinal parasites (Helminth eggs, *Cryptosporidium* spp and *Giardia* spp) parameters.

The examination of *E. coli, Salmonella sp, Enterococcus sp, Streptococcus and Vibrio sp* were carried out using membrane filtration technique in accordance with the Standard methods for the examination of water and wastewater (APHA, 2012). The prepared samples were filtered through 0.45 μm pore size membrane filters. Determination of *E. coli, Salmonella spp and Vibrio spp* were undertaken by placing the filter on Hicrome Coliform agar Media, SS agar and Thiosulfate Citrate-Bile salt (TCBS) agar respectively in petri dishes and incubated at 37 $\pm$0.5^{o}C for 16 – 24 hours. Slanetz and Bartley medium was used for the determination of *Enterococcus spp.* and was incubated at 44^{o}C $\pm$0.5^{o}C for 48 hours. Colonies were counted with the aid of colony counter and numbers were expressed as coliform forming unit (cfu) per 100ml (APHA, 2012).

Helminth egg, Giardia and Cryptosporidium analysis

Helminth egg analyses were conducted following the protocol stated in standard laboratory manuals (Ayres and Mara, 1996; Schwartzbrod, 1998). Analytical protocol for the determination of *Cryptosporidium* spp and *Giardia* spp in World Health Organization. (2003). *Manual of basic techniques for a health laboratory*. World Health Organization. Was employed. Helminth egg, *Cryptosporidium* spp and *Giardia* spp counts were expressed in number of eggs per gram.

Standards and guidelines

The microbiological characteristics of the irrigation water were compared to the Ghana Standards Authority (GSA) guideline value (10 cfu/100ml for E. coli) for the discharge of wastewaters into receiving water bodies

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(GS1212:2019) to establish whether the requirements were met. The recorded irrigation water values were compared with the WHO guideline value for unrestricted irrigation (3 log cfu/100 for *E. coli* and ≤ 1 for Helminth eggs per litre) and also with the European Union minimum requirements for irrigation of crops that are consumed raw which require values of E. coli to be less than 10cfu/100ml or below detectable limits.

3.2.5 Analyses of bacteriophage

Currently no institution in Ghana (including the CSIR) has the capacity to analyse samples for bacteriophage. Discussions have been ongoing with Czech Technical University (UCT) about the possibility of their laboratory processing samples from Ghana for bacteriophage count under the Wider Uptake Project. These discussions are yet to be concluded.

3.3 Results and discussion

3.3.1 Quality characteristics of irrigation water, soil, and vegetable samples

The physical-chemical characteristics of the wastewater were compared to the Ghana Standards Authority (GSA) guideline values for the discharge of wastewaters into receiving water bodies (GS1212:2019) to establish whether the requirements were met. The metal contents in the wastewater, soil and vegetables were compared with FAO/WHO 2001 (irrigation water and soils) and FAO/WHO 2007 (vegetables). The metal contents in the soil samples were also compared with EU minimum requirements. The results are presented in Table 15 (WRI results) and Table 16 (ARI results).

Bacteriological and parasitological analytical results are also presented for the wastewater and vegetable samples for the rainy and dry seasons.

3.3.2 Physical-chemical parameters

The results for the analyses of the samples obtained at WRI site are presented in Table 15. The results of the irrigated water analysis for the rainy season indicated low concentrations of the nutrients i.e., nitrates and phosphates compared to the Ghana Standard guideline value. The pH, BOD and COD values were also within the acceptable limit. However, the concentrations of ammonia which range from 5.3 to 39.8 far exceed the GSA guideline value of 1mg/l. The phosphate concentrations of two wastewater samples i.e., 2.11mg/l, and 2.06 mg/L, were also slightly higher than the 2.0 mg/l recommended value. In addition, concentrations of the heavy metals (Pb, Cd, Cr, Fe and Zn) in the irrigation water and soil samples were all below their respective FAO/WHO recommended limits (FAO/WHO 2001) while those of the vegetable samples also fell within the various FAO/WHO recommended limits (FAO/WHO 2007). It is important to note that the concentration of Pb, Cd, Cr, and Zn in the soil samples were also within the European Union (EU) minimum requirements for Pb (60 mg/kg), Cd (1 mg/kg) Cr (100 mg/Kg) and Zn (200 mg/Kg).

The results for dry season wastewater samples also followed the same trend. The concentration of all the parameters, except ammonia, fell within the acceptable values of GSA guideline. Although the ammonia concentration is higher than the 1 mg l^{-1} limit required by GSA, the results were comparatively lower than those of rainy season. On the other hand, the COD and BOD were higher than those of rainy season. Apart from one COD value of 929 mg/l which was above the GSA limit, the rest of the results l fell within the acceptable values. This high COD value could be due to the agitation of the water during sampling as the water was being abstracted for irrigation at the time of sampling at this particular site. For nitrates, results for the first batch of the dry season wastewater samples were higher than the results for the rainy season samples. The pH and nitrate results for the first batch of dry season wastewater samples were also noted to be higher than the last batch of dry season wastewater samples. The concentrations of the metals were also within the acceptable limits although Pb concentration is higher in the dry season.. These metals are mainly associated with vehicular emission, however, there is currently no studies done in the study area explaining high Pb concentration in the dry season.

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Table 16 contains the results of the analyses of the samples taken at the ARI site. For the irrigation water sample, all the parameters analysed, with exception of ammonia, recorded values below the respective GSA and FAO/WHO recommended values. With regard to the ammonia content, two samples had slightly higher values of 1.15 mg/l and 1.68 mg/l respectively compared to the 1 mg/l value set by GSA. The concentrations of the heavy metals in the wastewater samples were all within their individual FAO/WHO acceptable limits. The metal contents present in the soil samples were also acceptable as they all fell below the individual FAO/WHO and EU standard values. Chromium concentrations in the vegetables exceeded the recommended value of 2.3 mg/kg set by FAO/WHO. These concentrations range from 2.63 to 3.47 mg/kg. However, the concentrations of other metals (Pb, Cd, Fe and Zn) were far below the individual FAO/WHO and EU Standard values.

No major differences were observed in the pH, phosphate, and metal concentrations of dry and rainy season wastewater samples. Conversely, the ammonia and BOD contents in the dry season wastewater samples were higher than levels observed for the rainy season wastewater samples. However, the nitrate concentrations for dry season wastewater samples were generally lower than what was detected in the rainy samples.

3.3.3 Bacteriological and parasitological analyses

The mean *E. coli* count in wastewater at the WRI site of 6.15 log units/100ml and 6.45 log units/100ml recorded during the wet and dry seasons, respectively (Table 17), were above the Ghana Standard guideline value of 1 log unit /100 ml for discharge into freshwater bodies and WHO recommended guideline value of 3 log units/100ml for unrestricted irrigation. At the ARI site, a mean of 1.5 log unit/100ml and 1.8 log units/100ml were observed for rainy and dry seasons, respectively (Table 19). The wastewater at the ARI site seems to have a relatively less bacteria load than the WRI site. *Salmonella* sp concentration in the wastewater from Site 1 (WRI) were in the magnitude of 5 log units for both the dry and rainy seasons (Table 17), whiles that of Site 2 (ARI) were zero log units/100ml for rainy season and 2 log units/100ml for the dry season (Table 19). The mean *E. coli* count recorded during the rainy and dry seasons on vegetables at Site 1 (WRI) were 24cfu/g and 1cfu/g, respectively, while that at Site 2 (ARI) for rainy and dry seasons were 1cfu/g and 132cfu/g, respectively.

For parasitological analyses, both samples taken at Site 1 and 2 for both the dry and rainy seasons, showed the absence of oocyst of Cryptosporidium for both wastewater samples and vegetable samples (Table 17, Table 18, Table 20 and Table 21). Dry season samples from both Site 1 and 2 also showed the absence of *Giardia* ova for both wastewater and vegetable samples. However, Site 1 and 2 showed the presence of either larvae (Table 3-3.7) or eggs (Table 3-3.4) of some parasites of man such as *Ascaris lumbricoides* and *Trichuris trichuria*.

For the rainy season, while Site 1 recorded no ova for *Giardia*, Site 2 recorded a mean of 7 ova/litre of wastewater which included ova of *Giardia*. Rainy season samples at Site 2 also showed a mean of 8 ova/g of vegetables and this included *Giardia* ova. This may be due to the introduction of cow dung as manure for the vegetables at Site 2. Site 1 used chicken manure.

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Table 15: Physical-chemical quality results alongside the Ghana Standard Guideline Values and FAO/WHO Values of wastewater, soil, and vegetables at WRI Site

Wastewater/irrigation water samples (mg/l); b =Ghana standard value limit												
Parameters:		**pH**	**Nitrate**	**Phosphates**	**Ammonia**	**COD**	**BOD**	**Pb**	**Cd**	**Cr**	**Fe**	**Zn**
FAO/WHO (2001); Ghana Standard values:		**6 – 9[b]**	**50 [b]**	**2 [b]**	**1 [b]**	**250 [b]**	**50 [b]**	**5.00**	**0.01**	**0.10**	**5.00**	**2.00**
Location:	WRI; Rainy season	7.41	0.050	2.11	35.0	112	15.6	<0.005	<0.010	0.034	0.260	0.200
		7.47	0.031	2.06	34.7	106	6.78	<0.005	<0.010	0.033	0.219	0.046
		7.50	0.038	1.23	39.8	92.8	16.2	<0.005	<0.010	0.020	0.330	0.012
		7.36	0.852	0.307	5.34	104	6.70	<0.005	<0.010	0.017	0.138	0.014
		7.41	0.890	0.236	5.60	278	4.58	<0.005	<0.010	<0.005	0.470	<0.005
		7.46	0.861	0.217	5.84	62.4	5.30	<0.005	<0.010	<0.005	0.431	<0.005
		6.22	0.068	1.02	22.5	80.0	8.42	<0.005	<0.010	<0.005	0.389	<0.005
		6.79	0.070	0.227	21.4	106	10.3	0.012	<0.010	<0.005	0.289	<0.005
Location:	WRI; Dry season	7.04	1.36	0.099	2.46	147	81.6	0.045	<0.010	<0.010	0.318	<0.005
		7.16	1.52	0.783	2.39	182	74.1	0.048	<0.010	<0.010	0.208	<0.005
		7.18	1.27	0.208	1.64	110	28.2	0.030	<0.010	<0.010	0.250	0.006
		7.20	1.37	0.666	2.27	154	44.1	0.050	0.013	<0.010	0.219	<0.005
		6.84	0.760	0.913	1.07	184	40.2	0.066	<0.010	<0.010	0.806	<0.005
		6.75	0.028	1.19	0.852	928	126	0.046	0.010	<0.010	0.288	<0.005
		6.94	0.455	0.622	2.60	117	28.2	0.036	0.012	<0.010	0.258	<0.005
		6.94	0.705	0.937	2.00	128	18.6	0.025	<0.010	<0.010	0.282	<0.005
Soil samples (mg/kg)												
FAO/WHO (2001):								**100**	**3**	**50**	**5000**	**300**
Location:	WRI; Rainy season							<0.005	<0.010	0.270	36.1	0.650
								<0.005	<0.010	0.178	37.1	0.623
Location:	WRI; Dry season							<0.005	<0.010	0.160	41.0	0.425
								<0.005	<0.010	0.643	41.4	0.385
Vegetable samples (mg/kg)												
FAO/WHO(2007):								**0.30**	**0.20**	**2.30**	**425.5**	**60.0**
Location:	WRI; Rainy season	A. Spinach						<0.005	<0.010	0.090	24.8	0.735
		B. Amaranthus						<0.005	<0.010	0.085	23.7	1.59
Location:	WRI; Rainy season							<0.005	<0.010	0.025	32.7	3.11
								<0.005	<0.010	0.073	22.3	1.61

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Table 16: Physical-chemical quality results alongside the Ghana Standard Values and FAO/WHO Values of wastewater, soil, and vegetable at CSIR-ARI Site

Wastewater/irrigation water samples (mg/l); b =Ghana standard value limit												
Parameters:		**pH**	**Nitrate**	**Phosphates**	**Ammonia**	**COD**	**BOD**	**Pb**	**Cd**	**Cr**	**Fe**	**Zn**
FAO/WHO (2001), Ghana Standard values:		**6.0 – 9.0 [b]**	**50 [b]**	**2 [b]**	**1 [b]**	**250 [b]**	**50 [b]**	**5**	**0.01**	**0.10**	**5.00**	**2.00**
Sample:	ARI; Rainy season	7.02	0.476	0.077	1.15	41.6	1.94	<0.005	<0.010	0.019	0.392	<0.5
		7.11	0.393	<0.001	1.68	36.8	1.34	<0.005	<0.010	0.025	0.355	0.100
		6.91	1.11	0.057	0.534	64.0	2.36	<0.005	<0.010	0.015	0.102	<0.5
		7.02	1.23	0.166	0.689	30.4	2.42	<0.005	<0.010	0.034	0.090	<0.5
		6.86	1.27	0.030	0.715	61.0	1.89	<0.005	<0.010	0.008	0.190	<0.005
		6.91	1.11	0.057	0.534	64.0	2.04	<0.005	<0.010	0.015	0.102	<0.005
		7.04	1.09	0.088	0.514	16.0	2.24	<0.002	<0.010	0.019	0.263	<0.005
		7.02	1.23	0.166	0.689	30.4	2.42	<0.005	<0.010	0.034	0.090	<0.005
Sample:	ARI; Dry season	6.54	0.081	0.070	1.06	24.0	9.18	<0.005	<0.010	<0.010	0.176	0.060
		7.22	0.066	0.148	0.728	62.4	5.28	<0.005	<0.010	<0.010	0.123	0.010
		6.79	0.082	0.108	1.24	160	8.22	<0.005	<0.010	<0.010	0.125	0.007
		6.83	0.102	0.084	0.997	19.2	4.08	<0.005	<0.010	<0.010	0.063	<0.005
		6.68	0.509	0.054	1.94	12.8	10.2	<0.005	<0.010	<0.010	0.415	<0.005
		6.80	0.853	0.088	1.36	24.0	4.47	0.022	<0.010	<0.010	0.081	<0.005
		6.75	1.25	0.073	2.12	52.8	2.55	<0.005	<0.010	<0.010	0.148	<0.005
Soil samples (mg/kg)												
FAO/WHO(2001):								**100**	**3**	**50**	**5000**	**300**
Sample:	ARI; Rainy season							<0.005	<0.010	0.357	410	2.80
								<0.005	<0.010	0.293	556	2.56
Sample:	ARI; Dry season							<0.005	<0.010	0.276	544	4.60
								<0.005	<0.010	0.305	502	2.62
Vegetable samples (mg/kg)												
FAO/WHO (2007):								**0.3**	**0.2**	**2.3**	**425.5**	**60.0**
Sample:	ARI; Rainy season							<0.005	<0.010	2.63	23.8	1.16
								<0.005	<0.010	3.12	45.6	1.48
Sample:	ARI; Dry season							<0.005	<0.010	3.47	29.2	2.65
								<0.005	<0.010	2.82	54.7	4.10

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Table 17: Bacteriological and parasitological counts in wastewater samples from Site 1 (WRI)

	E.coli/100ml	*Salmonella* spp/100ml	*Enterococcus* spp/100ml	*Vibrio* spp/ 100ml	Helminth egg/1L	*Cryptosporadium* / 1L	*Giardia lamblia* /1L
Rainy season replicates	3 $x10^6$	$10x10^6$	6 $x10^3$	30 $x10^4$	<1	<1	<1
	3 $x10^6$	$9x10^6$	$1x10^3$	$12x10^4$	<1	<1	<1
	4 $x10^6$	$7x10^6$	$1x10^3$	$9x10^4$	1 (*A. lumbricoides*)	<1	<1
	$20x10^4$	$16x10^5$	$13x10^4$	$21x10^4$	<1	<1	<1
	$2x10^4$	$12x10^5$	$11x10^4$	$5x10^4$	<1	<1	<1
	$22x10^4$	$9x10^5$	$15x10^4$	$17x10^4$	<1	<1	<1
	$35x10^4$	$72x10^4$	$46x10^4$	$62x10^4$	<1	<1	<1
	$46x10^4$	$76x10^4$	$71x10^4$	$73x10^4$	<1	<1	<1
Dry season replicates	$21x10^5$	$5x10^5$	$7x10^5$	$1x10^5$	7 (*Trichuris trichuria*)	<1	<1
	$24x10^5$	$8x10^5$	$13x10^5$	$1x10^5$	22 (*Trichuris trichuria*)	<1	<1
	$24x10^5$	$7x10^5$	$13x10^5$	$2x10^5$	<1	<1	<1
	$25x10^5$	$8x10^5$	$7x10^5$	$1x10^5$	11 (*A. lumbricoides*)	<1	<1
	$36x10^5$	$36x10^5$	$20x10^5$	$6x10^5$			
	$32x10^5$	$33x10^5$	$21x10^5$	$11x10^5$			
	$30x10^5$	$9x10^5$	$19x10^5$	$6x10^5$			
	$36x10^5$	$11x10^5$	$17x10^5$	$5x10^5$			

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Table 18: Bacteriological and parasitological counts on vegetable samples from Site 1 (WRI)

Sample	*E. coli*/g	*Salmonella* spp/g	*Enterococcus* spp/g	*Vibrio* /g	Helminth Egg/g	*Cryptosporadium*/g	*Giardia lamblia*/g
Rainy season replicates	160	50	90	150	<1	<1	<1
	0	0	0	0	<1	<1	<1
	0	0	0	0	<1	<1	<1
	0	0	11	2	<1	<1	<1
	30	0	20	80	<1	<1	<1
	0	0	0	1	<1	<1	<1
	0	0	0	0	<1	<1	<1
	0	3	0	0	<1	<1	<1
Dry season replicates	0	3	4	4	2 (A. lumbricoides)	<1	<1
	0	2	4	4	2 (A. lumbricoides)	<1	<1
	0	0	4	0			
	0	0	4	0			
	0	0	0	0	4 (Trichuris trichuria)	<1	<1
	0	0	0	0	5 (Trichuris trichuria)	<1	<1
	4	0	4	19			
	3	0	3	7			

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Table 19: Microbial count in wastewater and on vegetable samples (ARI Site)

Period/Sample	*E. coli count*	*Salmonella spp*	*Vibro spp.*	*Strept. feacalis*
Rainy Season (Wastewater replicates) (cfu/100ml)	10^1	0	0	0
	0	0	0	0
	2.1×10^1	0	0	0
	1.8×10^1	0	0	0
	3.0×10^1	1.0×10^0	0	0
	0	0	0	0
	3.5×10^1	0	0	0
	1.5×10^2	0	0	0
Dry Season (Wastewater replicates) (cfu/100ml)	14.4×10^1	19.0×10^1	11.0×10^1	0
	25.0×10^1	13.0×10^1	1.0×10^1	0
	85.0×10^1	18.0×10^1	8.0×10^1	0
	3.0×10^1	35.0×10^1	7.0×10^1	0
	4.0×10^0	0	1.0×10^0	0
	0	0	0	0
	8.0×10^0	0	0	0
	10.0×10^0	0	1.0×10^0	0
Rainy Season (Vegetables- replicates/g)	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	0	0	0	0
	3.0×10^0	1.0×10^0	0	0
	1.0×10^0	0	0	0
	1.8×10^1	0	0	0
Dry Season (Vegetables- replicates/g)	11.0×10^1	0	5.0×10^1	0
	52.0×10^1	4.0×10^1	0	0
	36.0×10^1	1.0×10^1	1.0×10^1	0
	6.0×10^1	1.0×10^1	0	0
	0	0	4.0×10^0	0
	$4.0x 10^0$	0	0	0
	0	0	0	0
	0	0	21.0×10^0	0

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Table 20: Parasitological analyses of wastewater and vegetable samples in the rainy season (ARI Site)

SAMPLE	Infective Larvae	Helminth Ova	*Cryptosporidium* Oocysts
Rainy Season (Wastewater replicates) (No./Litre)	12	No Ova	No oocyst seen
	11	No Ova	No oocyst seen
	2	No Ova	No oocyst seen
	14	No Ova	No oocyst seen
	1	No Ova	No oocyst seen
	2	No Ova	No oocyst seen
	1	*Giardia lamblia (1)*	No oocyst seen
	29	*Eimeria oocyst (14)* *Giardia lamblia (43)*	No oocyst seen
Rainy Season (Vegetables- replicates) (No./g)	14	*Paramphistomum (2)*	No oocyst seen
	23	*Strongyle (2)* *Paramphistomum (3)* *Faciola (1)*	No oocyst seen
	26	*Paramphistomum (10)* *Faciola (3)*	No oocyst seen
	31	*Parmphistomum (7)* *Faciola (2)*	No oocyst seen
	8	*Entamoeba coli (6)* *Giardia lamblia (2)*	No oocyst seen
	29	*Giardia lamblia (5)*	No oocyst seen
	47	*Entamoeba coli oocyst (8)* *Giardia lamblia (3)* *Faciola (4)*	No oocyst seen
	63	*Entamoeba coli (2)* *Giardia lambli (4)*	No oocyst seen

Table 21: Parasitological analyses of wastewater and vegetable samples in the dry season (ARI Site)

SAMPLE	Infective Larvae	Helminth Ova	*Cryptosporidium* Oocysts
Dry Season (Wastewater replicates) (No./Litre)	No larvae seen	No ova seen	No oocyst seen
	No larvae seen	No ova seen	No oocyst seen
	No larvae seen	No ova seen	No oocyst seen
	No larvae seen	No ova seen	No oocyst seen
	2	No ova seen	No oocyst seen
	6	No ova seen	No oocyst seen
	No larvae seen	No ova seen	No oocyst seen
	No larvae seen	No ova seen	No oocyst seen
Dry Season (Vegetables- replicates) (No./g)	3	No ova seen	No oocyst seen
	No larvae seen	No ova seen	No oocyst seen
	4	No ova seen	No oocyst seen
	2	No ova seen	No oocyst seen
	34	No ova seen	No oocyst seen
	8	No ova seen	No oocyst seen
	No larvae seen	No ova seen	No oocyst seen
	4	No ova seen	No oocyst seen

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3.4 Concluding Remarks

Generally, the physical-chemical characteristics of wastewater, soil and vegetables sampled had levels below national recommended values results except for chromium.

At the WRI site (Site 1), the pH, BOD and COD values were within the acceptable limit, except for ammonia and phosphate. At the ARI site (Site 2), the concentrations of all the heavy metals in the wastewater samples were all within their individual FAO/WHO acceptable limits. The metal contents present in the soil samples were also acceptable as they all fell below the individual FAO/WHO standard values. Chromium concentrations in the vegetables exceeded the recommended value of 2.3 mg/kg set by FAO/WHO.

The wastewater at the ARI site seems to have a relatively less bacteria load than the WRI site. *Salmonella* sp concentration in the wastewater from Site 1 (WRI) were in the magnitude of 5 log units for both the dry and rainy seasons whiles that of Site 2 (ARI) were zero log units/100ml for rainy season and 2 log units/100ml for the dry season. The European Union minimum requirements for reclaimed water for irrigation of crops that are consumed raw requires E. coli concentration to be less than 10cfu/100ml or below detectable limits.

The mean *E. coli* count recorded during the rainy and dry seasons on vegetables at Site 1 (WRI) were 24 cfu/g and 1 cfu/g respectively while that at Site 2 (ARI) for rainy and dry seasons were 1 cfu/g and 132 cfu/g, respectively.

No oocyst of *Cryptosporidium* was observed for both wastewater and vegetable samples at Site 1 and 2 for both the dry and rainy seasons. Dry season samples from both Site 1 and 2 also showed the absence of *Giardia* ova for both wastewater and vegetable samples. In the dry season, Site 1 and 2 showed the presence of either larvae or eggs of some parasites of man such as *Ascaris lumbricoides* and *Trichuris trichuria*.

There were no ova of *Giardia* for the rainy season at Site 1. Site 2 recorded a mean of 7 ova/litre of wastewater which included ova of *Giardia*. Rainy season samples at Site 2 showed a mean of 8 ova/g of vegetables and this included *Giardia* ova.

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4 Baseline on use of wood-based fuels at selected SMEs in Accra

4.1 Introduction

Energy access and use in developing countries continue to remain low, and often to the detriment of its low-income earners. Although the general supply of modern energy in developing countries has generally increased over the years, access has not been equitable. Wood-based fuel remain the main source of fuel for millions globally. Energy from wood sources has been used for cooking and heating at the domestic and industrial levels. Wood fuel energy consumption consistently remained the largest household energy consumed according to the Energy Commission (2018), despite the efforts of the government and partners in reducing this ratio. Thus, there is reported depletion of forests directly linked to the consumption of wood fuel. According to the National REDD+ Secretariat, 1588429 trees have been depleted due to actions of deforestation for wood fuel and other activities, which is not surprising since wood fuel was used as the main source of cooking energy for 41% of households in Ghana with an estimated total consumption of 3902000 tonnes of oil equivalent (toe) (Forestry Commission, 2017). Against this background the need to reduce reliance on wood-based fuel cannot be overemphasised.

Thus, in light of the above, the Accra demonstration of the WIDER UPTAKE project intends to contribute to a reduction in the consumption of wood-based fuel by demonstrating that biochar made from sludge recovered from wastewater treatment can be a worthy substitute for wood-based charcoal. In preparation towards this demonstration, which will entail the production and supply of biochar to selected SMEs, a study was conducted to assess the pattern of wood-based fuel consumption among selected SMEs in Accra. This chapter presents the findings of the study.

4.2 Methods

The study involved the interview of 16 SMEs spread across Greater Accra Metropolitan Area (GAMA) (Table 22). To select the SMEs for interviews, a list of SMEs in the GAMA was obtained from the National Board for Small-Scale Industries. The list contained a total of 214 enterprises. Each one of these enterprises was contacted by telephone to ascertain whether they used wood-based fuel or not. At the end of this process, 23 enterprises were shortlisted for interview. Each of the 23 enterprises were then contacted and appointments made to have the owner, or “Officer-in-Charge” interviewed. Of these, the study was able to successfully complete interviews with 16 enterprises distributed across the GAMA in Table 22.

The data obtained from the personal interviews were analysed with STATA and SPSS and the results are presented below.

Table 22: Districts of survey

Local Government Area	Frequency	Percent
Accra Metropolitan	3	18.8%
Adentan Municipal	3	18.8%
Ashaiman Municipal	1	6.3%
Ga South Municipal	4	25.0%
GA West Municipal	1	6.3%
La Dade Kotopon Municipal	1	6.3%
La Nkwantanang Madina Municipal	2	12.5%
Tema Metropolitan	1	6.3%
Total	16	100.0%

Source: Field data, 2021

4.3 Demographic and business characteristics of enterprises

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In total, 14 females and 2 males were interviewed; respondents had an average age of 43 years with a minimum age of 26 years and a maximum age of 60 years old. All respondents interviewed had been formally educated with a large proportion (68.8%) reported to have attained tertiary education. Next, 18.8% of the respondents had secondary education while 6.3% of the respondents each had attained only basic/primary education and technical and vocational education and training (TVET) respectively.

Based on the business sector categorization of the National Board for Small-Scale Industries (NBSSI), 8 of the SMEs interviewed were in the agro-industrial sector, 7 in the agro-processing sector and 1 enterprise in the textile and garment business sector. The main product, nonetheless, produced by these enterprises include packaged water, cosmetics, food, sanitizers and detergents, and tie and dyed clothing (Table 23).

Table 23: Business sector categorisation of main products produced

Main products produced	Agro-Industrial	Processing	Textile
Water production	0	1	0
Cosmetics (Cocoa butter, coconut oil and shea butter)	2	3	0
Food (groundnut paste, pastries, drinks, etc)	3	1	0
Sanitizer, liquid soaps, Black soap, bleach, Antiseptic, detergents	3	2	0
Tie and dyed clothing			1
Total	8	7	1

Source: Field data, 2021

The results show that the enterprises surveyed had an average of about 7 years of active operation. The oldest and youngest enterprises in active operation were 13 and 2 years, respectively. Also, according to the respondents, an enterprise averagely operated for 8 hours a day. The enterprises were mostly (75%,) solely proprietors while the remaining quarter of the respondents were partnerships. All the enterprises interviewed employed labour for their operations. On average, each enterprise employed 6 persons, of which 94% of the time were paid either monthly or weekly for their services. Furthermore, it is important to note that just as most of the enterprises were female-owned, so were the employees. On average, there were more female employees than male (Table 24).

Table 24: Descriptive statistics of employees

Descriptive Statistics	N	Minimum	Maximum	Mean	Std. Deviation
How many employees are in your enterprise?	16	1	25	6.06	5.756
How many are male?	16	0	5	1.63	1.455
How many are female?	16	1	20	4.44	4.746

Source: Field data, 2021

4.4 Wood fuel usage

Since the basis for participation in the study was the use of wood-based fuel, the study sought to determine the extent to which wood fuel was used in the main productive activities of enterprises. It emerged that more than half (56.3%) of the enterprises used wood-based fuel as the main source of fuel for their enterprises' production processes. Respondents noted that their enterprises use more than 10 kg of wood fuel each week (93%). The remaining 6.7% of the respondents used between 5-10 kg of wood fuel each week. Often, enterprises kept stocks of wood fuel for an average of 33 days.

Respondents indicated that firewood (53.3%) and charcoal (46.7%) were the main type of wood fuel used in production. Probing further, the results show that firewood was often used by enterprises in agro-processing

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sector, whereas agro-industrial enterprises used a combination of charcoal and firewood. The only respondent in the textile and garment sector used charcoal only.

For majority of the respondents, who use wood fuel, 45.8% indicated they burn the fuel in metal firewood stoves while 18.8% use other specified stoves such as a custom fryer, grill, and stone hearths. Only 12.5% use improved stoves. Whiles the remaining 6.3% use conventional charcoal stoves.

On assessing the factors respondents consider before buying charcoal for use, the moisture content of the charcoal was ranked as the most important factor. Respondents explained that the moisture content of the charcoal helped in determining the quantity of charcoal to use to attain preferred heat and also to save costs. The calorific value was ranked as the second factor they consider before buying charcoal. Respondents closely scored price of the charcoal, which was ranked as the third factor. Friability and smoke lessness of charcoal were jointly ranked as the fourth factors respondents consider before buying or collecting charcoal to use for their production. Over 93% of the respondents buy their charcoal. Further, the study notes that on average, respondents spent Gh₵ 49 per purchase of wood fuel with a minimum cost of Gh₵ 2 and a maximum cost of Gh₵ 150.

For respondents who bought their charcoal, 42.9% of respondents who buy their charcoal find the cost of charcoal moderately expensive. The same proportions of 21.4%, rate the cost of charcoal as very expensive and a little expensive. An equal proportion of respondents, representing, 7.1% rated the cost as extremely expensive and not expensive at all.

Most of the enterprises that patronise charcoal revealed that distribution trucks and local retailers were their sources. The markets and respondents' own farms formed the lowest sources of wood fuel. Almost half of the respondents (46.7%) noted that the supply of wood fuel from their main sources was always available whenever they needed it. A small proportion of about 6.7% noted that their wood fuel source was seldom available (Figure 9). Furthermore, for all other respondents who do not buy from a distribution truck which offers door-to-door delivery, the average distance of such respondents and their wood fuel source was 11.84km from their enterprises.

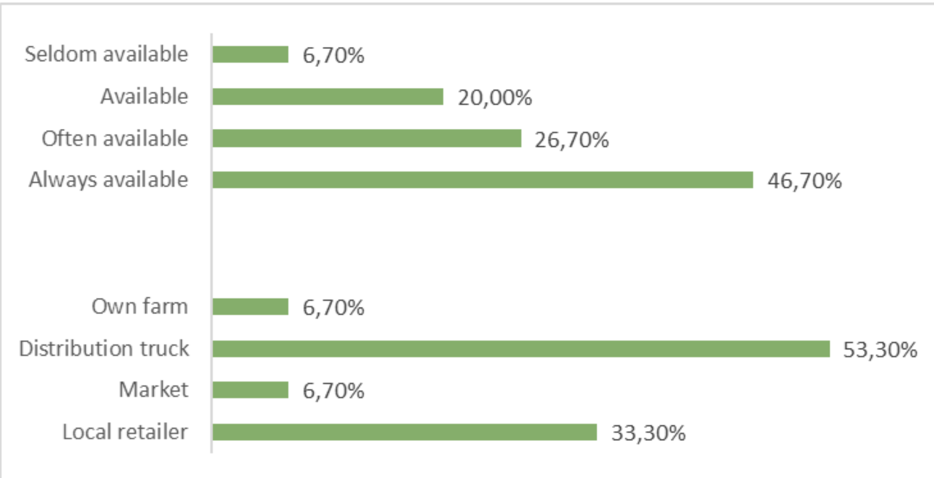

Figure 9: Source and Availability of Wood Fuel; Source: Field Survey, 2021

Additionally, two-thirds of the respondents answered that using wood fuels improved the time spent in enterprise activities. The remaining third indicated that they still used the wood fuels even though it did not improve the time spent on their activities because the wood fuels were relatively cheaper than other options such as LPG. Regarding the role of wood fuel in the quality of their products, 80% of the respondents asserted that the use of wood fuel did not affect the quality of their final products. For the remaining 20% who affirmed that their use of wood fuel affected the quality of their final products, they stated that the taste of using charcoal

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in grills and 'smokey' smell of charcoal improved the quality of their products. Also, two-thirds of the respondents noted that the use of wood fuel had an average net effect of decreasing the costs of production.

4.5 Transitioning from wood fuel to biochar use

The study sought to ascertain if the target market for enterprises interviewed were aware of the type and amounts of fuel used in their production activities. On this score, 68.8% answered in the negative while the remaining 31.3% explained that their markets knew of the types of fuel (wood fuel) used because their clients come to buy directly from them. Additionally, while 31.3% of the respondents expressed that they are indifferent about the environmental problems wood fuel usage causes, the remaining 68.8% answered said they cared. For such respondents, 90.9% were willing to switch from the use of charcoal or firewood to a fuel substitute if it led to a greener environment.

On biochar, more than half of the respondents had no knowledge of biochar. The majority of the respondents were, however, willing to use the biochar innovation if it burnt more efficiently than wood fuel, if it led to a greener environment, if it did not cause any health issues relating to smoke, if it would always be available to buy/use, and if it did not give any bad odour (Figure 10).

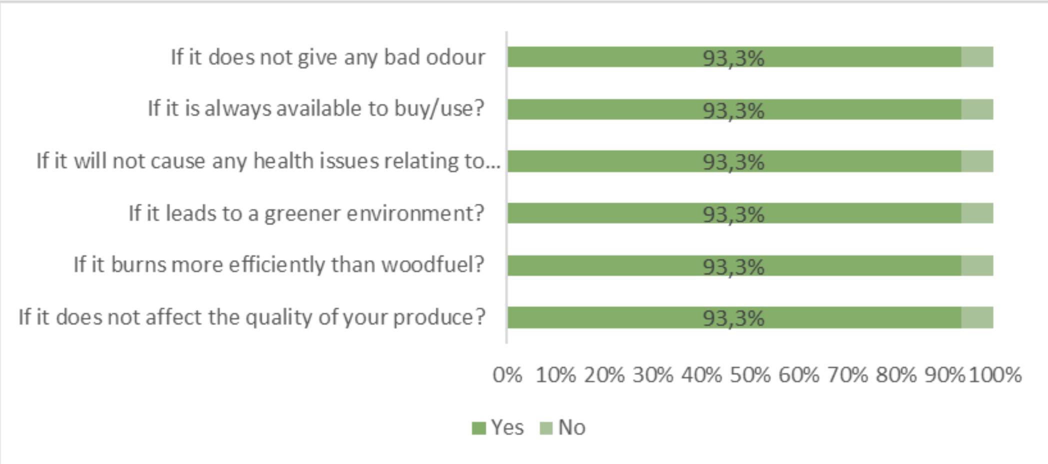

Figure 10: Willingness to transition from wood-based charcoal to biochar; Source: Field Survey, 2021

In terms of the factors that would influence their adoption of biochar, respondents ranked cost as the first factor. Efficiency was ranked as the second important factor while smell of the biochar and availability were ranked as the third and fourth factors respectively to likely influence the use of biochar by the enterprises interviewed. Nonetheless, three-quarters of the respondents were willing to pay for a much more efficient energy type (biochar). The average amount respondents were willing to pay for 1 kg of the biochar was Gh₵1.4 with a maximum amount of Gh₵ 2 per 1 kg and a minimum of Gh₵ 0.5 per 1 kg.

In assessing the expectations on the productive use of alternative energy sources to SMEs in Ghana, the respondents expressed that mainly, they would expect that the alternative energy source (biochar) would perform more efficiently than the current wood-based charcoal, be less expensive, readily available and ensure consistent quality. Other specified expectations included less smoke when burning, to be environmentally friendly, and must be rain (water) resistant.

4.6 Concluding Remarks

A baseline study was conducted on 16 selected SMEs in Accra. The results show that majority of the respondents/owners of the SMEs were female and on average had more female employees. All SMEs did use wood-based charcoal, consuming over 10 kg per week. The SMEs were willing to pay a little extra for an

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environmentally friendly alternative (biochar) to the wood-based charcoal provided such an alternative was efficient in providing the energy they required, did not have any offensive smell, and was readily available. The fact that SMEs in the capital of Ghana, Accra, continue to rely on wood-based fuel as their primary energy source is a concern. Hence the need to expedite action towards reducing such dependence and finding alternative energy sources is paramount.

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5 Baseline studies on the production of clean solid fuels (biochar) from faecal sludge in Accra

5.1 Introduction

Biomass is an important contributor to the energy mix in many developing countries. The final energy consumed in Ghana is mainly in the form of petroleum products and biomass (firewood, charcoal, and agricultural residue) with charcoal (annual production of about 1895299 tonnes) being the dominant source of cooking fuel in urban population of which 30% is consumed in Accra. The annual per capita charcoal consumption is 180 kg. Biomass contribution to primary energy supply has remained stable over a decade (ca 40%) in spite of Ghana becoming an oil producing country. This is primarily because of favourable biomass resources in the country (Energy Commission, 2019).

The heavy dependence on biomass as primary energy source has had some negative impact on the environment. In the last five decades the high forest zone cover has shrunk from 8.2 million hectares to 1.6 million hectares. Though biomass for energy may not be solely responsible for the drastic reduction, an estimated 20 million m^3 of wood consumed for energy production is a major driver to deforestation (GFC, 2018). Thus, Ghana's Renewable Energy Master Plan aims to reduce dependency on biomass as main fuel for heating by 2030 whilst pragmatically seeking to promote the utilization of biomass waste for the generation of electricity and heat (Energy Commission, 2019) by a gradual approach.

To achieve the Sustainable Development Goal for Clean affordable energy, the quality of the fuel produced is imperative. The fuel quality may be determined not only by their thermal characteristics (i.e., heating value, burning rate, and firepower) but also the environmental impact through gaseous emissions (CO, CO_2, SO_x, NO_x and PM emission factors) as well as noxious elemental composition (heavy metals) likely to be released into the environment during or after the combustion process.

Emission of noxious gases are characteristic of the combustion of solid fuels and exposure to these gases are the cause of upper respiratory diseases and mortality associated with indoor air pollution in many developing countries. Heavy metals in the environment are of paramount interest because of the health risks they pose on exposure in limited concentrations. The utilization of biomass waste, particularly waste from wastewater treatment, needs particular attention because humans are high on the food chain and therefore susceptible to exposure to heavy metals through bioaccumulation in the food chain. Cu, Fe, Pb, Cd, Zn and Mn have been reported in average concentrations of 3.978 mg/l, 2.492 mg/l, 0.16 mg/l, 0.045 mg/l, 2.235 mg/l and 4.571 mg/l, respectively, in faecal waste in peri-urban communities in the Ashanti Region of Ghana (Appiah-Effah, Nyarko, Ofosu, & Awuah, 2015). Thus, knowledge of the concentration levels is important in relating the material safety in the promotion and adoption of biochar from faecal sludge for burning in the Small and Medium Scale Enterprises in Ghana to reduce emissions and deforestation through reduction in dependence on wood fuel.

This chapter reports on the monitoring of the quality of processed biochar and products from the Mudor Sewerage Treatment Plant by Sewerage Systems Ghana Limited (SSGL). The specific objectives are to analyse the quality of the faecal sludge, optimize the carbonization process and determine the fuel quality i.e., emission characteristics and burning properties and to compare these features with that of existing biomass sources to give an indication of the level of market acceptability.

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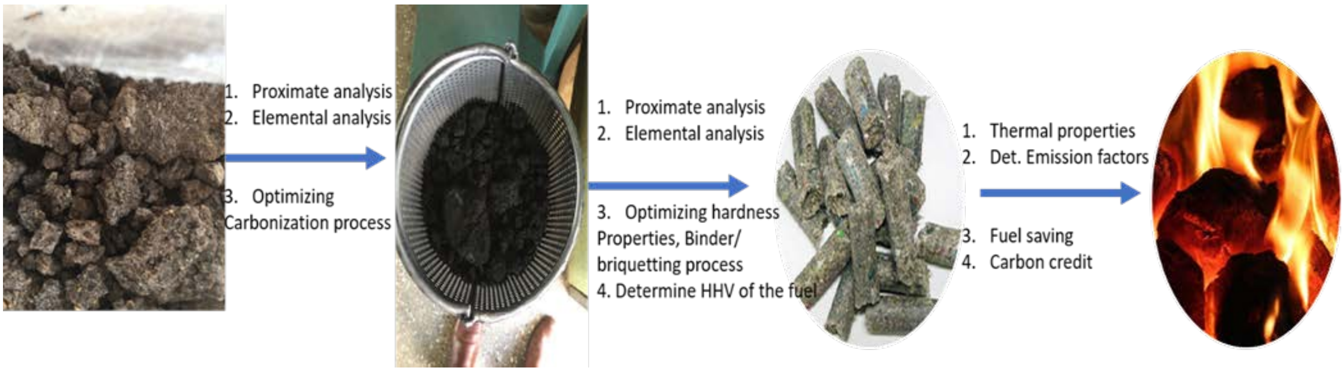

Figure 11: Faecal sludge to fuel flow diagram; Source: Authors

5.2 Methods

5.2.1 Sampling

A total of 120 kg of dewatered and air-dried faecal sludge samples was collected from the Mudor Treatment Plant in Accra into plastic jute bags lined with LDPE bags, sealed, and stored under dry ambient temperature of around 27-30 °C at the CSIR-Institute of Industrial Research, Accra. Three (3) kg of as-produced biochar briquettes were sampled from the continuous feed, charcoal fired rotary kiln biochar production line at SSGL and stored in plastic jute bags lined with LDPE bags, sealed, and stored under dry ambient temperature of around 27-30 °C.

5.2.2 Carbonization process at CSIR-IIR

To optimize temperature and time in the carbonization process, a batch loading, packed bed carbonization rig was fabricated. It was fuelled by Liquified Petroleum Gas (LPG) to enable finer control of temperature in the carbonization chamber. Typically, 15 kg of faecal sludge was charged into a stainless-steel basket and loaded into the carbonization chamber (shown in Figure 12). The rig was heated whilst monitoring the temperatures in the chamber and the biomass bed with k-type thermocouples.

Figure 12: Picture of the carbonization rig fabricated for the temperature and time optimization study; Source: Authors

5.2.3 Elemental analysis

Four (4) g of the powdered sample (< 100 um) and 0.9 g of the binder were weighed using an analytical balance. The two were put together in the mixing container and homogenized using the mill. The mixture was then poured into the die and pressed at 15 tons to a 32 mm pellet using the hydraulic press. Acetone was used to clean the mixing container and die set with the help of a tissue paper to prevent contamination. Acetone

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was preferred because it is very volatile. The pellet was then analysed for elemental (Mg to U) concentrations using the X-ray Fluorescence (XRF) Spectrometer (Model: VMR-Olympus Vanta M Series).

5.2.4 Proximate analysis

5.2.4.1 Moisture content

The Moisture content of samples was determined using a Standard Method (ASTM D3173, 2002) by drying 1.00 g sample in an oven at 105 °C for 2 hrs and cooling in a desiccator before measuring the mass change expressed as a percentage of the mass of the initial sample. The average of six (6) replicates was calculated and a P value < 0.05 was used to determine significant difference between samples.

5.2.4.2 Ash content

The Ash content of samples was determined using a Standard Method (ASTM D3174, 2002) by heating the dried sample at 750 °C for 2 hrs before cooling in a desiccator before determining the residual mass as a percentage of the dried sample. The average of six (6) replicates was calculated and the P value < 0.05 used to determine significant difference between samples.

5.2.4.3 Total volatile matter

The Volatile Matter content of samples was determined using the double-crucible method. A sample was placed in 10 ml crucible, which was then covered with another crucible of such size that it fitted closely to the sides of the outer crucible and its bottom rested 8.5 to 12.7 mm above the bottom of the outer crucible. The dried sample was heated to 950 °C for 7 minutes before cooling in a desiccator to determine the mass loss as a percentage of the dried sample (ASTM D3175, 2002). The average of six (6) replicates was calculated and the P value < 0.05 used to determine significant difference between different samples.

5.2.5 Calorific value determination

The calorific value was determined by bomb calorimetry.

5.2.6 Combustion characteristics

5.2.6.1 Burning rate

The burning rate defined as the amount of fuel consumed per unit time (g/min) was determined using the Water Boiling Test (WBT Version 4.2.3).

5.2.6.2 Firepower

The Firepower (W) defined as the amount of energy released by the burning fuel consumed per unit time was determined using the Water Boiling Test (WBT Version 4.2.3).

5.3 Results

5.3.1 Typical biomass fuels combustion characteristics

Burning requires a source of heat, air, and fuel. High fuel-air mixing is mostly desirable in lean and cleaner combustion. Fuels with high burning rates are preferred for thermally efficient systems. Figure 13 shows typical biomass fuels in Ghana and their burning rates in forced draft systems which gives an indication of how well it mixes with air during the combustion process. For systems that require high power in cold start mode, higher burning rate fuels achieve the most impact whilst lower burning rate may be desirable in operations requiring the simmering mode over longer periods.

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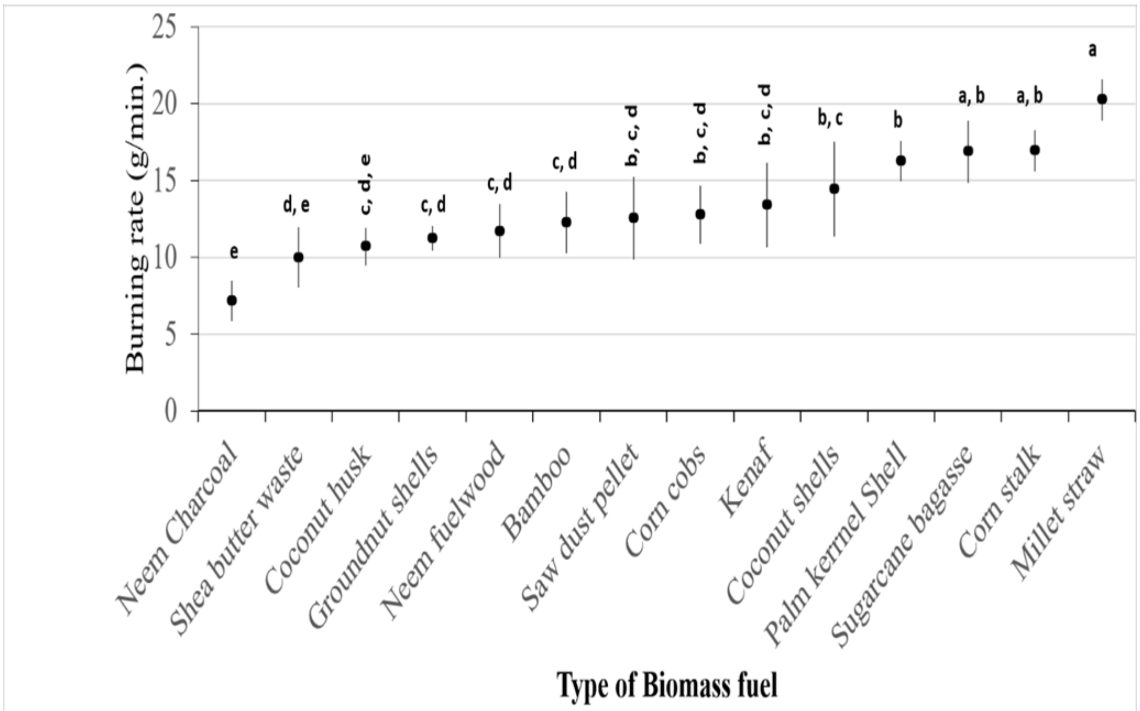

Figure 13: The mean ± SD burning rate (g/min) of typical biomass fuels in Ghana with significant difference (p=0.05) indicated by different alphabets; Source: Authors

The amount of energy released by the burning fuel over a unit time (Firepower) also influences the choice of a particular fuel in operations. Figure 14 depicts the firepower of typical biomass fuels in a forced draft system. Figure 13 and Figure 14 provide baseline performance of different biomass fuels which solid fuel from biochar briquettes must be compared to in order to provide an indication of how easily the fuels are likely to be adopted into the operations of SME industries.

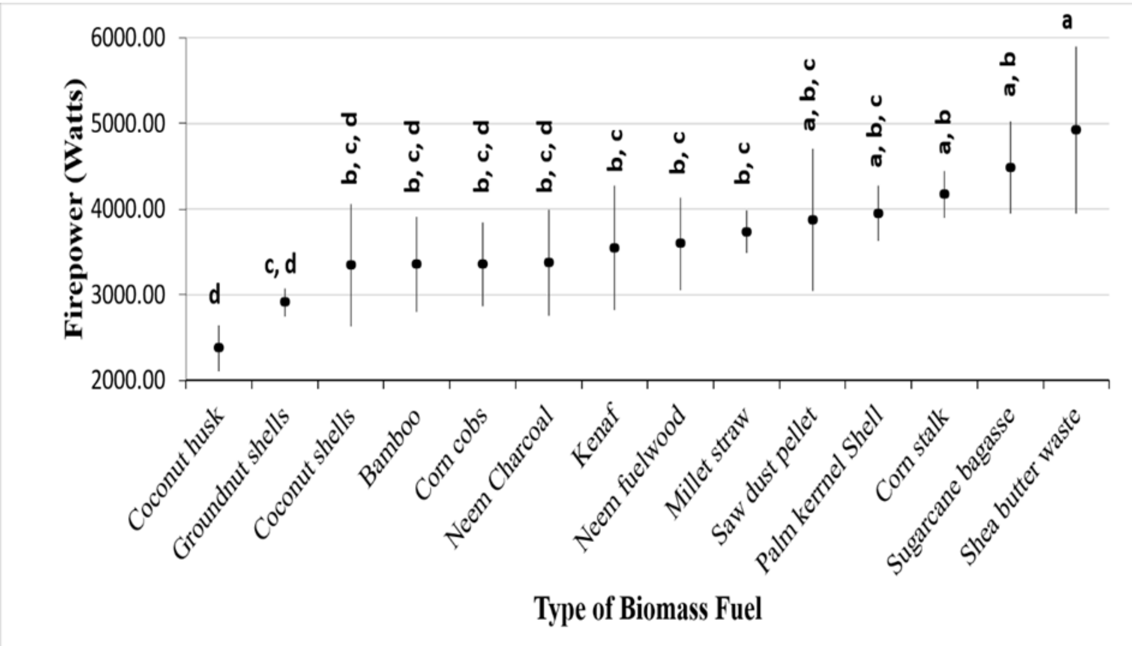

Figure 14: The mean ± SD Firepower (W) of typical biomass fuels in Ghana with significant difference (p=0.05) indicated by different alphabets; Source: Authors

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5.3.2 Proximate analysis on the faecal sludge and carbonized sludge

Table 25: Proximate and thermal properties of faecal sludge and its derived biochar fuels

Key Parameter	Faecal sludge	Biochar SSGL (undetermined temp.)	Carbonized sludge@ different temperatures (Degrees Celsius)		
			600	700	860
Moisture Content (% as received)	8.2 ± 0.5 [a]	3.6 ± 0.3 [b]	1.6 ±0.1 [d]	1.0 ±0.1 [e]	1.8 ±0.3 [c]
Ash Content (% as received)	36.5 ±1.2 [d]	60.0 ±2.1 [c]	72.8± 2.9 [b]	79.5± 3.8 [a]	82.9± 5.8 [a]
Volatile Matter (% as received)	59.6 ±3.16 [a]	38.9 ±2.3 [b]	27.2 ± 4.8 [c]	20.9± 1.5 [c]	18.4 ± 8.1 [d]
Fixed Carbon (%)	0.58	2.14	6.36	4.07	11.05
Calorific value (kJ/kg)	26320.23	26355.84	26368.92	ND	26356.55
Burning Rate (g/min)	ND	7.7	ND	ND	ND
Fire Power (W)	ND	5745.7	ND	ND	ND
CO Emission factor (g/kg)	ND	193.77	ND	ND	ND
CO_2 Emission factor (g/kg)	ND	235.33	ND	ND	ND
$PM_{2.5}$ Emission factor (g/kg)	ND	12.34	ND	ND	ND

ND means Not Determined; Source: Authors

Typical charcoal fuel from neem has ash content of 1.98 ± 0.53 %, moisture content 3.7 – 10%, and calorific value of 26575-29194.5 kJ/kg. This means the as-produced biochar briquettes (26355.84-26368.92 kJ/kg) have reasonable high calorific value that can be harnessed as an economically viable energy feedstock. From Table 25, high temperature carbonization is desirable for achieving lower volatile matter and higher fixed carbon which establishes the burning characteristics and value of the fuel. However, beyond 800 °C though the sulphur content in the biochar reduces the ash content increases.

5.3.3 Elemental analysis of the faecal sludge and carbonized sludge

The sulphur content as shown from Table 26 is still high, 1.4% composition in sludge to 1.0% on carbonizing at high temperature (860 °C). The heavy metals generally tend to be concentrated on carbonizing. The Pb content is particularly of concern because of its neurotoxic effect. A few drawbacks are related to the high sulphur content which gives a foul smell during combustion whilst the Pb in the ash will necessitate more stringent compliance to environmental safety during disposal. Also, the dense briquette fuel reduces heat diffusion through the sample leading to uncarbonized inner core as shown in Figure 15(d) and the fire takes a relatively longer time (10-15 mins) to set compared to wood charcoal (3-5 min.).

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Table 26: XRF analysis of the elemental composition of faecal sludge and the derived biochar at different carbonization temperatures

Elemental Composition		Faecal sludge	Biochar SSGL	Carbonized sludge@ different temperatures (°C)		
				600	700	860
Major:	Si (%)	5.4	9.5	10.0	10.3	12.8
	Ca (%)	3.9	3.3	3.9	3.8	2.3
	Al (%)	1.2	2.4	2.4	2.0	3.0
	P (%)	2.0	1.0	1.7	1.6	1.6
	S (%)	1.4	1.5	1.3	1.4	1.0
	Fe (%)	1.3	1.9	1.7	1.8	2.4
	K (%)	0.4	0.6	0.6	0.6	0.7
	Ti (%)	0.14	0.28	0.25	0.33	0.32
	Zn (%)	0.12	0.17	0.14	0.11	0.19
	Mg (%)	0.13	0.5	bdl	bdl	bdl
Minor:	Pb (ppm)	940	1681	755	256	1300
	Mn (ppm)	272	454	401	333	432
	Cu (ppm)	213	354	263	205	362
	Sr (ppm)	161	246	199	174	314
	Zr (ppm)	146	259	173	104	262
	Cr (ppm)	35	103	56	bdl	91
	Ni (ppm)	35	61	35	27	60
	V (ppm)	bdl	34	1	170	56
	Rb (ppm)	23	34	27	20	49
	Ag (ppm)	27	21	12	14	14
	Y (ppm)	15	25	14	8	24
	Cd (ppm)	17	7	bdl	bdl	bdl
	Nb (ppm)	4	10	12	5	11
	Mo (ppm)	bdl	7	8	8	16
	Th (ppm)	2	bdl	9	5	8
	U (ppm)	2	bdl	5	bdl	bdl

NB. bdl means Below Detection Limit, 1% equivalent to 10,000 ppm (Source: Authors)

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Figure 15: a) Sampled faecal sludge, b) biochar briquette from SSGL, c) sampled residual ash from WBT of b, d) Inner core of b showing unburnt carbon and e) Residual ash from WBT using Biochar briquettes from SSGL; Source: Authors

5.4 Way forward

The way forward is summarised in the following points:

1. Continue monitoring the elemental composition of the faecal sludge and the as-produced biochar.
2. Optimize the temperature and reaction time in the carbonization process including the use of hydrothermal means to maximize yield in terms of fixed carbon and calorific value of the biochar.
3. Optimize the briquetting process to enhance the combustion properties of the solid fuel
4. Make recommendations to SSGL on the carbonization process.
5. Assist SSGL to identify mechanisms to reduce sulphur and lead content

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6 Conclusion

This report, Deliverable 2.1 of WIDER UPTAKE presents four baseline studies conducted to prepare towards the demonstration of water-smart solutions in Accra, Ghana. Four studies were conducted for this report: a socioeconomic study of urban vegetable farmers in the city of Accra; a study of the quality of water presently being used by farmers; an assessment of the wood fuel needs of selected SMEs in Accra; and a study to establish baseline characteristics of the feedstock and laboratory-produced biochar. These studies have produced very pertinent information useful for the demonstration of the innovation solutions in the Accra Case of WIDER UPTAKE.

The socioeconomic baseline findings show that the patronage of vegetables produced in the city of Accra, albeit with wastewater, is high. Most of the farmers, who were male and aged about 40 years old, sold their produce onsite (at farm gate). The farmers did not convey their produce to market centres for sale — a sign of ready market. Furthermore, most of the farmers were solely engaged in urban farming as their main economic activity for livelihood. However, the fact that the land they cultivate does not belong to them gives cause for concern because landowners may request for custody of the land at any given time without prior information. Also, some farmers are 'squatters' on public land which use may change anytime there is need for such land.

The major sources of water apart from pipe-borne or dugout well were drains and streams in the city. Since most of the streams in the city are fed with water from the city's drains, especially in the inner-city areas, it is proper to conclude that most of the stream water has been mixed with drain water carrying municipal wastewater. It is therefore gratifying to note that farmers were willing to pay for treated wastewater to be delivered to them even though they would not pay an amount that was up to the amount they presently pay for treated piped water. The main characteristics farmers desired of treated wastewater include consistent availability, absence of bacterial/pathogen (safety), nutrients availability in the water.

In view of the concern for safety and nutrient levels of water for irrigation among farmers and also the fact that there is recognition for such needs, the second baseline study presented in this report looked at the characteristics of water currently being used for urban farming at two selected sites (these are the sites selected for demonstration). Also, the study looked at the characteristics of vegetables produced as well as that of the soil. Based on FAO/WHO standards, the results of this study show that generally, the water presently being used for urban agriculture meets national standards. It is important to underscore the fact that there are no national standards but for the FAO/WHO standards. This means that as Ghana embarks on the journey for resource recovery from wastewater treatment, there would be needed to develop standards for wastewater use in the country.

It is important to note that charcoal plays a very significant role in the energy mix in Ghana, even for urban SMEs, as the fourth baselines study shows. Hence, the interest of SMEs to adopt charcoal produced with alternative feedstock, such as faecal sludge is a key factor in pushing for the development of biochar that is readily available, burns well, and is safe to human and ecological health. Thus, in the delivery of sustainable energy, clean efficient burning characteristics of fuels are imperative. The fifth baseline study presented in this report highlights burning characteristics of typical biomass fuels in Ghana and how it compared with biochar produced at different temperatures using faecal sludge from the Mudor Treatment Plant. Also, the elemental composition of the faecal sludge and biochar produced from the sludge is presented to serve as a guideline for the future development of a standard for the production of an environmentally friendly and energy dense biochar from biomass waste.

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