ASSESSMENT OF EMERGING CONTAMINANTS IN COMPOST AND THE FACTORS INFLUENCING COMPOST ADOPTION IN GHANA

BY

MAXWELL KOGBE

(10049770)

A THESIS SUBMITTED TO THE INSTITUTE FOR ENVIRONMENTAL AND SANITATION STUDIES, UNIVERSITY OF GHANA, LEGON, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF DOCTOR OF PHILOSOPHY DEGREE IN ENVIRONMENTAL SCIENCE

SEPTEMBER, 2021

DECLARATION

I, Maxwell Kogbe, declare that this thesis, "Assessment of emerging contaminants in Compost and the Factors Influencing Compost Adoption in Ghana", is the outcome of my research. Prof Christopher Gordon, Dr Regina Dzidzo Yirenya-Tawiah, and Dr Daniel Nukpezah, all from the Institute for Environment and Sanitation Studies (IESS), University of Ghana (UG), supervised this research. I have acknowledged the references.

....4th January 2023

Maxwell Kogbe Date

(Student)

Chris Gordon

....9th January 2023

Prof Christopher Gordon Date

(Principal Supervisor)

D Tawiah

.... 10/1/2023

Dr Regina Dzidzo Yirenya-Tawiah Date

(Co-Supervisor)

....10th January, 2023

Dr Daniel Nukpezah Date

(Co-Supervisor)

ABSTRACT

Waste and soil management remain a critical environmental concern in many African cities, including Accra (Ghana), even though most of these wastes are biodegradable and compostable. With these challenges and prospects, compost adoption will help close the organic matter and nutrient cycle gap. However, compost comes with challenges, including adoption and contaminants issues. With progressive industrialisation and technology, emerging contaminants (ECs) could be present in compost, potentially affecting the environment and human health. Therefore, this study aimed to understand the risk of ECs in compost, the potential uptake of ECs in compost by plants (lettuce and carrot) and studying the factors influencing compost adoption. Here, this study involved three ECs (pesticides, PAHs and antimicrobial drugs) from three waste sources [mixed waste municipal solid waste (MWMW), source-separated municipal solid waste (SSMW) and municipal and agricultural solid waste (MAW)]. This study used the compost's maximum concentration of ECs to assess risk by comparing it with known ecological and human health criteria and identifying contaminants of potential concern (CPC). Also, the study predicted the optimum concentration of ECs in soils and the maximum risk quotient (RQ max) with two compost application rates [10 t/ha and 5 t/ha]. As there was no criterion for some quantified ECs, this research involved planting lettuce and carrot to identify the potential uptake and translocation of ECs with compost of known EC quantities. The study also examined the views of 350 farm-owners from Accra's key farming locations on compost adoption using structured questionnaires, focus group discussions, and key informants' interviews. The methodology involved descriptive statistics and probit analysis using an eleven-variable (biophysical and socio-economic) regression model to explain the key factors (including socio-cultural) influencing compost adoption. Further, there was an interaction within the predictor variables to evaluate their effect on adoption.

Of the targeted 49 pesticides, the study quantified glyphosate, atrazine, triclopyr, chlorpyrifos and lambda-cyhalothrin. The rests were methoxychlor, cyfluthrin, and hexachlorocyclohexane (HCH) isomers. These isomers were beta-HCH, gamma-HCH and delta-HCH. Thirteen (13) out of the 16 US EPA priority PAHs from the waste sources. They included acenaphthene, acenaphthylene, fluorene, anthracene, fluoranthene, chrysene, benzo(a)anthracene, and pyrene. The rest were phenanthrene, benzo (b) fluoranthene, benzo (a) pyrene, benzo[g,h,i]perylene and Indeno(1,2,3,c,d)pyrene. The antimicrobial residues identified included; amoxicillin trihydrate, danofloxacin mesylate, sulfadiazine, ciprofloxacin hydrochloride and amprolium hydrochloride. Two drugs (danofloxacin and ciprofloxacin) were in the compost samples. There was a drastic reduction in the compost, confirming the effectiveness of composting in treating antimicrobial residues. The maximum concentration of identified ECs (pesticides, PAHs and antimicrobial drugs) was within the ecological criteria (0.004mg/kg) except for the three isomers of hexachlorocyclohexane. The maximum residue of gamma-HCH, beta-HCH, and delta-HCH recorded in the composts were 0.024, 0.028 and 0.049 mg/kg, respectively. The maximum predicted soil residues of ECs after composts applications at 5 t/ha ranged from 0.0001 mg/kg for beta-HCH and gamma-HCH to 0.0002 mg/kg for delta-HCH. At 10t/ha of the composts, the maximum predicted soil concentrations were 0.0002 mg/kg for gamma-HCH and beta-HCH and 0.0004 mg/kg for delta-HCH. All the compounds had an RQ max of less than 1; therefore, these ECs were low priority. Regardless of the compost’s content of ECs, the vegetable analysis showed pesticides, PAHs and antimicrobial drugs uptake from the compost treatments during the study period. There were ECs in the compost, and no ecological or health risk was associated with compost. No uptake and translocation of contaminants by plants (lettuce and carrot). The study recommended continuous monitoring of these contaminants in compost and food.

The social survey findings showed that, although compost was available, the adoption rate was low (16%), mainly due to cost. Household size, per-capita income, and compost-specific training for farmers had a significant positive effect on adoption, while the farmers' age had a significant negative impact. A multivariate interaction between age and compost-specific training positively impacted adoption. Also, age and education showed a high possibility of the farmer adopting compost. As farm and household size increased, the farmer was more likely to adopt compost with a higher adoption rate. However, as age and farm size increase, the farmer is less likely to use compost. Male farmers who had received training were less likely to adopt compost than their female counterparts, and males with enormous households were not likely to adopt compost. It appears the male farmers were complacent regarding their attitude toward compost adoption irrespective of receiving training, increased household size or increased per capita income. Biophysical and socioeconomic factors affected compost adoption. Policymakers should involve female farmers by giving them compost-specific training without neglecting the males.

DEDICATION

To my dear family

ACKNOWLEDGEMENT

The demands of pursuing a PhD at the Institute for Environment and Sanitation Studies (IESS), University of Ghana, can only be achieved with the goodwill and support of others. First and foremost, I am grateful to Prof Christopher Gordon, Dr Regina Dzidzo Yirenya-Tawiah and Dr Daniel Nukpezah for their guidance and constructive criticisms. Thanks for your time in shaping my proposal and providing the necessary and timely feedback on the thesis. Special mention to IESS students and staff for their immense contributions.

The cost of pursuing a four-year PhD is challenging. I am therefore thankful for the timely support from the BANGA Africa project thesis completion grant during the final year.

Thanks to my employers (Ghana Standards Authority) for providing the necessary assistance and suitable laboratories for this study. I am grateful.

I appreciate Dr Adolf Awah, Dr Bright Kumordzi, Dr Godwin Dogbevia, Dr Samuel Nertey, Mr Prosper Adiku, and Mr Daniel Nayo-Gyan. Your encouragements were great, and I cannot catalogue your support here.

I could have captioned my thesis ‘experience with urban and peri-urban farmers in Accra’. Indeed, the farmers I engaged with were fantastic and provided the necessary assistance with their trove of wisdom. I enjoyed my interactions with them.

To my family, I dedicate this work to you! Yes, I temporarily abandoned you during the period. However, you survived.

Above all, to God be the Glory.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
ANOVA	Analysis of Variance
C	Carbon
CO_2	Carbon Dioxide
CPC	Contaminants of Potential Concern
DDT	Dichlorodiphenyltrichloroethane
EC	Emerging Contaminant
EC(s)	Emerging Contaminant(s)
EPA	Environmental Protection Agency
ESL	Ecological Screening Levels
EU	European Union
FAO	Food and Agricultural Organization
GAEC	Ghana Atomic Energy Commission
GDP	Gross Domestic Product
GSA	Ghana Standards Authority
GSS	Ghana Statistical Service
HCH	Hexachlorocyclohexane
HSL	Health Screening Levels
HtH	House to House
H_2SO_4	Sulphuric Acid
IESS	Institute for Environment and Sanitation Studies
K	Potassium
$K_2Cr_2O_7$	Potassium Dichromate
LCA	Life Cycle Assessment
LCMS	Liquid Chromatography with double Mass Spectrometer
MAW	Municipal and Agricultural Waste
MMDAs	Metropolitan, Municipal and District Assemblies
MOFA	Ministry of Food and Agriculture
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MWMW	Mixed Municipal Solid Waste
ND	Non-Detected

NS	No Standard
N	Nitrogen
P	Phosphorus
PAHs	Polycyclic aromatic Hydrocarbons
PET	Polyethene terephthalate
PPP	Public-Private Partnership
RCRA	Resource Conservation and Recovery Act
SDG	Sustainable Development Goal
SDGs	Sustainable Development Goals
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSMW	Source-Separated Municipal Solid Waste
TSCF	Transpiration Stream Concentration Factors
UG	University of Ghana
UN	United Nations
UPA	Urban and Peri-Urban Agriculture
USA	United States of America
WAI	Weight Average Index
WM	Waste Management

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Composting is an ecosystem-based technology for organic waste management (WM) in horticulture, which farmers have used for several years: records show over 5000 years ago (Zheng *et al*., 2020). However, the exact definition of organic waste composting is still broad and several studies based it on biological decomposition. Biological decomposition is an age-old natural process by which microorganisms break dead organic waste into simpler organic and inorganic forms like carbon dioxide (CO_2) and water (H_2O). In simple terms, as plants fall, it gradually decays, providing the necessary minerals and nutrients for the flora and fauna of the ecosystems, including microorganisms. Composting is often used synonymously with biological decomposition (Oppermann, 2018). However, they are different. The main difference is that composting requires specified and controlled conditions.

For this thesis composting is a technology that involves the biodegradation of various organic materials in a controlled and purposeful manner with microorganisms' help, as defined by Muscolo *et al*., 2018. Composting aims to convert organic material into a biologically functional and safe organic product called ‘compost’ that may enrich soil quality. Other composting products include CO_2, heat, H_2O, and gases like nitrous oxide, methane, and other volatile organic compounds. Composting offers many advantages and is considered a natural approach for efficiently managing waste and soils by humans mimicking organic matter mulching over time.

Environmentally, composting and compost use is one of the most preferred options to manage waste (Golubovi *et al*., 2019; Hariz *et al*., 2020; Tibu *et al*., 2019; Tubeileh and Stephenson, 2020; Vigneswaran *et al*., 2016) and for soil management (Adugna, 2016; Stacey *et al*., 2019). The main advantage of composting is the recycling of nutrients; nitrogen (N), potassium (K) and phosphorus (P). These elements can be recycled and reused in the soil during the process. Also, the organic fraction, carbon (C) of the waste, is recycled, thus, reducing the environment's effect. Besides the nutrient recycling advantage, the process can divert waste from landfills while increasing the soil's organic matter and carbon content. Compost helps in pest infestation management and bio-mediation (Uyizeye *et al*., 2019), pollution control (Ondarts *et al*., 2012), erosion control (Chaganti and Reddy, 2015) and plant disease control (Tubeileh and Stephenson, 2020). Thus, composting offers many environmental advantages, hence the need to promote it worldwide.

Globally, various statkeholcers have championed composting and its adoption in many area (Plana, 2015). This situation is because composting outweighs many of the several climate-smart approaches for waste management (WM). These friendly approaches include energy production from waste, biochar production through pyrolysis and liquid fertiliser through anaerobic digestion. All these WM issues have their advantages. However, one key benefit of compost is that it is scalable and straightforward in many world regions, particularly in developing and resource-poor countries. In these nations, composting and compost use can be crucial in many because of the composition of the waste stream.

The organic fraction of the waste stream in developing nations is vast, over 60 per cent (Godfrey, 2017; Hoornweg and Bhada-Tata, 2012). This composition contrasts with the low organic content (32 %) in developed countries (Bhada-Tata, 2012; Silpa *et al.*, 2018). And the high portions represent a massive opportunity for these nations to compost their waste. However, estimates show that only about 1.5 % of the organic part in these nations is composted (Bhada-Tata, 2012). Regrettably, the majority of the waste from these nations usually ends in non-engineered and uncontrolled landfill sites. Also, the citizenry may leave this waste in open places like the street, drains, beaches, wetlands and other essential sources (Oteng-Ababio *et al.*, 2013). This situation is common in many African cities, including Accra.

Over the years, waste management has continued to be a topical environmental issue in many countries. The organic fraction of the waste is the highest (67 %) in Ghana, with the remaining (plastic, leather, metals) being inorganic (Miezah *et al.*, 2015). As 67 % of the waste is organic, it is reasonable to suggest that proper organic WM will solve many of the overall waste challenges in the country. Besides, operators can compost in their homes, communities, regional, and even national levels. With all these advantages, various stakeholders have directed campaigns towards composting and compost use around the country. These campaigns have happened over the period.

The first Ghana Environmental Sanitation Policy emphasised the need to compost waste at the municipal, community and household levels (Ghana Sanitation Policy, 1999). It recommended adopting composting as an appropriate technology to handle the country's waste menace and enrich the soil. Again, as revised in 2010, the policy further recommended composting to solve WM issues. Similarly, the country's first-ever

Environmental Policy in 2012 echoed the role of composting (recycling) in addressing waste and soil management issues (Ghana Environmental Policy, 2012). Thus, compost use was one of the first Ghana National Environmental Policy grounds. This policy recommended compost adoption in many quarters.

1.1.1 Potential Application of Compost: Focus on Urban and Peri-Urban Agriculture

Globally, various composting programs have failed due to policy and technology issues. However, the underlying challenge is the programs' financial sustainability (Hussein *et al.*, 2018; Lohri *et al.*, 2014; Pandyaswargo and Premakumara, 2014). Due to farmers' reluctance to purchase the product at the right price, most composting systems cannot generate the required income from compost sales. The product's sale hardly covers processing, transportation, application and other vital costs. Transportation is a critical consideration in the pricing of compost due to its bulky nature. One key strategy is identifying potential consumers close to urban and peri-urban areas with significant organic waste. The organic waste will potentially serve as the raw materials for composting facilities.

Urban and peri-urban agriculture (UPA) became popular in African cities in the 1990s following structural adjustment programs. It involves cultivating, growing, and processing various foods, mainly for the city's inhabitants. Farmers' inputs and material resources in urban areas are usually within the immediate environment (Lee-smith, 2013). Agriculture in cities is typically complicated, capital-intensive, and predominantly involves the production of perishable crops. The UPA is prevalent in many African cities, including Accra, and stakeholders continue to champion it due to the continuous rise in urban population and demand.

Accra is a cosmopolitan city with critical environmental challenges, as mentioned earlier. More worrying is that the urbanised Ghanaian is more irresponsible and reckless towards the environment than the unurbanised (Cobbinah *et al.*, 2017). Another pressing issue is the lack of jobs. The city's unemployment rate is worrying, with many youths involved in menial jobs and some with none. Accra's primary economic activities include financial and commercial sectors, processed foods, lumber, clothing and textiles, fishing and tourism. However, many inhabitants are involved in Agriculture in the city.

About 1,000 farmers are involved in economically market-based UPA in Accra (Obuobie *et al.*, 2006). The majority of the farmers are engaged in the production of exotic vegetables such as lettuce (*Lactuca sativa*), carrot (*Daucus carota*) and spring onions (*Allium fistulosum*), with others producing local vegetables like okra (*Abelmoschus esculentus*) and jute leaves (*Corchorus sp.*). These farmers provide fresh vegetables to Accra's inhabitants daily. Various studies have also championed the need for fresh vegetables (Coelho-ravagnani *et al.*, 2020). Composting waste from Accra and compost adoption by farmers in and around the city will boost agricultural production. However, there are several pressing challenges.

The challenges with urban and peri-urban agriculture are varied and include health, safety, and environmental risks (Pramanik, 2013). These threats are worrying because of the proximity of UPA to highly populated areas. This activity competes with city inhabitants for space, air, and water. Threats to inhabitants' health and safety, including the farmers and consumers, originate from the potential contamination of crops with microorganisms through irrigation with wastewater and the uptake of heavy metals and other contaminants from polluted environments. In many cases, the unregulated and excessive use of agrochemicals, including fertilisers and pesticides, poses serious environmental threats that directly or indirectly affect city dwellers' health, safety and the environment. Therefore, there is a need to address these pressing and persistent challenges.

Composting municipal solid waste is an economical, environmental and social innovation with notable advantages for stakeholders involved in waste management, urban planning and circular economy. Government officials can integrate composting into urban SW management because of the significant organic waste from these areas. The compostable fraction of the SW within the peri-urban areas could be recycled to close the organic matter and nutrient cycle gap. There is considerable potential for compost production and adoption for agriculture in Ghana, particularly in urban areas; however, compost use has several challenges. These issues may be contaminants and adoption challenges.

1.2 Statement of the Problem

1.2.1 Emerging Contaminants Issues in Compost

Compost may contain contaminants that may affect the environment. Over the period, contaminants in compost have focused mainly on heavy metals and some microorganisms. However, with progressive industrialisation and technological advancement, emerging contaminants (ECs), otherwise called novel entities or contaminants of emerging concerns, may be present in compost. These ECs may come from anthropogenic or natural sources. Compost use may be a crucial entry route for ECs into the environment and humans, posing some risks. Also, ECs may enter the food chain through compost applications. The uptake of ECs is possible because plants are the producers in the ecosystem. Various recent studies have recognised pesticides, polycyclic aromatic hydrocarbons (PAHs), and antimicrobial drugs as emerging contaminants (Martín-pozo *et al.*, 2019; Omar *et al.*, 2019; Tousova *et al.*, 2017).

Several international bodies have also classified EC as dangerous, hence the need to target them for further studies. The European Union (EU) has included some pesticides and antimicrobial contaminants as emerging and included them in their watch list (Loos *et al.*, 2018). The United States (US) EPA has also targeted 16 priority PAHs for special attention monitoring in the environment due to their harmful effects (EPA USA, 2008) and further classified some pollutants for urgent attention and control (EPA USA, 2016). The contaminants included pesticides, PAHs, and antimicrobial hydrocarbons, hence the need for consideration in this study.

1.2.1.1 Pesticides

Globally, there is a continuous rise in pesticide use due to increased pests and diseases and the demand for year-round production (Idris *et al.*, 2020). These pesticides are uncontrolled and unregulated in many regions (including Ghana). However, due to their chemical nature, most pesticides are highly persistent in environmental systems (air, water and soil). Also, users have applied these pesticides in various quarters; homes, farms, and factories, among other sources. Studies suggest that pesticides may be present in different composting materials used in compost (Idris *et al.*, 2020; Kupper *et al.*, 2008).

Currently, there is an international ban on some pesticides, particularly organochlorines. Representatives of various nations championed the restrictions during the Stockholm convention in 2011 (Stockholm Convention, 2001). However, many studies continue to report pesticides and their derivates in raw materials for composting. For example, chlordecone, an organochlorine compound, was found in a radish pith (Létondor *et al.*, 2015). A study reported the uptake of dichlorodiphenyltrichloroethane (DDT) by various vegetables (Lorenz and Lal, 2016). Also, Létondor *et al.*, 2015 observed chlordecone uptake and translocation in many plants and vegetables. Similar studies have reported uptakes of chlorpyrifos in the Chinese cabbage (*Brassica rapa*) and other vegetables (Tereza Horská *et al.*, 2020; FAO and WHO, 2019).

1.2.1.2 Polycyclic aromatic Hydrocarbons (PAHs)

PAHs are critical environmental and human health issues of concern. This threat is because of the toxic nature, high persistence and ubiquitous nature of these compounds in the environment. They can travel over long distances and are in various media; air (Adesina *et al.*, 2021; PHE Centre for Radiation, 2018) and aquatic bodies (Kopeć *et al.*, 2017; Omer, 2020) and soil (Ciesielczuk *et al.*, 2014; Forján *et al.*, 2020). These PAHs compounds' formation is by the incomplete thermal decomposition of biomass. Studies show PAHs in various materials serve as the feedstock for composting (Kathi, 2011; Langdon *et al.*, 2019; Sądej and Namiotko, 2010). Therefore, PAHs can enter the food chain through compost applications.

Studies have shown that various PAH compounds can be taken and bioaccumulated in several plants' parts (Pullagurala *et al.*, 2018; Zhu *et al.*, 2018). Wang *et al.* (2018) found many PAH compounds in Chinese cabbage using gas chromatography-mass spectrometry. The above study proved the PAH's ability to bio-accumulate in plants. Zhang *et al.* (2017) demonstrated the uptake and bioaccumulation of PAHs compounds in the maize (*Zea mays*) plant. Despite the potential for uptake by plants, the literature suggests that plant uptake constitutes only a minute percentage (< 2 %), leaving the majority in the environment (Pullagurala *et al.*, 2018).

1.2.1.3 Antimicrobial Drugs

In livestock agriculture, farmers use antimicrobial agents to treat and prevent diseases leading to a positive growth rate. After administering drugs, they are metabolised, absorbed and finally excreted through various means. The renal system and the faeces are the predominant excretory routes for these drugs (Herago, 2018). Therefore, the manure of these animals can potentially contain high levels of these drugs. Compost operators can use urine and faeces as feedstock in composting. Studies also suggest that these drugs are difficult to disable in the natural environment due to their mobility and persistence (Pacios *et al.*, 2020). These drugs may then enter the plant and humans through the application of compost. However, relevant research is lacking in this field.

Most plants easily attract antimicrobial drugs. Studies suggest that plants take up and bioaccumulate these drugs, affecting their growth (Suk *et al.*, 2017). In radish (*Raphanus sativus*), chlortetracycline, enrofloxacin, and sulphathiazole are absorbed (Chung *et al.*, 2017). Michelini *et al.* (2015) concluded the common hazel (*Corylus avellana*) absorbed sulfadiazine, and its growth was affected. The plant absorption rate of antimicrobial drugs is also species-dependent (species of cabbage) (Wang *et al.*, 2016). Bártíková *et al.* (2015) observed several plant species that can potentially take up and translocate different antimicrobial drugs at different concentrations.

Global studies suggest increasing attention to ECs due to their ability to bio-accumulate and bio-magnify (Bilal *et al.*, 2019). Studies linked these ECs to several human health conditions. These conditions include functional disorders associated with the thyroid, cancers, disruptions in neuroendocrinology, behaviours and metabolism disorders (Kudłak *et al.*, 2015; Michal *et al.*, 2018; Wee and Aris, 2017). Another great interest in ECs is their negative effect on aquatic animals and humans' hormonal systems (Bhushan *et al.*, 2017). Again, Wee and Aris (2017) have shown ECs such as antimicrobial drugs and pesticides cause intersex in fish.

Researchers reported ECs in various foods (Chung *et al.*, 2017; Michelini *et al.*, 2015; Omar *et al.*, 2019) and some environmental systems (Niemuth and Klaper, 2015; Wee and Aris, 2017). The presence of some of these contaminants received some attention from some food safety authorities. For example, the European Union (EU) has non-trade regulations to control ECs in foods entering their markets. These include vegetables, fruits, fish and fishery products, among other food products. Composts may be used as a soil amendment and provide plants with essential nutrients. Emerging contaminants in compost may pose an ecological and human health risk. Plants may also take up these ECs via translocation from the soil. However, the levels of ECs in compost are understudied.

Recent studies have attempted to assess the compost's quality parameter and potential compost effect on the soil (Bo, 2017; Soudi and Thami-alami, 2020). Unfortunately, studies on the quality parameters regarding ECs in compost are relatively limited. In particular, the evidence remains inconclusive regarding a) the relative composition and amounts of ECs (pesticides, PAH, and antimicrobial drugs) in the compost, b) the ecological and human health risk related to ECs, in compost, c) the potential uptake and translocation of ECs by common vegetables.

1.2.2 Compost Adoption Issues

As mentioned, compost use is a sustainable option for managing waste and soil. However, studies on the factors influencing compost adoption are limited. Interestingly, studies on compost use have mainly focused on technical considerations. These studies proved that factors like feedstock availability (Matsui *et al.*, 2017), difficulty in making compost (Supaporn *et al.*, 2013), the experience of farmers (Blazy *et al.*, 2017) and the heavy metal content (Bo, 2017; Gong *et al.*, 2018) were essential consideration regarding compost adoption by farmers. Therefore, the other factors influencing compost adoption need to be understood to maximise the benefits of compost to waste and soil management.

Thus, this study also targeted the socio-economic and biophysical determinants underlying the use of compost, using the sub-Saharan African country Ghana as the case study. Accra, the capital city of Ghana, was considered. The city and the country face issues of WM (Amoah and Kosoe, 2014; Cobbinah *et al.*, 2017; Samwine *et al.*, 2017) and soil management (Owusu *et al.*, 2020). Hence, an urgent need to improve the challenges mentioned above. Also, like other developing nations, the organic and putrescible fraction of the waste generated is the highest, about 67 % (Miezah *et al.*, 2015). As 67 % of the waste is organic, it is reasonable to suggest that managing the biodegradable component will significantly tackle its waste management issues.

1.3 Aim of the Study

This study aimed to understand the ecological and human health risk of ECs in compost, the potential uptake of ECs in compost by vegetables and studying the factors influencing compost adoption (Fig 1.1). To this end, the study had the following specific objectives to achieve the intended goal.

1.3.1 Specific Objectives

- Identify and quantify selected ECs (pesticides, PAH, and antimicrobial drugs) in compost from diverse waste sources.
- Assess the ecological and human health risk of ECs (as determined in objective 1) in compost.
- Examine the potential uptake and translocation of ECs by two vegetables (lettuce and carrot).
- Examine the factors, including biophysical, socio-economic and cultural influencing compost adoption.

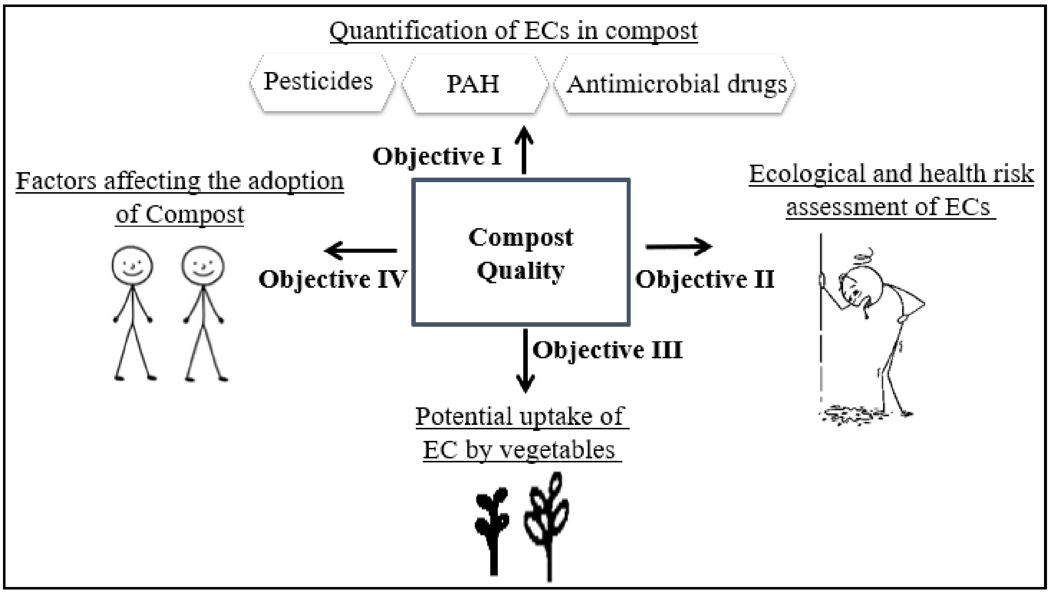

Fig. 1.1: The four objectives considered in this research

This thesis considers issues of emerging quality issues in compost production by identifying and quantifying emerging contaminants, ecological and human health risk assessment of compost application, possible uptake of ECs through compost application, the potential uptake and translocation of these ECs by vegetable plants and the various factors including socio-cultural influencing compost adoption. The roman numerals (I, II, III, and IV) represent the study's specific objectives.

1.4 Hypotheses

Several studies have indicated that EC risks humans and the environment (Wee and Aris, 2017). Composting process may affect some contaminants in compost. The ECs are present in diverse sources that can serve as feedstock for compost (Herago, 2018). Compost use can present an important route of contamination of the environment. The presence of ECs in compost can be an ecological and health risk. Studies suggest that different plants may take up various contaminants (Chung *et al.*, 2017; Michelini *et al.*, 2015).

Based on the above studies, the current thesis tested the following hypotheses:

1. H1: The composting process affects the levels of ECs in the compost from diverse waste sources.
2. H2: Emerging contaminants in compost present an ecological and human health risk.
3. H3: Different vegetables will contain different ECs due to their varied uptake and plant assimilation rates.
4. H4: The various factors affecting compost adoption are independent.

1.5 Research Questions

The central questions of each of the objectives in this thesis were:

1. What is the relative composition and amounts of selected ECs (pesticides, PAH, and antimicrobial drugs) in compost? What are the type and quantities of the ECs in compost? Is there an association between the composting material and the quality of compost produced concerning the selected ECs? Do the feedstock impact

the relative composition and amount of compost concerning the targeted EC? Which composting feedstock yields the most contaminant? (Objective 1).

2. Will the presence of ECs in compost present a risk? Are there ecological or human health concerns, and will it be the same risk? (Objective 2).
3. What are the uptake rate and translocation of ECs (pesticides, PAH, and antimicrobial drugs) by the different vegetable plants (lettuce and carrot)? Which vegetable will take up the most ECs? Are these vegetables grown on soil amended with compost containing these contaminants safe to consume? (Objective 3).
4. What are the factors influencing the adoption of compost in Ghana? Will there be any factor (variable) affecting compost adoption? Will the factors be socio-cultural, religious, socio-economic or biophysical? What are the univariate and multivariate interaction effects of the different variables on adopting compost? Will these interactions have a positive or negative impact on adoption? (Objective 4).

This thesis sought to enhance the conceptual understanding of ECs in compost. The study must address the following questions: the type and composition of ECs in compost, the ecological and health risks of ECs in compost, and the possible uptake and translocation of these ECs by common vegetable plants. The study also sought to assess the factors, including sociocultural influence on compost adoption and farmers' perception towards adoption (Fig. 1.2). The research is particularly crucial for compost production, its application risk and issues regarding food safety. Further, the study will inform various stakeholders, including policymakers, in risk management, communication, and composted adoption strategies.

1.6 Justification

With organic WM issues and the need for sustainable agriculture by providing adequate nutrients for the soil, composting organic waste and adopting compost appears to be a sustainable option for solving the issues mentioned earlier. Therefore, this thesis based the justification on the following eleven considerations;

1. Despite the high organic waste produced in developing nations, including Ghana (over 60 %), the soils in developing countries, including Ghana, have poor soil organic carbon (SOC). Owusu-Nimo et al. (2018) have given the low organic content of different soils in Ghana. The Ghana government's strategy and various campaigns by stakeholders in WM call for composting of organic waste. Compost use can also help manage SOC and enrich the soil's nutrient content (Nartey et al., 2017). Furthermore, inorganic fertiliser's ever-increasing cost calls for governments to consider sustainable means of organic matter amendment that will put less stress on foreign exchange.

2. At present, there are government concerns and the ever-changing consumer preference for organically produced foods, coupled with the increasing food safety issues awareness by consumers. In response to these concerns, an option (compost to soils) for the current agricultural production needs to be science-based.

3. Currently, Ghana is predominantly agricultural, with the sector contributing about 20 per cent of the Gross Domestic Product (GDP) and population directly or indirectly involved in agriculture (FAO, 2020).

4. Aside from the local consideration, all nations have global concerns about achieving Sustainable Development Goals (SDGs). The SDGs can't be met without proper WM, considering the central role of waste management in many SDGs. Composting of bio-waste is a sustainable approach to managing organic waste in the country and is environmentally friendly.

5. Although various studies reported compost contaminants, the specific, real, and quantitative data concerning ECs on compost in waste are understudied in Ghana. For these reasons, this study would improve the existing knowledge about ECs contents in compost in the country. Furthermore, the socio-cultural concerns and the factors influencing compost adoption in the context of an African nation (Ghana) burdened with WM issues have been considered. The outcome will help the country's organic waste and soil management planning and potentially scalable to other regions facing similar challenges.

6. There are increasing concerns about ECs on environmental systems, particularly from anthropogenic sources, due to EC's adverse effect on individuals' health and safety. Nevertheless, some studies reported on ECs in the environment (Huang *et al.*, 2018; Keerthanan *et al.*, 2021; Niemuth & Klaper, 2015). However, there are limited studies on EC in compost. The assessment of ECs associated with the quality of compost is limited.

7. Despite the studies of ECs on compost, studies linking compost to ecological and human health are limited.

8. Several authors have published on compost quality (Muscolo *et al*., 2018; Viaene *et al*., 2016; Wang *et al*., 2020). However, the quality of compost per potential contamination from ECs is understudied. The key among the issues is hardly any study that considers its potential uptake by plants through different compost sources and applications.

9. Accra, the capital of Ghana, was targeted because it is highly populated and urbanised with unsustainable waste. The per-capita waste generated in the city is 0.74kg/person/day compared to the national average of 0.47kg/person/day (Miezah *et al*., 2015). This situation has led to unsanitary and unsightly conditions in many parts of the city as state officials are overwhelmed. It is also a city with low soil organic matter and soil carbon content due to the nonexisting land fallow system

10. More than one thousand farmers produce vegetables in Accra. These farmers supply fresh vegetables to an estimated two hundred thousand Accra residents daily (Obuobie *et al*., 2006).

11. Currently, there is a lack of information on EC regarding compost use. Therefore, this study will guide regulators and policymakers in compost application regarding risk management and communication.

1.7 Thesis Structure

This study consisted of six (6) chapters (Fig. 1 2), as presented below.

Chapter 1: This chapter is the introduction, which give the study and its relevance. The chapter provides the background information of the study. The study's problem statement aims, objectives, hypothesis, and justification are considered in this section.

Chapter 2: This section reviews relevant literature about the study. It comprises a literature review on chemical and emerging contaminants; the ECs issues include occurrences, risk and potential uptake. Also, the study assessed composting issues and the various factors affecting compost adoption.

Chapter 3: This section describes the materials and methods used in the study and how they are used to achieve each study's objectives. The chapter also provides an in-depth description of the research area and the various statistical approaches.

Chapter 4 presents the study results and provides an overview of the analyses using annotated tables, graphs and other information displays. The section presented identified ECs, the risk assessed and the potential factors influencing compost adoption in the study area.

Chapter 5: Chapter 5 constitutes a detailed discussion of the study result’s implications. Here, it compared the results with other relevant studies, making the necessary deduction, inferences and the implication of this study.

Chapter 6: This chapter outlines the conclusions and makes the necessary recommendations based on the study's findings on the aims and objectives as presented in chapter 1. This section defines the contributions of the work to knowledge and defines the future perspectives for further research.

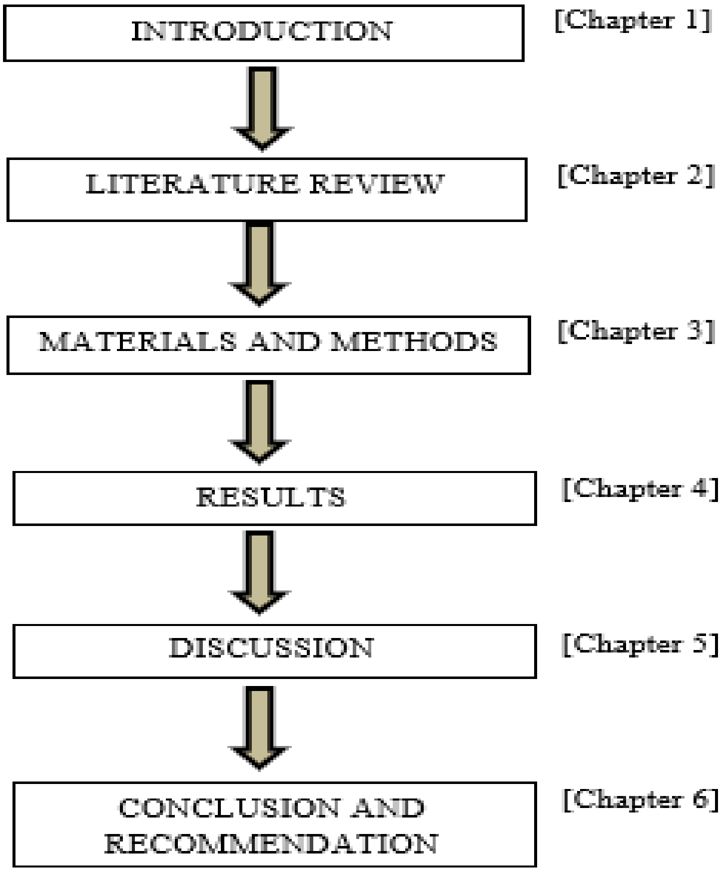

Fig. 1.2: The six chapters of the study.

Fig (1.2) above displays the chapters considered in this thesis, starting with the introduction through the literature review and then how the work was done. After, the following section presents the results and the discussion. The research ends with relevant conclusions and recommendations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction to Literature Review

This chapter reviews pertinent literature on emerging contaminants, composting and compost use. The chapter identifies gaps in the existing literature that will inform the study aim, the intended objectives, and the methodology. This chapter is organised into sections. The section includes issues the chemical usage and issue of emerging contaminants. The others include emerging contains, the potential uptake and translocation of EC. Also, there are sections on composting and a review of compost adoption strategies. The chapter ends with the critical conclusions from the relevant findings from the literature review, which is the basis of the study's conceptual framework.

2.2 Chemical Usage in the Environment

Chemicals are an essential part of life in the modern world and are used to disinfect, run machines, treat diseases and perform other relevant uses. Over the years, there has been substantial growth in chemical usage due to increases in industrial production, agriculture and everyday life. The world chemical industry is enormous and contributed about 5.7 trillion to the world GDP in 2017, representing about seven per cent of the world GDP (Oxford, 2019). The report (Oxford 2019) also indicated that the trend would continue until 2050. The report also showed a synergic association between the world’s production and the geographically relocating chemical industry. With this trend, it appears the chemical industry will continue to increase.

Oxford Economics approximated that the largest GDP of the chemical industry comes from the Asia-Pacific region (45 %), followed by Europe (23 per cent), with Africa and the Middle East providing the minimum (Table 2.1a). The report compared jobs in the industry. Asia-Pacific region had the most considerable number of jobs (83 million), with China alone at 72 %. Europe followed with 6 million, then Latin America and the Caribbean (6 million) (Oxford, 2019). Also, Africa and the Middle East had the lowest number of jobs (5 million) (Table 2.1 b). The provision of employment through the chemical industry has contributed significantly to many of the global goals. The evidence illustrates the enormous impact of the worldwide chemical industry and calls for ongoing studies.

Table 2.1a: The Chemical Industry's Total Global Economic Impact in 2017

Region	**Global economic impact**
North America	$866 billion total GDP contribution
Europe	$1.3 trillion total GDP contribution
Asia-Pacific	$2.6 trillion to total GDP contribution, of which $1.5 trillion in GDP.
Latin America and the Caribbean	$374 billion total GDP contribution
Africa and the Middle East	$550 billion total GDP contribution

Table 2.1b: World Wide Jobs Provision from Chemical Industry

Region	Global economic impact
North America	Six million employment supported
Europe	19 million jobs supported
Asia-Pacific	83 million jobs. China had 72 % of the employment; 60 million jobs in China.
Latin America and the Caribbean	Six million jobs supported
Africa and the Middle East	Five million jobs supported

2.3 Chemical and the Sustainable Development Goals

In Rio de Janeiro (Brazil), various member states (192) of the United Nations joined a complete developmental process defining the post-2015 agenda. The meeting was at a Conference on Sustainable Development in June 2012. It was termed Earth Summit 2012 or Rio+20 or Rio 2012 and aimed at achieving sustainable development with greater emphasis on environmental protection for the whole world (United Nations, 2012). This arrangement translated into the famous Rio+20 document (The Future We Want). This document was non-binding but renewed the political commitment to a sustainable future. The future we want campaign also mandated the establishment of sustainable development goals.

The SDGs, also known as the Global Goals, are a worldwide demand for action to end poverty, protect our earth, and ensure that the world can enjoy peace and prosperity by 2030. It was adopted by the UN member states, including Ghana, in September 2015 and came into force in January 2016. The objective is to achieve sustainable economic growth, ensure social inclusion and protect the environment (United Nations, 2015). It has seventeen (17) goals (Fig. 2.1) and 169 targets with their associated indicators. These goals address many facets of environmental management. The use of chemicals is among the factors since it adversely affects the environment. Therefore, healthy chemical content control is an essential component of the SDGs. The critical SDG for chemical management is goal 12 (United Nations, 2015).

Fig 2.1: The Sustainable Development Goals

Worldwide, various stakeholders are currently championing the seventeen sustainable development goals. It starts with Goal 1 (no poverty) and ends with goal 17 (partnership for the goals). Goal 12 (responsible consumption and production) is directly linked to prudent chemical management.

Sustainable development goal 12 requires a comprehensive approach across the chemical's lifecycle, including coordination among stakeholders throughout the supply chain. This chain starts with the manufacturers and ends with consumers. Specifically, objective 12.4 of goal 12 calls for environmentally sound management of chemicals. This objective also requires proper chemical disposal, in line with negotiated international frameworks, and substantially reduces their use. Every aspect of production involves chemicals; therefore, properly managing them would support several SDGs. These include SDG 3 (good health and well-being); SDG 6 (clean water and sanitation); SDG 7 (accessible and renewable energy); SDG 11 (sustainable cities and communities); and SDG 14 ("life underwater") (United Nations, 2015).

As mentioned earlier, chemical contributes immensely to SDGs and the betterment of human lives. These chemicals may harm the environment. Rachel Carson precisely and concisely raised this perspective in her world-acclaimed and popular book 'The Silent Spring'. This book was published in 1962 and increased awareness of the chemical's effect on the environment. Consequently, there are restrictions on the manufacture and use of several substances. Experts proposed these bans during the Stockholm Convention 2001 (Stockholm Convention, 2001). Various nations banned or restricted several chemicals, particularly persistent organic pollutants, at this convention. Given the global interest in chemical restrictions, there should be continuous research on monitoring environmental chemicals.

Despite the continuous attempt to ban and limit several chemicals usage, the overall decrease in chemicals is not evident in the environment. This situation is due to chemicals' initial and spontaneous benefit to man. New chemicals are manufactured and introduced to the public regularly. Of the synthesised chemicals, over 142 million are available globally, and nearly 30 000 products contain threatening health substances (UNEP, 2020).

There is also unintended usage in using these chemicals for their intended purposes. Most chemical ends up in the environment, with people not being conscious of them. The substances are diverse, and hence nation must consider therm. Of these chemicals, emerging contaminants have gained attention among several people, particularly scientists.

2.4 What are the Emerging Contaminants?

Generally, emerging contaminants have different names (Taheran *et al*., 2018). This study described them as ECs. They are also known as novel entities, micropollutants, pollutants of emerging concern, and chemicals of concern, among other titles. The various names imply the lack of consensus among experts in having a universal and globally accepted definition. The parent chemical of the EC may not be harmful, but the compound may change its physical and chemical properties and toxicity with time upon release into the environment. There is no universally accepted definition for these contaminants. However, various authors have classified ECs according to the following:

(a) An EC is a novel unregulated and uncontrolled human-made substance in the environment (air, soil and water). These chemicals may be in plants and animals, including human tissues and food in minute concentration. These contaminants persist and can alter an organism’s normal functions (Houtman, 2010).

(b) A novel group of human-made chemicals, including metal and compound use in the electronic and automobile industry. These compounds may also include micropollutants and undiscovered chemicals of interest (Arguello-Pérez *et al*., 2019).

(c) Contaminants that are well known in the environment and safe for usage. However, these chemicals may discover new characteristics dangerous to human health and safety (Lei *et al.*, 2015).

(d) Metabolites of human-made chemicals from the degradation, decomposition, or combination of these chemicals or their metabolites in polluted sites. These chemicals may include petrochemicals and their metabolites, usually measured in ppm (Sauve and Desrosiers, 2014).

(e) A combination of compounds from two or more harmless chemicals. The mixtures are classed as ECs if they can pose an ecological and human health risk (Kudłak *et al.*, 2015).

(f) A chemical can also be classified as ECs to discover a new pathway in human metabolism (Bunke and Moritz, 2014).

2.4.1 Classification of Emerging Contaminants

As mentioned earlier, there are many definitions of ECs. Therefore it is challenging to group them. However, some authors classed them regarding their uses. Pesticides, antimicrobial drugs, polycyclic aromatic hydrocarbons, flame retardants, personal care products, hormones, and their metabolites are ECs, (Lei *et al.*, 2015; Taheran *et al.*, 2018). Importantly, this list is dynamic; it may change with the development of new chemicals, a new detection method or a new risk threshold (maximum residual limit). This thesis focused on three ECs: pesticides, PAHs, and antimicrobial drugs. The study focused on these three because of their significance among the other ECs.

2.4.1.1 What are Pesticides?

Pesticides are chemicals or a mixture of substances intended to prevent, destroy, repel, or lessen any pest damage (Andersson and Isgren, 2021). Here, the pest may include organisms that compete with humans, insects, weeds, mammals, and fish that may spread disease. The common pesticides are insecticides, weedicides, fungicides and rodenticides. The less popular ones are swimming pool chemicals, plant growth regulators, defoliants, and surface disinfectants. They usually use public health (controlling mosquitoes) and the agricultural sector (pest control in plants and animals). In this thesis, the pesticides to be tested will include organochlorine, organophosphates and synthetic pyrenoids. Also, the research considered other pesticides broadly described as herbicides and commonly used in Ghana.

2.4.1.2 What are Polycyclic Aromatic Hydrocarbons?

Polycyclic aromatic hydrocarbons (PAHs) comprise many compounds (over 100) in the environment (Thompson and Darwish, 2019). They have two or more fused benzene rings and are ubiquitous. They are in the air (Adesina *et al.*, 2021), soil (Forján *et al.*, 2020) and water bodies (Omer, 2020). They are from the partial burning of several organic matters during natural or anthropogenic processes (Massone *et al.*, 2021). Soils are some of the natural sources of PAH, while automobile combustion, sludge, and oil spills are artificial sources. The ubiquitous nature of the PAHs suggests the need for continuous research in different matrices. Some PAHs are resistant to degradation and possess several toxic effects. Of the many known PAH, 16 can cause various health effects. The EU and the USA have classified them among the priority pollutants list. This study considered the 16 PAH priority list.

2.4.1.3 What are Antimicrobial Drugs

An antimicrobial drug is a chemical substance that prevents a disease-causing organism from infecting its host (Tufa, 2014). It may include antibiotics, antifungals and anti-protozoa. It is an essential antibacterial agent used to treat and prevent bacterial infections by killing or preventing organisms' growth. Several antimicrobial drugs also possess antiprotozoal activity. Antimicrobial contents can be against viruses such as the common cold or influenza drugs which inhibit viruses. There is extensive usage in animal production worldwide. Studies have reported antimicrobial use in several media (Bártíková *et al.*, 2015; Tufa, 2014), hence the need for continuous monitoring. The study considered some of the general antimicrobial agents of animal producers widely used in the country.

2.5 Policies and Strategies Towards the Management of EC

Around the globe, ECs appear not to have any strict regulations. However, there are attempts in the advanced continents (EU and North America) to make guidelines for producing these emerging contaminants. The lack of general guidelines is because of the limited information ECs, particularly the interaction between the ECs and their receptors and public health. The data scarcity accounts for the various government's failure to commit resources towards EC management. Pal *et al*. (2010) gave an overview of ECs' fate and transport in multiple systems and a risk-based analysis of EC's controls and complementary strategies. In another study, Naidu and Wong (2013) suggested integrating science and policy as the best regulation EC strategy in the environment. Therefore, a study needs to provide valuable compost data to facilitate policy formulation.

In proposing a policy framework for ECs, considerations must be for critical elements of EC; identification and prioritisation of ECs from various matrices; compost, soil, and food. Also, the safety, health, and environmental risk of ECs must be well evaluated in formulating policies on ECs in the environment. Available data must be well assessed and improved on the methodologies and techniques for analysing product ECs. The lack of regulation in a different world regarding EC reiterates the need for formal mechanisms and systems to exchange knowledge globally regarding policy formulation. Taheran *et al.* (2018) suggested the need for experts and a science-based coordinated approach towards EC management. Thus, the various stakeholder must play a crucial role in starting global policy and managing ECs worldwide. Several researchers believe government legislative intervention can help control this contamination (Naidu and Wong, 2013; Taheran *et al.*, 2018).

2.6 The Adverse Effect of Emerging Contaminants on the Environment

The continuous monitoring and evaluation of the adverse effects of ECs in environmental systems are essential. Bilal *et al.* (2019) assessed ECs in water bodies and the air, explicitly linking EC levels to their toxicity. Their analysis concluded that ECs from 1 to 10 mg/L are toxic, and more than 100 mg/L are lethal to organisms (plants and animals). Therefore, erythromycin and carbamazepine concentrations of more than 100mg/l were dangerous and threatened aquatic life (Bilal *et al.*, 2019).

A higher concentration of EC drugs affects microbial activity performance (Kudłak *et al.*, 2015). The content of these drugs also provides a path for producing anti-resistance bacteria and genes in the host organism. Also, ECs disturb the organism's endocrine system, mimicking and blocking the organism's pathways (Kudłak *et al.*, 2015). Plants can quickly absorb these drugs and transfer them into various organisms through the food chain (Pullagurala *et al*., 2018). Therefore, these accumulations disturb the food chain, causing abnormal estrogen ratios, thereby disturbing the organism's reproductive systems and functions.

2.7 Adverse Effect of Emerging Contaminants on Human Health

Many EC negatively impacts on health and safety of humans (Kudłak *et al*., 2015). These EC chemicals in the environmental system (air, water and soil) act as contaminants due to their unfavourable impact on human health, safety and the environment. ECs in systems (health, agriculture, farming) renders them readily available in concentration environmental systems that threaten human health (Ashbolt, 2004; Kudłak *et al.*, 2015; Pullagurala *et al*., 2018). The evidence suggests conscious attempts should be made to prevent uncontrolled, unregulated and illegal contaminants usage in various quarters

Emerging contaminants can harm host species, including cells, tissues and the whole system (Bilal *et al*., 2019; Kudłak *et al.*, 2015). For example, DDT has substantial acute toxicity to aquatic life, precisely benthos and zooplankton organisms. Other concerns with pesticide ECs are lung cancer and reproductive disorders (Michal *et al.*, 2018). The evidence suggests that there are probably other unidentified health effects of emerging contaminants.

Polycyclic aromatic hydrocarbons are another hazardous type of contaminant of potential concern. These contaminants' primary health issues are disrupting developmental functions and hypothalamic-pituitary-thyroid disorders (MDH, 2014). Most of them cause cancer and damage the liver (Massone *et al*., 2021; PHE Centre for Radiation, 2018). Many other PAH health issues are related to human reproductive dysfunction, breastfeeding effects, bad semen quality, and thyroid tissue complications (Jakovljević *et al*., 2020). Over the past few years, researchers have focused on investigating the mechanism of PAHs in environmental systems, but it is still inadequate.

Antimicrobial drugs are also of significant concern to humans (Tufa, 2014). In general, small quantities of these drugs are not hazardous to human health. However, continuous exposure to low doses of these drugs causes chronic toxic effects with the production of bacterial resistance organisms that affect human health (Suk *et al*., 2017). In recent days, excessive usage of antimicrobial drugs has caused accelerated growth and new resistant strains of bacteria. Humans spend billions of dollars developing new antimicrobial agents (WHO, 2018). Similarly, animal guts can absorb many of these drugs, yet, they excrete 30–90 % of the drugs through their faeces and urine. The waste can mix with water sources, thereby contaminating them.

2.8 Occurrence of Emerging Contaminants in the Environment

There have been several studies of emerging contaminants in various aquatic ecosystems. Niemuth and Klaper (2015); and Rathi *et al*. (2020) detected antiandrogenic, antiestrogenic, and antithyroid compounds with ultra-fluorescence. Others employed liquid chromatography and a mass spectrophotometer to measure selected ECs I environmental concentrations (Djouaka *et al*., 2018; Zhou *et al*., 2020). Others also used gas chromatography-mass spectrophotometers (Forján *et al*., 2020; Wlodarczyk-Makula, 2005). Therefore, there is a need to consider the appropriate equipment to identify and quantify these contaminants.

Sun *et al*. (2016) found several ECs and their metabolites in Jiulong River's estuaries during various seasons in China's southern part. They showed an extensive range of ECs (34) in the River estuaries; some contaminants included pesticides, PAHs and antibiotics. They reported significant variation in the detected contaminants' spatial and seasonal distributions. The myriads of emerging contaminants indicated a non-conservative behaviour in the estuary. Further, they compared their ECs to the discharge from a waste treatment plant. It showed a significantly higher ratio than the average value in the treatment plant, indicating the continuous release of untreated household waste into the river estuaries. The study also observed a higher level of bisphenol and pharmaceutical and personnel care products and concluded the possibility of untreated industrial waste in the river. Other waste treatment facilities, like composting systems, may also contain ECs.

The presence and metabolites of some ECs in the water system have received some attention from the Taiwanese EPA (Lei *et al*., 2015). The study targeted two rivers in different geographical regions in Taiwan, the Tamsui River in the north and the Donggang River in the south, to investigate ECs occurrences and their metabolites. It focused on pharmaceutical residues in surface and groundwater, commercial waste treatment plants, health care facilities and animal farms. In General, most of the EC were from the discharges from the treatment plants of municipal wastewater treatment plants and hospitals.

Evidence suggests ECs may be in areas with little human interaction. Zhang *et al*. (2017) reported various contaminants in Antarctica even though it is assumed to be a safe area. A study at the South Pole detected different ECs and their metabolites in seawater and penguin faeces samples (Huang *et al*., 2018). The detected contaminants included some antimicrobial drugs. The study compared the island seawater samples' results from the penguin tank in the National Museum of Marine Biology and an Aquarium. Comparatively higher drug levels were in the seawater sample of the Museum than on the island. Pesticides and their metabolites were also on the island. Therefore, they concluded that human activities on the island are responsible for the contaminants' presence.

2.9 Removal and Treatment Technologies of Emerging Contaminants

Numerous studies have attempted to develop technologies for removing and treating ECs from the environment. These attempts are because removing ECs from diverse matrices is imperative for individuals' health and safety. Biodegradation is perhaps the best ecosystem approach for removing contaminants from the environment. The contaminant's Kinetic constant explains and determines the biodegradation rate. Studies show that biodegrading the detected ECs was challenging (Kudłak *et al.*, 2015). The degradation difficulty was due to their high biodegradation constant. Contrarily, tetracycline and carbamazepine have low biodegradation constants, thus, are easy to degrade.

Studies have attempted to enhance the biodegradation of persistent pharmaceutical ECs over the years. The measures include fungi, oxidoreductase enzymes and nitrifying organisms (Zhang *et al.*, 2017). However, the process is complicated, with several challenges due to the factors influencing biodegradation. These factors may be biotic and abiotic. These factors include temperature, pH redox potential, contaminants availability and toxicity, molecular features, microbial diversity, physicochemical properties, and primary substrates that play a vital role in the overall degradation of hazardous contaminants (Bilal *et al.*, 2019; Rathi *et al.*, 2020). The biodegradation of ECs goes into metabolite or co-metabolite based on the contaminants' nature (Rathi *et al.*, 2020).

Therefore, the degradation of chemicals cannot be generalised, but it depends on the contaminant type.

In a study, Bilal *et al.* (2019) found that Pseudomonas *sp.* can transform estradiol with its metabolic activities. Similarly, enriched estradiol degrading bacterial culture can degrade estradiol using carbon for energy production (Bilal *et al.*, 2019). Interestingly some antimicrobial agents, particularly antibiotics, resist microbial growth and are hard to biodegrade. Therefore, they sometimes need salts (ammonium and carbonate salts) to sustain and activate enzymes' degradation. Heterotrophic and autotrophic bacteria are the primary organism involved in the biodegradation of ECs. Another group are the ammonium oxidising archaea microorganism.

Ammonium oxidising autotrophic bacteria, amongst others, are vital in the degradation of many ECs. These are crucial in the biodegradation of, i.e., trimethoprim. Utilising an anaerobic membrane eliminated some EC from the environment. However, some are difficult to remove with the anaerobic process using traditional and ordinary means. Like oestrogens, removing these ECs by conventional activated sludge treatment up to 92 % and 80 % by oxidation process is possible (Michal *et al.*, 2018). Despite the dangerous nature of emerging contaminants, a high removal rate is probable.

Financial viability is critical in designing methods for removing ECs from the environment. Some contaminants can persist in the environmental systems and require extensive expulsion methods, such as the advanced oxidation method (Haritash and Kaushik, 2009). However, these processes are not financially sound. Hence the need to identify a strategy that will effectively and efficiently address ECs, particularly in resource-poor nations.

Studies on the removal of ECs by Dantas and Dantas (2005) attempted to eliminate EC using ozonation from wastewater and inferred that the wastewater qualities affected the effectiveness and efficiency. This study was at different pH values (pH 6.0 and 7.5) and temperatures (10 - 30°C). There was a positive relationship between the rate constants of direct reaction and initiation as pH increases. In contrast, the promotion and inhibition rate constant did not show any critical change with increasing temperature, suggesting the complication associated with the degradation of these contaminants.

Chen *et al*. (2015) examined sulphonamide antibiotics' degradation in sludge with a diverse microbial community. They evaluated the biodegradation of EC (sulfamethoxazole and sulfamethazine). The study found a relationship between contaminants and sewage sludge compost microbial communities and observed the degradation of sulfamethoxazole by mushroom compost and its concentrates. Sulphonamide degradation was highest in sludge and mixtures, followed by sulfamethazine. The bioreactor investigation uncovered that the percentage of sulfonamide removal rates in sludge with mushroom compost was more satisfactory than in sludge alone.

Deemter *et al.* (2021) demonstrated the potential photodegradation of some ECs. The study was on salt's effect on the photodegradation of various EC from various waste treatment streams. They observed that Solar – photon - Fenton could degrade EC to lower concentration and residual levels. The pH of the media also affected degradation. Sturini *et al.* (2012) also observed the photodegradation of EC in the presence of a catalyst (TiO_2).

The study was in a laboratory reactor and reported a 90 % degradation rate with titanium dioxide. The study, therefore, concluded the photodegradation of EC with the catalysts was two to three times higher without it and was beneficial and comparable to other methods. Probably other factors may be crucial in ECs degradation.

2.10 Fate Processes of Emerging Contaminants in the Environment

The transportation and fate of contaminants describe the physical, chemical, and biological processes that affect how a particular contaminant moves from its point source to another location within the environment. The contaminant changes would undergo transportation from one point to another (Lalander *et al.*, 2016) and the transport is affected by several processes (Amir and Hafidi, 2005; Bártíková *et al.*, 2015). These processes determine an ECs persistence, movement, if any, and ultimate fate. Physical processes move contaminants through the environmental media, whereas chemical and biological contributions redistribute pollutants in diverse media and chemical forms (Lalander *et al.*, 2016).

Bilal *et al*. (2019) note that emerging micro-pollutants and pharmaceutical contaminants are highly stable and largely non-biodegradable. Hence, they persist and are widely distributed away from their sources. A study estimated that nearly 90% of all pharmaceutically active compounds enter the environment through releases from wastewater treatment facilities due to ineffective treatment (Bilal *et al*., 2019). The fate processes can be positive and negative relative to EC(s) effectiveness and their environmental impact. For example, pesticides may negatively impact the target and its immediate surroundings due to potentially harmful residues. Sometimes they can be detrimental, leading to reduced target pests, injury of non-target plants and animals and environmental damage.

Gogoi *et al*. (2018) reported that the water treatment facilities/plants were ineffective in removing ECs from the environment because of the limited EC removal efficacy and treatment techniques. Similarly, Snow *et al*. (2020), in an extensive review of ECs in agricultural settings, showed that a lack of wastewater treatment facilities coupled with dense populations positively correlated with high levels of ECs in rivers. They also concluded that human and antimicrobial pharmaceuticals are emergent contaminants in agricultural environments, including surface waters.

Today, particular interest is contaminant movement to water bodies, particularly groundwater and the increased bioaccumulation into the food chain (Rather *et al*., 2017). However, different soil characteristics (pH, clay, sand, organic matter, among others.), contaminants' physical and chemical properties characteristics (water solubility, soil adoption properties, persistence and resistance to degradation, etc.), climatic factors, application methods and different handling practices of pesticides, for instance, can promote or prevent each process (Braschi *et al*., 2011). With these critical properties, it is vital to understand the process that affects the degradation of pesticides. Therefore this study will consider the effect of compost on the degradation of these contaminants.

Understanding the fate processes of these contaminants will ensure proper risk management and application process to ensure a safe pesticide environment. In environmental samples, three effective methods are responsible for the fate and transformation of contaminants; these include ECs (e.g. human excretions of drugs in several of their metabolite forms), microbial transformation/degradation and physicochemical processes (Petrie *et al*., 2015). Among the factors are four major processes that serve as controls on the transportation and distribution (fate) of contaminants such as pesticides in the environment include (Wireman, 2012):

- Physical and chemical characteristics of earth materials, including organic matter and carbon content, cation exchangeability and pore and permeability
- Flow hydraulics, such as the velocity of groundwater (advection) system
- Nature of the contaminant in terms of its ability to easily dissolve in medium -(solubility) and vapour pressure, the Henry's Law Constant, viscosity.
- The natural processes that remove or degrade the environment's contaminants include advection, dispersion, and partitioning. The other process consists of sorption and biotic and abiotic transformations.

The uptake and translocation of various ECs by plant uptake are severe environmental and human health issues, particularly food safety. A study predicted the sorption equilibrium and uptake kinetics of different ECs in some common vegetables (leafy rape, Chinese mustard, lettuce and Chinese cabbage) (Thompson and Darwish, 2019). The study built a prediction model and concluded that vegetables with high lipid content took a high level of contaminants. As the type of vegetable is of concern in EC uptake, studies must target different crops in different regions.

2.11 Potential Sources of Emerging Contaminants in Compost

A comprehensive list of ECs categorised as Pharmaceuticals and Personal Care Products (PPCPs) and Industrial chemicals (e.g., fire retardants) has been provided by (Antunes et al., 2021). Waste Water Treatment Plants (WWTPs) remain an essential source of ECs to the soil, groundwater, and sea through the release into surface waters, primarily due to the inability to treat the low concentrations in wastewater. Emerging contaminants (ECs) are also present in kitchen wastewater, in varying degrees of complexity (Tang et al., 2022) and drinking water (Rempel et al., 2021). A study of the Yangtze identified 70 ECs, consisting mainly of pharmaceutical and personal care products and pesticides, in the surface waters of drinking water sources along the River's lower reaches (Tang et al., 2022). ECs, largely pharmaceuticals, endocrine-disrupting chemicals, personal care products, pesticides, and microplastics, have been found in Africa's conventional and unconventional water resources (Shehu et al., 2022). Disparities exist in the levels of ECs existing in rural and urban sources. For example, (Ozaki et al., 2017) found that urban sludge had higher concentrations of ECs such as PAHs, fragrance compounds, and triclosan, hence responsible for high levels in the resultant compost. Among the ECs, antibiotics are of special concern as they are important in the development of antibiotic-resistant bacteria, pesticides and endocrine disrupters are equally crucial as only a little is currently known about the potential toxicity and chronic effects (Antunes et al., 2021).

2.12 Removal of ECs in Compost

Conventional treatments and natural attenuation are reportedly limited in EC removal (Antunes et al., 2021; Chang et al., 2018). An extensive review of the state of technology for removing ECs from the environment concluded that adsorption is a potential technology for removing a wide range of contaminants of emerging concern (Antunes et al., 2021). In a study by (Šašek et al., 2003), 20–60% (54 days) and 37–80% (100 days of maturation) PAH removal rates were achieved using mushroom compost-assisted bioremediation in a thermally-insulated composting chamber. (Chang et al., 2018) obtained the highest bioremediation potentials using the mushroom *Pleurotus eryngii* in a spent mushroom compost (SMC) (mycoremediation) experiment to remove acetaminophen and sulfonamides from wastewater. The advantages of composting as a bio-remediation include, among others, operational ease and the ability to handle higher concentrations; for example, (Lin et al., 2022) documented that compost could remediate 26,315 mg kg−a of diesel from the initial composting material after 24 days, achieving more than 90% removal rates (Lin et al., 2022).

(Tang et al., 2022) noted that the alkali-modified biochar can be of significant application for eliminating ECs from complex kitchen waste systems with high organic contents. ECs such as bisphenol A tetracycline and ofloxacin were removed from a kitchen waste system with modified akali biochar. They achieved a removal rate of 95% of targeted ECs. Dynamic adsorption capacities for BPA and OFL were 55 and 45mg/g. This figure represents 75% and 83% of the static saturated adsorption capacities using a fixed-bed column alkali-modified biochar. The adsorption of TC and OFL was significantly affected by the initial pH values of kitchen waste. Environmental factors (COD, NH4 + and PO4 3−) had no significant effects on the adsorption of the contaminants (Tang et al., 2022). In the removal of triclosan (TCS) in soils amended with different three differently sourced composting stocks, it was found that compost addition significantly enhanced TCs removal and in the order of effectiveness in the order food waste compost (FS) > cow dung compost (CS) > sludge compost (SS), respectively with 20% (w/w) dosage being the most efficient with TCs concentration reductions of 76.67%, 67.90% and 56.79% respectively (Dang et al., 2022).

(Lin et al., 2022) reviewed the literature and noted that the robustness, low cost, and easy operation of composting as a bioremediation technology presents an attractive strategy for removing organic contaminants such as total petroleum hydrocarbons, plasticisers, and persistent organic pollutants (POPs) from soils and sediment. Researchers argued that many traditional EC removal techniques remain expensive and difficult to manage. They proposed optical fibre microfluidic coupled sensors as the potential and logical device for screening and identifying environmental contaminants because of their advantages, including increased measurement reliability (Yuan et al., 2023).

2.13 Uptake and Translocation of Emerging Contaminants

Studies have researched the active transport of nutrients and contaminants across plants (Gworek *et al.*, 2016; Pullagurala *et al.*, 2018; Suk *et al.*, 2017). Others have studied contaminants' transport in various environmental systems, like aquatic soil, sediments, and air (Kudłak *et al.*, 2015; Niemuth and Klaper, 2015; Teheran *et al.* (2018). Hence, there could be other studies targeted at ECs uptake using soil amendments. Over the years, plants have evolved extensive root tissue to move nutrients and water efficiently and effectively. The roots must be permeable to solutes of interest to allow them to move nutrients from the soil even in the scarce environment. These allow several pollutants to enter the root. Other factors are crucial in determining the uptake of chemicals by plants.

Contaminant's (ECs) physicochemical properties play a vital role in the overall uptake of these contaminants from the media plant (soil, air or water) and the subsequent transport to the plant system. This property is because some of the ECs are chemically more stable than others. Some of these ECS may remain in their original state during the uptake overall uptake process. An important consideration is the transpiration stream concentration factor (TSCF). This factor is the ratio of EC content in the transpiration stream to the residual contaminant content found in an external media (Coleman *et al*., 1997). Therefore, this factor plays a crucial role in the uptake and translocation of substances. The equation for the TSCF is below (Eq. 2.1).

$$\text{TSCF} = \frac{C_{\text{Shoot}}}{C_{\text{Media}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 2.1}$$

Where:

C_{Shoot} is the aqueous chemical concentration in the plant shoot xylem

C_{Media} is the aqueous chemical concentration in the growing medium

The TSCF is crucial in determining the EC's uptake and translocation of the external media (soil, water, among others) to the plant's xylem. The TSCF depends on the nature and the bioavailability of the compound. Li *et al*. (2019) proved that EC, which is more hydrophilic, has a higher TSCF than relatively hydrophobic neutral compounds in vegetable plants. The difference observed indicated that hydrophilic-based EC can move through the Casparian strip of plants and translocate to the leaves and branches faster than more hydrophobic contaminants (Li *et al*., 2019).

Plants contain several enzymes, including glutathione, carboxylesterases, cytochromes P450, N-malonyltransferases and transferases. Plants can absorb and translocate these ECs with the help of these enzyme-based metabolisms. Some of these ECs are lipophilic and can be taken up and translocated across the plant. After the initial uptake, enzyme-based chemical reactions of contaminants occur in three phases (I, II, III) (Coleman *et al*., 1997).

Phase I involves a reaction between the absorbed contaminants' reactive functional groups leading to the contaminants' hydrolysis. Also, in phase I, there is a redox conversion of pollutants into the appropriate metabolites. In phase II, a transformation between the metabolites through a conjugation using amino acids glutathione or sugars. Finally, in phase III, untransformed metabolites are stored in vacuoles or incorporated into cellulose cell walls. Unlike animals, plants do not generally have an excretory system. Therefore, these three phases play a critical role in detoxifying the various metabolites (Coleman *et al*., 1997).

2.13.1 Uptake of Pesticides

The presence of pesticide residue in plant food is of significant concern. A study reported chlordecone, an organochlorine compound in radish pith (Létondor *et al.*, 2015). Another study showed the potential translocation of DDT and their metabolites by various vegetables through the roots (Lorenz and Lal, 2016), but the percentage uptake was a level of 0.1 %. The uptake was due to active absorption and passive adsorption. Also, Létondor *et al.* (2015) reported chlordecone uptake and translocation in many plants and vegetables. Similar uptakes of chlorpyrifos have been reported in the Chinese cabbage (*Brassica* rapa), cabbage and other vegetables (Tereza Horská *et al.*, 2020; FAO and WHO, 2019). These studies demonstrate the ability of different crops to uptake and translocate pesticides,

A trumpet flower (*Tacoma stans*) study revealed the uptake and translocation of organic contaminants in various plant parts (Reis *et al.*, 2015). Myriads of factors are known to impact these pesticides' uptake and potential translocation. For instance, plants grown in outdoor conditions take up less than those under controlled environments. The less uptake in outdoor conditions could be due to the photodegradation of the pesticide compounds and soil dispersion (Pullagurala *et al.*, 2018)

Also, the uptake of pesticides is plant-specific. Chlordecone uptake was higher in zucchini and pumpkin than in cucumber plants (Létondor *et al*., 2015). Pesticide uptake harms plant's growth and development. For example, 1.0 ppm of chlorpyrifos had significant inhibitory effects overall growth and development of Chinese cabbage (Zhou *et al*., 2020). Overall, pesticide pollutants' major threat would be the foliar's application rather than soil irrigation or soil-based additions.

2.13.2 Uptake of Polycyclic aromatic Hydrocarbons

The uptake of PAH residue is of concern to scientists. PAH compounds reported alfalfa plants' roots and shoots (*Medicago sativa L*.) with fluorescence microscopy (Pullagurala *et al*., 2018). The above study proved the potential of PAH to be taken and translocated inside plant tissues. Other studies confirmed PAH uptake, translocation, and eventual bioaccumulation in rice plants (Zhang *et al*., 2017) and palm trees (Adieze *et al*., 2015). However, studies suggest only an insignificant percentage of PAHs are taken and eventually bioaccumulated in plants, below 2 %. Several factors affect PAH uptake (Pullagurala *et al*., 2018).

Studies have shown that various PAH compounds can be taken and bioaccumulated in several plants' parts (Pullagurala *et al*., 2018; Zhu *et al*., 2018). Wang *et al*. (2018) found many PAH compounds in Chinese cabbage using a gas spectrometry mass spectrometer. The above study proved the PAH's ability to bioaccumulate in plants. Zhu *et al*. (2018) demonstrated the uptake and bioaccumulation of PAHs compounds in the maize plant. Most of the PAHs determined in the plant could come from soil particles adhered to the root surfaces, while the transpiration stream flux would drive the subsequent translocation from the root to the shoot. However, other studies indicate that a carrier system mediates phenanthrene uptake by wheat plants (*Triticum sp*.) (Zhu *et al*., 2018).

Despite the potential for uptake by plants, the literature suggests that plant uptake constitutes only a small percentage leaving the majority in the environment (< 2 %) of PAHs (Pullagurala *et al*., 2018). Several factors account for the uptake of a particular polycyclic aromatic hydrocarbon.

The molecular weight of PAH influences its uptake from the soil. It is crucial to point out that the lower molecular weight (LMW) PAHs; 2–3 are more likely to be taken up and translocated than PAHs with medium and higher molecular weights (Capozzi *et al*., 2021; Gworek *et al*., 2016). Probably there is the retention of HMW PAHs in the roots and soil. However, the potential absorption of LMW and volatile PAHs absorption from the air through leaves' stomata is also possible. The type of plant (monocots or dicots) is another factor influencing PAH uptake. These PAHs have been detected in both the root and aerial parts of monocots while in only the roots of dicotyledons (Gworek *et al*., 2016).

There appears to be a relation between the lipid content and the potential bioaccumulation and translocation of the PAHs in plant tissues. A study showed a strong association between PAHs' bioaccumulation in maize plants and lipid content; it is directly proportional to the lipid content in the tissues of the plants (Wang *et al*., 2018). They concluded that since PAHs are lipid-soluble, they bind to the fat content, facilitating free movement within the cell. Therefore, plants with high lipid content are more likely to uptake and translocate PAH than those with lower lipid content. Therefore, the type of vegetable may be crucial in the uptake and translocation of a particular contaminant.

2.13.3 Uptake of Antimicrobial Drugs

Antimicrobial drugs may enter the environment due to animal usage, industrial discharges and improper disposal. Based on their therapeutic use, a study has classified the following: analgesics, antibiotics or antimicrobials. Other classifications include cytostatics anticonvulsants, antihistamines, antidepressants and beta-blockers. Various published works have detected antimicrobial drugs in environmental samples (Chen *et al.*, 2017; Suk *et al.*, 2017; WHO, 2018) and may pose a risk to humans and the environment because of their continuous release (Bilal *et al.*, 2019; Kudłak *et al.*, 2015; Lei *et al.*, 2015).

There is an association between the type of plant and the potential bioaccumulation and translocation of the residue. A study showed drugs' bioaccumulation in *Brassica sp* and *Ipomoea sp* (Chen *et al.*, 2017). The concentration in the leaves and stem were much higher. The plants' part also depends on the bioaccumulation rate as the lower side accumulated more than the stem and the leaves. Also, the concentration of the residue in the root was much higher than in the media. Chen *et al.* (2017) attributed this property to the drug's ability to activate the transport process.

Studies suggest different plants' potential uptake of ECs (Keerthanan *et al.*, 2021; Pullagurala *et al.*, 2018). The evidence suggests emerging contaminants affect the environment. These chemicals have the potential to affect the many facets of production. It can affect compost production and subsequently impact the usage and adoption of compost worldwide.

2.14 Composting

Composting is an adopted technology that involves the bio decomposition of different organic matter in a controlled and purposeful manner with the help of microorganisms. Composting aims to convert more extensive organic materials into a biologically functional and safe product, referred to as 'compost' with the help of a diverse microbial community (Muscolo *et al.*, 2018). Other products from the composting include carbon dioxide (mainly), heat, and water. Therefore, composting is an ecosystem-based approach for managing waste and soils by mimicking the mulching of organic matter over time. Chemically composting can be represented below (Fig. 2.2).

Composting comprises two main stages; decomposing and curing (Desiraju, 2015; Zheng *et al.*, 2020). The first phase is called high-rate composting because of the intense decomposition of bulk organic matter into smoother compounds. This phase results in the release of extreme heat. During the latter stage, the product is "cured, and the process is associated with a much slower decomposition. This depletion of the microorganisms can slow activities at this stage.

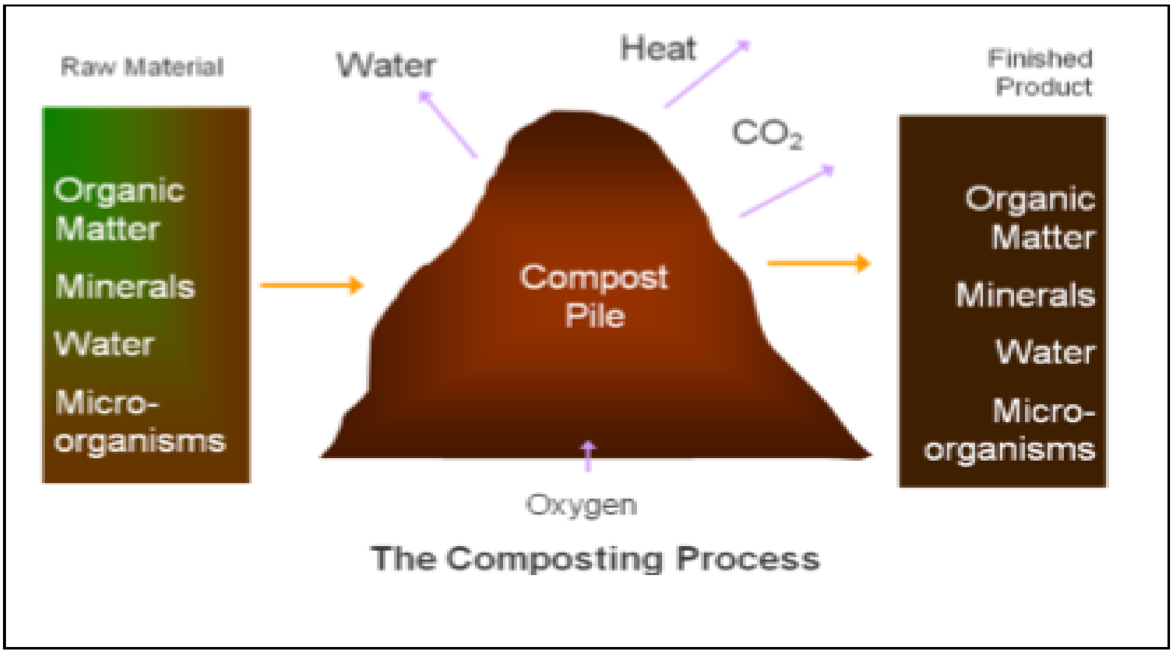

Fig 2.2: The composting process

Fig 2.2 displays the composting process where there is the convention of raw organic matter into the finished product (compost) with the help of oxygen and the release of water, carbon dioxide and heat.

The exact history of waste management and composting is problematic to trace. Chinese records date to over 5000 years ago (Zheng *et al*., 2020). However, with Sir Albert Howard, the modern-day composting of organic matter started in 1934. He is considered the father of modern-day composting and compost use, with his work being the first attempt to document the composting process principles (Desiraju, 2015; Zheng *et al*., 2020). With the help of others, Sir Howard developed the famous "Indore Process" in 1934. In 1939, the Bangalore Process was created, followed by the Dano composting type (Zheng *et al*., 2020); with this system, the composting material was placed in a stabiliser for proper temperature control. In 1987, T. van Maanen used composting as an ecosystem-based approach to recycling. The various accounts suggest composting has not been static and appears to change with time. Therefore, there is a need to improve the composting process to solve waste and soil management issues.

2.15 Municipal Waste Generation and Management: Justification for Compost Use

The global population is over seven billion, with a growth rate of 1.1% per year and an expected rise to over eight billion by 2025 and more than nine billion by 2050 (United Nations, 2019). From this point and coupled with the associated industrialisation, waste management (WM) presents a critical challenge for the world (De Feo *et al.*, 2019; Mishra, 2020; Stoeva and Alriksson, 2017). Regarding municipal solid waste (MSW), there are significant increases in the volumes across nations, and management is a critical and topical environmental issue. Solid WM is particularly worrying, and the evidence suggests that the generation trend will increase with time, hence the need to find ways to address them.

In 2012, Africa generated about 125 million tonnes of MSW (Bhada-Tata, 2012). The figure is estimated to double (244 billion tonnes) by 2025. The average waste per person will increase to 0.85kg/capita/day in 2025 from 0.78kg/capita/day (Hoornweg and Bhada-Tata, 2012). Of the total waste generated on the African continent, sub-Saharan countries generate 65 % (81 million tonnes). Again, the average waste in sub-Saharan Africa is 0.65kg/capita/day, ranging from 0.09 kg/capita/day to 3.00kg/capita/day (Scarlat *et al.*, 2015). Significant differences exist in Africa, and sub-Saharan nations' total waste, with countries like Ghana recording lower rates (Waste Outlook, 2018).

Ghana generates about three (3) million tonnes of MSW annually, consisting of 67 % organic components and 0.5kg/person/day (Miezah *et al.*, 2015). The organic fraction of the waste is the highest (67 %) in Ghana, with the remaining (plastic, leather, metals) being inorganic (Miezah *et al.*, 2015). As 67 % of the waste is organic, it is reasonable to suggest that proper organic WM will solve many challenges. Also, with the sizeable organic element of the waste stream in Ghana, composting can be an essential element of the WM system.

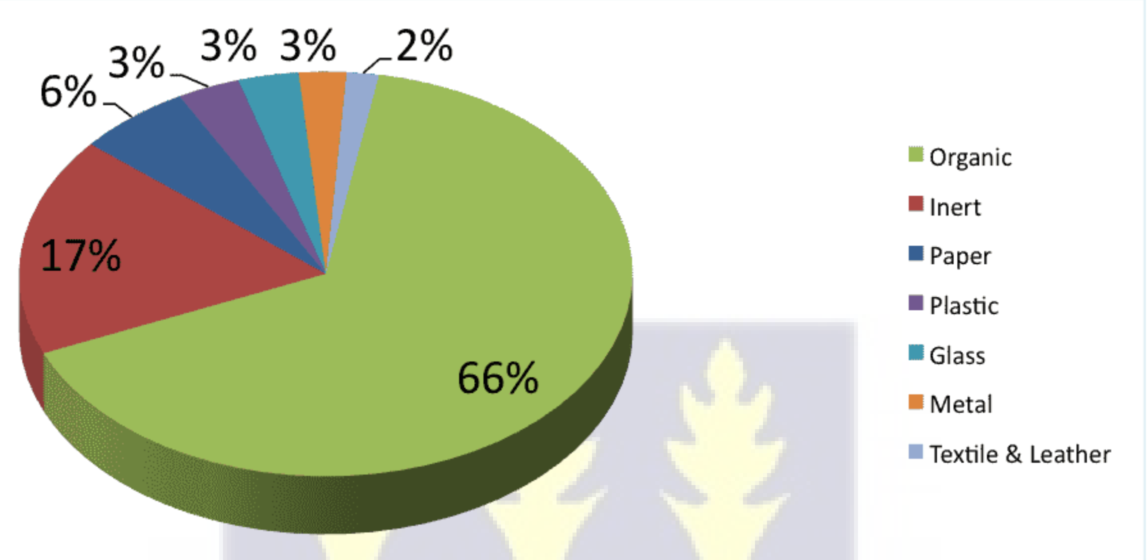

Fig. 2.3 The waste composition in Ghana

The figure shows the various solid waste generated in Ghana, with organic being the highest. The other waste includes plastic, leather, metals, among others.

Although the total MSW generated in the country is low and biodegradable, effective and efficient management has been critical. Reasons responsible for the inadequate WM in Ghana include a) lack of political will, b) weak institutional and financial challenges, c) infrastructural challenges, d) human capacity challenges, and e) lack of proper education. However, the attitudes and behaviours of the citizenry towards the environment are the underlying reasons for inadequate WM issues in Ghana (Cobbinah *et al.*, 2017)

The typical Ghanaian is irresponsible toward the environment and WM. Most people litter their surroundings even when waste bins are provided, expecting another individual to be responsible for collection. The individual frequently puts the responsibility of WM on the local government. Local governments also expect the central government to deliver them from WM issues. Strangely, the national government then expects aid from foreign donors to solve the nation's WM challenges (Cobbinah *et al.*, 2017). Hence, nobody appears to take responsibility for managing waste (Amoah and Kosoe, 2014). However, there is a whole ministry responsible for WM.

Improper and unsustainable waste practices have greatly affected the country's environment. The challenge has resulted in many public health and environmental impacts, including flooding and the outbreak of diarrhoeal diseases, which contribute to the loss of lives and properties (Amoah and Kosoe, 2014). The infamous and annual deadly floods in Ghana (Fig.1) are due to human negligence on WM (Cobbinah *et al.*, 2017). These challenges have placed a lot of financial burden on the government as it responds to them. In light of this, WM is considered one of Ghana's most topical environmental challenges and needs improvement. The promotion of compost may help solve these issues.

2.16 Nutrients and Soil Organic Carbon Management: Justification for Compost Use

Globally, soil management is another topical and growing issue that presents many environmental problems. These related soil challenges include loss of fertility, soil degradation, desertification, and erosion, as these constraints are from the sharp decline in soil organic matter (SOM) content. The SOM is the organic portion of the soil, consisting of the biodegradable component at various stages of decomposition. An estimated 33 % of agricultural lands worldwide have low SOM content (Pennock, 2017). The organic carbon in the SOM is the soil organic carbon (SOC), which plays a crucial role in soil management (Muvvala and Subbaraya, 2020; Nwakwasi *et al.*, 2019).

There is a strong association between the SOC and its strength to deliver its ecosystem functions to support sustainable agriculture. Overall the SOC is a good indicator of the soil's health due to its role in forming soil structure, water-holding capacity, control of greenhouse gases, and the land's ability to degrade organic matter (Mu *et al*., 2014; Maher *et al*., 2020). Global studies also suggest that low SOC contents make soils more susceptible to climate and variability changes and prone to drought, erosion, and flooding (FAO, 2017). A higher (more than 2 %) SOC is ideal for maintaining a good soil structure for sustainable agriculture, with several factors accounting for the levels (FAO, 2017).

In general, the natural vegetation's continuous clearing for agricultural purposes leads to a sharp decline in SOC levels. Irrigation, land preparation, various farming practices, and other human activities significantly affect SOC levels (Chiti *et al.*, 2016). The temperature, rainfall pattern and soil type of location are also critical determinants of SOC levels. There is a close association between the soil textures, bulk density, microbial activity, and soil organic carbons. Due to different climatic conditions, anthropogenic factors and historical soil management, there are significant variations in SOCs and organic matter levels in specific locations.

According to Hoffmann et al. (2014) and Shelukindo et al. (2014), the soil organic matter and SOC are higher in colder climatic regions than in warmer zones. Therefore the levels of SOC in Africa are low due to the warmer climatic conditions. Also, farming practices in Africa, particularly sub-Saharan, usually involve inadequate farm equipment (hoes, axe, etc.), and continuous cropping on the same land leads to SOC depletion. Agricultural practices in sub-Saharan Africa, such as reduced or no-tillage land, also decrease the SOC and organic matter levels.

The SOC in Ghana is low (Owusu *et al.*, 2020). The contributing factors include the annual bush burning as part of land preparation and hunting. Other factors include illegal, uncontrolled, and unregulated livestock movement in the dry season, particularly in grassland ecological zones, and climate are critical considerations for low SOC. Higher mean annual rainfall comes with lower mean temperature and higher mean SOC concentration in Ghana (Owusu *et al.*, 2020).

The present low SOC levels have resulted in many farmers adopting alternative means of providing nutrients for the soil. The farmers mainly rely on imported fertilisers, which are expensive and environmentally destructive. Inorganic fertilisers' low carbon content meant that farmers tended to over-fertilise the land to avoid low yield due to a lack of nutrients. The long-term and excessive dependence on inorganic fertilisers lead to greater weed competition and pest attacks while the excess nitrogen pollutes the land and water bodies. With the challenges mentioned above, SOC is an environmental issue that needs much attention. An ecosystem-based approach like compost use may potentially address these concerns.

2.17 The Importance of Compost

2.17.1 Carbon Sequestration

Compost addition to soils can improve carbon sequestration (Jcu, 2017; Mishra *et al.*, 2014). It is the primary means of eliminating carbon from the atmosphere, thereby reducing CO_2 emissions. The reduction of CO_2 has a positive impact on “Global Warming." Various studies observed that time is crucial when assessing carbon sequestration's value and global warming's role (Gondek *et al*., 2020; Komakech, 2014). A 100-year time frame is essential for estimating carbon sequestration contributions to global warming (Mishra *et al.*, 2014). Significant differences are in the values recorded for carbon retained in the soil. The variability is due to the synergy between the numerous environmental and location-specific factors. These observations imply estimates should not be generalised but should be specific.

2.17.2 The Suppression of Pest and Diseases

The addition of compost can reduce or eliminate the application of pesticides. This advantage is because the application decreases pest occurrence, including weeds and diseases (Akhtar and Ansari, 2020). Therefore, the prevented use of pesticides can serve as an environmental saving. Nevertheless, while there has been considerable resistance to certain diseases in most cases, the benefits are so complicated that it is impossible to generalise the number of saved pesticides. Assessing pesticides' environmental and health risk impact is complex, requiring exposure–fate–toxicological models. The complexity is because dynamic and realistic models are rare and usually need comprehensive data, which is difficult to obtain (Nigam *et al.*, 2016).

2.17.3 Crop Yield

From the life cycle assessment point, the application of compost can affect agricultural production systems. Compost application to soil is associated with an increased crop yield (Adugna, 2016; Tomocsik *et al*., 2016). The production is also dependent on the existing challenges in a location. If arable land is easily accessible in a given area, there is the prevention of a net gain in crop yield. If the sites are restricted, the increase in output will affect the expansion of crop production. The situation will eventually impact indirect land-use changes.

2.17.4 Prevents Soil Erosion

Erosion prevention avoids the loss of arable lands. First, soil-avoidable losses within a particular location can be modelled and then classify crops' failure through diminished arable lands. Also, soil can be considered a resource with the effect of erosion. (Manirakiza *et al*. (2021) discussed the impacts of erosion on crops' productivity and C's loss based on the soil carbon content. Various studies suggested minimising soil erosion using compost on soils (Sayara *et al*., 2020). Other studies examined the effects of erosion on soil compost (Risse *et al*., 2013) and compost's effect on agricultural production systems (Sayara *et al*., 2020).

2.17.5 Soil Moisture Content

A possible advantage of the compost addition to land is enhancing the soil's ability to maintain green water, rainfall and irrigation water (Kanat and Erguven, 2020). This water can be trapped in the soil, minimising blue water (ground and surface). There is, therefore, the saving of groundwater and surface water in areas with no proper irrigation system. The overall effect can lead to an improvement in crop yield. However, the quantity of water withheld depends on numerous factors, including the condition of crops. There has been a comprehensive review of farming methods, crop production, and freshwater applicability indicators in farming in compost application (Komakech, 2014).

2.17.6 Soil Workability

Compost addition to soils can improve the soil's overall workability (Kelley *et al.*, 2020; Mensah and Frimpong, 2018). Improved workability is likely to minimise the energy requirements of agricultural production systems. A study focused on fuel consumption patterns in the agricultural production system and compost application. If there is reduced consumption from compost application, it would positively impact global warming (Agegnehu *et al.*, 2015). Also, avoiding nitrogen oxide combustion emissions affects acid water, eutrophication, and other harmful environmental factors.

2.17.7 Soil Biodiversity

The effect of compost addition on the microbial diversity of the soil is an interesting one (Kelley *et al.*, 2020). This biodiversity change can be positive or negative in delivering essential ecosystem services. These services include water recycling and nutrient recycling. Studies can model the linkages between changes in ecosystem service and soil biodiversity. However, data linking compost use, biodiversity, and ecosystem services are scarce. The scarce data is because land management practices depend on regional and site location factors. Adugna (2016) have established some baseline biodiversity indices for different microorganism under different soil conditions. There is a need for quality data to support the impact of compost on soil microbial diversity.

2.17.8 Nutritional Crop Quality

Crops' nutritional value can be affected by composting the soil (Tomocsik *et al.*, 2016). A study on yield showed a general increase in phosphorus and potassium content was higher in soils with compost (Ameziane *et al.*, 2020). In general, compost addition has other qualitative aspects regarding the nutrient content of crops. This effect would impact food production systems around the world. If compost adoption increases, crops' nutritional content will positively affect crops' nutritional content (Agegnehu *et al.*, 2015). Also, avoided compost addition will negatively affect the quality of produce.

2.18 Factors Affecting the Composting Process

Several factors influence the efficiency and effectiveness of composting. Several factors include the quantity of heat (temperature), pH, and air availability (aeration). The other related to the feedstock have moisture content, carbon/nitrogen ratio, particle size, and compaction.

2.18.1 Heat Content During Composting

There is the generation of heat during composting. The heat generated during composting is crucial in the final compost because it determines the microorganism's survival (Swami, 2019). These microbes are critical determinants of the composting process. The temperatures also ensure the termination of harmful organisms during the process, leaving useful ones. There is an appropriate temperature required for composting. Generally, temperatures beyond 55°C could exclude pathogenic microorganisms. If there are delays in the thermophilic phase, eliminating harmful microbes is easy. This approach makes compost sanitation effective and efficient. However, temperatures greater than 65°C would kill many beneficial microorganisms and ultimately affect the final product (Vaddella *et al.*, 2018).

2.18.2 Aeration During Composting

By definition, composting is aerobic and, therefore, dependent on oxygen during the process (Meena and Dutta, 2021). The technology uses O_2 while producing CO_2 and H_2O. Several effects can happen with proper aeration—oxygen provision and excess moisture evaporation in the substrate. Increased aeration can increase the evaporation rate. Consequently, keeping aeration within an optimum for better performance is crucial. Failure to adhere can lead to unnecessary cooling at the thermophilic stage, leading to improper decomposition and affecting the compost's quality (Xiong *et al.*, 2017). The aeration rate would also impact microorganisms and, therefore, on the process and final compost.

2.18.3 The Moisture Content

Fundamentally, the moisture content refers to the total water content in the organic matter during the composting. It is a crucial determinant of the process. The importance is that it impacts the decomposing microorganism and the rate of oxygen uptake, the air spaces, and temperature. There is evidence suggesting the effect of moisture and compost quality. Studies on the optimum moisture for efficient composting is contradictory, with no conclusive evidence for practical, effective and efficient composting (Hettiarachchi *et al.*, 2019). The inconclusiveness is because high moisture content during the process will lead to a reducing rate in aeration. Then the rate of O_2 uptake may not meet the expected metabolic needs of microorganisms.

Due to aerobic microorganisms ' limitations, the aerobic process could face anaerobic challenges (Owusu *et al.*, 2018). But moisture content can't be minimal. Low moisture is inappropriate because it is crucial in distributing soluble nutrients suitable for optimum microbial performance (Ameen *et al.*, 2016). It can lead to dehydration at the initial composting stages, restricting the process (Hettiarachchi *et al.*, 2019).

A study also reported that the moisture content requirements during composting depend on the initial organic feedstock (Muscolo *et al.*, 2018). For example, the optimum moisture content for composting poultry manure and wheat straw is 70 % (Sánchez *et al.*, 2017). Generally, the initial moisture content in food waste is high, making them unsuitable for composting. Therefore, adjusting the initial percentage of water in food waste is crucial for optimum microbial activity.

2.18.4 The Carbon to Nitrogen Ratio of Organic Matter

The microorganisms for composting require three major nutrients (C, N, K) (Forján *et al.*, 2016). The acquisition of nutrients is through the breakdown of organic compounds to obtain the needed microbial metabolism requirements (Xiong *et al.*, 2017). Of the three nutrients, C and N are crucial. They are vital in the production of energy because of the C source. On the other hand, N is used to form the cell structure (Yulin *et al.*, 2020). In the presence of limited nitrogen, microbial growth becomes inhibited, and carbon decomposition slows down (Yulin *et al.*, 2020). If nitrogen is in excess, the process may face some other challenges. In this situation, the aerobic microorganism will use carbon more than the expected use of nitrogen. Therefore C/N ratio should be under control.

In a low C/N ratio, the extra N comes out as a pungent smell (ammonia) and many salts' potential release. This situation makes the compost unsuitable for plant growth. Contrarily if the C/N ratio is high, the N needed for microbial activity is hindered, leading to a slowdown in the process (Mu *et al.*, 2014). Composting the initial C/N ratio is essential; therefore, several materials, called bulking agents, are recommended to add to the feedstock if needed. These agents include sawdust, corn cobs, peanut shells, and urea (Wang *et al.*, 2016; Zhang *et al.*, 2019). Neugebauer *et al.* (2017) concluded the initial C/N ratio of compost can impacts feedstock mineralisation.

2.19 Feedstock for Composting

The composting feedstock has a lot of influence on compost quality (Muscolo *et al.*, 2018). These usually come from households, solid waste collection systems, parks and gardens, and marketplaces, among other sources. The organic material can be mixed with other non-decomposable materials, hence the need to obtain well-separated organic matter to aid composting. With a separated feedstock, clean and rich organic matter works well for the process. Another factor is the hygienic status of the compost material. The phytosanitary quality is crucial for the process and the final product. In general, operators should not compost diseased animals and plants. It is also essential to avoid animals' faeces like cats and dogs (Ozturk *et al.*, 2015).

2.19.1 Physiochemical Properties of Some Composting Materials

A study by Ozturk *et al.* (2015) has provided an extensive overview of some of the physiochemical properties of some materials that operators can compost. They broadly grouped into animal manure (Table 2.1a), wood and paper (Table 2.1b) and stalk and dry grass (Table 2.1c). Table 2.1 depicts the mineral composition of manure from various animals (horse, chicken, sheep, cattle etc.), with table 2.1b showing the mineral composition of wood and paper organic matter. The materials included hard and softwood and newsprint, among others. The third table (Table 2.1c) displays stall and dry grass. The materials include corn and dry grass.

Table 2.1a Mineral Component of Animal Manure as Composting Materials (Ozturk et al., 2015)

Manure				
Organic Matter	% N (Dry Wt)	C/N (wt/wt)	% H_2O (Wet Wt)	Density (kg/m^3)
Horse	1.4-2.3	22-50	59-79	760-1010
Chicken	1.6 -3.9	13 -30	22 - 46	470 - 640
Sheep	1.3 -3.9	13 -20	60-75	< 1080
Cattle	1.5-4.2	11-30	67-87	820 -1040
The dairy barn (free bovine)	3.7	13	83	-
Racehorse	0.8-1.7	29 -59	52-67	-
The dairy barn (tied bovine)	2.7	18	79	-
Swine	1.9-4.3	5-19	65-91	< 1010

Table 2.1b Some physical and chemical properties of wood and paper (Ozturk et al., 2015)

Wood and paper				
Organic Matter	% N (Dry Wt)	C/N (wt/wt)	% H_2O (Wet /Wt)	Density (kg/m3)
Hardwood bark	0.1- 0.41	116 - 436	-	-
Paper fibre sludge	-	250	66	710
Soft tree bark	0.04 - 0.39	131-1285	-	-
Corrugated cardboard	0.1	563	8	160
Hardwood	0.06 - 0.11	451- 819	-	-
Newsprint	0.06 - 0.14	398 - 852	3-8	120 -150
Paper dough	0.59	90	82	870
Waste timber dough	0.13	170	-	-
Sawdust	0.06-0.14	100-750	19-65	220 -280
Tree crumb	-	40 -100	-	276 -385
Paper pulp sludge	0.56	54	81	-
Softwood	0.04 - 0.23	212 -1313	-	-

Table 2.1c Mineral Component of the Stalk and Dry grass as Composting Materials (Ozturk et al., 2015)

		Stalk and dry grass		
Organic Matter	% N (Dry Wt)	C/N (wt/wt)	% H_2O (Wet Wt)	Density (kg/m3)
Corn	1.2-1.4	38-43	65-68	-
Stalk	0.3-1.1	48-150	4-27	36-240
Wheat stalk	0.3-0.5	100-150	-	-
Seedless herbs	0.7-2.5	-	-	-
Dry weed	0.7-3.6	15-32	8 - 10	-
Oat stalk	0.6 - 1.1	48 - 98	-	-
Flowering herbs	1.8-3.6	15 -19	-	-

The feedstock used in composting can be into the following groups:

a. Biosolids from MSW. This waste includes domestic and industrial sewage sludge, among others.

b. Plant-based materials, like wood chippings, sawdust, plant materials, waste from food processing operators, shrubs etc

c. Animal-based materials like cow dung, and chicken droppings, among others

Compost presents many nutrients to the soil. It can be implied that these nutrients' content depends on the composting feedstock and the technology employed. Composting from plant-based feedstock generally is lower in nitrogen and phosphorus than biosolids-based compost (Sánchez *et al*., 2017). These feedstocks have high organic content and some micro and macronutrients. The N content of plant-based compost on a dry mass basis is usually less than 1 %. However, manures-based compost is higher than 1 %. The phosphorus of a biosolids compost is between 1 to 2 %, while the plant or manure-based compost ranges from 0.2 to 0.4 % P (Grau *et al.*, 2017)). They stated that the compost from yard trimmings and animal manures has higher potassium than biosolids.

A recent study by Kelley *et al.* (2020) concluded that food-based compost has more advantages than compost from manure regarding the nutrient content. Also, the study supported the nitrogen-rich content of compost from animal waste. Ruminant manure (cow, sheep and goat) does have less nutrition content than non-ruminant (pig, chicken) (Van der Wurff *et al.*, 2016). The differences are because ruminants can digest well their food content due to the nature of their food. Therefore, adding wood-based feedstock (rich in carbon) to manure is necessary, particularly non-ruminants. It is easy to achieve the required product (Sánchez *et al.*, 2017). With the composting of municipal solids, the concern is to remove physical substances like plastics and pieces of metals. When this is of concern, initial screening is essential.

2.20 The Adoption of Compost in Various Parts of the World

As earlier described, compost use is critical; therefore, various attempts promoted compost adoption worldwide. In 2015, a European Commission Circular Economy Action Plan introduced a new specification to the commission's compost regulations. This activity gave European nations wide acceptance of organic fertiliser, especially compost, to help horticulture production (European Commission, 2015). In 2018, there was an arrangement for various actors and countries to boost recycling waste for use as compost (European Commission, 2018). Therefore, it is vital to identify the variables influencing compost adoption. The review of the factors will be in the following paragraphs.

Wei *et al*. (2017) detailed the challenges of composts' nutrient content as a significant worry for adopters in various European nations. In contrast to inorganic fertilisers, the adopters gave two challenges associated with compost use. First, information is scarce on the N, P and K in compost and the difficulty obtaining compost. The nutrient inconsistency due to the lack of data significantly hinders adopters. With these issues, the farmers concluded it would be challenging to adopt compost as a fertiliser.

A study presented an overview regarding the information accessibility for waste that adopters can use. This study's relevant information on the total volume was unavailable in several nations (Lupton, 2017). They concluded that without much information on the composition of organic waste, it is difficult to estimate the amount used for composting. Therefore, it was challenging for adopters to plan. The perceived overall benefit of applying compost was not readily available and was a significant factor in the adoption. Lupton (2017) further suggested that transport and spreading costs are critical for adoption.

Therefore, Lupton (2017) concluded the engagement of various stakeholders in deciding the adoption of compost. They recommended that farmers-based associations, the retail industry and food processing companies influence compost adoption. The area of engagement should be on feedstock's nature for compost and policy formulation, among others. In the Caribbean islands, low education and the absence of farmer-based associations negatively influence adoption (Blazy *et al.*, 2017). Additionally, they suggested the need for spreaders and more information on the compost to promote adoption.

The quality of products is the primary determinant for far farmers’ adoption of compost. What's more, cost increment would demoralize the farmers. The two factors don't have an undeniable effect (Chen *et al.*, 2018). As suggested by European farmers, if the compost has the assured N content and could produce the needed nutrient in time (like inorganic fertilizers), it would positively affect adoption. Without these clear indications, the farmers would find it challenging to adopt.

Additionally, compost from diverse sources has different nutrient requirements, which make farmers hesitant to adopt it. If the product's information is scarce, their best option is to avoid usage. The situation is so because the farmers, like other consumers, want a guaranteed assurance for their produce. Farmers fear the compost may pose harm to their crops. Also, treating soils with compost may face additional challenges due to inadequate distribution channels (Jean and Folefack, 2015).

In South America, there are significant reasons for farmers to adopt compost. The factors include pressures from administrative enactments and the "manual or guide for compost application." In those nations, manure is a significant component of composts. To suitably use a lot of compost has both ecological and asset benefits. However, the handling advances and manure-based compost are new to the potential adopter, hence the government's promotion and proper guidelines. In Italy, several issues have affected the adoption of compost. The main problem is the information on the compost, particularly their N content, which is considered the main issue regarding compost use (Pampuro and Caffaro, 2018).

In China, farmers rely on the use of animal manure and the use of chemical fertilisers. The farmers are reluctant to adopt compost, which could yield the same results as animal manure. The reluctance is because there is no premium price for compost-produced crops due to the absence of a traceability system. The lack of traceability has significantly affected compost adoption in China. Therefore, the correct labelling of compost products could urge farmers to use compost. Furthermore, if the farmers could have a certification system for their farms, they may be prepared to use compost (Wang *et al*., 2020).

A study in Italy suggests that compost and application cost are the two concerns affecting farmers' decisions to use compost (Vigoroso *et al*., 2021). In that study, farmers were more concerned about the price than the product's availability. Additionally, the means of transport of natural composts could impact individuals' choices. In Northern China, farmers' concerns were about the composts' nutrient requirement and heavy metals content than the compost cost. They feared these metals (Cr, Cu, Zn, As, and Cd) could enter the food value chain and affect consumers' lives (Gong *et al*., 2018).

2.21 Review of the Factors Influencing Compost Adoption

The potential factors impacting the adoption of compost can fall into three, a) compost quality, which includes heavy metals and other contaminants; b) the full economic advantage of organic compost (fertilizer price, labour cost, among others) as compared to chemical fertilizers and c) government promotion of compost adoption and the related policy promotion initiatives.

Compost quality is an essential consideration for farmers in adoption (Cerda *et al*., 2018). One fundamental concern is the transfer of the heavy metal content of compost to plants

(Paradelo *et al*., 2020). Studies suggest compost may contain toxic metals such as Pb, Cd and As and other heavy metals Cu, Zn and Cr. These metals' presence is of concern because plants could take them up and enter the food chain (Paradelo *et al*., 2020) and animals (Soliman *et al*., 2019). There are restrictions on heavy metals in Europe and advanced nations (the European Directive 86/278/CEE (Verdonck, 2008).

Another significant concern is the high concentration of salts in compost, especially animal manure compost. High salt can affect soil composition and ultimately inhibit plant growth (Gondek *et al*., 2020). Also, metals and plastics, among other physical hazards, can affect plant growth (Paradelo *et al*., 2020). Therefore, separating the waste at the source is crucial to eliminate these hazards. Compost's stability and maturity are other critical considerations in deciding the quality. The usage of the two terms is often interchangeable. But the former is the compost's ability to resist further decomposition, while maturity refers to the compost's ability to support plant growth. However, these terms relate because the decomposition state significantly affects stability.

It is essential to develop and provide appropriate data for potential adopters worldwide regarding the potential hazards affecting compost quality, especially in developing nations. A study concluded in seven European countries stressed the importance of data in compost adoption (Long *et al*., 2016). They observed that the percentage N and the compost's ability to release nitrogen are critical factors in the adoption of compost. Therefore concerns of farmers from other locations must be considered.

Other adoption promotion factors include the percentage of carbon and the product's price. The suitability of replacing chemical fertilizer with organic compost is a significant consideration by farmers (Mustafa-Msukwa *et al*., 2011). The element may include compost cost, transport cost and labour costs (Blazy *et al*., 2017; Lupton, 2017), spreading costs (Blazy *et al*., 2017), geographic area (Lupton, 2017), accessibility of compost (Blazy *et al*., 2017; Jean and Folefack, 2015), farm size among other factors. There are no accessible insights on the advancement costs for various waste-fertilizing soil items (Lupton, 2017).

More countries are encouraging farmers to use organic fertilizer over inorganic due to the advantages of organic-based ones. These promotions are through the use of policies and regulations. However, there is a rise in chemical fertilizers worldwide due to the continuous demand for year-round food production. Excessive fertilizer use comes with its challenges. These problems include air and water pollution and soil acidification (Wang *et al*., 2020). These chemicals have the potential to affect the environment and the production industry. Therefore there is a need to focus on compost use.

The review involved literature on emerging contaminants, health effects of, and uptake of these contaminants. Also, factors affecting the adoption of compost were targeted. In conclusion, the evidence from prior studies has been inconsistent concerning: a) the composition and levels of ECs in compost from diverse sources, b) the ecological and health risk assessment of ECs in compost, c) the uptake and translocation of EC by plants through the application of compost and d) the factors influencing compost adoption. Continuing research must address these gaps in the current understanding of ECs and compost usage. In particular, there is a need to demonstrate whether there is a threshold concentration for ECs in compost that plants will take up and that concentration that will be risky to the environment and humans

To this effect, this study's design was based on the conceptual framework described in Fig.2.4. to determine the levels of EC in compost from selected composting facilities in Accra, Ghana. The city is highly burdened with waste management and soil organic carbon issues. As a necessary step towards addressing this primary goal, this study's protocol assessed the risk of ECs in compost and farmers' socio-cultural concerns regarding compost use in an African country burdened with waste and soil management issues.

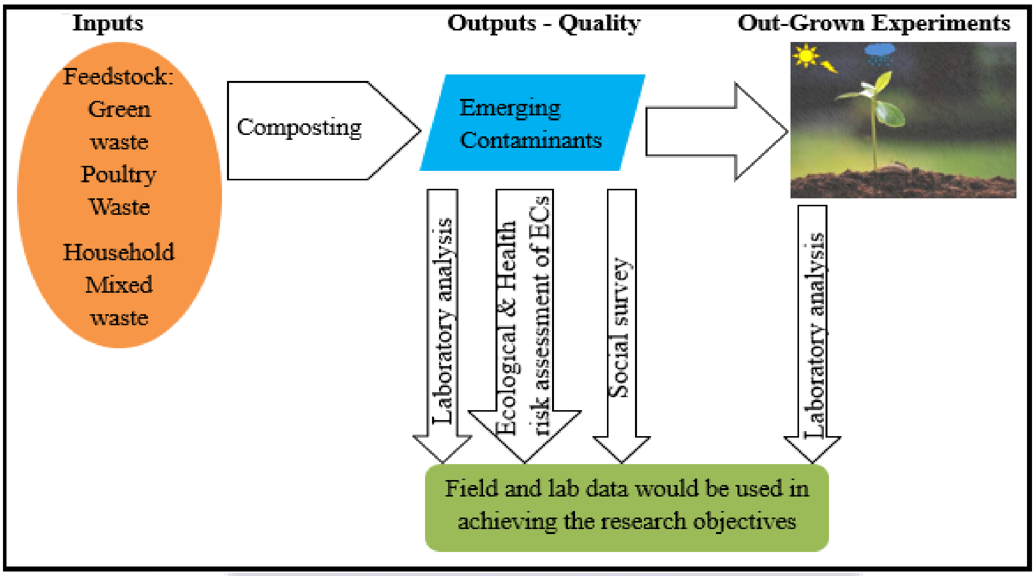

Fig. 2.4: Conceptual Framework of Study

The conceptual framework involved determining three ECs (pesticides, PAH and antimicrobial drugs) in compost from diverse waste sources. After that, there was a determination of the ecological and human health risk of these ECs in compost. Further, the concept involved an outgrown experiment determining EC's potential uptake and translocation in compost by vegetable plants (lettuce and carrot). The approach also involved a social survey of various stakeholders to collate information on the possible factors influencing compost adoption. The study pooled and analysed the laboratory and field data to address the study questions and achieved the overall aim and objectives.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

This chapter vividly describes the study area and the methodology employed. The study area details the geographical location, climate, vegetation, geology demographic, and other socio-economic settings. Secondly, the chapter captures the various laboratory methods and techniques used in this study and describes the planting methodology. Further, there is a description of the research sampling, sampling data collection methods and instruments. To conclude, the chapter describes the processing, analysing and presentation of the various data.

3.2 The Study Area

Accra, the capital of Ghana, was the study area, and it is within the Greater Accra Region of Ghana. The city has an estimated land area of 200 km^{2,} which is 61 m above sea level. Located at 5.33°N to 21.67°N; 0.11°E to 48.84°E, it lies on the Gulf of Guinea (Fig. 3.1). Accra is into 12 local government districts comprising 11 municipal districts and the Accra Metropolitan area. Accra is generally considered the hub of the nation's commercial economy and contributes significantly to the total Gross Domestic Product. Accra's primary economic activities include; financial and commercial, manufacture of processed foods, lumber, clothing and textiles, and tourism. About 4.6 per cent of the population is currently unemployed (Survey, 2017).

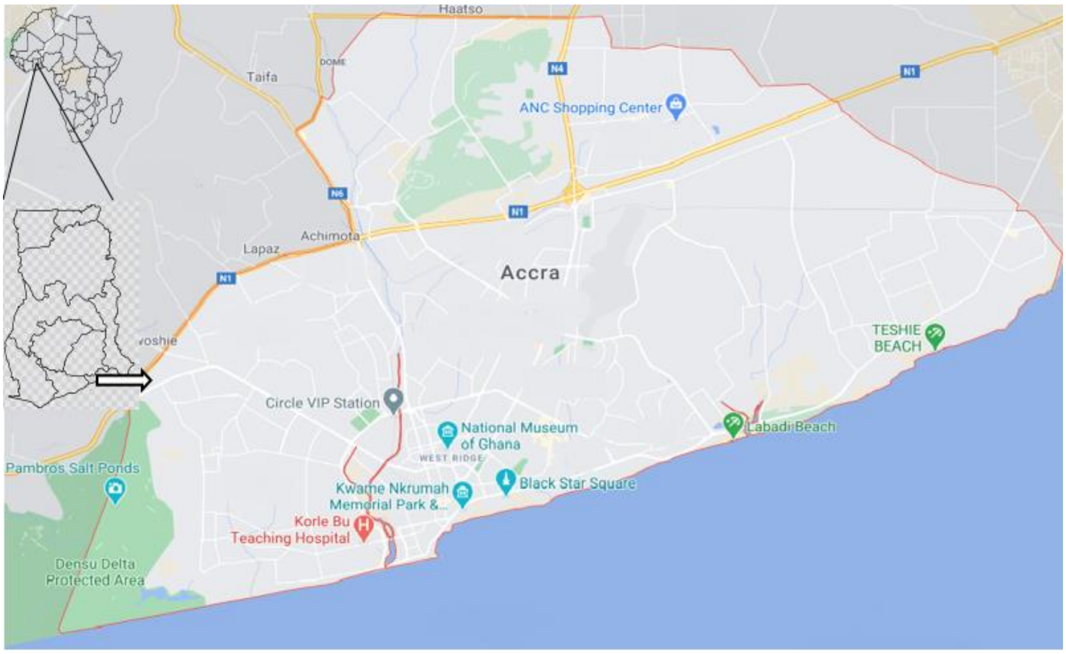

Fig. **3.1: Map of Accra**

Accra's population is about 4.2 million, comprising 51.8 % (males) and 48.2 % (females) (Ghana Statistical Service, 2014). The city is the most populated in Ghana, with very youthful inhabitants; 56 % are under 24 years. Accra consists of people of diverse backgrounds and cultures. Akans (39.8 %) are the highest group of people in the region, with Ga-Adangbe (30.7 %) being the second largest, followed by the Ewe (18 %). Immigrants constitute about 1.4 % of the inhabitants in Accra (Ghana Statistical Service, 2014).

The city has tropical savannah and hot semi-arid climatic conditions with few precipitations. The climatic condition is coastal and pre-coastal, with very little rainfall. Accra has a bimodal rainfall pattern with a mean annual of between 500 and 1000 mm. The city has above-average humidity, with January being the least humid (64 %) and August the most humid (83.0%). The temperature is warm to very high. The highest mean temperature (28°C) occurs in March, while the lowest (24°C) occurs in August. The climatic condition does not support various crops such as cocoa, palm, cashew, etc.

Agriculture is not a significant activity in Accra. However, about 6 % of the people are involved in Agriculture (Ghana Statistical Service, 2014). Urban and Peri-Urban Agriculture is popular in Accra. In this city, about 800 to 1,000 farmers are involved in the production of vegetables. Most of these farmers (over 60 %) produce exotic produce like lettuce and carrot, with the rest growing local vegetables (Obuobie *et al*., 2006). The plot sizes ranged from 0.01 and 0.02 ha per farmer within the city. However, the dimensions around the city can be a maximum of 2.0 ha. These plot sizes have dwindled due to indiscriminate land grabbing by estate developers. Other challenges the farmers face include the insecurity of the tenure of land and poor soils.

The soil type in Accra is tropical black, with general gneiss as the parent material. The soil may contain pieces of rock within 120cm deep, and the topsoils in Accra are generally thin (<30 cm), ranging from dark brown to black clay. Gilgai micro-relief can be on the topsoil. The subsoil can be found within 30-126 cm and contain calcium carbonate. There are some rivers in some portions of Accra. These rivers are mostly polluted and used as water sources to cultivate vegetables (Ghana Statistical Service, 2014).

In General, the soils do not support many plants' growth due to their compact nature. The topsoils are generally thin (< 30 cm), ranging from dark brown to black clay plastic when wet and hard when dry. The soil nature makes nutrients not easily accessible to plants. Ploughing of the soil is difficult due to its thick nature. Inhabitants rarely cultivate crops in the city, with a few exceptions due to the scarcity of land. However, urban and peri-urban agriculture is prevalent in the city.

3.3 Selection of Sampling Facilities

A visit was made to several composting facilities in the study area in September 2019 to select suitable composting facilities for the study and various composting operators. The aim was to discuss with operators the content of the research. Confidentiality of their facility was assured. The facilities' sampling design was purposive. The selection criteria included a) the preparedness of the facility operators to partake in the study, b) the nature of their process, and c) the business continuity aspect of their operation. Finally, the experimental design settled on three composting facilities.

During the study, composting feedstock and the resulting compost were sampled from three facilities (as described in the subsequent three paragraphs). The composting material used in these facilities was varied and included municipal, poultry, garden, and farm waste. In the facilities studied, composting materials were sorted at the reception to remove physical components such as glass bottles, metals, stones, and polyethene before composting. Afterwards, the feedstocks were composted to break the organic matter into simpler forms. The process involved stabilisation and maturation phases in minimizing harmful microorganisms and curing. All the selected facilities had been in operation for more than three years. Also, they have staff with considerable knowledge and experience in composting.

3.3.1. Mixed Waste Municipal Solid Waste

Composting feedstock and the resultant compost produced from mixed-waste municipal waste (MWMW) were obtained in a study area composting facility. This facility aims to provide a sustainable WM option for Accra and its environs. The facility receives mixed municipal solid waste and then mechanically separates the organic component before composting. The facility adds poultry manure from nearby plants to the segregated organic solid waste to enrich the compost's nitrogen content. The compost produced is sold in 50 kg bags to various consumers within and outside the Greater Accra Region.

The facility has sophisticated equipment for the composting of municipal waste. It has installed screening systems capable of separating the inorganic component from the organic matter. The plant has a large area for intensive decomposition of the substrates (active phase) formed as windrows (long, narrow piles) where a high temperature is developed (65–70 ◦C). There is also an area dor compost maturation for compost maturing (curing phase)

3.3.2 Source Separated Municipal Solid Waste

This facility aims to provide a sustainable solution to Tema's waste menace. Composting materials and the subsequent compost produced from source-separated municipal waste (SSMW) were obtained from a composting plant close to a busy market in Tema, Ghana port city. The composting materials were from the sorted organic waste from the market and the Tema Harbour. Even though the waste collected is segregated at the source, there is an additional screening to remove pieces of metal, plastic, and other unwanted substances before composting. Compost products from this facility are usually branded in 30 kg bags and sold to interested users for various activities.

The facility can receive a sizeable amount of organic matter and then breaks it down with the help of digestion. A carefully designed pipe network captures the methane gas which generates electrical energy. The emerg produced is connected to the national grade.

3.3.3 Municipal and Agricultural Waste Compost

The third source was municipal and agricultural solid waste (MAW) composting materials and the subsequent composts. A research institute located in Accra owns this facility. As part of its objectives, this facility conducts research on composting and the use of compost. However, the facility is also involved in the commercial production of compost. The feedstock used for the compost was mainly from the facility's municipal and agricultural waste (leaves, grass and shredded branches). Plant operators sell the composts from this facility to nearby farmers and the general public.

This composting involves forming organic waste into rows of long piles called “windrows” and aerating them periodically with a spade. With this facility, the organic waste is mixed in a large pile and layered. The organic matter is piled into a long row and watered periodically. Also, there is the periodic turning of the piles to allow maximum aeration. The pile height is about ten feet, with about 14 feet. This size pile is large enough to generate enough heat and maintain temperatures. It is small enough to allow oxygen to flow to the windrow’s core.

3.4 Sampling for Laboratory Analysis

The sampling for composting materials was done in November 2019, whereas the resultant compost was in March 2020. The composting materials' sampling was during four weeks post sanitation, while the finished products were taken after the products had been stabilised and cured (after 16 weeks). During the process, three samples were selected from the following locations a) the top, b) middle, and c) bottom sections of three compost piles from each facility and placed in buckets. A subsample was drawn from the respective sample to form a composite. The composite was placed in a container and mixed on-site before being transported to the laboratories. This approach accounted for variabilities within the samples.

The laboratory procedure involved freeze-drying, keeping at −18°C in the darkroom, and testing within 24 hours. Some composting material contained oversized materials; operators screened to 20 mm before laboratory analysis. Conversely, the facility operators screened finished products in their facilities as part of their process before the various analytical test. The physicochemical properties (pH, electrical conductivity, total nitrogen and carbon) and three targeted ECs (pesticides, PAHs and antimicrobial drugs) were analysed. The procedure of analysis for physicochemical properties and ECs are described in sections 3.8 and 3.9, respectively.

3.5 Identification of Criteria Values for Risk Assessment of Contaminants

There was a need to obtain criteria/standards/guidelines (ecological and health) for the detected EC in this study. The identified criteria were preliminary screening and risk assessment of the detected contaminants. Since this study is in Ghana, the preferred sources of standards were that of Ghana. However, no documented specification of compost ECs exists in the country and also no international screening levels. Therefore, the study sourced each matrix and receptors' specifications from other locations, as shown in Table 3.1.

The Australian National Environmental Protection Measure (NEPM) (NEPC, 2013) was the source of criteria to evaluate the Human Screening Levels (HSL) after exposure to the composts or soil amended with the composts containing EC (s). This study obtained the Ecological Screening Levels (ESLs) for terrestrial ecosystems from the ECOTOX database (US EPA, 2007). This source document assessed the receptors' ecological impacts. The US EPA based the ESLs on toxicity to plants. This source provides risk-based HSLs for several land-use simulations. For the evaluation, the health screening levels account for residential with garden/accessible lands was used. This source provides risk-based HSLs for various compost usage scenarios.

Table 3.1. Source of criteria/Screening Levels for Preliminary Screening and Risk Evaluation

Receptor	**Sources**
Ecological	Ecological Screening Levels for terrestrial ecosystems sourced from the ECOTOX database (US EPA, 2007)
Human health	Health Screening Levels for human health criteria evaluations adopted from Australian National Environmental NEPM HILs (2013)

3.6 Risk Assessment

Applying composts with ECs (pesticides, PAHs and antimicrobial drugs) is risky to ecological and exposed human receptors. This risk applies to where the compost was applied. Therefore, the risk assessment was to identify the key contaminants that may pose risks after compost application. The evaluation considered ecological receptors, particularly plants and direct exposure to humans through compost or soil amended with it. This study evaluated environmental and human health screening levels/criteria for each contaminant. The screening/guidelines levels are the content of the emerging contaminants that, when exceeded, will require further evaluation.

3.6.1 Initial Screening Assessment

The initial screening evaluations involved identifying contaminants of potential concern (CPC) that needed additional investigations in a preliminary risk assessment. This study considered all the pollutants measured in the composts above the Limits of Quantitation (LOQ) in the initial screening assessment. The approach involved the contaminant's maximum concentration in the compost for the screening assessment (compared to the ecological and human health criteria). An evaluation of some contaminants was impossible. This challenge is due to the lack of standards/criteria/guidelines/specifications for them.

3.6.2 Risk Assessment and Characterization of Contaminants of Potential Concern

The identified CPC were further evaluated in a preliminary risk assessment to identify priority contaminants of interest. This approach enabled the identification of contaminants that could pose an environmental and human health risk based on two compost applications.

The study adopted two compost application rate scenarios as described below:

(i) A single application rate of 5 t/ha (0.5 kg/m^2) is the average application rate used by farmers (Partey *et al*., 2018).

(ii) An application of 10 t/ha (1 kg/m^2), Mensah and Frimpong (2018) described an optimum plant improvement rate.

3.6.3 Risk Assessment of Contaminants of Potential Concerns

For lnad application of compost there is the potential for human and ecological receptors to be exposed. Therefore, the study assessed the ecological and human health risk of identified contaminants of potential concerns. The approach predicted the maximum soil concentration after compost application using Eq. (3.1) for each measured concentration in the compost.

$$M_{SC} = \frac{MC}{MS+MC} \times MCC \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 3.1}$$

(Langdon et al., 2019)

Where M_{SC} = maximum soil concentration,

MC = mass of compost (5t or 10 t) based on 5 t/ha and 10 t/ha application rates, respectively.

MS = mass of soil assumed to be 1300 t (considering a bulk density of 1.3 g/cm^3 and an incorporation depth of 10 cm, resulting in 1300 t/ha of soil into the compost (Langdon *et al.*, 2019).

MCC = maximum (optimum) concentration of each contaminant in the compost.

After the optimum soil concentrations, compared to the screening levels/criteria (ecological and human health) by calculating a maximum risk quotient (RQ_{max}) for each CPC using Eq. (3.2).

$$RQ_{max} = \frac{Msc}{Criteria} \text{ ……………………………………………………………Eq. 3.2}$$

MSC = maximum soil concentration predicted from the first equation Eq. (1), and the criteria were obtained from the initial screening assessment described earlier in Table3.1.

After each contaminant was prioritized (low, medium, high and very high), ECs were low priority if obtained RQ $_{max}$ values (for the two land-applications rates, 5 t/ha and 10 t/ha) were below 1. If the RQ $_{max}$ exceeds 1, the contaminant exceeded the criterion, and there may be a potential risk that calls for further investigation.

Ecological and health screening values/criteria were unavailable for some identified contaminants. These include organophosphate, synthetic pyrenoids, antimicrobial drugs, and higher molecular weight PAHs. However, the absence of screening criteria does not imply low risk. Therefore, this study assessed the potential uptake of contaminants through a field experiment.

3.7 Field Experiment

3.7.1 Vegetable Crops for the Field Experiments

The field experiment considered lettuce and carrot. The experimental setup considered the following in selecting the crop a) the agricultural significance and importance to society and b) the time scale of these crops to produce the needed vegetables for the analysis. Also, these vegetables are usually eaten uncooked and may present some potential ECs risk to consumers. The seeds were in good condition and obtained from Agrimat Company Limited in Accra and imported from France. They were certified by the European

Commission rules and standards and approved for importation by the Seed Division of Ghana's Plant Protection Services Division.

3.7.2 Location of the Field Trial

The trials' location was the experimental field of the Biotechnology and Nuclear Agricultural Research Institute of the Ghana Atomic Energy Commission (GAEC). This area is one of the largest farm sites in Accra and is located within the GA-East Municipal Assembly (GEMA). The area lies within latitudes 5° 6'7"N to 5° 6'9"N and longitude 0° 21'W to 0° 26'W at 64 m above sea level. It covers about 36 km^2, with one of the largest concentrations of urban vegetable farmers. The location was separated from the rest of the field by a 4 m buffer zone to reduce the immediate surroundings' effect and the corners marked with a wooden post.

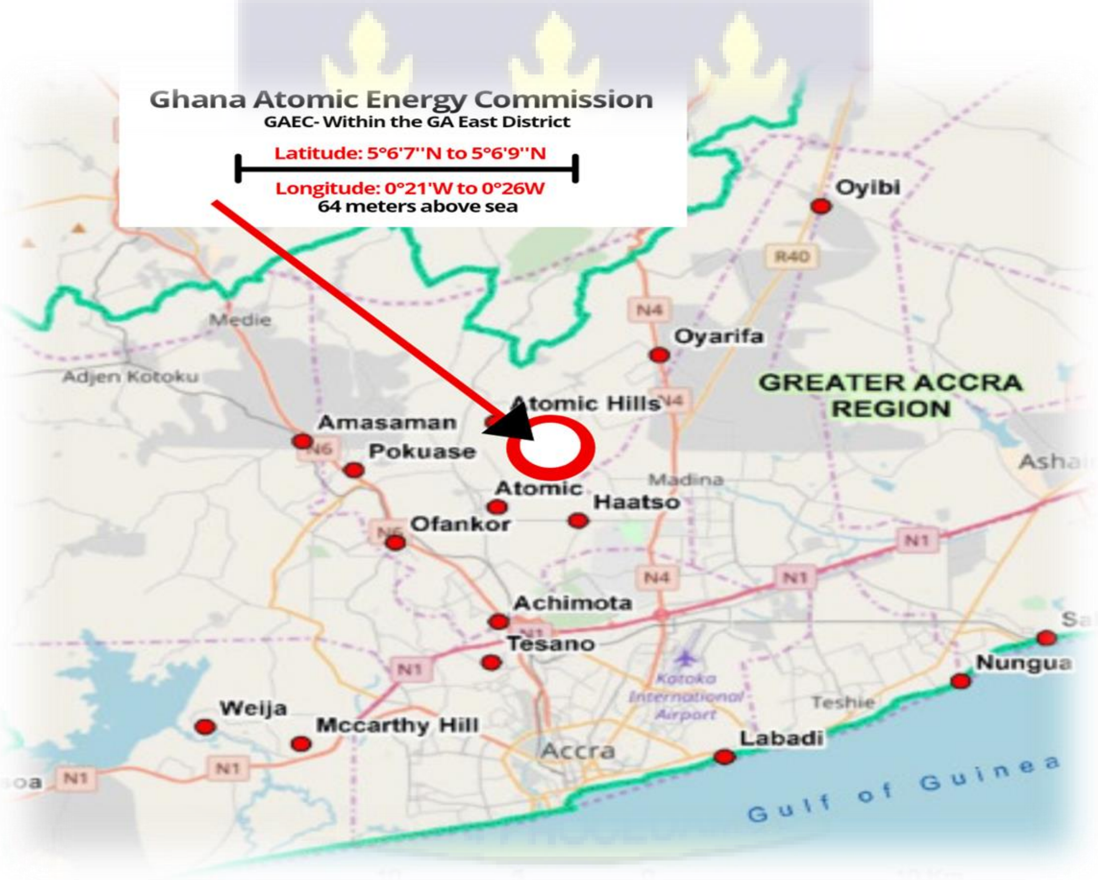

Fig. 3.2 Location for the Planting of Vegetables

3.7.3 Soil at the Location

The soil textural classification was generally clayey, with an organic matter content of approximately 3.8 %. The soil pH was 6.5, with a nitrogen content of 0.31 per cent. The details of the soil properties are below (Table 3.1)

Table 3.2 Topsoil Properties of the Location

pH	Organic matter (%)	K	Total N	P
6.5	3.8	1.88	0.13	0.6

3.7.4 Beds at the Locations

The experimental site was cleared and ploughed with a pickaxe and a hoe, and the beds prepared; 5 m x 1.2 m. The experimental design was in three replications for each treatment. The treatment location was separated from the others to prevent cross-contamination of the beds and given the following treatment:

I. Compost from MWMW
II. Compost from SSMW
III. Compost from MAW
IV. No compost application (Control)

Before the experiment, the Gas Chromatography-Mass Spectrometer (GCMS) and Liquid Chromatography-Mass Spectrometer (LCMS) were used to measure contaminants' concentration in compost, soil, and water to determine potential ECs. This approach was to identify the initial contaminants in the compost before the experiment. Targeted ECs were below detection limits in the soil and water used in the investigation except for PAHs in the soil samples. The means were reported in the table below. The procedure is as described in subsection 3.9.

Table 3.3: The means of Polycyclic aromatic Hydrocarbons from the Soil Location

Contaminant	Concentration (mg/kg)
Fluoranthene	0.023
Indeno[1,2,3-c,d]pyrene	0.030
Pyrene	0.0690
Naphthalene	ND
Fluorene	0.0028
Acenaphthene	0.083
Benz[a]anthracene	0.023
Dibenzo[a,h]anthracene	0.083
Benzo[a]pyrene	0.006
Benzo[g,h,i,]perylene	0.026
Chrysene	0.034
Benzo[k]fluoranthene	ND
Benzo[b]fluoranthene	0.046
Anthracene	0.070
Phenanthrene	0.020
Acenaphthylene	0.113

The sixteen (16) US EPA priority PAHs were tested from various locations in the soil sample. Of these, 14 of the PAHS were detected. The non-detected PAHs were naphthalene and benzo[k]fluoranthene. The highest was Acenaphthylene.

3.7.5 Application of Compost

The recommended compost amount applied was 10 t/ha. This amount relied on the recommended compost application rate by Mensah and Frimpong (2018) as the optimum plant improvement rate. Another setup used 50 % of 10 t/h of Mensah and Frimpong's recommended quantities, 5 t/h. After compost application, the plots were left to stand for one week before planting. Partey *et al.* (2018) described the 5 t/h application rate as the amount commonly used by farmers. There was a control where there was no compost application. Pictorially it is described in Fig. 3. 3 for a vegetable.

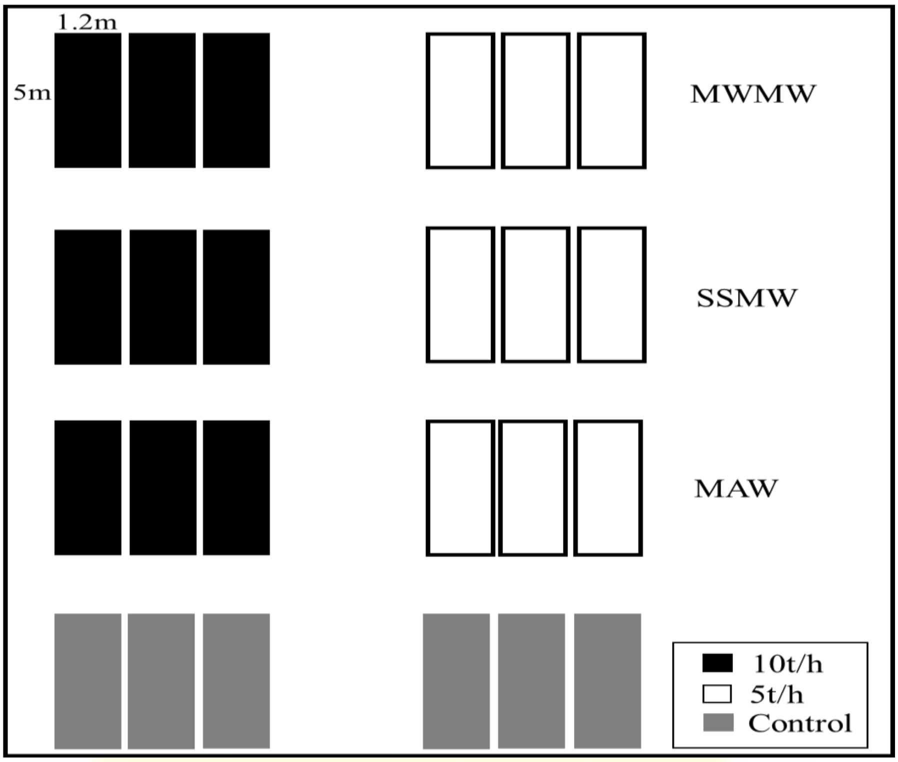

Fig 3.3 Different Compost Applications during the Field Experiment

Fig 3.3 displays the various application rate (10 t/h, 5 t/h and the control) of the different compost and the dimensions of the beds. The compost had known concentrations of ECs.

3.7.6 Nursing and Planting of seeds

The germination of lettuce seeds on topsoil under greenhouse conditions (day/night temperature of 28°/24° ± 2°C, and 70 ± 10 % relative humidity) on 2020/04/02. One month (2020/05/02) after sowing, uniform plantlets were selected and transplanted into the beds.

The carrot seeds were sown by hand to a depth of 1cm, spaced at 15 x 10 cm, and planted on 2020/05/02

3.7.7 Crop Maintenance

Manual watering (irrigation) was done in the mornings and evenings to ensure a continuous moisture supply in the soil. There was manual weeding with a hoe for a clean field and frequent earthing-up to prevent vegetables from direct sunlight, which causes undesirable green colouration. In this experiment, pesticides and other agrochemicals were not allowed. There was no pesticide application, so the study followed recommended cultural management practices to control pests and diseases.

3.7.8 Growth Measurements

There were measurements of the agronomic parameter of the vegetable. The following agronomic parameters were taken; the fresh weight of leaves, the number of leaves, root length and stem diameter. There were also measurements of the parameters of carrots. The agronomic data are reported in Anne 1B

3.7.9 Harvesting

After planting, harvesting was 70 days and 100-120 days for lettuce and carrots, respectively. This harvest was when the roots and leaves reached the desired sizes. After harvesting, the study determined EC's potential contaminants uptake and translocation by analysing lettuce and carrot contaminants. There were also analyses of in-between samples to identify potential ECs in the vegetables. The analytical procedure for the vegetables is described in section 3.9.

3.7.10 Experimental Procedure for Uptake of Targeted Emerging Contaminants

As part of the study, a pot experiment was conducted in the greenhouse facility located at the Ghana Atomic Energy Commission to identify the vegetables' potential uptake. The greenhouse used in the 10 x 6 m greenhouse was constructed with a galvanised metal structure. The greenhouse had a metallic coated frame, 7.0 m x 18.0 m, 126 m^2 of area, floor/ceiling height of 4 m, and an arched roof with transparent plastic film to protect against ultraviolet rays. This setup was to compare with the situations on the field.

Soil samples were collected from the GAEC location and tested samples' general characteristics in Table 3.2. The soil was dried at room temperature, sieved through a mesh, and grew vegetables in buckets (61.2 cm x14 cm) in the greenhouse facility.

The composts were collected from the three waste sources (MWMW, SSMW and MAW) described above and applied in combination as 2 % weight by weight; compost: soil basis. The treatments involved in the experiment were from the three sources and the control. The soil was weighed and placed in the buckets divided into groups using the compost from the following sources (MWMW, SSMW, MAW and the Control). Water was regularly supplied to provide enough moisture on the soil surface.

The seeds were hand-sown thinly in three rows in pots. The glasshouse temperature was between 25 - 32°C during the day and 23 – 25°C at night, and soil moisture at field capacity. Daily irrigation was to maintain enough water. There was no pesticide application, so the study followed recommended cultural management practices to control pests and diseases.

After planting, harvesting was 70 days and 100-120 days for lettuce and carrots, respectively. After harvesting, the samples were analysed to identify potential contaminants uptake by the lettuce and the carrot. This harvest was when the roots and leaves reached the desired sizes. The analytical procedure for the vegetables are as described in section 3.9

3.8 Physicochemical Analysis of Compost Material and Compost

The study analysed the composting materials' physicochemical parameters and the finished compost at the Chemistry Department of the Ghana Standards Authority. The selected physicochemical parameters include pH, electrical conductivity, total nitrogen and carbon.

3.8.1 pH and Electrical Conductivity of Composting Materials and Compost

A mass of 10 g of samples (feedstock and compost each) were weighed into a 50ml polythene beaker, and 10ml of deionised water was added. The resulting solution was continuously stirred with a magnetic stirrer for 15 mins and left to stand for 1hr. The pH was taken by inserting the probes into the superannuation after calibrating the pH meters with various standards (4.0, 7.0 and 10.0). The solutions' electrical conductivity (triplicates) was read with a Jenway conductivity meter. The stabilisation state was determined when the equipment signal was steady after 2 mins.

3.8.2 Total Carbon of Composting Material and Compost

Walkley and Black (1934) were used in determining the samples' organic carbon content. It involves about 0.1 g of the samples taken into a 550 ml flask and then added 10 ml of 1 M potassium dichromate (K_2Cr_2O7) solution. To this, 20 ml concentrated sulphuric acid (H_2SO_4) was added to the samples, vigorously swirled, and allowed to stand for 30 minutes to oxidise the organic matter. After oxidisation, 0.2 M ferrous ammonium sulphate was used to titrate the unreduced K_2Cr_2O7. During the titration of 10ml of orthophosphoric acid and 1mL barium, diphenylamine was the indicator solution. The colour changed from a dirty brown to a bright green endpoint.

Based on the titre, the calculation of the percentage carbon was done per the equation below:

$$\% \, \mathrm{OC} = \frac{[0.3\mathrm{x}(10-\mathrm{XN})]}{\mathrm{w}} \mathrm{x}1.33 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq.3. 3}$$

X = Titre value.

N = Molarity of the ferrous ammonium sulphate (0.2M)

W = weight of the sample. Additionally, the percentage of organic carbon is converted to organic matter using the following equation: % Organic Matter (OM) = % Organic carbon x 1.724.

3.8.3 Total Nitrogen of Composting Feedstock and Compost

The study used the Kjeldahl (1883) method to determine the N of the composting material and the feedstock. Samples (2 g) were placed into a 300 ml Kjeldahl flask and then added to a digestion accelerator (selenium catalyst) tablet. Five (5) ml of concentrated H_2SO_4 was added to digest till it was transparent. The sample (feedstock and compost) was then cooled and transferred to a 100 ml volumetric flask. The solution was then topped to the 100ml point using water. The resulting solution was distilled with the Markham distillation apparatus, and 10 ml (40 %) was added. The free gas (ammonia) was collected into a 5ml test tube with 2 % boric acid (H_3BO_3) and titrated against 0.01 M HCL with methylene blue and methyl red as the indicators. The solution changed from green to reddish, and the titre value was calculated.

Based on the titre value, the calculation of the % nitrogen was with the equation below (Eq. .4).

$$\%\ \mathrm{N} = \frac{0.01 \text{ x titre volume x } 0.014 \text{ x volume of extract x } 100}{\text{Compost sample weight (g) x volume of aliquot (mL)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Eq 3.4}$$

3.9 Analysis of Pesticide, PAH and Antimicrobial Drugs in Composting Feedstock, Compost, Soils, Water and Vegetables

3.9.1 The Certified Reference Standards Used in the Study

The reference standards (Table 3.4 a) used in the identification and Quantification of targeted EC consisting of the following; a) 49 individual certified reference standards materials pesticides, b) 16 priority mixed ten mg/l PAH, and c) six mixed ten mg/l of antimicrobial drugs. All the standards were of high purity (98 – 99 per cent. The manufacturer of the chemicals was Dr Ehrenstorfer GmbH (Augsburg, Germany). Per manufacturer's instruction, standards were in freezers throughout their storage period.

The certified reference standards used for the analysis of Emerging Contaminants consist of the following:

- Forty-nine pesticides (Table 3.4 a),
- The 16 US priority US PAH classified as carcinogenic (Table 3.4 b)
- Six commonly used antimicrobial drugs used in Ghana (Table 3.4 c)

Table 3.4a: The Certified Reference Pesticides for the Study.

Pesticides		
Thiamethoxan	gamma-chlordane	Chlorpyrifos
Imidacloprid	alpha-endosulfan	Malathion
Acetamiprid	Dieldrin	Fenitrothion
Bromacil	Endrin,	Parathion
Atrazine	beta-endosulfan	Chlorfenvinphos
Triclopyr	p,p´- DDT	p,p;-DDD
fenpropathrin	Profenofos	Allethrin
Indoxacarb	Propanil	Bifenthrin
Emamectine Benzoate	Endosulfan sulfate	p p,-DDE
Butachlor	Methoxychlor	λ-cyhalothrin
Pendimethalin	Methamidophos,	Permethrin
Lindane,	Phorate	Cyfluthrin
beta- HCH	Fonofos	Cypermethrin
delta-HCH	Diazinon	deltamethrin
aldrin	Dimethoate	Fenvalerate
Heptachlor	Pirimiphos-methyl	Glyphosate
Imazethapyr		

Table 3.4 b: The Certified Reference PAHs for the Study.

PAH		
Acenaphthylene	Benzo(a)anthracene	Benzo[k]fluoranthene
Naphthalene	Pyrene	Benzo[g,h,j]perylene
Acenaphthene	Phenanthrene	Benzo(a)pyrene
Fluorene	Fluoranthene	Indeno(1,2,3,c,d)pyrene
Anthracene	Fluoranthene	
Chrysene	Benzo[b]fluoranthene	

Table 3.4 c: Certified Reference Antimicrobial Drugs for the Study.

Antimicrobial Drugs		
Amprolium	Ciprofloxacin	Sulfadiazine
Danofloxacin	Amoxicillin	Metronidazole

3.9.2 Reagents and Materials Used for the Analysis

The chemical and material came with the relevant certificate of analysis and conformance. The chemicals were sourced from certified producers and kept according to the manufacturer's instructions. Information on the grade, the chemical (Table 3.5 a) and materials and equipment sources are presented in Table 3.5 b.

Table 3.5 a: Information on Chemicals for Analysis

Regent	Grade	Manufacturer
Acetone	Pesticides	BDH Laboratories, UK
Acetonitrile	Pesticides	BDH Laboratories, UK
Ethyl Acetate	Analytical	BDH Laboratories, UK
Toluene	Analytical	BDH Laboratories, UK
Dichloromethane	Analytical	BDH Laboratories, UK
Anhydrous Sodium sulphate	Pesticide	BDH Laboratories, UK
Anhydrous Sodium chloride	Pesticide	BDH Laboratories, UK
Polyethylene Glycol-200	Pesticides	BDH Laboratories, UK
Dipotassium hydrogen phosphate	Pesticides	BDH Laboratories, UK
Potassium dihydrogen phosphate	Pesticides	BDH Laboratories, UK
Anhydrous Magnesium sulphate	Pesticides	BDH Laboratories, UK
Filter paper	Not applicable	Whatman Int. Ltd, UK
Envi-Carb/LC-NH_2 500mg/500 mg/6 mL	Not applicable	Phenomenex, USA
Strata C18-E 55um, 70A, 1000 mg/6ml	Not applicable	Phenomenex, USA
Bond elute C18 solid-phase extraction cartridge, 1g/6ml	Not applicable	Supelco, USA
Silica gel (1000 mg/ 6ml)	Not applicable	Phenomenex, USA
Distilled water	Not applicable	

Table 3.5 b Information on Materials and Equipment for the Analysis

Equipment	Description of equipment
GC	Varian CP-3800 type couple to an autosampler. It had two detectors; pulse photometric flame and electron capture
LC/M//MS	Agilent type triple quadrupole
Analytical column	Varian manufactured columns 30 m + 10 m EZ-guard, the internal diameter of 0.25mm fused with silica capillary coated; (0.25µm film thickness).
Weighing Balance	High-performance Mettler toledo weighing balance
Centrifuge	Thermo electronic Jouan CR3i multifunction centrifuge
Vacuum manifold	Varian-type solid-phase extraction vacuum manifold
Macerator	IKA Ultra-Turrax homogenizer
Vial	Glass type (2 mL)
Heating bath	G130066 Buchi, B-491
Extraction jars	Nalgene type, 250ml volume
Preparation equipment	Wearing Lab. Blender, Hobart
Vortex mixture	Mai Max-plus
Recirculating chiller	Buchi B-740 with a temperature range of -10 to 20
Rotary evaporator	Buchi Ratoevapoator r 11 R-210 series
Horizontal shaker	Ika HS 501 Digita from Sigma-Aldrich
Ultrasonic baths	Grant XUB 18 from Tierratech

3.9.3 Preparations of Standard Solutions

Various ECs standards were prepared using methanol from a selected stock solution of 1000 µg/mL. These standards were obtained by diluting the in-between working ECs with blank samples (composting materials, compost, soil, water and vegetables). Contaminants standards were kept in amber vials at −28°C per the manufacturer's instructions.

3.9.4 The Extraction and Clean-up of Samples

3.9.4.1 The Concentration of ECs in the Various Samples

Approximately 10.00 g ± 0.001 homogenate composite samples (composting material and resulting compost, soil samples and vegetables) were weighed into a polypropylene centrifuge tube (50 ml) and labelled. To each test item, acetonitrile (10 ml) was added and vortexed for one min at a speed of 2500 rpm. Extraction salts consisting of NaCl (1 g), $MgSO_4$ (4 g) and trisodium citrate (1 g) dehydrate and disodium hydrogen citrate (1g) was added to the vortex for 5 min at a speed of 3500 rpm. The sample solutions were then centrifuged; (speed: 3000 rpm time: 5 min) and allowed to settle for 10 min. Afterwards, the solution (6 ml) was taken, dried over 2 g anhydrous $MgSO_4$ and filtered through a filter paper (No. 4) into a 50 mL round bottom flask. The extract was then ready for the necessary cleanup.

3.9.4.2 Clean-Up Process

A previously activated Silica gel (1 g) at a specified condition (130ºC for 10 hrs), loaded into a 10 mL polypropylene cartridge (already conditioned with acetonitrile (6 mL)]. The resultant solutions were eluted using a rotary evaporator to about 1ml. The extract was loaded into the column and eluted into a pear-shaped flask (50 ml). After that, acetonitrile (50 mL) was eluted the column and concentrated the filtrate to just dryness (conditioned at 38ºC). The residue was dissolved in ethyl acetate (1mL) and transferred into a two vial (2 mL) before identifying and quantifying targeted ECs (pesticides, PAH or antimicrobial drugs) with either GC or LCMS/MS at the stated conditions as described in section 3.9.6 and 3.9.7.

3.9.5 The Concentration of Emerging Contaminants in Aqueous Samples

3.9.5.1 Extraction

The extraction technique was the US EPA Method 3510 for an aqueous matrix to analyse semi-volatile and non-volatile organics. The samples were filtered through a Whatman NO. 4 filter paper. After filtration, the water sample (1 L) was transferred into a 2 L volume glass-separating funnel. Then, 30 ml of saturated NaCl was added to salt out the solution. It was well mixed by turning the flask several times (about four times). After that, the addition of dichloromethane (as extraction solvent) was vigorously shaken manually (about 3min) and released the in-built pressure at regular intervals. The resulting solutions' were separated for 5mins, and the organic layer (upper layer) was collected from the aqueous layer (bottom layer). The extraction was repeated twice with 100 ml of organic extract. All the dichloromethane extracts were put together and dried over anhydrous magnesium sulphate ($MgSO_4$). The aqueous samples' extracts were concentrated using a rotary vacuum evaporator to about 2 ml and subjected to a clean-up and purification process as previously described in section 3.9.4.2.

3.9.6 Condition of Gas Chromatography for EC Analysis

3.9.6.1 Organochlorines and Synthetic Pyrethroids Contaminants

As described, the Gas Chromatograph (Varian CP-3800) was used to determine organochlorine and synthetic pyrethroids pesticides in the various samples. The Gas

Chromatograph allows for the detection of compounds in ppb. The tested items included the composting materials and the resulting compost, water, soil and vegetables. A 63Ni electron capture detector (ECD) was coupled to the GC to detect contaminants in low concentrations. The sensor and the GC condition matched the relative and response time specified by the Japanese analytical procedure for agricultural products (Syoku-An, 2006).

The GC conditions used for the analysis were capillary column coated with VF-5 ms (30 m + 10 m EZ guard column x 0.25 mm internal diameter, 0.25 µm film thickness). The inlet temperature was set at 270ºC, while that of the detector was at 230ºC. The oven temperature set at 70 ºC for 2 min, ramp at 25 ºC for 1 min to 180 ºC, held for 1 min, and lastly, ramp at 5ºC min-1 to 300 ºC. Nitrogen gas was the carrier; the flow rate of 1.0 ml per min, and the detector make-up gas was 29 mL/min. The injection volume was 1.0 µL and had a run time of 36.7 min per sample.

3.9.6.2 Organophosphorus Residues

The organophosphorus pesticide residues in the various samples were analysed with a GC (Varian CP-3800) coupled with a PFPD detector to detect contaminants at low concentrations. Also attached to the GC was an autosampler manufactured by Agilent. The sensor and the gas chromatography conditions matched the relative response time specified by Japanese analytical methods for agricultural products (Syoku-An, 2006).

The GC conditions used for the analysis were capillary column coated with VF-1701ms (30 m + 10 m EZ guard column x 0.25 mm internal diameter, 0.25 µm film thickness). The inlet temperature was set at 270ºC, while the detector was at 2300ºC. The oven temperature set at 70 ºC for 2min, ramp at 25 ºC for 1mim to 200 ºC, held for 1 min, and lastly, ramp at 5ºC min-1 to 250 ºC. Nitrogen gas was the carrier gas with a flow rate of 2.0mLper min. The detector had make-up gas of $H^{2=}$17 mL/min, Air 1 =14mL/min and Air 2=10mL/min, and the injection volume was 2.0 µL. A sample had a run time of 15.7min.

3.9.6.3 Polycyclic Aromatic Hydrocarbons

A Gas Chromatograph Mass Spectrometer manufactured by Agilent (7000C) was used to measure Sixteen Priority PAH samples. This equipment allowed the detection of PAH in low concentrations of ppb. The detector and the GC's condition matched the relative response time (specified by Japanese analytical methods for agricultural chemicals) (Syoku-An, 2006) and the manufacturer's instruction.

The GCMS conditions used for the analysis were capillary column coated with VF-5 ms (30 m + 10 m EZ guard column x 0.25 mm internal diameter, 0.25 µm film thickness). The inlet temperature was set at 250ºC, while that of the ion source was at 300ºC. The oven temperature set at 80 ºC for 1min, ramp at 25 ºC/min to 180 ºC, held for 1 min, and ramp at 5ºC min-1 to 300 ºC. Nitrogen gas was the carrier. The ionisation voltage was 70eV, and the temperature of the Quadrupoles was up to 150 ºC each. The injection volume was 1.0 µL and had a run time of 39.4 min per sample.

3.9.7 Condition of Liquid Chromatography for Emerging Contaminants Analysis

3.9.7.1 Antimicrobial Drugs and Herbicides

The antimicrobial drugs and herbicides in the various samples (compost and resulting compost, water, soil and vegetables) were analysed with Liquid Chromatography coupled to a triple, quadruple Mass Spectrometer manufactured by Agilent (6420). The equipment allowed for the detection of targeted contaminants in ppb. Attached to the Liquid

Chromatograph is an autosampler manufactured by Agilent. Japanese analytical methods for agricultural chemicals specified the liquid chromatography's conditions and detected matched response time (Syoku-An, 2006).

The liquid chromatography conditions used for the analysis were capillary column Phenomenex ® Kenetex 2.6 u XB-C18 (100 mm x 2.1 mm). The Electron Source Ionisation mode was Positive Mode. The Chamber Current was up to 0.2 1uA. The source Gas Flow Rate was at 13 L/min. The Nebulizer pressure was 30 psi, and the Acquisition Mode was set to MRM. The injection volume of the LC was 5 ul. The details of the conditions are in table 3.6.

Table 3.6 The Column Conditions and flow program are in the table below

Temperature	40 °C
Flow	0.2ml/min
Post Time	2 mins
Injection Volume	5ul
Run Time	32 mins
Program	Gradient:
	Solvent A: 0.1 % Formic Acid in Water
	Solvent B: 0.1 % Formic Acid in Acetonitrile

	Time (mins)	Solvent (%)
1.	0.0	5
2.	5.0	0
3.	10.0	15
4.	15.0	50
5.	18.0	70
6.	25.0	70
7.	32.0	5

3.9.7.2 Laboratory Quality Control and Assurance

To achieve a reliable test result, the GSA laboratory follows ISO/IEC 17025:2017. The ISO 17025 gives the requirements for testing and calibration laboratories. As part of the conditions, the laboratory frequently partakes in proficiency testing with other similar laboratories. Also, the laboratory follows strict quality assurance and control procedures. Items were soaked, washed with laboratory detergent, and rinsed with deionised water and acetone to minimise potential cross-contamination. The glassware dried overnight in an oven to remove excess water. The items were then removed and allowed to cool and secured in chambers.

Chemical and reagents used for the sample preparation were of high grade. The calibration standards were of high purity (98 - 99 per cent). All analyses were in triplicates, and their means recordings were recorded based on the number of positive samples. The methodology used the procedural blank and quality control material spikes to monitor potential cross-contamination for every batch. This activity gives adequate assurance to the efficiency of the extraction process and monitors the clean-up process. The method detected no analysts of interest in the blank for each extraction procedure.

3.9.7.3 Quantification and Detection Limits Contaminants

The residue levels of target contaminants (ECs) are determined using peak area by the standard external technique. The measurements were within the linear range of the appropriate detector. A mixture of the selected contaminants' content was run, and the detector's response for individual EC was established. The peak area whose retention times matched the known contaminants were extrapolated on their appropriate calibration curves to obtain the quantity. The analyses were in triplicates, and the mean content was calculated. The detection limits of the targeted EC were on the extracts of each contaminant.

There was the dilution of the fortified samples by a factor of two for various concentrations. This approach estimates the statistical significance of differences between low-level analyte responses and the combined uncertainties in the analyte and bank recordings. The limit of detection (LOD) for organochlorine and organophosphorus was 0.002 mg/kg. The LOD for synthetic pyrethroids and PAH were both 0.001mg/kg. The LOD for the antimicrobial drugs and the herbicides were 0.01mg/kg.

Recalibration curves run with batches of samples to check the correlation coefficient (above $r^2 > 0.99$). The various internal standard recoveries determined the analytical procedure efficiency (the extraction and clean-up methods). The extraction efficiency for all selected pesticides, PAHs and antimicrobial drugs was satisfactory, with a recovery percentage ranging from 75 % to 120 %. The standards' recoveries ranged between 85 % and 110 % for organophosphorus and 86 -104 % for synthetic pyrethroid pesticides. Between 75 to 110 for organochlorine and 85 -120 for herbicides were the ranges for these contaminants. The PAH showed 87 to 110 % ranges, and the antimicrobial drugs ranged from 89 to 110 %. The recoveries show that the method used was reproducible. The approach did not detect interfering substances. The linearity of compounds was evaluated from a series of standard solutions (0.10 ng/kg).

3.10 Research Design of Social Survey

3.10.1. Sampling Technique and Data Collection

The data collection was in February 2020, and it involved interviewing 350 vegetable farmers, representing about 35 % of the vegetable farmers in the city. The selected farming areas were the Ghana Atomic Energy Commission, Weija, Dzorwulu, Ashiaman, and Korle-bu. The descriptions of the sampling areas are in the subsequent paragraphs.

Ghana Atomic Energy Commission (GAEC) Lands

The GAEC farming area is within the Ga East District of Accra. The site lies within latitudes 5° 6'7"N to 5° 6'9"N and longitude 0° 21'W to 0° 26'W at 64 m above sea level. This area is one of the largest farm sites of the study area (GAMA) located within the GA-East Municipal Assembly (GEMA) of GAMA. It covers about 36 km^2, with one of the largest concentrations of urban vegetable farmers. The land belongs to the Atomic Energy Commission and is therefore classified under government institutional lands. Recently there have been some misunderstandings between the GAEC and other government institutions.

A mutual agreement covers the agricultural operations in the area, formalized with the Ghana Atomic Energy Commission for farming activities. This arrangement is to maintain the land and prevent any nonagricultural encroachment, such as real estate developers. Over the years, the number of farmers engaged in agricultural activities in the area varied. Currently, about 150 farmers are cultivating these sites, with only ten per cent (10 %) being women. The farm owners migrated from the Dzorwulu site, and the other farmhands (labourers) are varied from varying locations.

Weija Farming Site

The Weija farming area is located within the municipal capital of Weija-Gbawe Municipality, located in the southwestern part of Accra. The site lies within longitude 5^o 48 North 5^o 29 North and latitude 0^o 8 ’West and 0^o 30’ West. It lies in the South-Western part of Accra. The farmers are from Tubakrom, Kokrobite, Bortianor and Kasoa; very few are located at Oshiyie and Weija in the Ga South (Weija) Municipality. The areas have a popular and extensive irrigation Scheme.

The Ghana government designed the scheme to pump and sprinkle water to increase productivity and improve farmer incomes. The project has a potential area of 1500 ha, out of which only 220 ha are currently under irrigation. It is located in the peri-urban areas of Accra and was the irrigation system was designed to support the farmers. Farmers typically grow vegetables (okra, pepper, garden eggs, tomatoes, cabbage, lettuce and onions), cassava and maize. The average farm size per farmer is about 0.8 ha.

Dzorwulu

The Dzorwulu sites used for farming cover an estimated 10 ha, with famous residential areas. The Onyasia stream is channelled in this area like a drain (with a similar function) that cuts across the farming sites. Some farmers use this water to irrigate their crops. Some farmers use pipe-borne water; however, water from the drain or smaller drains is channelled into shallow reservoirs (dug-outs). There are about 130 such small ponds on this site. Some are interconnected, and several others are also filled with piped water.

The area served as a model farm for the Ministry of Food and Agriculture (MoFA) in the early 1970s. The agricultural operations in the area are covered by a mutual agreement formalized with the local authorities for farming to maintain the land and prevent any nonagricultural encroachment. Over the years, the numbers of farmers engaged in agricultural activities in the area varied. Currently, about 100 farmers are cultivating these sites, with only ten per cent (10%) being women. The majority of the other farmhands (labourers) are young migrants from neighbouring Burkina Faso. Over the years, some farmers have relocated to other areas.

Korle-Bu

This site is close to Ghana's most prominent medical facility (hospital), the Korle-Bu Teaching Hospital. Many farmers here are hospital staff and include security officers, cleaners, etc., who adopt farming to supplement their salaried incomes. Here, the land belongs to the hospital, and farming occurs under an informal arrangement to keep the area clean and prevent nonagricultural encroachment. In 2008 about 8 ha were cultivated by 70 farmers (all men). The drains running through the hospital compound and staff apartments serve as a substantial water source for agricultural activities.

Ashaiman

Ashaiman Farming area is one of the suburbs of the Greater Accra Region. Located at 5.6931°N, 0.0327°W in the North-East-East of Accra, covering about 80 ha and close to a massive dam. It is located in the peri-urban areas of Accra and close to Tema's industrial area. It is close to the Ashiaman market. The land belongs to the Ministry of Food and Agriculture (MoFA), thus falling under government institutional land. This area's farm owners are from varied cultural and ethnic backgrounds. Farmers typically grow vegetables (okra, pepper, cabbage, lettuce and onions). There are over 160 male-dominated farmers in this location.

Number of Respondents

The number of respondents from each location is in Fig. 3.3. This survey was to determine the factors influencing farmers' adoption of compost. The Investigator and three trained research assistants conducted face-to-face interviews with semi-structured questionnaires (Annex 2A). The questionnaires were pretested before using them. Although the questionnaire's language was English, the discussions were mainly in the respondent's local dialect (Twi, Ewe or Ga).

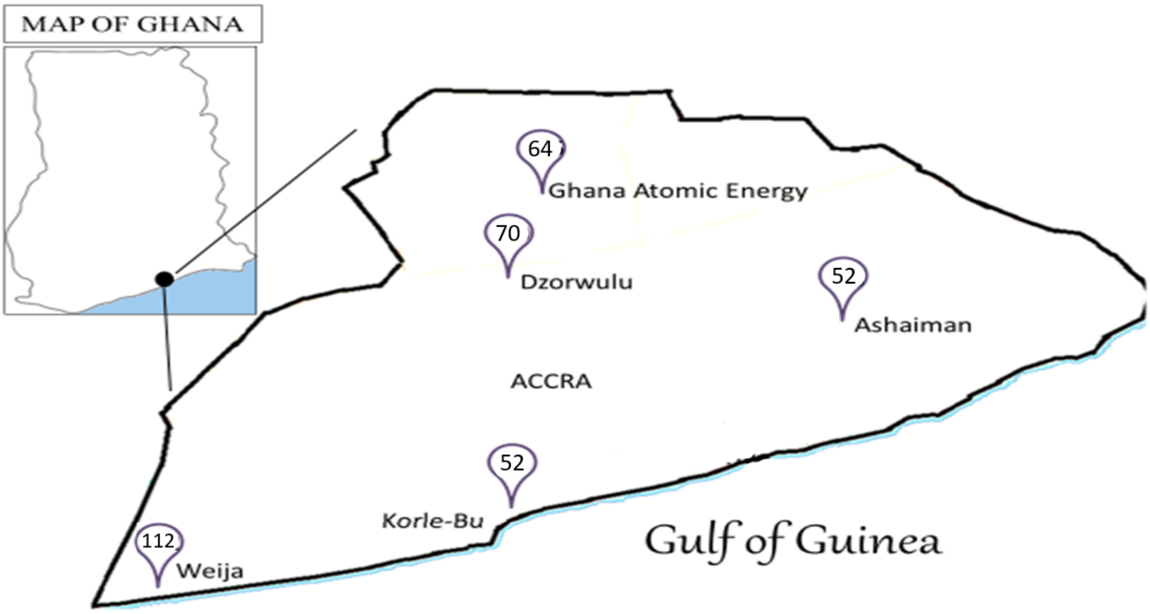

Fig. 3.4 Map of sampling locations indicates the number of respondents from locations

Figure 3.4 shows the targeted farming locations from Accra. The numbers indicate the number of respondents from each area. The highest number of respondents were from Weija (92), followed by Dzorwulu (60) and then the Ghana Atomic Energy farms (56). Forty-eight (48) respondents each from Ashaiman and Korle-bu, The total number of respondents was 350, representing about 35 per cent of the vegetable farmers in Accra.

The questions consisted of open-ended and close-ended types. Some of the options for responses were on a Likert scale, where respondents had to choose the most suitable choice. The questionnaires were in two sections; they included farm-related characteristics such as age, education level, farming experience and land tenure system, household size, farm size, and per capita income. The second was to solicit information on the reasons for using (or not using) composts, socio-cultural factors, perceptions of farmers to compost use. The study also obtained data on potential incentives to facilitate adoptions, quality issues, and safety precautions, among others.

Key Informant Interviews

Additionally, in-depth interviews with twenty key stakeholders complemented the farmer's survey and ascertained their perception of compost adoption and ways to improve compost. The personnel interviewed were from Research and Academic Institutions, including the Ghana Atomic Energy Commission, the International Water Management Institute and the University of Ghana. Other stakeholders included District Assemblies, Ministry of Food and Agriculture, Ghana Lands Commission, Ministry of Water and Sanitation, Ministry of Health and Waste Business Operators. The rest were civil society groups, chiefs, opinion leaders and the media. A checklist guided the discussions. The relevant areas included – knowledge and experience in compost, involvement in composting, merits and demerits of compost, policy barriers with composting, the marketing and health issues with composting, ways of improving the price of compost, among others. The checklist used is in Annex 2B.

Focused Group Discussion

The team conducted focused group discussions (FGD) (Fig 3.4) to collate information from farmers. The investigator conducted four (4) FGDs in the following areas (Ghana atomic, Weija Irrigation farms, Dzorwulu and Ashiaman) with the farmer in the study area. . The number of Participants for the Focus Group Discussion was Weija Irrigation Farms (44), followed by Dzorwulu (34), Ashiaman (25) and then the Ghana Atomic Energy Commission (22)

Fig 3.5: A Section of the Focus Group Discussion

Figure 3.5 shows a section of the focus group discussion at the Ghana Atomic Energy Commission farming area. The person standing is the principal investigator (Maxwell Kogbe) for this study.

The FGD used a checklist (Annex 2C) which guided the discussions. This guide used the general layout of the group discussions and provided the techniques for conducting the sections. Areas covered during the FGD included composting, challenges with composting, socio-cultural and religious issues, and health hazards with compost. During the discussion, a secretary was assigned to record a comment and general observations. The Group discussion was held in English and mixed local languages (Ga, Twi and Ewe).

3.10.2 Analytical Techniques

3.10.2.1 Farmer’s Perception of Compost Use on Vegetable Production

The study determined the perception of farmers on compost adoption using the weighted average index (WAI). This research considered and evaluated ten critical statements (listed below) in table 3.7 to assess farmers' understanding and perception of composting and compost use.

Table 3.7: Statements to understand the perception of farmers on adoption

The use of compost helps solve waste issues
Compost is good for the soil amendment.
Compost gives essential elements to the land
Compost harms the environment
Compost causes odour problems
Compost use can cause problems for human health
Compost use can cause vegetable contamination
Compost brings pest to vegetable
Compost gives low-quality foods
Working with compost is difficult

Mathematically;

$$WAI = \frac{\sum F_i \times W_i}{\mathrm{N}} \quad \ldots\ldots \text{Eq. 3.5}$$

Where Fi is the frequency of response to the ith factor,

Wi is the weight of the ith factor

and N represents the total number of respondents

The study measured the degree of perception on a five-point scale with varying weights; 5 for strongly agree, 4 for agree, 3 for not sure, 2 for disagree and 1 for strongly disagree. The study tested the statistical differences of the WAI of the adopters and the non-adopters using the T-test. An adopter was a sampled farmer in the studied area and must have applied compost regularly on the farm for at least the last three years.

3.10.2.2 Modelling of Factors Affecting the Use of Compost

The model measured a farmer's decision to adopt compost or not as a binary and qualitative variable. This decision may take two forms; adopter (1) and non- adopter (0) in modelling. Since the decision is a dichotomous dependent variable (Y), the probit, specifically the logit, was used (Goswami *et al.*, 2012). This model can explain the estimated probability and falls within 1 and 0. There is also a non-linear relationship between the binary decision and the independent explanatory variables. Studies on introduced technology showed that adoption is a function of several factors. Here, the study hypothesised that various independent factors (Table 3.7) affect Y. There were six and five continuous and discrete variables, respectively. These factors' choice was based on a review of the literature on adoption and from local experts.

First, the study considered farmers' human capital such as age, educational status, farming experience, and access to research/extension officers. Human capital and access to information are critical considerations in technology adoption (Tey *et al.*, 2014). The next category was the size of the farm, the household size and other non-farm activities. These factors, according to Long *et al.* (2016), are critical considerations for technology adoption. The last factors were the sex of the individual, which per local knowledge and experts, are crucial in adoption.

The probit model was

$Y^{*} = \sigma + \delta X_i + U_i$ (1)……………………………………………………………Eq. 3.6

Y* is the probability of a farmer using compost; σ is the intercept; δ is the variables' coefficient; Xi is the vector of the variables in table 1; Ui = random error term with a mean of zero; i = 1.   N

Table 3.8: The description and nature of the explanatory variables used in the probit regression model

Independent variables	Variable name	Description of variables	Type of variable
X_1	Age (yr)	The age of the farmer	Continuous
X_2	Experience (yr)	The number of farming years	Continuous
X_3	Farm Size (ha)	The size of the farms in ha	Continuous
X_4	Proximity(km)	The relative position of farm and source of compost	Continuous
X_5	Household size	The number of people in the household	Continuous
X_6	Per - capita Income	The per – capita income of the farmer	Continuous
X_7	Sex	The sex of the farmer	Dummy
X_8	Education	The farmer has at least a secondary education.	Dummy
X_9	Part-time Farmer	The farmer does other activities.	Dummy
X_{10}	Extension Officers	The farmer had access to extension officers.	Dummy
X_{11}	Training on Compost	The farmer had received specific training on compost use.	Dummy

The study tested eleven farmers' biophysical and socio-economic factors influencing compost adoption. There were six continuous and five discrete variables, as shown in Table 3.7.

3.10.2.3 Cross-tabulation Among the Predictor Variables

There was a cross-tabulation of the predictor variable with each other. This approach involved running a multi-varied interaction of the eleven variables (socio-economic and biophysical). The approach also involves performing the ward test. The Wald test deduced which model variables were contributing something significant. If the Wald test shows that the parameters for particular explanatory variables are zero, the variable can be removed from the model. Mathematically the equation for the model is expressed is

logit(p) = -1.511 + (0.121 × Age-sex) + (-0.169 × Age-location) + (0.333 × Age-training) +…..n. ………………………………………………………………………..Eq 3.7

3.11 Statistical Analysis

Data collected from this study were analysed using the GentStat (12th Edition). This software-generated means of contaminants (pesticides, PAHs and antimicrobial drugs) and the physicochemical parameters. Analysis of variance (ANOVA) was used to test the significant similarities and differences between contaminants from the composting feedstock and the subsequent compost from the three waste sources (MWMW, SSMW and MAW). This analysis tested the normality of samples using the Shapiro-Wilk test before conducting the ANOVA. Differences that resulted in $p \leq 0.05$ were considered significant.

In the social survey, the study used the statistical package to calculate the descriptive statistics. These statistics included the percentages, frequencies, means and weighted averages for ease of understanding of variables. The logit probit model predicted the eleven physical and socio-economic variables influencing compost adoption. A multi-interactive regression model was used to examine the variables capable of affecting the frequency of compost adoption. The study regarded a $p < 0.05$ as statistically significant.

3.12 Institutional Approval and Ethical Considerations

The College of Basic and Applied Science of the University of Ghana's ethical clearance committee gave ethical clearance (Annex IV) before the study's commencement. Also, team members sought permission from Opinion Leaders, Compost Facility Operators, and Participants consent before being included in the study. The approval included the laboratory analysis, the experimental setup and the field survey. The investigator and the team described all procedures and the confidentiality of the procedures to all the respondents and other relevant authorities.

3.12.1. Inclusion and Exclusion Criteria

All composting facilities and respondents within the study area were included, and the study excluded operators and farmers not prepared to be part of the research. The methodology excluded minors (less than 18 years) from participation.

3.12.2 Access and Approval of Study Area

The Investigator visited the study area to notify the appropriate authorities about the intention to conduct the study. An introductory letter was obtained from the Institute for Environment and Sanitation Studies, University of Ghana, to Opinion Leaders and Composting Operators of selected facilities for permission to conduct the research. Subsequently, the author gave copies of the UG ethical approval to opinion leaders, facility operators, and other relevant authorities.

3.12.4 Data Storage and Usage

Data collected in this study were for research purposes only. The data were passwords protected on electronic media and other documents in safe locks. The team ensured findings from this study was confidential as their names of respondents and composting facilities were not published.

3.14.5 Training of Enumerators

Six field enumerators were trained using a detailed training protocol in January 2020. The content of the training includes but was not limited to the following; the aims and objectives of the study, way of seeking an appointment, manners and etiquette, the requirements of social research, detailed instructions on the stated questions, expected duration of the face-to-face sections, expected difficult situation among others. The enumerators were familiar with the study area's primary language (Twi, Ga, Ewe). The training took five days, and the trainees were evaluated at the end of the course — selecting three enumerators for the study, with the rest acting as backup staff.

3.12.5 Privacy and Confidentiality of Respondents

There was coding of the questionnaires and the facilities used in this study to ensure privacy and confidentiality. Individual interviews were in a secluded area for privacy and confidentiality purposes. Participants did not mention their names during the discussions, and all information gathered on participants, and the various composting facilities were kept strictly confidential.

3.12.6 Compensation to Participants

There was no compensation for the study participants. This declaration was made known to them before they were enrolled. However, some participants were given snacks (water, drinks, and biscuits) after administering the questionnaires and group discussions.

3.12.7 Risks and Benefits of the Study

The study did not involve invasive risks; however, facility operators might have felt uncomfortable assessing their facilities, resulting in minimal privacy and confidentiality loss. The questionnaire time may be of concern to some respondents. This study did not directly benefit participants; authorities of the district assembly and other institutions would receive the study's findings to improve compost production and use in their communities.

3.12.8 Voluntary Withdrawal from the Study

Participation in this study (Facility Operators and Social Survey) was not mandatory, and participants were at liberty not to answer any particular question(s). Also, the Participants had the right to withdraw without prior notice. However, participants were encouraged to participate in the study thoroughly. This approach was to ensure a non-biased outcome of the study. In the event of withdrawal by a participant, researchers deleted all data gathered on that individual. Critical issues explained to respondents involving voluntary withdrawal and participation included: assurance of zero risks to participants during the study and the respondent's freedom to withdraw without any explanation or sanctions.

3.12.9 Informed Consent and Consenting Process

Before the commencement of data collection, the Principal Investigator sought the informed consent of participants. The investigators approached study participants approached, and explained the aim, objectives and process of this research. The decision to be involved was voluntary, and their refusal did not affect the relationship between the participant(s) and the researcher. Respondents signed a copy of the written consent form after explaining the purpose and process.

3.12.10 Declaration of Conflict of Interest

There was no conflict of interest on the part of the Principal Investigator. However, the author conducted this research to fulfil the University of Ghana's requirements for a PhD in Environmental Science at the Institute for Environment and Sanitation Studies. The principal investigator (Maxwell Kogbe) with this declares no conflict of interest.

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction of Study Results

This chapter presents the study's results. It is divided into four broad sections. The first section summarises the results of the targeted emerging contaminants in feedstock and compost. The second section presents the various computation of the initial screening assessment and risk calculation of the quantified ECs. The next is the result obtained after the vegetable (lettuce and carrot) analysis after planting with compost of known ECs content. The last section presents the rate of compost adoption, perception of compost adoption on compost use, outcomes of KPI and FGD, safety precautions on compost use, the various socioeconomic and biophysical factors influencing compost, and the multi-interaction of the factors affecting adoption.

4.2 Pesticide Residues Levels in the Feedstock and Compost from the Waste Sources

Samples analysed showed ten pesticide residues; chlorpyrifos, lambda-cyhalothrin, glyphosate, atrazine, and triclopyr. Others were three isomers of hexachlorocyclohexane (beta-HCH, gamma-HCH, delta-HCH). Additionally, methoxychlor and cyfluthrin residues were found only in compost feedstock from the waste sources; MWMW, SSMW, and MAW. The results showed that 40 % of these pesticides belonged to the organochlorine group (Fig. 4.1). The other pesticides were synthetic pyrethroids (Fig. 4.2) and organophosphates pesticides (Fig 4.3), representing 20 % and 10 %, respectively. The rest (30 %) belonged to classes of pesticides broadly used as herbicides (Fig. 4.4).

4.2.1 Organochlorine Residue in the Composting Feedstock and Compost

The organochlorine pesticides detected were three isomers of hexachlorocyclohexane (beta-HCH, gamma-HCH, delta-HCH). There was no significant difference ($p > 0.05$) within isomers of HCH quantified in this study. Also, methoxychlor was present in the composting feedstock. The content of methoxychlor was low compared to the other organochlorines ($p < 0.05$).

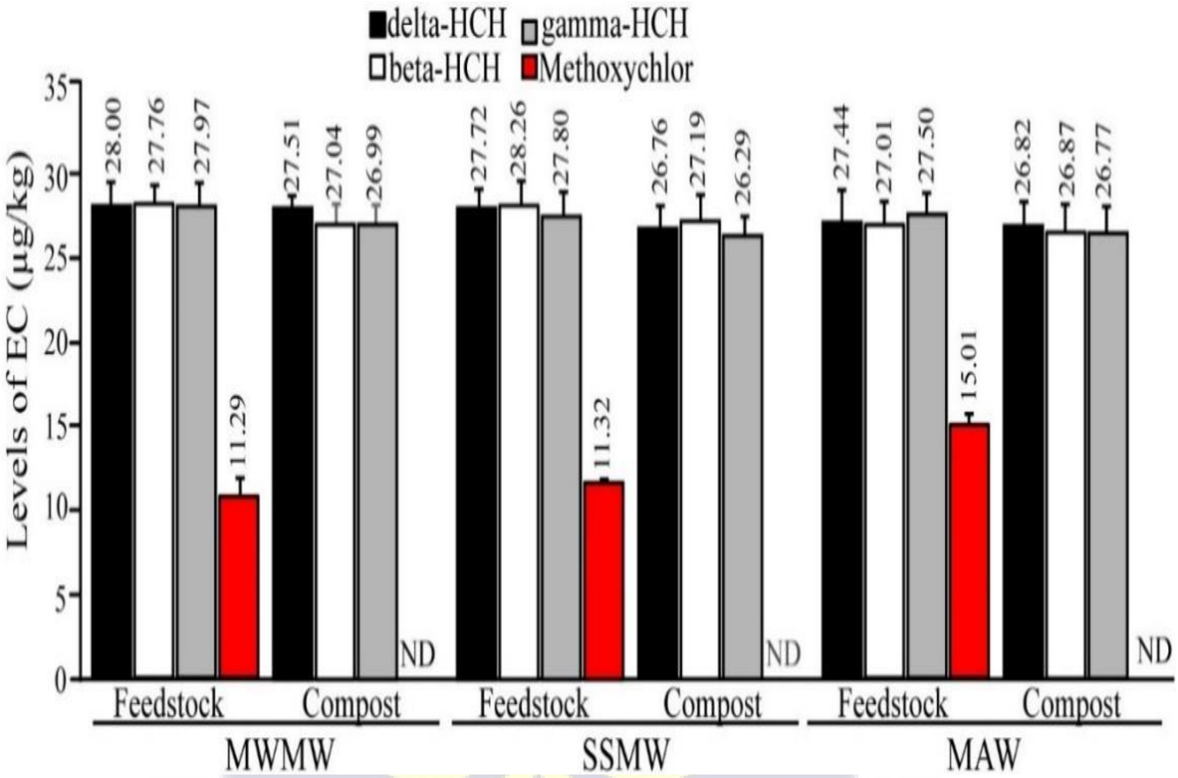

Fig 4.1 Organochlorine Concentration of Feedstock and Compost Sourced from the Waste Facilities in Accra.

Legend: Vertical bars indicate standard deviations of the mean EC content at 95 % intervals. ND: not detected.

Delta-HCH residues were present in feedstock and the compost from the three sources with a narrow range of 26.82 µg/kg to 28.00 µg/kg. The delta-HCH concentration in feedstock was 28.00 while the resultant compost was 27.51 for MWMW. In SSMW, delta-HCH feedstock was 27.72 µg/kg and 26.76 µg/kg for compost. A similar trend for MAW samples, where the mean residual level in the feedstock was 27.44 µg/kg and that in the compost was 26.82 µg/kg.

The residue of beta-HCH was in the feedstock and compost from the different waste sources. The levels in the feedstock were 27.76 µg/kg, 28.26 µg/kg and 27.01 µg/kg for MWMW, SSMW and MAW, respectively. The compost was 27.04 µg/kg for MWMW, 27.19 µg/kg for SSMW and 26.89 µg/kg for MAW. The range for the residue in both feedstock and compost was narrow.

For gamma-HCH, the mean residue level in the feedstock and the compost from the three sources also showed a narrow range (26.29 to 27.97 µg/kg). For MWMW, the feedstock was 27.97 µg/kg, and the resulting compost was 26.99 µg/kg. In SSMW, gamma-HCH, feedstock was 27.80 µg/kg and 26.29 µg/kg in the compost. The trend was similar to the MAW samples, where the mean residual level in the feedstock was 27.50 µg/kg) and compost was 26.77 µg/kg.

The concentration of methoxychlor in the feedstock ranged from 11.29 µg/kg to 15.01 µg/kg in the feedstock. The residual level recorded in feedstock from MAW was 15.01, and MWMW was 11.29 µg/kg. The methoxychlor concentration in feedstock from SSMW was 11.32 µg/kg. The compost samples did not contain methoxychlor residue from the three waste sources.

4.2.2 Synthetic Pyrethroid Residue in the Composting Feedstock and Compost

The results showed residual lambda-cyhalothrin and cyfluthrin in all the feedstock materials from the three facilities. However, cyfluthrin residues were not detected (ND) in any three facilities' compost samples. Also, lambda-cyhalothrin was not present in the composting feedstock from the MAW composting facility (Fig 4.2).

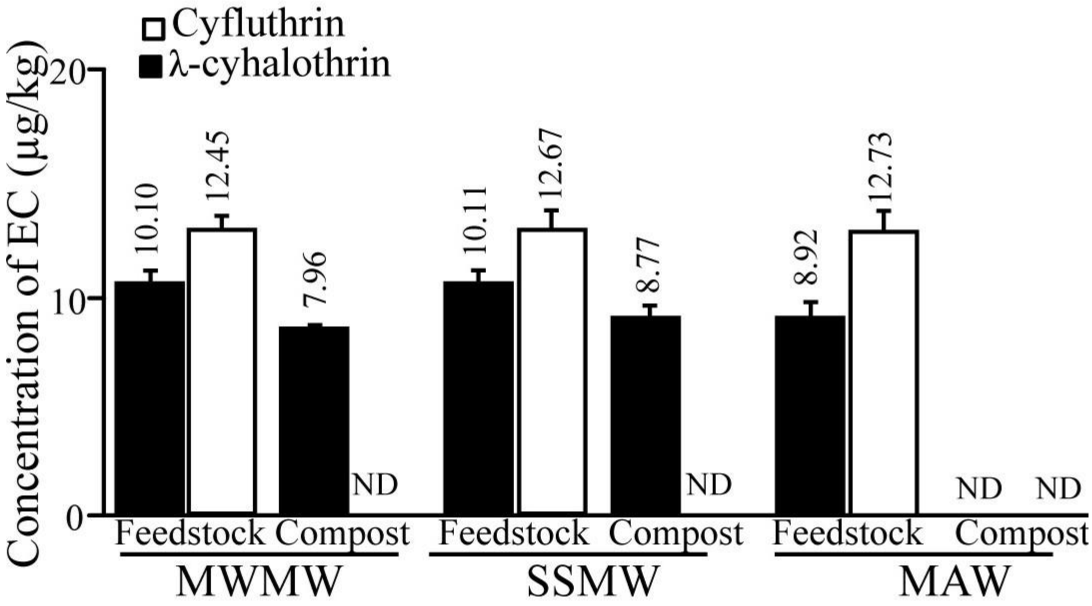

Fig 4.2 Synthetic Pyrethroid Concentration of Feedstock and Compost Sourced from the Waste Facilities in Accra..

Legend: Vertical bars indicate standard deviations of the mean EC content at 95 % intervals. ND: not detected.

Lambda-cyhalothrin residue was detected in the sample ranging from non-detection to 10.11 µg/kg. The levels in compost were; 8.77 µg/kg for SSMW and 7.96 µg/kg for MWMW) and the feedstock was: 10.11µg/kg for SSMW and 10.10 µg/kg MWMW, and 8.92 µg/kg for MAW. Lambda-cyhalothrin was not detected in the compost from MAW.

The results showed that the mean cyfluthrin residue level detected in feedstock from the facilities was 12.45 µg/kg, 12.67 µg/kg, 12.73 µg/kg, respectively. Cyfluthrin residues were not detected in the compost from the three waste facilities (MWMW, SSMW and MAW) samples.

4.2.3 Organophosphate Residue in the Composting Feedstock and Compost

The samples' results showed the presence of only one organophosphate pesticide; chlorpyrifos. The chlorpyrifos concentration ranged from 26.08 µg/kg to a maximum of 28.42 µg/kg. The mean chlorpyrifos level in the compost from MWMW (26.76 µg/kg) and the same facility's feedstock sample was (27.78 µg/kg). A similar trend was for the residual levels in the compost feedstock from the SSMW and MAW facilities. The chlorpyrifos level in the feedstock was 28. µg/kg, and compost was 26 µg/kg. A similar trend was observed in the MAW samples. The results are displayed in Fig 4.3

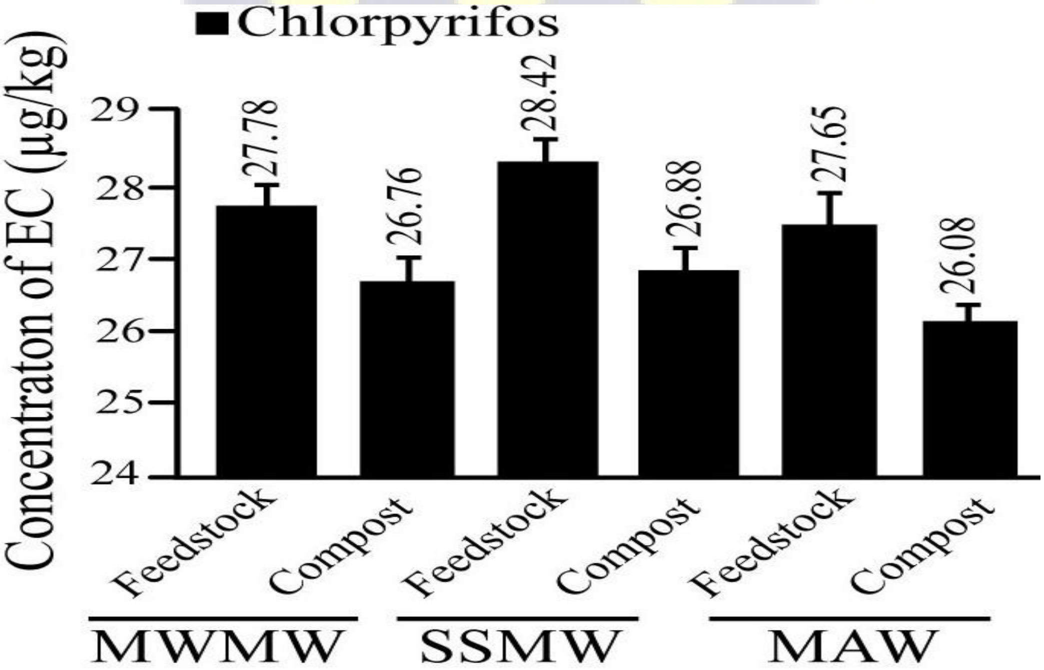

Fig 4.3 Organophosphate Concentration of Feedstock and Compost Sourced from the Waste Facilities in Accra

Legend: Vertical bars indicate standard deviations of the mean EC content at 95 % intervals.

4.2.4 Other Pesticide Residue in the Composting Feedstock and Compost

Glyphosate, atrazine and triclopyr are the pesticides broadly described as herbicides identified in this study. The three herbicide residues were detected from the three waste sources and compost samples (Fig 4.4). Glyphosate was the highest, followed by atrazine and then triclopyr. There were significant differences within the feedstocks. Also, there were statistical differences ($p < 0.05$) within the three residues in the compost.

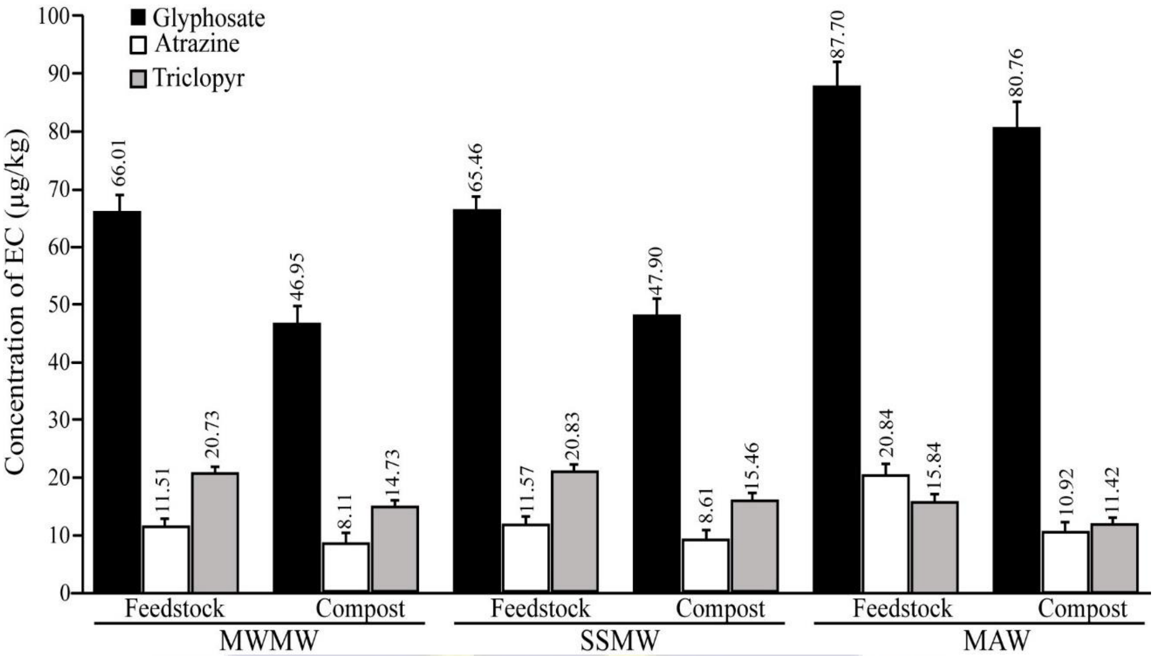

Fig 4.4 Herbicide Concentration of Feedstock and Compost Sourced from the Waste Facilities in Accra.

Legend: Vertical bars indicate standard deviations of the mean at 95 % intervals

Glyphosate recorded the highest mean concentration among the herbicides studied. The concentration ranged between in the feedstock samples 47.90 µg/kg and 87.70 µg/kg. For feedstock samples, glyphosate residues recorded were 66.01 µg/kg, 65.46 µg/kg and 87.70 µg/kg for MWMW, SSMW and MAW facilities, respectively MAW samples recorded the highest mean residue level of 80.76 µg/kg for the compost, followed by SSMW (47.90 µg/kg) and MWMW (46.95 µg/kg). The level in the MAW was statistically different

The Atrazine concentration in the compost was in the order: of MWMW (8.10 µg/kg), followed by SSMW (8.61 µg/kg) and MAW (10.92 µg/kg. The atrazine level in feedstock from the MAW was 20.84 µg/kg, and SSMW was 11.57µg/kg. The atrazine level recorded in feedstock from MWMW was 11.50 µg/kg. The range for atrazine was narrow.

Triclopyr residues ranged between 11.42 µg/kg and 20.83 µg/kg. Triclopyr concentration was lower in the compost (14.73 µg/kg) than in the feedstock (20.73 µg/kg) for MWMW A similar pattern was in samples from SSMW, where the mean residual level in the compost (15.46 µg/kg) was lower than the feedstock level (20.83 µg/kg). For MAW, the triclopyr was higher in the feedstock (15.84 µg/kg) than in the compost (11.42). Triclopyr concentration in samples from SSMW (15.46 µg/kg) was recorded the highest for all the compost from the three sources.

4.3 Levels of Polycyclic Aromatic Hydrocarbons in the Compost and Feedstock

Thirteen of the PAHs in the compost and feedstock collected from the MWMW, SSMW and MAW sources were listed in the USA EPA priority list. The non-detected PAHs were naphthalene, benzo[k]fluoranthene and dibenz[a,h]anthracene. The identified hydrocarbons were classified into three groups according to their number of aromatic rings as low molecular weight (LMW), medium molecular weight (MMW) and high molecular weight (HMW). The values obtained are as presented in Fig. 4.5 (LMW), Fig 4.6 (MMW) and Fig. 4.7 (HMW).

4.3.1 Polycyclic Aromatic Hydrocarbons with Low Molecular Weight (3 rings) in the Composting Feedstock and Compost

The low molecular LMW PAH identified were acenaphthene, acenaphthylene, and anthracene and fluorene. The PAH concentration in the compost and feedstock ranged between18.33 µg/kg to 86.87 µg/kg (Fig. 4.5), with Acenapthene recording the lowest value. Fluorene content was the highest recorded. These were statistically significant at $p < 0.05$.

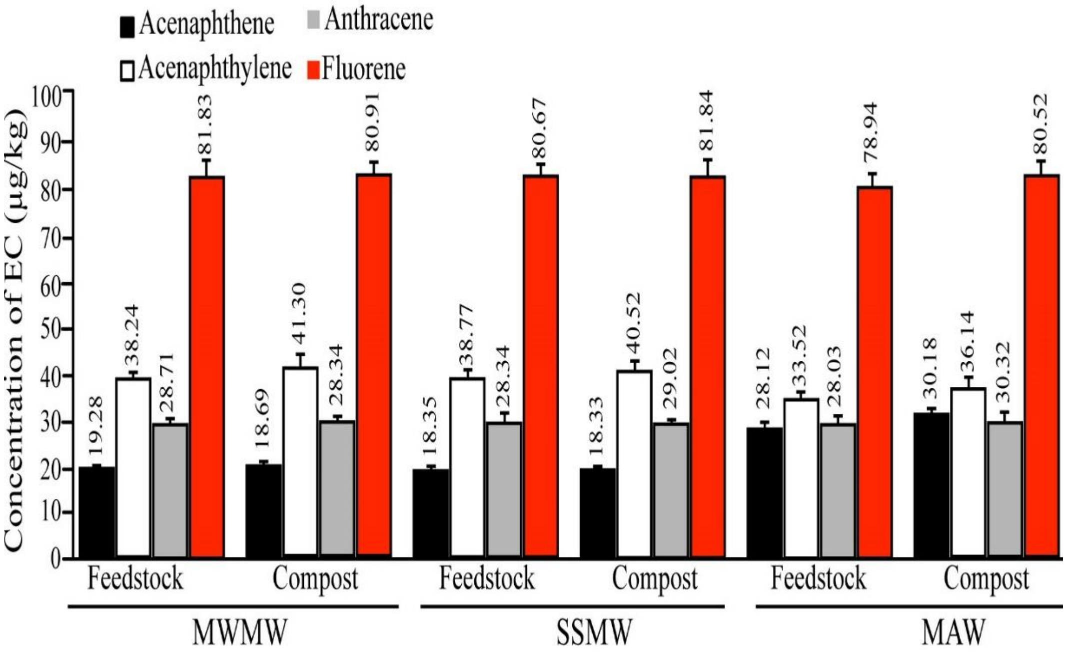

Fig 4.5 Concentration of LMW PAH Feedstock and Compost Sourced from the Waste Facilities in Accra.

Legend: Vertical bars indicate standard deviations of the mean at 95 % intervals.

The samples recorded the presence of Acenaphthene ranging from 18.33 µg/kg to 30.18 µg/kg Acenaphthene in compost from SSMW was 18.33 µg/kg, and feedstock was 18.35. A similar trend was observed for MWMW, feedstock (19.28 µg/kg) and compost (18.69 µg/kg). MAW's compost and feedstock levels were 30.18 µg/kg and 28.12 µg/kg, respectively.

Acenaphthylene concentration in the feedstock ranged from MAW (33.52 µg/kg) to SSMW (38.77 µg/kg) in the waste sources. The lowest level of acenaphthylene in the compost was observed at MAW (36.14 µg/kg), followed by SSMW (40.52 µg/kg) and MWMW (41.30 µg/kg). Among the feedstock, Acenaphthylene was lowest at MAW (33.52µg/kg), followed by MWMW (38.24 µg/kg) and then SSMW (38.77 µg/kg).

The mean anthracene residues in the feedstock from MWMW was 28.70 µg/kg, and the compost was 28.34 µg/kg. The levels in SSMW were 28.34 µg/kg for feedstock and 29.02 µg/kg for compost. The mean value in MAW of 28.03 µg/kg for feedstock and 30.32 µg/kg for compost. Among the feedstock, anthracene was lower at MAW (28.03 µg/kg), followed by SSMW (28.35 µg/kg) and MWMW (28.70 µg/kg). Anthracene was highest in compost from MAW (30.32 µg/kg).

The mean concentrations of fluorene in feedstock and compost were significantly ($p < 0.05$) higher than the other lower molecular weight PAHs. It ranged from a minimum of 78.94 µg/kg to a maximum of 81.84 µg/kg. Fluorene concentration in MWMW feedstock was 81.83 µg/kg, and compost was 80.91 µg/kg. The lowest level of fluorene in SSMW feedstock was 80.67 µg/kg, and compost was 81.84 µg/kg. A similar trend was observed in residues from MAW, where feedstock recorded values of 78.94 µg/kg and compost was (80.52 µg/kg).

4.3.2 Polycyclic Aromatic Hydrocarbons with Medium Molecular Weight (4 rings) in the Compost and Feedstock

The MMW PAH that were found in the from the three waste source were Fluoranthene, chrysene, benzo[a]anthracene and pyrene (Fig. 4.6). The concentrations of these MMW PAHs ranged from 20.79 µg/kg to 98.36 µg/kg.

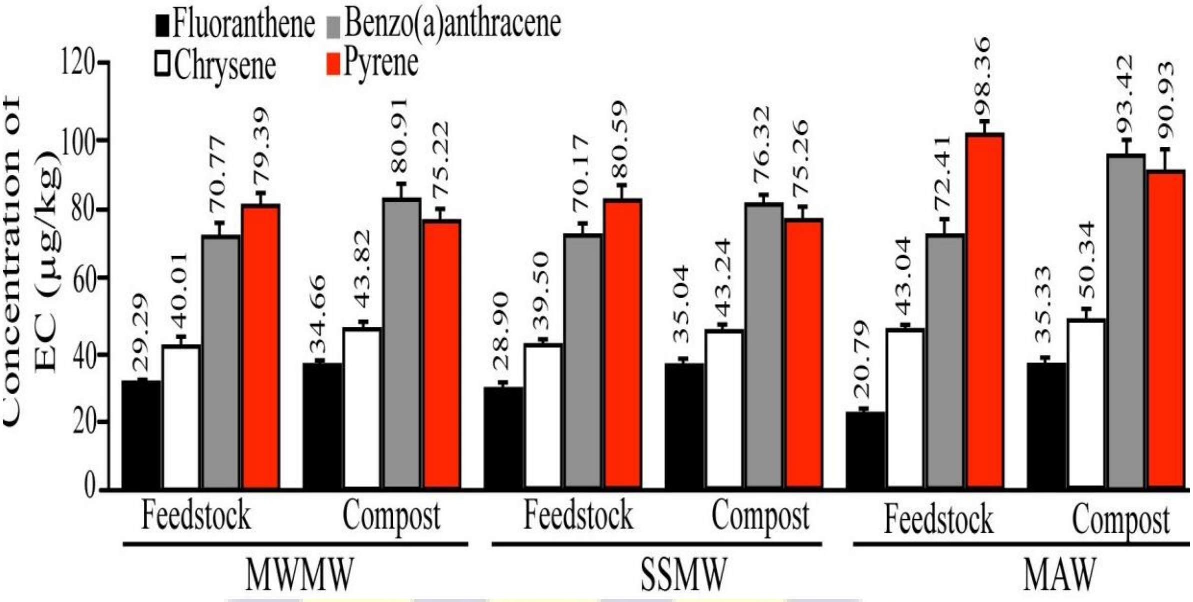

Fig 4.6: Concentration of MMW PAH Feedstock and Compost Sourced from the Waste Facilities in Accra.

Legend: Vertical bars indicate standard deviations of the mean EC content at 95 % intervals. ND: not detected.

The fluoranthene level was lower in the feedstock from MWMW (29.92 µg/kg) than in the same facility compost (34.66 µg/kg). A similar trend was observed in the other facilities. The fluoranthene residues in SMSM were feedstock (28.90 µg/kg) and compost (35.04 µg/kg). The feedstock levels at MAW were 20.79 µg/kg, and the compost was 35.33 µg/kg. Fluoranthene in compost was lowest at MWMW (34.66 µg/kg), followed by SSMW (35.04 µg/kg) and MAW (35.33 µg/kg).

The levels of chrysene concentrations were significantly lower ($p > 0.05$) in the feedstock than in the compost at all composting facilities. Chrysene level in compost from SSMW (43.24 µg/kg) was lower than the level in the form MWMW (43.82 µg/kg) but highest in compost from MAW (50.34 µg/kg). The level in the feedstock was 40.01 µg/kg, 39.50 µg/kg, and 43.04 µg/kg, respectively for MWMW, SSMW and MAW.

Benzo (a) anthracene concentrations were lower in the feedstock than in the compost at all three waste facilities. For benzo (a) anthracene, the lowest concentration was recorded in feedstock from SSMW (70.17 µg/kg), followed by MWMW (70.77 µg/kg) and MAW (72.41 µg/kg). The lowest concentration was recorded in compost from SSMW (76.23 µg/kg), followed by MWMW (80.91 µg/kg) and MAW (93.42 µg/kg) composting facilities.

The analysis showed significantly higher pyrene levels in the feedstock than in the compost from all the facilities. Generally, the levels from the facilities were high compared to the other three medium molecular weight PAHs. The residual concentrations ranged from a minimum of 75.22 µg/kg to a maximum of 98.36 µg/kg. The values in the compost were 75.22 µg/kg, 75.26 µg/kg and 90.93 µg/kg for MWMW, SSMW and MAW, respectively, while the levels in the feedstock were 79.39 µg/kg for MWMW, 75.26 µg/kg for SSMW and 98.36 µg/kg for MAW compost facilities.

4.3.3 Polycyclic Aromatic Hydrocarbons with High Molecular Weight (5-6 rings), in the Composting Feedstock and Compost

Five higher molecular weight PAHs were in the compost feedstock and compost. This included phenanthrene, benzo (a) pyrene, benzo [g,h,i]perylene and indeno (1,2,3,c,d) pyrene, benzo (b) fluoranthene and are given in Fig. 4.7. Benzo[g,h, i]perylene levels were the highest.

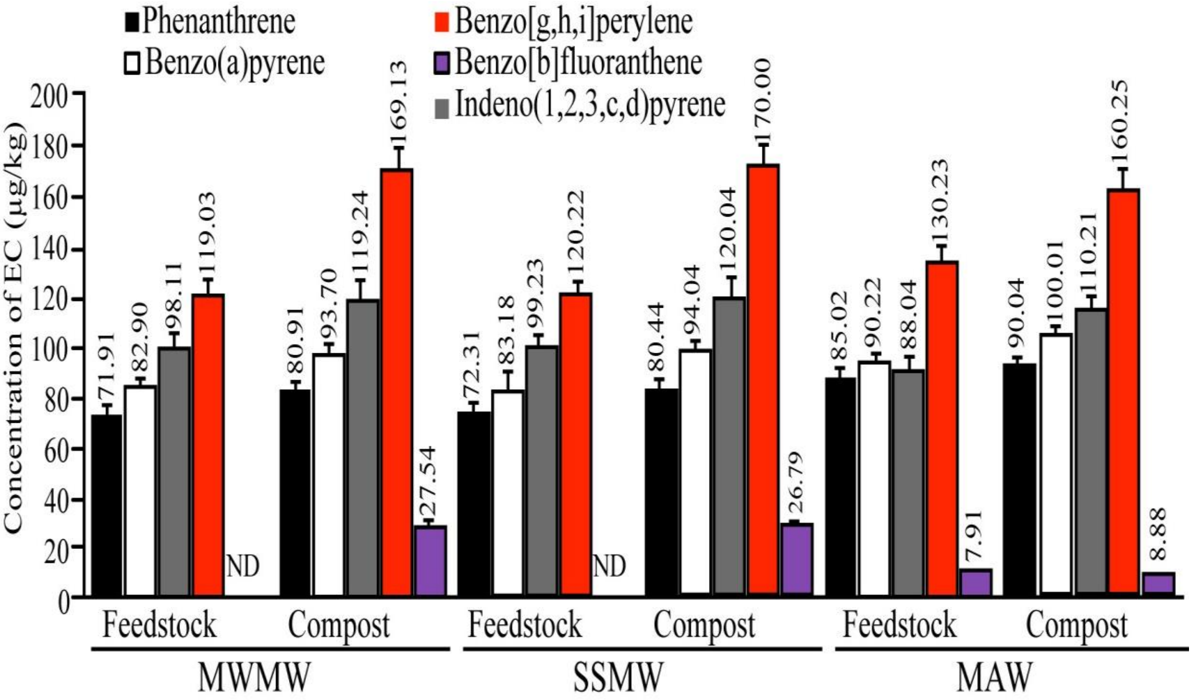

Fig 4.7 Concentration of HMW PAH Feedstock and Compost Sourced from the Waste Facilities in Accra

Legend: Vertical bars indicate standard deviations of the mean EC content at 95 % intervals. ND: not detected.

Phenanthrene concentration was generally higher in the compost compared to the feedstock level. The concentration of Phenanthrene was lowest in the feedstock at MWMW (71.91 µg/kg) and highest at MAW (85.02 µg/kg). The levels in feedstock from SSMW was 72.31 µg/kg. The lowest level of Phenanthrene in the compost was observed at SSMW (80.44 µg/kg), followed by MWMW (80.91 µg/kg) and MAW (90.04 µg/kg).

Benzo(a)pyrene level in the feedstock from MWMW (82.90 µg/kg) was least compared to compost levels from the same facility (93.70 µg/kg). A similar trend was observed for benzo (a)pyrene levels in samples from the SSMW and MAW waste sources, where the feedstock levels were lower than those in the compost. Among the feedstock, benzo (a)pyrene was the least at MWMW (82.90 µg/kg), followed by SSMW (83.18 µg/kg) and MAW (90.20 µg/kg). Benzo(a)pyrene was highest in compost from MAW (100.01 µg/kg) source.

For Indeno (1,2,3,c,d) pyrene, the concentration ranged between 88.04 µg/kg and 120.04 µg/kg and was lower in the feedstock than in the compost at all facilities. Concentrations in feedstock were lowest at MAW (88.04 µg/kg). The feedstock recorded 98.11 µg/kg for MWMW and 99.23 µg/kg for SSMW. The compost concentration was lowest from 110.21 µg/kg (MAW) to 119.24 µg/kg (MWMW) and then 120.04 µg/kg (SSMW).

Benzo[g,h,i]perylene concentration in feedstock was lowest at MWMW (119.03 µg/kg), followed by SMW (120.22 µg/kg) and MAW (130.23 µg/kg). The concentration in the compost was 160.13 µg/kg 170.00 µg/kg and 160.25 µg/kg for MWMW, SSMW and MAW, respectively.

Benzo[b]fluoranthene levels in the materials were the least recorded among all the identified HMW PAHs analysed. Also, it was the least among all the 16 US priority PAH targeted in this study. The contents were lower in the feedstock than in the compost for each facility. In the feedstocks, benzo[b]fluoranthene concentration was below the detection levels except for the MAW sample (7.91 µg/kg). The levels in the compost were highest in MWMW (27.54 µg/kg), followed by SSMW (26.79 µg/kg) and then MAW (8.88 µg/kg).

4.4 Antimicrobial Drugs Residues in the Feedstock and Compost

This study tested antimicrobial drug residues in composting feedstock and compost samples from the three facilities. The residues include; amoxicillin, danofloxacin, sulfadiazine, ciprofloxacin, amprolium and metronidazole. The various residue concentrations recorded in µg/kg from three waste sources are recorded. Metronidazole was not in feedstock and compost from the three sources. Amprolium, amoxicillin and sulfadiazine were also not detected in the compost. However, ciprofloxacin and danofloxacin were present in feedstock and compost from all waste sources. Fig. 5.8 displays all the targeted antimicrobial drugs from the three waste sources (MWMW, SSMW and MAW).

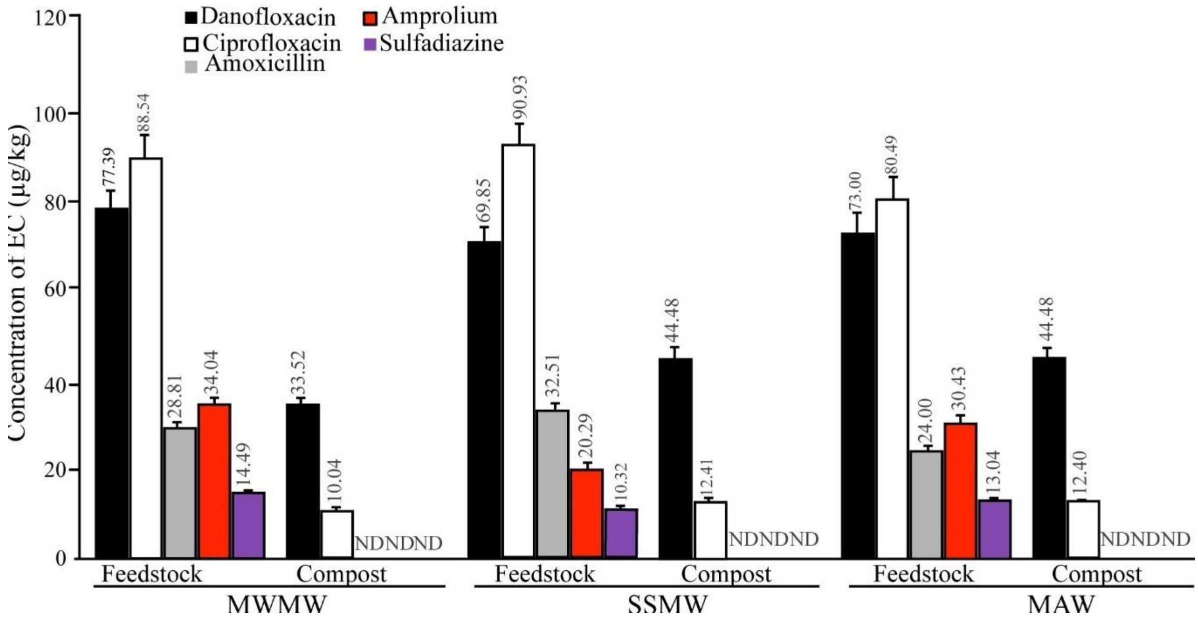

Fig 4.8 Antimicrobial Drugs Concentration of Feedstock and Compost Sourced from the Waste Facilities in Accra

Legend: Vertical bars indicate standard deviations of the mean EC content at 95 % intervals. ND: not detected.

Feedstock and compost from MWMW, SSMW and MAW showed Danofloxacin. For the feedstock, samples from SSMW recorded the least mean concentration of 69.85 µg/kg, followed by MAW (73.00 µg/kg) and MWMW (77.39 µg/kg). Danofloxacin residues in the compost ranged from 33.52 µg/kg to 44.48 µg/kg. The compost samples recorded the lowest residue level from MWMW. Danofloxacin levels were significantly higher ($p <$ 0.05) in the compost than in the feedstock for the facilities studied.

The samples (feedstock and compost) detected ciprofloxacin from the three composting sources (Fig. 5.8). The mean residual levels of ciprofloxacin hydrochloride in feedstock were 88.54 µg/kg, 90.93 µg/kg and 80.49 µg/kg MWMW SSMW and MAW, respectively. Ciprofloxacin hydrochloride residues in the compost reduced compared to the compost materials; 10.04 µg/kg for MMW, 12.41in µg/kg (SSMW) and 12.40 µg/kg for MAW. Compost from MWMW recorded the least mean concentration (10.04 µg/kg).

Fig. 5.8 shows the mean levels of amoxicillin residues in the feedstock from MWMW, SSMW, and MAW sources. Amoxycillin residue in feedstock from SSMW recorded the highest mean concentration of 32.51 µg/kg. Feedstock from MAW recorded the lowest amoxicillin residue concentration (24.00 µg/kg). The residues were not detected in the compost.

All feedstock samples tested positive for amprolium residue. The mean concentrations ranged from 20.29 µg/kg to 34.04 µg/kg. The concentration of amprolium residue was highest in feedstock from MWWW (34.04µg/kg). Amprolium in feedstock from SSMW (20.29 µg/kg) was lower than the concentrations in feedstock from the MAW (30.43 µg/kg). All the feedstock did not detect amprolium residues from the various waste sources.

Sulfadiazine concentrations were present in feedstock samples obtained from the three waste sources. Feedstock from SSMW recorded the least mean concentration of 10.32 µg/kg, followed by feedstock from MAW (13.04 µg/kg) and MWMW (14.49 µg/kg). The study did not record sulfadiazine residue from the three (3) composting facilities in any compost.

4.5 The Maximum Concentration of EC in Compost from the Waste Source

In this study, the maximum concentration for each ECs in the compost was for the screening assessment (compared to the ecological and human health guidelines). Tables 4.1 to 4.3 presents the maximum concentration of each contaminant. The maximum concentration of pesticides from the three waste sources is shown in Table 4.1.

Table 4.1 Maximum concentration of Pesticides (mg/kg) sourced from selected Composting Facilities in Accra

	MWMW	SSMW	MAW
delta-HCH	0.040	0.049	0.038
beta-HCH	0.028	0.028	0.024
gamma-HCH	0.024	0.022	0.018
Cyfluthrin	ND	ND	ND
λ-cyhalothrin	0.017	0.016	0.014
Chlorpyrifos	0.056	0.066	0.043
Glyphosate	0.076	0.068	0.097
Atrazine	0.020	0.018	0.024
Triclopyr	0.021	0.019	0.025

NB: Maximum recorded of each contaminant for the initials screening for further assessment.

Table 4.2 Maximum concentration of PAH (mg/kg) soured from selected composting facilities in Accra

	MWMW	SSMW	MAW
Acenaphthylene	0.045	0.042	0.033
Acenaphthene	0.034	0.031	0.029
Fluorene	0.090	0.100	0.084
Anthracene	0.029	0.031	0.036
Fluoranthene	0.038	0.037	0.041
Chrysene	0.046	0.044	0.051
Benzo(a)anthracene	0.080	0.088	0.100
Pyrene	0.088	0.080	0.099
Phenanthrene	0.089	0.096	0.100
Benzo[b]fluoranthene	0.030	0.028	0.015
Benzo(a)pyrene	0.101	0.105	0.115
Benzo[g,h,i]perylene	0.177	0.181	0.172
Indeno(1,2,3,c,d)pyrene	0.122	0.130	0.121

Table 4.3 Maximum concentration of antimicrobial drugs (mg/kg) sourced from selected composting facilities in Accra

	MWMW	SSMW	MAW
Danofloxacin	0.046	0.051	0.059
Ciprofloxacin	0.014	0.011	0.015

4.6 Identification of Preliminary Contaminants of Potential Concern for Risk Assessment

Following the application of composts with ECs (pesticides, PAHs and antimicrobial drugs), there is the likely ecological and human receptors to be exposed directly to the soil where the composts are applied. Therefore, this study assessed the key contaminants that may pose risks following compost application to the land. The study evaluated direct human and ecological receptors, particularly plants.

Currently, there is no established criterion for ECs in compost in Ghana. Therefore, the study adopted standards from other countries. The ASC NEPM (NEPC, 2013) was the source of criteria to evaluate the human health risk after exposure to the composts or soil amended with the composts containing ECs. This source provides risk-based HSLs for land-use scenarios. The Ecological Screening Levels (ESLs) for terrestrial ecosystems sourced from the ECOTOX database (US EPA, 2007) were the source document to assess the plants' receptors' impacts. The US EPA based the ecological screening levels on toxicity to plants.

Tables 4.4 to 4.7 present preliminary risk assessments of the ECs to identify a priority list of CPC that will potentially pose environmental (plants) and human health risks at compost location sites. The approach involved comparing to the maximum concentration (Tables 4.1 to 4.3) recorded from objective one. The initial screening for the ecological and human health impact for the pesticide contaminants is in Table 4.4.

Table 4.4: Initial Screening Assessment of Pesticide and Identifying Contaminants of Potential Concern Assessment

Analytes	Maximum conc. (mg/kg)	ESL		HSL	
		Criteria conc. (mg/kg)	CPC	Criteria conc. (mg/kg)	CPC
Atrazine	0.024	NS	-	320[a]	no
λ-cyhalothrin	0.017	NS	-	NS	-
Cyfluthrin	0.017	NS	-	NS	-
gamma-HCH	0.024	0.004[b]	yes	NS	-
Triclopyr	0.025	NS	-	NS	-
delta-HCH	0.049	0.004[b]	yes	NS	-
beta-HCH	0.028	0.004[b]	yes	NS	-
Glyphosate	0.097	NS	-	NS	-
Chlorpyrifos	0.099	NS	-	160[a]	no

HSL (Health Screening Levels) used for human health criteria sourced from NEPM HILs (2013).

ESL (Ecological Screening Levels) for terrestrial ecosystems sourced from the ECOTOX database (US EPA, 2007) NS (No standard): No appropriate standard or guideline exists

The maximum organophosphate herbicides and pesticides concentrations recorded in the compost were 0.097 mg/kg for glyphosate, 0.024 mg/kg for atrazine, 0.025 mg/kg for triclopyr and 0.099 mg/kg for chlorpyrifos (Table 4.4). Ecological screening values/criteria were not available for these organophosphate and herbicides. Synthetic pyrethroids pesticides (Lambda-cyhalothrin and Cyfluthrin) recorded in the compost could not be screened since ecological criteria were unavailable for the compounds.

The maximum concentration of gamma-HCH recorded in all composts samples was above the ecological screening value of 0.004 mg/kg recommended by US EPA (2007). No screening value and empirical studies were available in the ECOTOX (US EPA, 2007) database for beta-HCH and delta-HCH. However, due to the close similarities between gamma-HCH, beta-HCH and delta-HCH (all are isomers of hexachlorocyclohexane), the study also adopted the screening value for gamma-HCH (0.004 mg/kg) for beta-HCH and delta-HCH. The maximum concentration of gamma-HCH, beta-HCH, and delta-HCH recorded in the composts were 0.024, 0.028 and 0.049 mg/kg, respectively. These levels exceeded the ecological screening value of 0.004 mg/kg recommended by the US EPA (2007). The compounds were considered contaminants of potential concern and assessed further to identify priority Contaminants that could pose an environmental risk.

The maximum predicted soil content of these EC(s) after land application of the composts at 5 t/ha ranged from 0.0001 mg/kg for beta-HCH and gamma-HCH to 0.0002 mg/kg delta-HCH (Table 4.5). At 10 t/ha of the composts, the maximum predicted soil concentrations were 0.0002 for beta-HCH and gamma-HCH and 0.0004 mg/kg for delta-HCH. All the compounds had an RQ max of less than 1; therefore, these contaminants were a low priority.

Table 4.5 Ecological risk assessment for Contaminants of Potential Concern in compost for land application at two rates (5 t/ha and 10 t/ha).

Analytes CPC	5 t/ha scenario			10 t/ha scenario			Priority group
	Max soil conc. (mg/kg)	RQ max	% RQ> 1	Max soil conc. (mg/kg)	RQ max	% RQ> 1	
gamma-HCH	0.0001	0.025	ND	0.0002	0.050	ND	Low
delta-HCH	0.0002	0.050	ND	0.0004	0.100	ND	Low
beta-HCH	0.0001	0.025	ND	0.0002	0.050	ND	Low

Table 4.6 shows the preliminary risk assessment of PAH in the compost. The maximum concentrations of the low and medium molecular weights PAHs ranged between 0.034 mg/kg and 0.10 mg/kg. These values did not exceed the ecological screening level of 10 mg/kg specified for both low and medium molecular weights PAHs. The high molecular weight PAHs also were within the acceptable ecological criteria set at 1.2 mg/kg. Screening assessment for human health impacts showed that the concentrations of Benzo(a)anthracene (0.100 mg/kg), Benzo[b]fluoranthene (0.030 mg/kg), Benzo(a)pyrene (0.115 mg/kg), Benzo[g,h,i]perylene (0.181 mg/kg), Indeno(1,2,3,c,d)pyrene (0.130 mg/kg) and Chrysene (0.051 mg/kg) did not exceed the health screening level of 3.00 mg/kg.

The total PAH value (1.069 mg/kg), the sum of all the individual PAHs, did not exceed the ecological and health screening levels of 18.00 and 300 mg/kg, respectively. Therefore, the procedure did not retain them for further risk analysis.

Table 4.6 Initial Screening Assessment of PAH and Identifying Contaminants of Potential Concern (CPC)

Analytes	Maximum conc. (mg/kg)	ESL		HSL	
		Criteria conc. (mg/kg)	CPC	Criteria conc. (mg/kg)	CPC
Acenaphthylene	0.045	10.00[c]	no	NS	-
Acenaphthene	0.034	10.00[c]	no	NS	-
Fluorene	0.100	10.00[c]	no	NS	-
Phenanthrene	0.100	10.00[c]	no	NS	-
Anthracene	0.036	10.00[c]	no	NS	-
Fluoranthene	0.041	1.200[c]	no	NS	-
Pyrene	0.099	1.200[c]	no	NS	-
Benzo(a)anthracene	0.100	1.200[c]	no	3.00[a]	no
Chrysene	0.051	1.200[c]	no	3.00[a]	no
Benzo[b]fluoranthene	0.030	1.200[c]	no	3.00[a]	no
Benzo(a)pyrene	0.115	1.200[c]	no	3.00[a]	no
Benzo[g,h,i]perylene	0.181	1.200[c]	no	3.00[a]	no
Indeno(1,2,3,c,d)pyrene	0.130	1.200[c]	no	3.00[a]	no
Total PAH	1.069	18.00[b]	no	300[a]	no

HSL (Health Screening Levels) used for human health criteria sourced from NEPM HILs (2013)

Ecological Screening Levels for terrestrial ecosystems sourced from USEPA Eco-SSLs (US EPA, 2003b)

Ecological Screening Levels for terrestrial ecosystems sourced from the ECOTOX database (USEPA, 2007a)

NS (No standard): No appropriate standard, guideline, or criterion exists to use to develop a soil quality standard.

The preliminary risk assessment of the residues of the compost's antimicrobial drug is in Table 4.7. Ecological and health screening guideline values were not available for antimicrobial medicines. Therefore, further risk assessment was not possible.

Table 4.7 Initial screening assessment of antimicrobial drugs residues and identifying contaminants of potential concern (CPC) for further evaluation

Analytes	Maximum (mg/kg)	ESL		HSL	
		Criteria (µg/kg)	CPC	Criteria (µg/kg)	CPC
Ciprofloxacin hydrochloride	0.0151	NS	-	NS	-
Danofloxacin mesylate	0.0548	NS	-	NS	-

NS (No standard): No appropriate standard, guideline, or criterion exists to use to develop a soil quality standard. ESL (Ecological Screening Level). HSL (Health Screening Level).

4.7 The Content of Pesticides, PAHs and Antimicrobial Drugs in Carrot and Lettuce

The study involved cultivating vegetables in the field and under the greenhouse to determine EC's potential uptake and translocation by two vegetable plants (lettuce and carrot). Also, the study involved vegetable analysis in determining the potential uptake and translocation of contaminants (pesticides, PAHs and antimicrobial drugs). No targeted contaminant was detected in the vegetables from the two experiments at the various stages of growth. This observation was regardless of the three compost sources (MWMW, SSMW and MAW) and the control and at the two application rates (5 t/ha and 10 t/ha).

4.8 Physico-Chemical Properties of Composting Materials and Compost

The results of physicochemical parameters from the composting feedstock and the compost as presented in table 4.8. The physicochemical parameters included pH, electrical conductivity, total nitrogen, and organic matter.

Table 4.8 Physico-Chemical Properties of Composting Feedstcok and Compost from the three waste sources.

	MWMW		SSMW		MAW	
	Feedstock	Compost	Feedstock	Compost	Feedstock	Compost
pH	8.2	8.5	7.9	8.4	7.2	8.6
Electrical Conductivity	0.84	0.93	0.66	0.83	0.73	0.88
Total Nitrogen	0.12	0.12	0.14	0.12	0.34	0.34
Organic Matter	17.8	15.6	18.3	16.4	19.3	17.3

The mean pH of the compost from the MWMW, SSMW and MAW was higher than the composting material's pH. The compost's pH was in the increasing order of ranking; SSMW, MWMW and MAW were 8.2, 8.5 and 8.6, respectively. The pH of composting feedstock was 8.2 for MWMW, 7.9 for SSMW and 7.2 for MAW.

Generally, the electrical conductivity of compost was higher than that in the composting feedstock. The sample's mean conductivity ranged from 0.66 (composting material in SSMW) to 0.93 (compost from MWMW). In increasing order, the compost's conductivity was 0.83 in SMSM, 0.88 in MWMW and 0.92 in MWMW). The composting feedstock's value was 0.84 in MWMW, 0,66 in SSMM and 0.73 in MAW.

Table 4.3 shows the mean levels percentage N from the MWMW, SSMW, MAW sources. The mean percentage N was generally low, ranging from 0.12 % to 0.34 %. Percentage N in both the composting material and the MAW source's compost was high (0.34 per cent).

Table 4.3 shows the mean percentage of organic matter from waste sources (MWMW, SSMW, MAW). The organic matter in the feedstock from MAW recorded the highest mean, 19.3 %. Compost from SSMW recorded the lowest percentage of organic matter (16.35).

4. 9 Social Survey

4.9.1 Compost Use Among Farmers

Compost was available in the study area, and respondents acknowledged the importance of compost use. Therefore, to investigate compost adoption among farmers in Accra, 350 farm owners were sampled. The results showed only 16 per cent (57) adopted compost while 84% (293) did not (Fig. 4.9a). The low rate is due to farmers' preference for manure (poultry droppings) and chemical fertilisers. All adopters obtained their compost from commercial sources, and the mode of application was manual.

Also, the study analysed the reasons for using compost among farmers. Nearly half (49 %) of the adopters declared that the primary reason for using compost was to amend the soil, 21 % as a form of fertiliser, and 19 % used it to replace chemical fertiliser. Other adopters used it to prevent pests and lower soil erosion, as depicted in Fig. 9b.

The study determined the constraints associated with compost adoption among farmers. Interestingly, the challenges declared by adopters and non-adopters were similar. The study observed that compost cost was the main challenge, as 45 % of adopters and 61 % of non-adopters indicated. The other challenges identified were the labour-intensive nature of compost application and the inadequate information (including improper labelling) (Fig. 9c). The farmers also mentioned issues like the low quality of compost, the high-water composting requirements, and the facilities' proximity to farms.

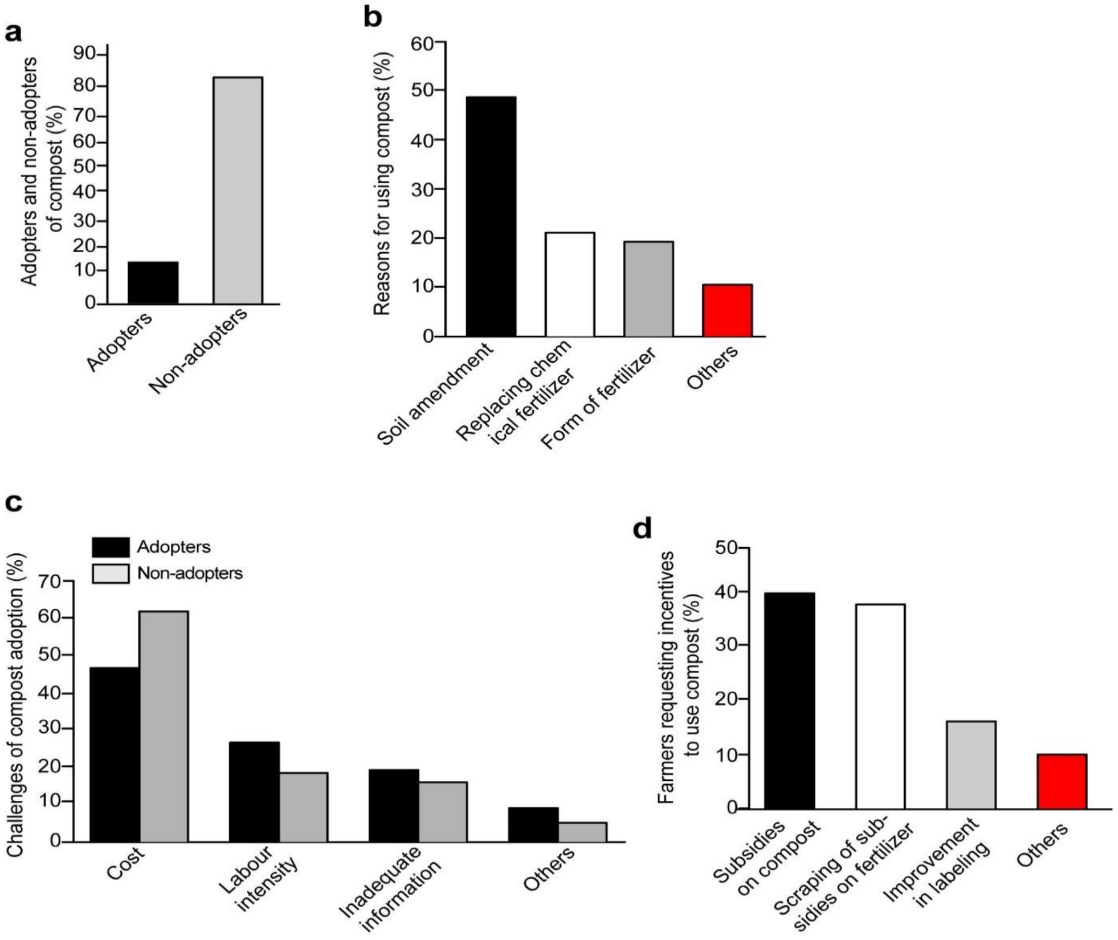

Fig 4.9: Compost Adoption: a) The adopters and non-adopters of compost b) Different reasons (%) for farmers adopting compost. c) Challenges of farmers when deciding whether to adopt compost or not. d) Farmers' requesting various incentives to be able to use compost.

An analysis of improving adoption within the study area indicates that most (76 per cent) farmers mentioned subsidies; 39 % suggested government subsidies on compost while 37 % stated the scraping of the current support on inorganic fertiliser. Fifteen per cent (15 %) indicated the need to improve the current labelling; labels should be per the nutrient requirement for the vegetable involved. The rest stated providing training on compost and need to improve the quality (Fig. 2d). Furthermore, we probed what individual farmers could do to improve the current adoption. Current adopters (100 %) maintained they would continue to use compost, whereas most non-users (95 %) were not prepared to adopt.

4.9.2 Biophysical and Socio-Economic Characteristics of Farmers

The study analysed farmers biophysical and socio-economic factors to using compost and presented the results in Table 4.5. The average ages of farmers are above 50 years. The ages represent a growing farmer population in Accra. The average household size of farmers in this study was 5.7 persons, which is low. It implies that family labour may not be adequate for farm activities, so hiring other hands may be needed. Given the high wage rate, any agricultural practice or technology, which is labour-intensive, will not be attractive to the farmers. These results were similar for the two groups (adopters and non-adopters). Farmers had substantial years of farming experience; Adopters had 17.5 years, whereas non-adopters had 14.5 years of experience.

The finding suggests that farming in the study area was male-dominated; about 89 % of the respondents were males. The female prefers non-farming activities, which are probably less labour-demanding. Also, in the city, other minor activities may be more accessible to females. The percentage of farmers with at least a secondary education was low. Most of the farmers are full-time. Although most farmers had frequent contact with the extension workers, about 90 % had not received specific training on compost use. Some training was conducted, including pest management, reducing pre-harvest losses and financial management, and marketing, and facilitated by extension officers. The lack of specialised training may have accounted for the low usage of compost in these areas

Table 4.9: The description and nature of the explanatory variables used in the probit regression model

Variable	Overall N =350	Adopters N = 57	Non-Adopters N = 293
Age (yrs)	51.17	51.05	51.59
Experience (yrs)	15.42	17.45	14.87
Farm Size (m^2)	0.3742	0.5186	0.3355
Proximity (km)	11.73	16.26	10.58
Household Size	5.717	6.014	5.609
Per capita income ($)	3418	3781	3327
Sex*	0.8800	0.7973	0.8618
Education*	0.4714	0.3784	0.3913
Part-time*	0.4657	0.2297	0.4891
Extension Officers*	0.8771	0.9474	0.9457
Training on compost*	0.1137	0.3243	0.0471

*Dummy variables

4.9.3 Land Tenure Arrangement of Farmers

The land tenure system is the primary constraint faced by farmers. The central government owns the lands. More worrying to farmers was the lack of a formal land tenure agreement with the government. However, there was an unwritten mutual understanding between the various government Ministries and the farmers. The farmers bitterly raise issues about the land tenure system. Given that the real benefits of investing in compost and the application accrue over time, farmers' lack of a secure land tenure system might have contributed to the low usage of compost.

4.9.4 Socio-Cultural and Religious Background of Farmers

Through focus group discussion with the farmers and interviews with key personnel, there were no local norms or taboo against compost use. Also, their practice and beliefs do not restrict farmers from compost use or composting. The findings suggest that farmers are not interested in the raw material used for the compost. Buyers are also not interested in compost produced vegetables or otherwise. The environmental benefits of composts appear not to concern the respondents. The size of the vegetable is of concern to the buyer and the farmer. The findings suggest no cultural or religious belief against the use of compost. The farmers' view appears to support compost use.

4.9.5 Farmer's Perception of Compost

The study examined farmers' perceptions of ten statements regarding compost among the two groups and presented the WAI results (Table 4.10).

The findings revealed that the two groups perceived compost as good for the soil and managed waste control. There was no significant difference between the perception of adopters and non-adopters ($p > 0.05$). However, the degree of agreement was higher for the adopters. Farmers agree that compost is tedious and labour demanding and could also bring about pests and other vermins. Here, the degree of agreement was higher for the non-compost adopters than adopters, although not significant.

Table 4.10: Farmer's perception of compost adoption

Factors	WAI for adopter	WAI for Non-adopter	*T-test*	*p-value*
The use of compost helps solves waste issues.	3.72	3.29	0.78	0.06
Compost is good for the soil amendment.	4.93	4.91	0.54	0.17
Compost harms the environment.	1.73	1.71	0.74	0.12
Compost gives essential elements to the land.	3.93	3.71	0.94	0.08
Compost causes odour problems.	1.76	1.85	0.88	0.14
Compost use can cause problems for human health	3.61	3.27	0.76	0.07
Compost use can cause vegetable contamination.	3.56	3.26	0.78	0.06
Compost brings pests to vegetables.	3.61	3.81	0.77	0.07
Compost gives low-quality foods.	3.99	3.98	0.50	0.14
Working with compost is difficult.	4.87	4.97	0.52	0.11

Framers disagreed that compost is unfriendly to the environment and can cause odour problems; the two groups' degree of disagreement was similar. Also, they disagreed that compost may contain harmful chemicals and can cause health problems, and the degree of variance was typical for the two groups. Farmers oppose that compost can contaminate crops. The disagreement was usual for the two groups.

4.9.6 Safety Precaution on the Use of Compost

This study involved an investigation of safety precautions among adopters during compost usage. Therefore, all the adopters were interviewed. Most adopters (92 %) indicated they don't take any safety precautions when using compost. However, 5 % stated hand gloves, with 3 % used hand gloves with safety boots. No adopter used a face mask. This result is represented in the figure below.

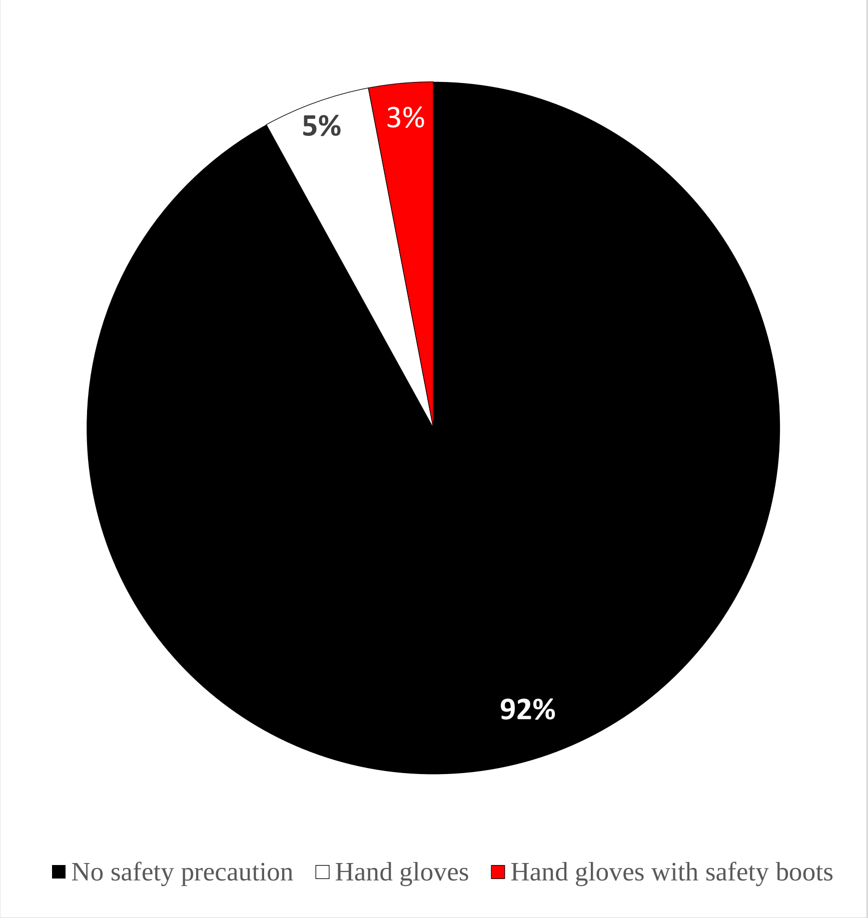

Fig. 4.10 Safety Precautions Regarding Compost Use

The figure above depicts the various preventive measures compost adopters employ when using compost. The majority of them do not use any preventive measures.

4.9.7 Determinants of Compost Adoption

The study approach involved a multivariable analysis in identifying the biophysical and socio-economic variables affecting a farmer's decision to adopt compost. The study adopted the probit model and fitted it with several specifications to the data to obtain the best fit. The model had the best predictive fit at R^2 99 % and was significant at 5 %. The results are in Table 4.11

Table 4.11 Analysis of the predictor variables influencing compost adaption in

Response Variable		*Compost Adoption*			*N = 350*
	Predictor variable	Coefficient	Standard errors	R^2 (%)	*p*-value
X_1	Age (yr)	-0.002^{**}	0.006	99	0.020
X_2	Experience (yr)	0.044^{NS}	0.005	93	0.830
X_3	Farm size (m^2)	-0.196^{NS}	0.055	51	0.124
X_4	Distance (km)	-0.013^{NS}	0.002	65	0.165
X_5	Household size	0.047^{*}	0.018	96	0.010
X_6	Per-capita income	0.001^{*}	0.000	92	<0.001
X_7	Sex	-0.084^{NS}	0.061	85	0.171
X_8	Education	0.010^{NS}	0.045	52	0.840
X_9	Part-time Farmer	-0.176^{NS}	0.043	49	0.721
X_{10}	Extension Officers	0.047^{NS}	0.099	95	0.634
X_{11}	Training on Compost	0.489^{*}	0.066	45	<0.001

Accra

N= number of observations *Significant at 1 % **Significant at 5 % NS = Not Significant

Of the 11 variables tested, the effect of six on compost adoption was positive. The six variables were farmers' experience, household six, per capita income and education of farmers and contact with extension and receiving specific training on compost. However, the six were significant: household size, per-capital income, and specific training provision. Five variables had a negative effect, with one being significant (farmer's age). The four negative non-significant variables were farm size, farm location, sex of the farmer and being a part-time farmer.

4.9.8 Results of Multivariable Interaction of the Individual Factors Influencing Adoption

There was a cross-tabulation of the predictor variable. This approach involved running a multi-varied interaction of the eleven variables (socio-economic and biophysical) to make inferences. This approach involved performing the ward test. The results of some of the interactions are presented in Table 4.12.

Table 4.12 Results of some multi-interaction within the preditor variable

	Maximum likelihood estimates				Odds ratio (OR)		
Parameter	Estimate	S.E.	Wald	Sig.	Point estimates	95 % C.I. for OR	
						Lower	Upper
Age _Sex	.121	.048	6.307	.012	1.129	1.027	1.241
Age _Farm Size	-.169	.727	.054	.816	.844	.203	3.513
Age_ Training	.333	.289	1.331	.249	1.395	.792	2.457
Age_ Education	.016	.035	.206	.650	1.016	.948	1.089
Age_ Proximity	.000	.034	.000	.997	1.000	.935	1.069
Per-capital income_ Sex	.000	.000	.169	.681	1.000	.999	1.001
Per-capital income_ Farm Size	-.001	.004	.027	.869	.999	.992	1.007
Per capital income _Training	.000	.001	.034	.853	1.000	.997	1.003
Per capital income_ Education	.000	.000	.396	.529	1.000	1.000	1.001
Per capital income_ Proximity	.000	.000	.043	.836	1.000	1.000	1.000
Training_ Sex	-18.643	14.536	1.645	.200	.000	.000	18895.270
Training _Farm Size	-40.230	35.547	1.281	.258	.000	.000	745.220
Training_ Education	1.370	1.587	.745	.388	3.934	.175	88.240
Training_ Proximity	2.033	1.756	1.341	.247	7.637	.245	238.513
Household size_ Farm Size	1.927	5.289	.133	.716	6.866	.000	218270.667
Household size_ Education	-.328	.320	1.051	.305	.720	.385	1.349
Household size_ Sex	-1.026	.435	5.570	.018	.359	.153	.840
Household size_ Proximity	-.021	.247	.007	.933	.979	.603	1.590
Constant	-1.511	.649	5.414	.020	.221		

N= number of observations *Significant at 1 % **Significant at 5 % NS = Not Significant

The test models show that the interactions of some predictor variables are predictors contributing significantly to compost adoption. The Wald tests show that explanatory variables contribute significantly to the model (i.e. not Zero). The results are seen in the confidence intervals for the odds ratios. This study shows it had a 95 % confidence limit, which can be repeated 95 % of the time. The results show the estimated estimates (likelihood) for the various interactions and point estimates.

An interaction between age and specific training positively impacted compost adoption. Also, an interaction between age and education showed a high possibility of the farmer adopting compost. In this study as age increases and farm size increases, the farmer is less likely to use compost. Male farmers who had received training were less likely to adopt compost than their female counterparts. There was a positive association between training and education on adoption. As age increases and the farmer receives compost-specific training, the individual is more likely to adopt compost, evident by cross-tabulations. As farm and household size increased, the farmer was more likely to adopt compost with a higher adoption rate. An interaction between farm size and specific training negatively influenced adoption. Compost-specific trained male farmers were not likely to adopt compost. Also, male farmers with enormous households were not likely to adopt compost. It appears the male farmers were complacent regarding their attitude toward compost adoption irrespective of receiving training, increased household size or increased per capita income.

4.10 Outcome of Key Personnel Interviews

Also, in-depth interviews with twenty key stakeholders complement the farmer's survey and ascertain their perception of compost adoption and ways to improve compost. The personnel indicated there was subsides on artificial fertilizers; however, there was none on compost and the absence of source segregation of waste segregation system. Other challenges include the lack of a national policy on compost and proper financing structure targeted for composters, national standards for compost, and the labelling requirement. The rest had the proximity of facilities to farmers, the bulkiness of the application, the lack of national promotion strategies and the absence of premium on compost-produced products in the country. Lack of scalable technology for farmers. Lack of a proper financing structure and the unwillingness of farmers to pay for compost, among other challenges.

The key personnel interviews included officials from local government, composters, key farmers, civil society, media, and waste management companies. They recommended solutions for composting and compost issues. They were knowledgeable about composting and compost used. No individual accepted the responsibility for the composting and compost use. Personnel from government institutions placed the burden on composting on the farmers.

.

4.11 Outcome of Focused Group Discussion

There was a focused group discussion at various locations to collate the view of farmers regarding compost. Cost, the yield of compost cultivated crops, and the bulkiness of the compost were topical among the issues farmers raised. Other matters included labelling requirements, proximity, and spreading requirements. The farmers acknowledged compost's vital role in waste and soil management. However, most of them were unprepared to adopt compost. They placed the responsibility of composting on their local and central government. Others also blamed the consumers for focusing on the size of produces with little regard to the chemical for the planting process

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Introduction to Discussion

This chapter discusses the research findings per the literature. It begins with discussions on the various ECs from the three waste sources, discusses the associated ecological and human health risks of the quantified EC in compost and a detailed analysis explaining the failure of vegetable uptake of these contaminants from the compost. Further discussion on the socio-economic and biophysical variables affecting compost adoption and a cross-tabulation of the individual factors on adoption.

5.2 Pesticide Residues Levels in the Feedstock and Compost from the Waste Sources

The research identified ten pesticide compounds in the sampled feedstock and compost from the three facilities. These were lambda-cyhalothrin, cyfluthrin, and three isomers of hexachlorocyclohexane (beta-HCH, gamma-HCH, delta-HCH). The others were methoxychlor, chlorpyrifos, atrazine, triclopyr, and glyphosate were the identified pesticides. These numbers were lower than those reported by Kupper *et al.* (2008), who found 28 pesticide compounds in compost and feedstock in their study. However, the number recorded in this study is higher than the six reported by Langdon *et al.* (2019) in municipal solid waste compost.

The pesticides identified in this study belonged to the organochlorines, synthetic pyrethroids and organophosphates classes. Others (atrazine, triclopyr and glyphosate) were pesticides that consumers broadly used as herbicides in the environment. Some studies have reported these compounds in compost and feedstock (Lalander *et al.*, 2016; Yañez-ocampo *et al.*, 2016). According to Gunnell *et al.* (2017), most pesticides originate from agricultural applications to control pests. It is becoming challenging to eliminate these persistent chemicals in the environment (Gupta *et al.*, 2015; Pereira, 2014)

Delta-HCH, in particular, has been detected in several studies (Bhardwaj *et al*., 2015; Kupper *et al*., 2008). Kupper *et al.* (2008) reported a higher and broader range of delta HCH (36 and 101 µg/kg) than this study (26.76 to 27.51 µg/kg). Comparisons of delta-HCH concentrations in the compost and feedstock showed that composting tends not to impact the concentrations positively from the three facilities studied. Other studies have reported similar outcomes for delta HCH in compost (Bhardwaj *et al*., 2015).

Ali *et al*., 2014 found that beta-HCH exhibits lower compost concentrations and assumed that it was due to the degradation during composting. Kupper *et al*., 2008; Wang *et al*. (2020) did not detect beta-HCH residue in compost from various sources, proving negligible for influencing compost quality. However, this study reported levels of beta-HCH in both feedstock and compost from the three waste sources. This observation may be crucial to the development of compost.

According to Ali *et al*. (2014) compounds such as γ-HCH (Lindane) exhibit lower compost concentrations. Several studies did not detect lindane in compost (Lalander *et al*., 2016; Langdon *et al*., 2019). The presence of lindane in the samples may be due to wood chips' addition to biowaste, which ends up in the compost. Other studies have reported lindane's presence in the bark and other plant parts (Kubovsk, 2020).

Methoxychlor residues were absent (not detected) in all three facilities' compost. The absence of these pesticides in the compost suggests that these compounds are well degraded, diluted or lost during composting. There may be some microorganisms responsible for using methoxychlor as a carbon source. Studies by Fogel *et al.* (1982) suggest the ability of methoxychlor to be degraded, particularly under anaerobic conditions. Other studies on methoxychlor pesticides in compost indicated residues below the detection limits (Langdon *et al.*, 2019; Yañez-Ocampo *et al.*, 2016).

Globally organochlorine pesticides are banned. However, organochlorine pesticides accounted for most (40 %) of the pesticides detected in the waste facilities' materials, with isomers of HCH-compounds the dominant. Research findings have shown that these pesticides are resistant to biodegradation (Lester *et al.*, 2021; Vodyanitskii *et al.*, 2014). Consumers illegally use these pesticides to control insects on crops (Olutona and Aderemi, 2019). Therefore, it is reasonable to assume that the feedstock at the waste facilities contained high portions of plant-based materials or other materials treated with organochlorine insecticides or compounds that have persisted due to past application. The mean residual levels of organochlorines in the compost and feedstock ranged between 11.29 and 28.26 μg/kg for all the waste facilities.

This study revealed low concentrations of synthetic pyrethroids in the feedstock and compost (average range: non-detection -10.10 μg/kg for lambda-cyhalothrin and non-detection - 12.73μg/kg for cyfluthrin). Although several studies reported low synthetic pyrethroids concentrations (Huang *et al.*, 2018; Varjani *et al.*, 2020), only a few studies offer any basis for identifying what makes a low or high concentration (Cheng and Deming, 2011; Wang *et al.*, 2020). The average residual concentration of 25.06 μg/kg in compost reported by Aparicio *et al.* (2018) was low and well within the range of concentrations typically found in soils. Therefore the levels reported in this study can be considered low.

Cyfluthrin, a synthetic pyrethroid residue, was not present (not detected) in all three facilities' compost materials. Studies have reported cyfluthrin residues in the feedstock used for compost (Huang *et al*., 2018). Findings from other studies conducted on Cyfluthrin pesticides in compost have indicated residues below the detection (Langdon *et al*., 2019; Yañez-ocampo *et al*., 2016). The absence of these pesticides in the compost suggests microbial organisms' potential ability to improve the compost quality regarding cyfluthrin.

Some studies did not detect lambda-cyhalothrin concentrations on compost (Brändli *et al*., 2007; Kupper *et al*., 2008; Langdon *et al*., 2019; Mcgowin *et al*., 2001), and they assumed it was due to the degradation during composting. This observation is in line with the current study, which observed differences between the feedstock and the compost levels from the three waste sources. The photolytic degradation of lambda-cyhalothrin has been reported (Djouaka *et al*., 2018). The presence of lambda-cyhalothrin in the feedstock is due to its usage as agricultural pesticides (Djouaka *et al*., 2018; Imoro *et al*., 2019).

Chlorpyrifos was the only organophosphate present in the feedstock and compost. It ranged from 26.08 and 27.78 µg/kg with no apparent differences among the waste but a trend of higher concentrations in the feedstock than the compost for all three facilities. Generally, organophosphate insecticides are rarely in compost samples (Kaushal *et al*., 2021). However, Mcgowan *et al*., 2001 reported chlorpyrifos concentrations recorded and aligned with this study. Various studies in Ghana have reported a wide usage of chlorpyrifos (Imoro *et al.*, 2019). The use may account for the presence in the compost and the feedstock.

This research found atrazine, triclopyr and glyphosate pesticides broadly used as herbicides in all the materials from the three waste sources. Brändli *et al.* (2007); Kupper *et al.* (2008) also reported herbicides in feedstock and composts. They attributed the observed concentrations to the feedstock. Langdon *et al.* (2019) recorded triclopyr in compost samples but no atrazine or glyphosate in a South Australia study.

Glyphosate content in feedstock and composts from MAW was higher than in other waste sources. Glyphosate is used in crop farms in Ghana to control weeds (Imoro *et al.*, 2019; Mcgowin *et al.*,(2001). Traces of this herbicide are in leaves, grass and shredded branches (Braschi *et al.*, 2011). With these materials predominantly used at the MAW to generate compost, it may be right that this compound in feedstock and compost at higher levels may be due to the higher glyphosate rate. According to Langdon *et al.* (2019), municipal waste resources are examples in which biomass resources exhibit glyphosate risk.

Atrazine, in particular, has been detected in several studies (Bhardwaj *et al.*, 2015; Kupper *et al.*, 2008; Mcgowin *et al.*, 2001). Atrazine levels, 36 and 101 µg/kg in compost reported by Kupper *et al.* (2008), were higher than those reported in the feedstock and the resulting compost in this study (8.11 to 20.84 µg/kg). Ghanaian farmers sometimes use Atrazine as herbicide hence their presence on the feedstock, ending in the compost chain. Comparisons of Atrazine concentrations in the compost and feedstock showed that composting impacts the concentrations positively from the three facilities studied. This study is in line with others on atrazine in compost.

Comparisons of triclopyr residues in the compost and feedstock showed that composting decreases the concentrations for the facilities studied. Langdon *et al*. (2019) reported low levels of triclopyr in compost. Potential volatility in the triclopyr's physical, chemical, and biochemical degradation accounts for the low levels (Kupper *et al*., 2008).

5.3 Levels of Polycyclic Aromatic Hydrocarbons in the Compost and Feedstock

Of the US EPA's sixteen (16) priority PAHs, 13 were detected in the compost and feedstock collected from the SSMW, MWMW and MAW facilities (Fig. 4.5 4.6 and 4.7). This observation confirms the predominant nature of the pollutants (Wang *et al*., 2018). Similarly, others have reported these PAHs feedstock and compost in several studies (Brändli *et al*., 2007; Chen *et al*., 2015; Houot *et al*., 2012; Langdon *et al*., 2019). The levels recorded in their studies ranged from 63.2 to 1264.7 µg/kg dry matter, which was higher than the average range levels (ND to 170.00 µg/kg) recorded in this study. The waste sources and the level of contamination and other factors may account for the content in this study.

Four LMW PAHs concentrations identified in the feedstock and compost were generally lower than the medium and high-weight molecular weight PAH concentrations determined. The LMW PAH were acenaphthene, acenaphthylene, fluorene and anthracene. Low molecular weight PAHs have the highest biodegradability rate than medium and high molecular weight PAHs and show less resistance to degradation (Brändli *et al*., 2007; Kopeć *et al*., 2017)). Other studies have also reported low LMW PAH levels than MMW and HMW in feedstock and the resulting compost.

Several studies reported low acenaphthene concentrations (Amir and Hafidi, 2005; Poluszyńska *et al*., 2017). They assigned the lower concentrations to the low molecular weight of Acenaphthene, hence its volatility and biodegradability. This study reported a low concentration of acenaphthene in compost than in the feedstock, which is in line with others (Houot *et al*., 2012; Sądej and Namiotko, 2010). The low concentrations may be due to the volatility of acenaphthene.

Houot *et al*. (2012): and Poluszy (2017) found that acenaphthylene exhibits lower compost concentrations than the degradation during composting. This observation aligns with the current study, which observed differences between the feedstock and the compost levels from the three waste sources. (Amir and Hafidi, 2005) found that acenaphthylene residues in compost are low and therefore pose little risk to the environment.

During the composting process, there is potential volatility in anthracene's physical, chemical and biochemical degradation (Amir and Hafidi, 2005). Comparisons of anthracene concentrations in the compost and feedstock showed that composting did not affect the levels of residues from the three facilities. However, Brändli et al. (2007) study showed that anthracene in raw feedstock generally decreases substantially after composting.

Some studies have reported fluorene in compost (Amir and Hafidi, 2005; Kopeć *et al*., 2017). This study's fluorene levels (78.94 to 81.84) were low compared to the other MMW

PAH. However, higher levels (130 and 230 µg/kg) of fluorene in compost were reported by Kopeć *et al*. (2017). Other studies have reported similar outcomes in compost (Houot et al., 2012). Comparisons of fluorene concentrations in the compost and feedstock did not show that composting reduces the levels of the contaminants.

The concentration of fluoranthene in the feedstock and compost ranged from 20.79 to 35.33 µg/kg. Amir and Hafidi (2005), Ozaki *et al*. (2017), Poluszyńska *et al*. (2017) have reported similar outcomes. The average residual concentration in compost was considered low and well within the range of concentrations of fluoranthene typically found in soils (Juan Zhang *et al*., 2018)

Chrysene was recorded in the feedstock and compost. The value recorded is low considering the requirement of soils (the primary recipient of compost). Other studies reported chrysene (Sądej and Namiotko, 2010) only a few studies offer any basis for identifying what makes a low or high concentration. The average residual concentration of 25.06 µg/kg in compost was low and well within the range of concentrations typically found in soils.

Others found that benzo[a]anthracene exhibits lower compost concentrations (Sądej and Namiotko, 2010) and they assumed it was due to the waste source. This observation is in line with the current study that observed low concentrations of benzo[a]anthracene in the feedstock and compost levels from the three waste sources. The concentration reported in this study will pose little risk to the environment.

Comparisons of pyrene concentrations in the compost and feedstock prove the ability of compost to decrease the residual levels of compost of the facilities studied. A study conducted by Kopeć *et al*. (2017) showed comparatively higher pyrene residues in compost from various feedstock concentrations (280 to 968 µg/kg). The values recorded in this study (70.77 to 93.42 µg/kg) are low, considering the values reported by other studies.

Tomczyk *et al*., (2020) concluded that phenanthrene had a unique binding ability to activate the centres within various substances, displacing other already absorbed compounds. The process is irreversible when bound to the organic matrix, increasing phenanthrene. This explanation can be applied to other studies which reported higher compost levels than the feedstock from the facilities studied.

Benzo (a) pyrene is the most toxic form of the 16 US priority PAH targeted in this study (PHE Centre for Radiation, 2018). Therefore many studies used it as an indicator pollutant in PAH studies ((MDH, 2014). In this study, the highest mean recorded was 100.01 µg/kg. Other reported low benzos (a) pyrene levels 43 in sewage sludge µg/kg (Kopeć *et al*., 2017). However, another study reported higher benzo (a) pyrene levels in 481 compost with biochar (Kopeć *et al*., 2017).

In particular, Benzo[b]fluoranthene has been detected in several studies (Bhardwaj *et al*., 2015; Kupper *et al*., 2008). Benzo[b]fluoranthene, 36 and 101 µg/kg in compost reported by Kupper *et al*. (2008) were higher than those reported in this study (8.10 to 20.84 µg/kg). Comparisons of the compost and feedstock concentrations showed that composting impacts the concentrations positively from the three facilities studied. Other studies have reported similar outcomes for atrazine in compost (Bhardwaj *et al.*, 2015).

A study conducted by Poluszyńska et al. (2017) showed that Benzo[g,h, i]perylene in raw feedstock generally increases substantially after composting. A comparison of Benzo[g,h, i]perylene residues shows an increase in the compost concentration relative to the feedstock for the three facilities. Other researchers have reported similar findings.

Indeno(1,2,3,c,d)pyrene, in particular, has been detected in several studies. (Kopeć *et al.*, 2017) reported a range (21 and 499 µg/kg) of Indeno (1,2,3,c,d) pyrene levels in compost compared to this study (a range of 119.03 to 170.00). Comparing concentrations in the compost and feedstock showed that composting tends to increase the content from the three facilities studied. This observation aligns with the line (Sądej and Namiotko, 2010).

Fluorene, Phenanthrene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(a)pyrene, Benzo (g,h, i) perylene, Indeno (1,2,3,c,d) pyrene concentrations were generally higher in the compost. There was comparatively lower PAH in feedstock for all the facilities studied. The levels of these PAHs in the feedstock and compost for each waste facility varied. The higher levels in the compost may be due to the thermal generation during compost or microplastics in the composting material. A study by (Brändli *et al.*, 2007) also found higher PAH concentrations in compost than in the feedstock. However, in another study (Kupper *et al.*, 2008), PAH showed no differences between feedstock and compost.

Noticeable contamination in the compost may be due to compostable materials from extraneous materials (e.g., ashes) entering the process. According to Brimo *et al*. (2017) the levels of PAH compounds, mainly the high molecular weights, do not quickly degrade and tend to become more concentrated as composting proceeds due to the reduction of organic matter.

Brändli *et al*. (2007) concluded that the potential intake of hydrocarbons by microorganisms and their subsequent release after the disintegration of cells might increase compost PAH residues. After the breakdown of cells, PAHs are rereleased into the atmosphere because microorganisms can pile up aromatic compounds. The incubation period influences the effectiveness of PAHs biodegradation within metabolic processes. However, a study emphasised the relevance of PAHs degradation by composting organisms mainly at the thermophilic phase (Ma, 2010).

PAHs can undergo substitution and addition reactions leading to the destruction of unsaturated bonds. Aromatic hydrocarbons are sensitive to light, oxygen. Some PAHs undergo a photochemical reaction and transformation to diol forms. However, during composting, light penetration may be limited, but aeration is an essential factor in the transformation processes of PAHs. Ciesielczuk *et al*. (2014) found that a lack of air may cause an increase in the content of PAHs during the composting process and create a real risk to the biotic environment.

Considerably high p^H may also have resulted in the persistence of PAH in the feedstock and the subsequent compost. The p^H of the composts from the waste facilities was slightly above the optimal values (6 to 7.5) (Table 4.8) necessary to support biodegradable microorganism growth (Haritash and Kaushik, 2009). The breakdown of PAHs by microorganisms occurs if compost p^H is favourable. The high p^H recorded (8.4 to 8.6) may result in their low bioavailability and limit biodegradation. The p^H will result in the compost's PAHs persistence (Lü *et al*., 2021).

This study observed higher HMW PAH levels in compost than feedstock for all the facilities studied. However, the PAH concentrations in the composts are not considered toxic to the soil microbial community and may not negatively affect their efficiency (Sayara *et al*., 2020). The Council for European Community (CEC) (2000), cited by Oleszczuk (2006), did not recommend the usage of compost with high PAH (above six ppm) unless it is amended to reduce the level.

The feedstock's and compost's naphthalene levels were below the detection limits from the three waste facilities. The non-detection could be due to the high rates of the compound's volatilisation, which is significant in warm areas (Haritash and Kaushik, 2009). This study's findings align with others who did not report naphthalene in feedstock and compost (Mcgowin *et al*., 2001). However, Amir and Hafidi, (2005), Brändli *et al*., (2007) observed a low level of naphthalene in compost.

There is no established specification for PAH in municipal solid waste compost. And therefore the most appropriate matrix for comparison was the set threshold for sewage sledge. The EU and China have set the indicator compound requirement for total PAHs as benzo(a) pyrene 2000 mg/kg. In this study, the value of benzo (a) pyrene in the compost ranged from 90.22 and 100.01 ug/kg, thus much lower than the allowable value for sewage sledge.

Though the PAH levels detected in this study are not considered toxic to the soil microbial community. The tendency of PAH to bioaccumulate depicts a significant ecological risk. This risk is because they are resistant to biodegradation and are carcinogenic, mutagenic teratogenic (Wang *et al.*, 2018). Accordingly, they are of great environmental concern at these sites.

There were differences in the PAH concentrations in the compost and feedstock from the three waste sources. However, the variation in levels (ND to 170 µg/kg) was not considerable compared to those reported in other studies (Chen *et al.*, 2015). (Chen *et al.*, 2015) reported PAH levels in municipal waste compost over a wide range (1 to 250 ppm). Wiera and Anna (2010) observed such variation in their studies. The waste sources had some influence on PAH concentration, although this showed no general trend.

The facilities' PAH levels in compost and feedstock at the studied facilities depend on the waste collection system and composition of raw materials. The MWMW facility aiming to provide a sustainable waste management option for Accra and its environs, adds fresh animal manure from nearby plants to the segregated organic solid waste to increase the compost's nitrogen content. Therefore, this study expected poultry manure with a high nitrogen content could contribute to PAH-degrading microorganisms' growth (Sayara *et al.*, 2020) and thus be more favourable in degrading the pollutant. Lu *et al.* (2019) also showed a positive reduction of compost PAH by adding poultry waste. According to Sayara *et al*. (2020) and Zhang *et al*. (2017,) PAH reduction is efficient in composting fresh organic waste. This reason could explain the lower PAH levels in compost from

MWMW than SSMW, and the observation may be crucial in further compost quality development studies.

This study can attribute the presence of PAH in feedstock and compost from the SSMW to the composting location. The facility is close to a busy market in the port city of Tema with heavy industrial and vehicular activities. Industries near urban areas in their production operations generate PAHs (Okere, 2011). Studies have reported higher PAH concentrations near industrial sites in Tema, Ghana (Botwe *et al*., 2017). The study can attribute PAH to the vehicular traffic, iron smelting, refinery and coal gasification wastes distributed because of disposal and accidental spills of petroleum products. Considering that PAH levels are directly related to industrial activities (Gilio *et al*., 2020), their presence is also found in waste dumps, feedstocks, and subsequently in compost near urban areas, making PAH monitoring necessary removal in feedstock and compost urgent at their sites.

5.4 Antimicrobial Drugs Residues in the Feedstock and Compost

Feedstock and compost samples from the facilities showed antimicrobial drug residues. The identified compounds included amoxicillin trihydrate, danofloxacin mesylate, sulfadiazine, ciprofloxacin hydrochloride, and amprolium hydrochloride. These antimicrobial medicines were common antibiotics and anti-protozoal drugs (Huang *et al*., 2018; Zhang *et al*., 2019). According to Zhang *et al*. (2019) and Hu *et al*. (2011), residues in animal faeces and urine from medical treatments find their way into feedstock and compost.

This research detected amprolium, amoxicillin, and sulfadiazine in all feedstock but not in compost samples. Few studies reported these compounds in composts (Liu *et al*., 2015). Amprolium hydrochloride, amoxicillin trihydrate, and sulfadiazine residues have been considered negligible in feedstock (Houot *et al*., 2012). The findings align with others who did not observe these drugs' accumulation in compost (Hu *et al*., 2011).

Concentrations of the antimicrobial drug residues in this study ranged from 10.04 to 90.93 µg/kg. There was evidence of concentration reduction after composting at all waste facilities. Higher concentrations have been reported by Taheran *et al*. (2018) and Martínez-Blanco (2012), who also observed reductions in antimicrobial drug residues levels in feedstock after composting. In their study, feedstock levels were in the range of 123.3–35.2 mg/kg but reduced to 35.4–20.7 mg/kg at the end of composting. The loss or lower levels of antimicrobial drug residues appeared primarily due to biodegradation. Other studies observed the degradation of antimicrobial drug residues in compost (Chen *et al*., 2019). According to Martínez-Blanco, (2012), microorganisms degrade these compounds under aerobic conditions, explaining the relatively low concentration reported.

The residue level in feedstock from MWMW was generally the highest. The MWMW facility added poultry manure from nearby plants to their segregated organic solid waste. Concern has been expressed that the animals may excrete the parent compounds of the antimicrobial drugs or their bioactive metabolites through poultry faeces or urine, which may find their way into feedstock and subsequently in compost(Huang *et al*., 2018). Kelova *et al*. (2021) found elevated feedstock concentrations with high household and poultry waste. Interestingly, the compost residues from MWMW were lower than in compost from SSMW and MAW, partly due to the high degradability of these compounds in compost with high nitrogen contents. Keenum *et al*. (2021) report the breakdown of antimicrobial drugs during composting mixed municipal solid wastes when operators add nitrogen sources to create favourable conditions for biodegrading microorganisms.

5.5 Risk and Ecological Assessment of Emerging Contaminants

The study assessed ECs in the composts to identify CPC that may pose risks following the compost's land application. The evaluation considered direct exposure to human and ecological receptors, particularly plants. The assessment considered the maximum concentration for each EC in the compost and compared it to the environmental and human health criteria or screening levels sourced from the ECOTOX database (US EPA, 2007) and the Australian National Environment Protection Measure for assessing site contamination (NEPC, 2013). A similar approach has been used in several studies by various researchers where they compared data regarding compost pollutants to standards or criteria to reflect the maximum tolerable risk of ecological exposure (Jin *et al.*, 2019; Langdon *et al.*, 2019; Wang *et al.*, 2020; Zhou *et al.*, 2020).

The risk assessment results showed that the maximum concentrations of gamma-HCH, beta-HCH, and delta-HCH recorded in the composts were above the acceptable ecological criteria or screening level established in the US EPA (2007) guidelines for plants. This observation suggests that the compounds are a significant group of pollutants or contaminants that should be considered in terms of their potential to impact ecological function at sites where the composts were applied. The inference is based only on the maximum concentrations that this study recorded.

Langdon *et al.* (2019) also reported gamma-HCH, beta-HCH, and delta-HCH in compost. They concluded that the compounds are potential human health and environmental risk. In this study, further analysis in the preliminary screening assessment categorized the compounds as low priority (Table 4.9), evidenced by their RQ max values (less than 1) for all isomers. Studies by Song *et al*. (2021) and Siles-Castellano *et al*. (2021) also reported isomers of hexachlorocyclohexane in compost and classified them as contaminants of potential concern. However, as this study and Langdon et al. (2019) observed, the identified HCH posed low or acceptable environmental or human health risks since RQmax calculated were below 1. Zhou *et al.* (2020) also reported similar results who found that beta-HCH and delta-HCH in pesticide-contaminated compost pose low to medium risk to the environment.

It is worth noting that no screening value and empirical studies were available in the ECOTOX (US EPA, 2007) database for beta-HCH and delta-HCH. However, due to the close similarities between gamma-HCH, beta-HCH, and delta-HCH (Vijgen *et al*., 2018) and the lack of any specific toxicological data for the effects of beta-HCH and delta-HCH on the environment (Danciulescu *et al*., 2015), the ecological screening value for gamma-HCH (0.004 mg/kg) was used for beta-HCH and delta-HCH. The standard-setting practice primarily focused on criteria relating to one element or compound and was subsequently used as a surrogate for other related compounds (NEPC, 2013). Such standards limit the number of ECs but often do not address the possibility that the risk per unit of weight may differ for various contaminants (NEPC, 2013).

The initial screening for human health for three ECs (chlorpyrifos, methoxychlor, and atrazine) was acceptable. The criteria were (NEPC, 2013). This finding is similar to the results obtained by Langdon *et al.* (2019), who also reported these pesticide compounds in composts at concentrations lower than the acceptable standard criteria. Furthermore, (Cheng and Deming, 2011) investigated the toxicity risk of pesticides in compost to humans. They concluded ECs below 100mg/kg showed no detrimental or synergistic toxic effects on the environment. These ECs included chlorpyrifos, methoxychlor, and atrazine, similar to this study.

The preliminary risk assessment of PAH in the compost showed that all the PAHs did not exceed the ecological screening levels. Several studies on PAH risk assessment in compost showed that values in compost identified m*et al*l acceptance criteria. These criteria are in the ECOTOX database (US EPA, 2007) and the Australian National Environment Protection Measure for Site Contamination Assessment (NEPC, 2013). These studies were for the LMW and MMW-PAHs (Chen *et al*., 2015; Farrell and Jones, 2009; Langdon *et al*., 2019; Ozaki *et al*., 2017).

Screening assessment for human health impacts based on the carcinogenic PAHs showed that the maximum concentrations of these compounds did not exceed the health screening level of 3.00 mg/kg (NEPC, 2013). The carcinogenic PAHs included benzo(a)anthracene, benzo[b]fluoranthene, benzo(a)pyrene, benzo[g,h,i]perylene, indeno(1,2,3,c,d) pyrene and chrysene.

The preliminary risk assessment showed that background exposure to the ECs poses a low risk. These ECs are chlorpyrifos, methoxychlor, and atrazine. Also, PAHs of LMW and MMW in all the compost from the three waste treatment facilities carry no risk. The specified level (maximum) of compost pollution has a tolerable or acceptable risk for humans and plants. Therefore this study did not retain all the ECs for further risk analysis.

Ecological screening values were unavailable for some identified pesticides in the compost. These included organophosphate (chlorpyrifos) and herbicides (glyphosate, atrazine, triclopyr). The rest are synthetic pyrethroids (lambda-cyhalothrin and cyfluthrin). Therefore they could not be screened for risk assessment. Accordingly, they do not require ecological risk analysis of the environmental burden with these compounds, as Langdon *et al.* (2019) posited. These contaminants are not necessarily of low concern. There is not enough information to conclude that ecological risks are very low or non-existent (NEPC, 2013).

Similarly, this study could not do an initial health screening of some PAHs; to identify CPC due to the unavailability of HSL (NEPC, 2013). These PAHs included acenaphthylene, acenaphthene, fluorene, anthracene, pyrene, fluoranthene, and phenanthrene. Similarly, Langdon *et al.* (2019) found various PAHs in compost, but all lacked HSL and therefore did not screen them. Again toxicity studies for adverse effects of these low molecular weight (LMW) and medium molecular weight (MMW) PAHs in composts and soil on human health have not been established (US EPA, 2007). A study conducted by Omar *et al.* (2019) also reported no health criteria values for these compounds in composts and soil.

Ecological criteria for plant receptors were unavailable for the antimicrobial drugs in the composts. No studies have derived ESL and HSL criteria for the studied compounds (US EPA, 2007). This finding is concurrent with the research results presented by Wang *et al.*

(2018), who did not report Ecological criteria values for antimicrobial drugs. Similarly, Suk *et al.* (2017) did not report Ecological and health criteria for antimicrobial residues.

This research failed to assess the potential ecological risk of organophosphate herbicides, synthetic pyrethroids, PAHs, antimicrobial agents, among other contaminants. This challenge was due to the lack of available screening values/criteria/standards or guidelines. As stated, the non-existence of screening levels does not connote these contaminants are not of concern. These ECs can pose health, safety and environmental issues. They may enter the food chain and negatively impact plants and man. Therefore, the study carried out planting to assess the potential uptake and translocation of these ECs by two vegetables; lettuce and carrot.

5.6 Uptake and Translocation of Emerging Contaminants

The study quantified the vegetable's uptake of identified pesticides, antimicrobial drugs, and PAH concentrations with the recommended quantities of compost from the MWMW, SSMW, and MAW sources. Regardless of the compost's concentrations added to the soil in the field, the vegetables (carrot and lettuce) showed no uptake of PAH, antimicrobial drugs, ot pesticides from the compost treatments. This study's findings agreed with other authors' results, describing that plants do not take up contaminants in compost (Keerthanan *et al.*, 2021; Medyńska-Juraszek *et al.*, 2020). The outcome is critical information for stakeholders in the composting industry.

Although some identified pesticide residues were present in the compost, the vegetables' analysis did not show any pesticide residues. Keerthanan *et al.*, (2021) and Yang *et al.* (2019) posited that compost contaminants do not necessarily correspond with their bioavailability. Glyphosate, triclopyr, atrazine, and other pesticide residues in compost are strongly adsorbed onto soil particles reducing their availability to plants (Zhang *et al*., 2017). The other pesticide included organophosphorus and organochlorines. Compost added to the soil for planting supplies organic matter with an appropriate carbon source (dissolved organic carbon). The addition increases the binding capacity for ECs to compost and limits the bioavailability and subsequent uptake by plants.

In this study, PAHs were present in the compost and soil for the field experiment; however, the vegetable analysis did not show any PAH residues. Studies have reported PAH uptake by vegetables in varying concentrations from the non-detectable level to 11.8 µg/g and significantly lower than levels reported in the compost (Sayara *et al*., 2020). According to Soliman *et al*. (2019), plant uptake of PAH from contaminated compost accounts for a small portion (usually less than 0.1 %) of total PAH in compost. The determination of the PAH content of plants was even considered unnecessary by (Pullagurala *et al*., 2018). Compared to the compost's initial concentration, the absence of PAH in the vegetables implies potential degradation by soil microorganisms and removal via volatilisation. Studies reported that indigenous microbes have an increased capability for degrading PAHs with compost addition (Forján *et al*., 2020). Kopeć *et al*. (2017) found that the level of microorganisms contributed to an efficiency of 82 % in PAH removal using a compost treatment, thereby limiting their availability for plant uptake.

Some studies revealed the presence of antimicrobial drugs in vegetables. These vegetables were grown on soils amended at different antimicrobial drug concentrations to determine whether plants absorb residues present in the compost (Azanu *et al*., 2016; Tasho and Cho, 2016). Contrary to this study’s findings, many studies have reported the uptake of antimicrobial drug residues in compost by carrots, lettuce, and other vegetables (Pullagurala *et al*., 2018; Soni *et al*., 2016)). Their study, however, showed that plants usually take up not more than 2 % of the residues of the antimicrobial drug with compost addition. These studies also were with higher doses of ECs, and the soils with the contaminants.

Yang *et al*. (2019) found that carrots and lettuce absorbed sulfadiazine (1.1 mg kg^{-1} DW) from soils mixed with antibiotic-containing compost. Further studies conducted in the summer showed that all antibiotics in the studied vegetables were less than the quantification limits. They concluded that seasonal variations, also observed by (Michelini *et al*. (2015)), affect the vegetable's uptake and distribution of antimicrobial drugs. High volatilisation rates are in warm climate regions (Song *et al*., 2021). Massé *et al*. (2014) and Van Epps and Blaney et al. (2016) volatile contaminants like ciprofloxacin hydrochloride and amprolium hydrochloride, which were recorded in the compost in this study have a low potential for accumulation in plants because they quickly escape to the air. These explanations are in line with the findings of this study.

This study shows that antimicrobial drugs not taken by the vegetables may not enter the food chain for the planting period. Therefore, consuming these vegetables grown in soils with compost containing the observed concentrations was safe.

5.7 Compost Use Among Farmers

The average household size of farmers in this study was approximately six persons, which is low. It implied that family labour might not be adequate for farm activities, so hiring other hands may be needed. Given the high wage rate, any agricultural practice or technology, which is labour-intensive, will not be attractive to the farmers. These results were similar for the two groups (adopters and non-adopters). Farmers had substantial years of farming experience; Adopters had 17.5 years, whereas non-adopters had 14.5 years of experience.

The finding suggests that farming in the study area was male-dominated; about 89 % of the respondents were males—the females preferred non-farming activities, which are probably less labour-demanding. Also, in the city, other minor activities may be more accessible to females.

Compost was available in the study area, and respondents acknowledged the importance of compost use. Therefore, to investigate compost adoption among farmers in Accra, we sampled 350 farmers. A low rate of compost adoption has been reported by (Blazy *et al.*, 2017) in the Caribbean Islands. However, in Cameroon's urban areas, Jean and Folefack (2015) observed a much higher rate (49 %). All adopters obtained their compost from commercial sources, and the mode of application was manual.

The study determined the constraints associated with compost adoption among farmers. Interestingly, the challenges declared by adopters and non-adopters were similar, probably due to sharing information among the farmers. The study observed that compost cost was the main challenge, as 45 % of adopters and 61 % were non-adopters. Viaene *et al.* (2016) and Lupton (2017) also observed cost as the main constrain to compost adoption among on-farm compost users in diverse locations in northwest Europe. The other challenges identified were the labour-intensive nature of compost application and the inadequate information (including improper labelling) (Fig. 4.9d). The farmers mentioned issues like the poor quality of compost, the composting facility's high-water compost, and proximity requirements.

5.8 Land Tenure Arrangement of Farmers

The land tenure system is the primary constraint faced by farmers. The central government owns the lands. More worrying to farmers was the lack of a formal land tenure agreement with the government. However, there was an unwritten mutual understanding between the various government Ministries and the farmers. The real benefits of investing in compost and the application accrue over time; therefore, the absence of a secured land for farmers might have contributed to the low usage of compost. Studies by Kassie *et al.* (2009) and Nigussie *et al.* (2015) mirrors the current study's finding.

5.9 Socio-Cultural and Religious Background of Farmers

Through focus group discussion with the farmers and interviews with key personnel, there was no local norms or taboo against compost use. Also, their practice did not restrict farmers from compost use or composting. The findings suggested that farmers were not interested in the raw material used for the compost. Buyers were also not interested in compost-produced vegetables or otherwise. The environmental benefits of composts appear not to concern the respondents. The findings aligned with that of Chen *et al.* (2018). The size of the vegetable is of concern to the buyer and the farmer.

The study suggested no cultural or religious belief against the use of compost. It aligns with Appiah-Effah *et al.* (2015) studies involving farmers from various religions in Ghana's Ashanti region. The studies also aligned with Paz and Ayalon (2014), comprising Muslim-dominated respondents of Beit Netofa in Israel. The farmers understand that compost is a natural-based product and will not harm plants, unlike chemical fertilisers. The belief of farmers appears to support compost use.

5.10 Farmer's Perception of Compost

The examined farmers' perception of ten statements regarding compost among the two groups. The WAI results are in Table 3.

The findings revealed that the two groups perceived compost as good for the soil and managed waste control. There was no significant difference between the perception for adopters and non-adopters ($p > 0.05$). However, the degree of agreement was higher for the adopters. Farmers agreed that working with compost was tedious and labour demanding and could also bring about pests. Here, the degree of agreement was higher for the non-compost adopters than adopters, although not significant.

5.11 Safety Precaution on the Use of Compost

To investigate safety precautions, we interviewed all adopters. Most adopters (92 per cent) don't take any safety precautions when using compost, 5 % use hand gloves and 3 % use gloves with safety boots. These findings were probably because the farmers perceived compost was safe and presented no health risk. However, adopters must use appropriate safety measures since bioaerosol from compost can travel in the air for a long time (Nygård *et al*., 2008)and may pose a health risk to farmers (Nygård *et al*., 2008). A potential beneficial human health effect of bioaerosol from compost, such as the improved immune system from early exposure, particularly in children, cannot be ruled out (Bloomfield *et al*., 2016; Mirabelli *et al*., 2006). A more recent systematic review by Robertson *et al.* (2019) linking bioaerosol from compost to health risks was inconclusive.

5.12 Determinants of Compost Adoption

This study was analyzed to identify the biophysical and socio-economic variables that affect farmers' decisions to adopt compost. The study adopted the probit model and fitted several specifications to obtain the best fit. The model had the best predictive fit at R^2 at 99 % and was significant at 5 %. Of the 11 variables tested, six effects on compost adoption were positive, with three being significant; household size, per-capital income, and specific training provision. Five variables had a negative impact, with one being significant (farmers' age). The results are in Table 4.8

5.12.1 Factors with a Positive Impact on Compost Adoption

There was a significant positive relationship between household size and compost adoption. Meaning farmers with less household size are less likely to adopt compost. These findings are because of the voluminous nature of compost and the need for many workforces. Olaoye *et al.* (2017), Ajewole (2010), and Mustafa-Msukwa *et al.* (2011) also found a strong association between household size and compost use. In some African settings, it is not uncommon to find farmers, particularly males having more wives. The situation increases children and more workforce for compost farms (Sotamenou & Parrot, 2013).

As indicated earlier, the associated cost was the primary constraint associated with compost adoption. Therefore, we hypothesised that increasing farmers' per-capita income would increase farmers' probability of purchasing compost. The findings showed a positive and significant association between the adoption of compost and per-capita revenue. The study's observations align with Tey *et al.* (2014) studies on sustainable adoption studies. They identified compost cost as the primary constraint; therefore, increasing farmers' per-capita income resulted in compost adoption probability.

There was a significant positive relationship between receiving specific training on compost and the adoption of compost. Probably, the tailored activities positively influenced the perception of the farmer towards compost use. The study's findings are incomparable to others as studies on compost-specific training were limited. However, Blazy *et al.* (2017) assess the impact of access to extension officers and compost adoption. They concluded that farmers having access to an extension officer are most likely to receive the necessary training, including the agronomic effect on compost. Therefore, they are more likely to be adopters.

The probit results showed the number of years of farming (farmer experience) had a positive relationship with the adoption of compost, even though not significant. The observation can be compared to Tey *et al.*,(2014) studies on sustainable agricultural practices. However, Ajewole, (2010) studies found a statistically positive impact between age and the adoption of commercially available compost. They explained that farmers with longer years of experience might have higher authority when experimenting with new ideas.

The study tested the impact of a farmer receiving at least a secondary education on compost adoption. The model results indicate that a high level of education positively influences the probability of adopting compost, although not significant. This outcome is because educated farmers may better understand the many advantages associated with compost use.

Also, educated farmers should easily understand the techniques related to compost. Findings support other adoption studies (Blazy *et al.*, 2017; Tey *et al.*, 2014).

Farmers who had frequent contact with extension officers were more likely to use compost. Here, we assumed that those who regularly meet extension officers are more likely to get the necessary explanation on compost from officers. Results indicated a positive association between the contact officers and the adoption of compost, although not significant, and it is in line with other studies (Tey *et al.*, 2014). They explained that such farmers might have received explanations on sustainable agricultural practices (like compost use on soils) from officers, resulting in adoption. In contrast, farmers without contact with extension officers would not know the merits associated with compost adoption.

5.12.2 Factors with a Negative Impact on Adoption

The study suggests that the farmer's age had a negative and significant effect on compost adoption. Thus older farmers are less likely to adopt compost compared to the younger ones. It appears the older farmers considered themselves too experienced to change their attitude regarding their farming practices. Our findings and explanations align with other studies (Blazy *et al.*, 2017; Long *et al.*, 2016; Viaene *et al.*, 2016). Jean and Folefack (2015) suggest that older farmers may be unwilling to adopt more demanding technology. This explanation cannot be applied in our studies because most farmers use poultry manure, an equally demanding technology. Sotamenou and Parrot (2013) concluded that the farmer's age had negative and positive impacts on compost adoption. They explained that the older the farmer, the more complex the person to handle compost. However, the possibility of the old farmer owning land is high and therefore, more likely to invest in compost with long-term benefits.

Considering all adopters obtained their compost from a commercial source, the study hypothesised that farmers close to a commercial source of compost are more likely to use compost. However, the analyses showed a negative effect, although not significant. In other words, farmers who are close to compost sources were less likely to use compost. These findings imply accessibility and closeness of compost sources will not necessarily have a positive influence on adoption. Our observations agree with other authors (Long *et al*., 2016). They gave other factors, including the cost, to be a vital element in adoption. Considering that farmers manually apply compost and the high cost, the study hypothesised that large farm size would have a negative and significant effect on the adoption of compost. Although our finding suggests a negative impact, it was insignificant. The observations agree with Sotamenou and Parrot (2013). They concluded that farm size is a relative variable specific to the socio-economic context and may not be suitable to generalise it. By contrast, farm size significantly negatively influenced compost adoption due to its manual application (Jean and Folefack, 2015; Olaoye *et al*., 2017).

The study obsessed a negative but not significant effect of gender on compost adoption. Gender was of little importance to compost adoption in the two islands in the Caribbean because of social change that has reduced the influence of gender (Blazy et al., 2017). Earlier studies by Kassie *et al.* (2009) and Sotamenou and Parrot (2013) had a positive relationship between males and compost use. They explained that men generally have more strength to carry bulky farm inputs like compost than women. Therefore, women prefer to use mineral fertilisers which are less labour-demanding.

The probit model proves that farmers with part-time activities are less likely to use compost, although it was not significant. However, other researchers observed a considerable impact of off-farm activities on compost adoption (Jean and Folefack, 2015). The study's findings on off-farm activities on compost adoption were also observed by Blazy *et al*. (2017). They explained that farming is stressful; hence, people will not hesitate to abandon it. Aside from the stress, non-agricultural activities were more lucrative than the money gained for compost spreading. The lack of a significant effect on our studies was difficult to explain.

5.13 Multi-Interactive Effect of the Predictor Variables

An interaction between age and specific training positively impacted compost adoption. Also, an interaction between age and education showed a high possibility of the farmer adopting compost. This outcome may be the impact of the training and the education on the older farmer. A study suggested older farmers were unprepared to use compost (Jean and Folefack, 2015). In this study as age increases and farm size increases, the farmer is less likely to use compost. An interaction between age and sex was surprising. This observation is because the older male farmer was possible to adopt. Studies have suggested the African male farmer is usually dominant and unprepared to assume (Tian *et al*., 2015).

For the univariate independent factors influencing adoption, a farmer receiving compost-specific training positively affected compost adoption. However, an interaction between training and sex showed an exciting outcome. Male farmers who had received training were less likely to adopt compost than their female counterparts. Studies by Tian *et al*., (2015) suggest males are usually authoritative and less likely to adopt. This explanation can be applied to the current research. There was a positive association between training and education on adoption. This observation may be because educated farmers quickly understood the benefits of compost and adopted it.

As age increases and the farmer receives compost-specific training, the individual is more likely to adopt compost, evident by the cross-tabulations. The explanation could be that the older the farmer, the likelihood of using compost than the younger ones. Interview key stakeholders suggested the young one was unprepared for strenuous activities. Closeness and an increase in per-capita income did not affect adoption. This observation makes adoption quite complex because it was expected to be massive as the income increases and the farmer is close to the source. Other studies have supported the idea that farmer adoption of compost is a complex issue influenced by several factors (Tey *et al*., 2014).

Other studies have linked the non-adoption of compost to the cumbersome and tiring nature of compost use (Jean and Folefack, 2015). As farm and household size increased, the farmer was more likely to adopt compost with a higher adoption rate. This outcome is plausible because more household members may be available to work with compost (an energy-demanding activity). However, an interaction between farm size and specific training negatively influenced adoption. Trained farmers may not be using the compost if the size of the farms is enormous. Here also, the reason can be linked to the tedious nature of compost. This explanation corroborates the observation through the farmer's interview, FGD and KPI, and all indicated compost's heavy and tiring nature.

Compost-specific training had a significant positive impact on adoption in the univariate analysis. However, trained male farmers were not likely to adopt compost. Again, male farmers with enormous households were not likely to adopt compost. The males in the study area probably were unprepared to adopt, unlike their female counterparts. It appears the male farmers were complacent regarding their attitude toward compost adoption irrespective of receiving training, increased household size or increased per capita income. Gender was unimported in studies by Blazy *et al*. (2017). However, it will be difficult not to recognize gender in the current study.

CHAPTER SIX

6.0 RESEARCH SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter involves the research summary, conclusions, and recommendations deduced from this study. It begins by giving the research summary. The summary includes the study background, relevant literature review, how (methodology) the results were obtained, and the relevant discussion. The subsequent section is the conclusions based on the results of the study. The third section deals with the recommendations drawn from the study.

6.2 Research Summary

Composting is an ecosystem-based approach for organic waste and soil management, which farmers have used for several years. It is often confused with biological decomposition. However, composting is more purposeful. Compost aims to convert complex organic material into a biologically functional and safe organic product called 'compost' that may enrich soil quality. Other processes include CO_2, heat, H_2O, and other gases like nitrous oxide, methane, and volatile organic compounds. Composting offers many advantages and is considered a natural approach for handling waste and soils by humans mimicking organic matter mulching over time.

Composting and compost use is one of the most preferred options to manage waste and for soil management. The main advantage of composting is the recycling of nutrients. Besides the nutrient recycling advantage, the process can divert waste from landfills while increasing the soil's organic matter and carbon content. Compost is also used in pest infestation bio-mediation, pollution control, erosion control and plant disease control.

Thus, composting offers many advantages to the environment hence the need to promote it worldwide but compost use some challenges.

Compost may contain ECs that may affect the environment. These ECs may come from anthropogenic or natural sources. Compost use may be a crucial entry route of ECs into the environment, posing some risk. Also, ECs may enter the food chain through compost application. The uptake of ECs is possible because plants are the producers in the ecosystem. Another key compost issue is with adoption. The compost adoption rate is usually low, but studies on compost adoption have been more technical. These studies proved that factors like feedstock availability (Matsui *et al*., 2017) difficulty making compost (Supaporn *et al*., 2013). Therefore, the other factors need to be understood to maximize the benefits compost provides to waste and soil management

Therefore, this study was designed to understand ECs issues in the production and use of compost by identifying ECs, identifying the ecological and human health risk associated with compost use and understanding the possible uptake by two vegetable plants (lettuce and carrot). There was a further study to understand biophysical and socio-economic factors and their interaction influencing compost adoption. To this end, the study had the following specific objectives: a) to identify and quantify selected ECs (pesticides, PAH, and antimicrobial drugs) in compost from diverse waste sources, b) determine the ecological and human health risk assessment of ECs in compost, c) examine the potential uptake and translocation of ECs by two vegetables (cabbage and carrot), and d) examine the factors including socio-cultural influencing compost adoption and their interactions.

The review of the relevant literature involved literature on emerging contaminants, health effects of and uptake of these contaminants and factors influencing compost adoption. The review suggested inconclusive literature regarding: a) the composition and levels of ECs in compost from diverse sources, b) the ecological and health risk assessment of ECs in compost, c) the uptake and translocation of EC by plants through the application of compost and d) the factors influencing compost adoption. These were gaps in the current understanding of ECs and the compost usage that continuing research must address. In particular, there is a need to demonstrate whether there is a threshold concentration for ECs in compost that plants will take up.

The conceptual framework involved determining three ECs (pesticides, PAH and antimicrobial drugs) in compost. And the determination of the ecological and human health risk of these ECs in compost. Further, the concept involved an outgrown experiment in determining EC's potential uptake and translocation in compost by two plants; lettuce and carrot. The approach also involved a social survey of various stakeholders to collect information on the possible factors influencing compost adoption. The study pooled the laboratory and field data to address the study questions and achieve the overall aim.

The methodology involved analysing three ECs (pesticides, PAHs and antimicrobial drugs) from three waste sources [MWMW, SSMW, MAW using LCMS and GCMC three selected composting facilities in Accra; a city burdened with waste and soil management issues. This study used the compost's maximum concentration of ECs to assess risk by comparing with known ecological and human health criteria and identifying contaminants of potential concern with two compost application rates [10 t/ha and 5 t/h]. This study predicted the optimum concentration of ECs in soils and the RQ max. As there were no criteria for some quantified ECs, this research involved planting lettuce and carrot to identify potential uptake and translocation of ECs with compost of known EC quantities.

This study also examined the views of 350 farms owners from Accra's key farming locations on compost adoption using structured questionnaires, focus group discussions, and key informants' interviews. The methodology involved descriptive statistics and probit analysis using an eleven-variable (biophysical and socio-economic) regression model to explain the factors (including socio-cultural) influencing adoption within the study area. Further, there was an interaction within the predictor variables to determine their effect on adoption.

The GenStat (12th Edition) software-generated EC's the means (pesticides PAHs and antimicrobial drugs) and the physicochemical parameters of the samples. Analysis of variance was used to test the significant similarities and differences between contaminants from the composting feedstock and the subsequent compost from the three waste sources (MWMW, SSMW and MAW). This analysis tested the normality of samples using the Shapiro Wilk test before conducting the ANOVA. The study set the observed differences were significant at $p \leq 0.05$. In this analysis, the study tested the normality of samples before the various statistical test. The statistics included the percentages, frequencies, means, and weighted averages to understand variables in the social survey. The logit probit model predicted the eleven physical and socio-economic variables influencing compost adoption. Further, a multi-interactions analysis of the predictor variables was conducted to examine their effect on compost adoption.

The College of Basic and Applied Science of the University of Ghana ethical clearance committee gave ethical clearance (Annex IV) before the study's commencement. Also, team members sought permission from Opinion Leaders, Compost Facility Operators, and Participants consent before being included in the study. The approval included the laboratory analysis, the experimental setup and the field survey. The investigator and the team described all procedures and the confidentiality of the procedures to all the respondents and other relevant authorities.

Samples analysed showed ten pesticides residues; chlorpyrifos, lambda-cyhalothrin, glyphosate, atrazine, triclopyr. The rest were three isomers of hexachlorocyclohexane (beta-HCH, gamma-HCH, delta-HCH). Additionally, methoxychlor and cyfluthrin residues were found only in compost feedstock from the waste sources; MWMW, SSMW, and MAW. The results showed that 40 % of these pesticides belonged to the organochlorine group. The other pesticides were synthetic pyrethroids and organophosphates pesticides representing 20 % and 10 %, respectively. The rest belonged to classes of pesticides broadly used as herbicides.

Of the Sixteen (16) US priority PAHs US EPA tested in this study, thirteen were present in the compost and feedstock collected from the MWMW, SSMW and MAW sources. The identified hydrocarbons were classified into three groups, according to their number of aromatic rings as low molecular weight (LMW), medium molecular weights (MMW) and high molecular weight (HMW). Acenaphthene, acenaphthylene, fluorene and anthracene are the LMW PAHs present in the compost and feedstock. Four MMW PAH were detected. These included fluoranthene, chrysene, benzo[a]anthracene and pyrene in the compost and feedstock. Five HMW PAHs were in the compost feedstock and compost and included phenanthrene, benzo (b) fluoranthene, benzo (a) pyrene, benzo[g,h, i]perylene and indeno(1,2,3,c,d) pyrene.

This study tested antimicrobial drug residues in composting feedstock and compost samples from the three facilities. The residues include; amoxicillin trihydrate, danofloxacin mesylate, sulfadiazine, ciprofloxacin hydrochloride, amprolium hydrochloride and Metronidazole. The various residues' concentrations in each sample in µg/kg were recorded. This study did not identify metronidazole in both feedstock and compost from the three sources. Amprolium hydrochloride, amoxicillin trihydrate and sulfadiazine were also not detected in the compost. However, ciprofloxacin and danofloxacin were present in both composting materials and compost from the three sources

The maximum concentration of gamma-HCH recorded in all composts samples was above the ecological screening value of 0.004 mg/kg recommended by US EPA (2007). No screening value and empirical studies were available in the ECOTOX (US EPA, 2007) database for beta-HCH and delta-HCH. However, due to the close similarities between gamma-HCH, beta-HCH and delta-HCH (all are isomers of hexachlorocyclohexane), the study also adopted the screening value for gamma-HCH (0.004 mg/kg) for beta-HCH and delta-HCH. The maximum concentration of gamma-HCH, beta-HCH, and delta-HCH recorded in the composts were 0.024, 0.028 and 0.049 mg/kg, respectively. These levels exceeded the ecological screening value of 0.004 mg/kg recommended by the US EPA (2007). The compounds were considered contaminants of potential concerns and assessed further to identify priority contaminants that could pose an environmental risk.

The maximum predicted soil residues of ECs after composts applications at 5t/ha ranged from 0.0001 mg/kg for beta-HCH and gamma-HCH to 0.0002 mg/kg for delta-HCH. At 10t/ha of the composts, the maximum predicted soil concentrations were 0.0002mg/kg for gamma-HCH and beta-HCH and 0.0004 mg/kg for delta-HCH. All the compounds had an RQ max of less than 1; therefore, these contaminants were a low priority.

No targeted contaminants were detected in the vegetables from the two experiments at the various stages of growth. This observation was regardless of the three compost sources (MWMW, SSMW and MAW) and at the two application rates (5 t/ha and 10 t/ha) and the vegetable's maturation period. Also, vegetables from the greenhouse and field environment had no contaminants present.

The social survey findings showed that, although compost was available, the adoption rate was low (16 %), mainly due to cost. Household size, per-capita income, and the provision of compost-specific training to farmers had a significant positive effect on adoption, while the farmers' age had a significant negative impact. Socio-cultural and religious concerns did not affect compost adoption. The low rate is due to farmers' preference for manure (poultry droppings) and chemical fertilisers. All adopters obtain their compost from commercial sources, and the mode of application was manual. Nearly half (49 %) of the adopters declared that the primary reason for using compost was to amend the soil, 21 % as a form of fertiliser, and 19 % used it to replace chemical fertiliser.

The study determined the constraints associated with compost adoption among farmers. Interestingly, the challenges declared by adopters and non-adopters were similar. The study observed that compost cost was the main challenge, as 45 % of adopters and 61 %

non-adopters indicated. The other challenges identified were the labour-intensive nature of compost application and the inadequate information. The farmers also mentioned issues like the low quality of compost, the high-water composting requirements, and the facilities' proximity to farms.

There were no local norms or taboo against compost use. The practice and beliefs do not restrict farmers from composting or compost use. The findings suggest that farmers are not interested in the raw material used for the compost. Buyers are also not interested in compost produced vegetables or otherwise. The environmental benefits of composts appear not to be a concern to the respondents. Of concern to the buyer and the farmer is the size of the vegetable. The findings suggest no cultural or religious belief against the use of compost. The farmers' view appears to support compost use.

Of the 11 variables tested, the effect of six on compost adoption was positive. The six variables were farmers' experience, household six, per capita income and education of farmers and contact with extension and receiving specific training on compost. However, the six were significant: household size, per-capital income, and specific training provision. Five variables had a negative effect, with one being significant (farmer’s age). The four negative non-significant variables were farm size, farm location, sex of the farmer and being a part-time farmer. The test models show the effect variables are contributing something significant. The Wald tests show that all explanatory variables contribute significantly to the model (i.e. not Zero). The results are seen in the confidence intervals for the odds ratios. This study shows had 95 % confidence limit. Meaning it can be repeated 95 % of the time. The results show the estimated estimates (likelihood) for the various interactions and point estimates.

Globally organochlorine pesticides are banned. However, organochlorine pesticides accounted for most (40 %) of the pesticides detected in the waste facilities' materials, with isomers of HCH-compounds the dominant. Research findings have shown that these pesticides are resistant to biodegradation (Lester *et al.*, 2021; Vodyanitskii *et al.*, 2014). Consumers commonly use these pesticides to control insects on crops (Olutona and Aderemi, 2019). Therefore, it is reasonable to assume that the feedstock at the waste facilities contained high portions of plant-based materials or other materials treated with organochlorine insecticides or this compound's persistence. The mean residual levels of organochlorines |in the compost and feedstock ranged between 11.29 and 28.26 µg/kg for all the waste facilities.

Fluorene, Phenanthrene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(a)pyrene, Benzo (g,h, i) perylene, Indeno (1,2,3,c,d) pyrene concentrations were generally higher in the compost. There was comparatively lower PAH in feedstock for all the facilities studied. For each waste facility, levels of these PAHs in the feedstock and compost varied. The higher levels in the compost may be due to the thermal generation during compost or microplastics in the composting material. A study by (Kupper *et al.*, 2008) also found higher PAH concentrations in compost than feedstock.

There was evidence of concentration reduction after composting at all waste facilities. Higher concentrations have been reported by Taheran *et al.* (2018), who also observed reductions in antimicrobial drug residues levels in feedstock after composting. In their study, feedstock levels were in the range of 123.3–35.2 mg/kg but reduced to 35.4–20.7 mg/kg at the end of composting. The loss or lower levels of antimicrobial drug residues appeared to be primarily due to biodegradation. Other studies observed the degradation of antimicrobial drug residues in compost (Chen *et al*., 2017). According to Martínez-Blanco, (2012), microorganisms degrade these compounds under aerobic conditions, explaining the relatively low concentration reported.

In this study, further analysis in the preliminary screening assessment categorized the compounds as low priority, evidenced by their RQ max values (less than 1) for all isomers. Studies by Aamir *et al*. (2016) and Yang *et al*. (2019) also reported isomers of hexachlorocyclohexane in compost and classified them as contaminants of potential concern. However, as observed in this study and Langdon *et al.* (2019), a preliminary risk assessment study considered these compounds to pose a low and acceptable risk to human health, or the environment since RQ max calculated were below 1. Zhou *et al.* (2020) also reported similar results, who found beta-HCH and delta-HCH in pesticide-contaminated compost to pose low to medium risk to the environment

Although some identified pesticide residues were present in the compost, the vegetables' analysis did not show any pesticide residues. Keerthanan *et al*. (2021) and Yang *et al*. (2019) posited that compost contaminants do not necessarily correspond with their bioavailability. Glyphosate, triclopyr, atrazine, and other pesticide residues in compost are strongly adsorbed onto soil particles reducing their availability to plants (Liu *et al*., 2015). The other pesticide included organophosphorus and organochlorines. Compost added to the soil for planting supplies organic matter with an appropriate carbon source (dissolved organic carbon). The addition increases the binding capacity of ECs to compost and limits the bioavailability and subsequent uptake by plants (Keerthanan *et al*., 2021).

An interaction between age and specific training positively impacted compost adoption. Also, an interaction between age and education showed a high possibility of the farmer adopting compost. In this study as age increase and farm size increase, the farmer is less likely to use compost. Male farmers who had received training were less likely to adopt compost than their female counterparts. There was a positive association between training and education on adoption. As age increases and the farmer receives compost-specific training, the individual is more likely to adopt compost, evident by cross-tabulations. As farm and household size increased, the farmer was more likely to adopt compost with a higher adoption rate. An interaction between farm size and specific training had a negative influence on adoption. Compost specific trained male farmers were not likely to adopt compost. Also, male farmers with enormous households were not likely to adopt compost. It appears the male farmers were complacent regarding their attitude toward compost adoption irrespective of receiving training, increase in household size or increase in per capita income.

6.3 Contribution to Knowledge

Compost use is an ecosystem-based, environmentally friendly approach for waste and soil management; however, compost usage has challenges, including contaminants and adoption challenges. These issues warranted this study, which focused on quantifying emerging contaminants and understanding the ecological and human health risk of ECs in compost and the potential uptake of ECs in compost by vegetable plants. The discussions above, backed by sound analytical studies, proper reasoning, and correct inferences, established that although compost may contain ECs, vegetables (lettcuce and carrot) grown with compost did not contain ECs. This observation was regardless of the vegetable type (lettuce or carrot), compost source, and the vegetable's maturation period. This observation is fascinating and newsworthy for farmers, food safety authorities, consumers, among other stakeholders in risk management and communication relating to compost safety.

With this vital information, the study drifted into the social survey. Here, it maximized the understanding of the effect of various biophysical and socio-economic variables on adoption. Instead of the traditional prediction by one variable, the study also used interactive variables that better predict adoption rate, which is a critical design path for any improvement strategy for compost adoption. A multivariate interaction of the predictor variables revealed the role of males in compost adoption. Male farmers were complacent in their attitude toward compost adoption irrespective of receiving training, increasing household size, or increasing per capita income. Therefore, this information is critical for policymakers in developing strategies for compost adoption.

6.4 Conclusion

The study recorded ten of the 49 pesticides analysed from the three waste sources. Generally, the contents in the composts were lower than in the feedstock. Therefore, this study can assume a reduction in the toxic effect of pesticides due to composting. The research can conclude that produced composts' quality is improved compared to the related input materials concerning quantification and pesticide residues' availability.

Generally, the compost pesticide concentrations of sample from the three waste sources (MWMW, SSMW, and MAW) were similar except for lambda-cyhalothrin, glyphosate, and triclopyr. Glyphosate in MAW sample was higher than the recorded values in MWMW and SSMW. Glyphosate content in feedstock and composts from MAW was significantly higher ($p < 0.05$) than other waste sources attributing to the significant agricultural waste in MAW. Lambda-cyhalothrin was below the quantitation in MAW. HCH compounds in feedstock from MWMW did not differ from the feedstock levels from MAW and SSMW.

Thirteen of the sixteen (16) priority PAHs of the US EPA, were detected in the samples sourced from waste facilities in Accra. The high number confirms the ubiquitous and predominant nature of pollutants. The identified hydrocarbons consisted of four low molecular weights (LMW), four medium molecular weights (MMW) and five high molecular weights (HMW). Acenapthene, acenaphthylene, and anthracene and fluorene were the lower molecular weight PAHs identified. Fluoranthene, chrysene, benzo[a]anthracene and pyrene in the compost and feedstock were the MMW PAH present in the samples. Phenanthrene, benzo (a) pyrene, benzo[g,h, i]perylene indeno (1,2,3,c,d) pyrene, and benzo (b) fluoranthene and were the higher molecular weight PAH identified sourced samples. Generally, the level of HMW PAH was significantly higher ($p < 0.05$) in the compost than in the feedstock.

Feedstock and compost samples from the facilities showed antimicrobial drug residues. The compounds included amoxicillin, danofloxacin, sulfadiazine, ciprofloxacin, and amprolium. The concentration ranged from 10.04 to 90.93 µg/kg. There was evidence of concentration reduction after composting at all waste facilities. This research detected amprolium, amoxicillin, and sulfadiazine in all feedstock but not in compost samples. The two identified drugs in the compost showed a drastic reduction in the compost, confirming the effectiveness of composting in treating antimicrobial residues.

.

Residue level in feedstock from MWMW was generally the highest, and the study attributed it to the addition of poultry manure from nearby plants to their segregated organic solid waste. Interestingly, the compost's residues from MWMW were lower than in compost from SSMW and MAW, partly due to the high degradability of these compounds in compost with high nitrogen contents

The risk assessment results of all the identified pesticides showed that the maximum concentrations of gamma-HCH, beta-HCH, and delta-HCH recorded in the composts were above the acceptable ecological criteria or screening level established by US EPA (2007) guidelines for plants. This observation suggests that the compounds could be risky to the environment when applied. However, further analysis in the preliminary screening assessment categorised the compounds as a low priority based on their RQ max values (less than one) for the identified isomers.

The preliminary risk assessment of LMW and MMW PAH in the compost showed that all the PAHs did not exceed the ecological screening levels. PAH risk assessment in compost showed that PAH values in compost identified m*et all* acceptance criteria. There were no established criteria for the HMW PAH. Similarly, this study could not do initial health screening of some PAHs; to identify contaminants of potential concerns since HSL was unavailable for the PAHs hence could not be screened. These PAHs included acenaphthylene, acenaphthene, fluorene, anthracene, pyrene, fluoranthene, and phenanthrene.

Ecological criteria for receptors were unavailable for the antimicrobial drugs in the composts. No studies have derived an ESL and HSL criteria for the studied compounds (US EPA, 2007). This finding is concurrent with the research results presented that did not report Ecological and Health Screening levels for antimicrobial drugs. The was no ecological and human health risk based on the identified emerging contaminants,

Although some targeted ECs were present in the compost, no targeted contaminants were detected in the vegetables ((lettuce and vegetables) from the various experiments at the different stages of growth. This observation was regardless of the concentration of the compost applied. The study supposed that the ECs presence in compost does not necessarily correspond with their bioavailability for the vegetables. This study can assume that ECs (not observed in vegetable analysis) may not enter the food chain during the planting period per lettuce and carrot. Therefore, consumers may not be at risk of adverse health effects from consuming these vegetables (lettuce and carrot) grown in soils with compost containing the observed concentrations.

The compost adoption rate in the study area was low (16 per cent). The most significant constraint was the cost associated with compost adoption. All farmers agree that compost helps solve waste issues, is suitable for the soil structure, and provides essential nutrients. Farmers perceived working with compost as complex. Only a few farmers take preventive measures to use compost, which may expose them to some risks.

There were no local norms or taboos against compost use. The practice and beliefs do not restrict farmers from composting or compost use. The findings suggest that farmers are not interested in the raw material used for the compost. The size of the vegetable is of concern to the buyer and the farmer. The findings suggest no cultural or religious belief against the use of compost.

The equation obtained by fitting the probit model was beneficial in assessing the effect of biophysical and socio-economic variables on the adoption of compost. Out of the 11 biophysical and socio-economic variables tested, six positively influenced the adoption of compost, with three being significant; household size, the farmer's per-capital income, and providing compost-specific training to farmers. The other five negatively affected compost adoption, with the age of the farmer being significant.

A multi-interactive effect of the studied variable was crucial in making a further conclusion on adoption issues in Ghana. Age age and specific training positively impacted adoption. Also, an interaction between age and education showed a high possibility of the farmer adopting compost. In this study, the farmer is less likely to use compost as age increases and farm size increases. Male farmers who had received training were less likely to adopt compost than their female counterparts. There was a positive association between training and education on adoption. As age increases and the farmer receives compost-specific training, the individual is more likely to adopt compost, evident by cross-tabulations. As farm and household size increased, the farmer was more likely to adopt compost with a higher adoption rate. Male farmers were complacent regarding their attitude toward compost adoption irrespective of receiving training, household size increase or per capita income.

6.5 Recommendations

This study aimed at considering emerging contaminants in compost and the risk of these ECs, the potential uptake of these plants by plants and the factors influencing the adoption of compost. Based on the finding, the study recommended the following area for further research:

1. Researchers and government agencies like the environmental protection agency, the Ghana Standards Authority, and the crop research institutes of the scientific and industrial research council should continually monitor levels of ECs. This monitoring should be varied and cover various waste sources and technologies.

2. This study considered three ECs (Pesticides, PAHs, and antimicrobial drugs). Therefore, future researchers should expand the scope of these emerging contaminants. These may include phthalates, petroleum products, among other substances, to consider their potential impact.

3. Researchers should conduct fate and transport studies on specific sites in addition to adequate laboratory studies. These studies should consider the details of the contaminants' formations, their fate, and metabolites.

4. Stakeholders should develop a database that will allow for the association between ECs usage, environmental occurrence resistance, and effects. Such an association will help classify challenging ECs, determine the impact on environmentally sensitive organisms, and link them to sources. The information will be vital in making suggestions regarding controlling ECs in compost.

5. Researchers must expand toxicity tests on various organisms, particularly susceptible species (marine and freshwater) and the maximum EC database. These values will serve as guidelines for health and environmental risk assessment. Such studies should also study the effects caused by contaminant mixtures.

6. Future Researchers should consider EC's compost content considering the different times (seasonal changes) and space (diverse locations). Also, in assessing the uptake of these contaminants in compost, various applications may be considered in different soil conditions and times.

7. The Ghana Standards Authority must expand its standards-setting activities to include setting standards for compost. This standard must engage diverse stakeholders and have EC in compost as they pose a critical health risk to consumers.

8. The Ministry of Agriculture and the Environmental Protection Agency needs to check and enforce regulations on using banned pesticides in Ghana since the study found some of these pesticides in the compost.

9. In collaboration with the farmer-based organisation, the Crop Research Division of the Council for Scientific and Industrial Research should research compost adoption strategies in Ghana.

10. Current compost on the market should be healthy, nutrient-rich, and well-labelled (specific to vegetables) and cheaper than chemical fertilisers.

11. Policymakers should target female farmers by giving them specific training. Compost adoption policies should target the young farmers to adopt compost by providing compost specific training to them. Also, the current policies and

campaigns directed at compost should incorporate socio-economic and biophysical variables.

12. Researchers should conduct studies on improving compost quality regarding the nitrogen content, such as vermicomposting, under Ghana's different climatic and soil conditions.

13. Composters should ensure that the packaging is informative to buyers. It should display a reliable brand and quality guarantee, and the appearance should be attractive and comparable to other artificial fertilizers. The compost itself must be beautiful in its outward appearance. For example, compost in pellets and powder may be suitable for communities using synthetic fertilizers available in those forms. Composters should ensure there build an impressive reputation for their brand. The areas may be in the form of content, quality, and amount.

14. The government of Ghana should provide incentives for the citizenry to source their waste. Composters should target the purest possible waste streams since the additional sorting and processing are expensive. Concerning siting, the plants should be close to the raw materials since transportation is crucial. Composters may even seek to source feedstock, such as municipal market or landscaping waste, free of cost.

15. The cost of compost is a significant issue and an operational concern. The most composting system fails because the profit from the product's sale is usually inadequate to sustain the process..

16. Regarding composter facilities, operators should adopt approaches that are low-tech rather than complex and sophisticated solutions. Typically an open windrow system composting approach may be better than a complex and mechanised approach. Comparable labour can be less costly than acquiring and running a complex system.

17. It will be prudent for producers to plan sales relative to clients demand and purchasing patterns. This approach will prevent unnecessary transportation and excess stock. Compost should contact farmers and retailers for an effective system, and they will be a rich source of information.

18. Operators must follow the underlying principles of the financial management approach in composting. They must conduct rigorous economic forecasts and maintain a strong capital buffer to avoid variations in product demand. Financially, compost prices should be at a price that will provide a sufficient margin over costs while considering customer willingness to pay. Prices should be high enough to allow for the industry's growth; however, not be so low that they generate suspicion.
19. The prospects for compost adoption exist due to several advantages. The adoption could complement the soil and integrated WM system in the city. However, there is a need for a multifaceted approach to compost adoption. First, farmers could adopt nutrient-rich and well-labelled compost (specific to vegetables) cheaper than chemical fertilisers. Also, the current policies and campaigns directed at compost should incorporate socio-economic and biophysical variables.

REFERENCES

Aamir, M., Khan, S., Nawab, J., Qamar, Z., & Khan, A. (2016). Tissue distribution of HCH and DDT congeners and human health risk associated with consumption of fish collected from Kabul River, Pakistan. *Ecotoxicology and Environmental Safety*, *125*, 128–134. https://doi.org/10.1016/j.ecoenv.2015.12.005

Adesina, O. A., Nwogu, A. S., & Sonibare, J. A. (2021). Indoor levels of polycyclic aromatic hydrocarbons (PAHs) from environmental tobacco smoke of public bars. *Ecotoxicology and Environmental Safety*, *208*(January), 111604. https://doi.org/10.1016/j.ecoenv.2020.111604

Adieze, I. E., Orji, J. C., Nkechinyere, R., & Nwabueze, G. O. C. (2015). Changes in residual concentration of PAHs in planted and bioaugmented crude oil polluted tropical soils. *Journal of Biodiversity and Environmental Sciences (JBES)*, *6*(6), 307-316.

Adugna, G. (2016). A review on impact of compost on soil properties, water use and crop productivity. *Academic Research Journal of Agricultural Science and Research*, *4*(3), 93–104. https://doi.org/10.14662/ARJASR2016.010

Agegnehu, G., Bass, A. M., & Nelson, P. N. (2015). Biochar and biochar-compost as soil amendments : Effects on peanut yield, soil properties and greenhouse gas emissions in tropical North Queensland. *Agriculture Ecosystems & Environment*, *March*. https://doi.org/10.1016/j.agee.2015.07.027

Ajewole, O. C. (2010). Farmer's response to adoption of commercially available organic fertilizers in Oyo state, Nigeria. *African Journal of Agricultural Research*, *5*(18), 2497-2503.https://doi.org/https://www.researchgate.net/publication/267939287_Farmer's_response_to_adoption_of_commercially_available_organic_fertilizers_in_Oyo_state_Nigeria

Akhtar, N., & Ansari, A. M. (2020). *Important insect-pests and diseases of mango and their management (ISSN. July*.

Yadav, S. K., Kumar, A., Aman, A. S., & Mishra, P. K. Integrated Management of Mealy bug (Drosicha mangiferae) and Fruit fly (Bactrocera dorsalis) in Mango Orchard.3(13) pp 174-178

Ali, M., Kazmi, A. A., & Ahmed, N. (2014). Study on effects of temperature, moisture and pH in degradation and degradation kinetics of aldrin, endosulfan, lindane pesticides during full-scale continuous rotary drum composting. *Chemosphere*, *102*, 68–75. https://doi.org/10.1016/j.chemosphere.2013.12.022

Ameen, A., Ahmad, J., & Raza, S. (2016). Effect of pH and moisture content on composting of Municipal solid waste. *International Journal of Scientific and Research Publications*, *6*(5), 35-37.

Ameziane, H., Nounah, A., & Khamar, M. (2020). Olive pomace compost use for fenugreek germination.vol 18(3)

Amir, S., & Hafidi, M. (2005). *Fate of polycyclic aromatic hydrocarbons during composting of lagooning sewage sludge*. *58*, 449–458. https://doi.org/10.1016/j.chemosphere.2004.09.039

Amoah, S. T., & Kosoe, E. A. (2014). Solid Waste Management in Urban Areas of Ghana: Issues and Experiences from Wa. *Journal of Environment Pollution and Human Health*, *2*(5), 110–117. https://doi.org/10.12691/jephh-2-5-3

Andersson, E., & Isgren, E. (2021). Gambling in the garden : Pesticide use and risk exposure in Ugandan smallholder farming. *Journal of Rural Studies*, *82*(January), 76–86. https://doi.org/10.1016/j.jrurstud.2021.01.013

Antunes, E., Vuppaladadiyam, A. K., Sarmah, A. K., Varsha, S. S. V., Pant, K. K., Tiwari, B., & Pandey, A. (2021). Application of biochar for emerging contaminant mitigation. In *Advances in Chemical Pollution, Environmental Management and Protection* (1st ed., Vol. 7). Elsevier Inc. https://doi.org/10.1016/bs.apmp.2021.08.003

Aparicio, J. D., Raimondo, E. E., Gil, R. A., Benimeli, C. S., & Polti, M. A. (2018). Actinobacteria consortium as an efficient biotechnological tool for mixed polluted soil reclamation: Experimental factorial design for bioremediation process optimization. *Journal of Hazardous Materials*, *342*, 408–417. https://doi.org/10.1016/j.jhazmat.2017.08.041

Arguello-Pérez, M. Á., Mendoza-Pérez, J. A., Tintos-Gómez, A., Ramírez-Ayala, E., Godínez-Domínguez, E., & Silva-Bátiz, F. D. A. (2019). Ecotoxicological analysis of emerging contaminants from wastewater discharges in the Coastal Zone of Cihuatlán (Jalisco, Mexico). *Water*, *11*(7), 1386.

Ashbolt, N. J. (2004). *Microbial contamination of drinking water and disease outcomes in developing regions*. *198*, 229–238. https://doi.org/10.1016/j.tox.2004.01.030

Azanu, D., Mortey, C., Darko, G., Weisser, J. J., Styrishave, B., & Abaidoo, R. C. (2016). Uptake of antibiotics from irrigation water by plants. *Chemosphere*, *157*, 107–114. https://doi.org/10.1016/j.chemosphere.2016.05.035

Azim, K., Soudi, B., Boukhari, S., Perissol, C., Roussos, S., & Thami Alami, I. (2018). Composting parameters and compost quality: a literature review. *Organic agriculture*, *8*(2), 141-158. https://doi.org/10.1007/s13165-017-0180-z

Bártíková, H., Skálová, L., StuchĺÍková, L., Vokřál, I., Vaněk, T., & Podlipná, R. (2015). Xenobiotic-metabolizing enzymes in plants and their role in uptake and biotransformation of veterinary drugs in the environment. *Drug Metabolism Reviews*, *47*(3), 374–387. https://doi.org/10.3109/03602532.2015.1076437

Hoornwerg, D., & Bhada-Tata, P. (2012). A Global Review of Solid Waste Management. *Washington, District of Columbia: Urban Development & Local Government Unit World Bank*.

Bhardwaj, P., Sharma, A., Sagarkar, S., & Kapley, A. (2015). Mapping atrazine and phenol degradation genes in Pseudomonas sp. EGD-AKN5. *Biochemical Engineering Journal*, *102*, 125–134. https://doi.org/10.1016/j.bej.2015.02.029

Singh, A. N., Mohan, D., Bhushan, P., Gautam, D., Singh, U. K., & Kumar, P. Emerging Contaminants–A Concise Overview. *Emerging Issues in Environmental Science*, 121.

Bilal, M., Adeel, M., Rasheed, T., Zhao, Y., & Iqbal, H. M. (2019). Emerging contaminants of high concern and their enzyme-assisted biodegradation–a review. *Environment international*, *124*, 336-353.

Paul, J., Sierra, J., Causeret, F., Guindé, L., & Blazy, J. M. (2017). Factors affecting the adoption of compost use by farmers in small tropical Caribbean islands. *Journal of Cleaner Production*, *142*, 1387-1396.

Bloomfield, S. F., Rook, G. A., Scott, E. A., Shanahan, F., Stanwell-Smith, R., & Turner, P. (2016). Time to abandon the hygiene hypothesis: new perspectives on allergic disease, the human microbiome, infectious disease prevention and the role of targeted hygiene. *Perspectives in public health*, *136*(4), 213-224.

Bożym, M. (2017). Heavy metal content in compost and earthworms from home composters. *Environmental Protection and Natural Resources*, *28*(4), 1-4.

Botwe, B. O., Kelderman, P., Nyarko, E., & Lens, P. N. L. (2017). Assessment of DDT, HCH and PAH contamination and associated ecotoxicological risks in surface sediments of coastal Tema Harbour (Ghana). *Marine Pollution Bulletin*, *115*(1–2), 480–488. https://doi.org/10.1016/j.marpolbul.2016.11.054

Brändli, R. C., Bucheli, T. D., Kupper, T., Mayer, J., Stadelmann, F. X., & Tarradellas, J. (2007). Fate of PCBs, PAHs and their source characteristic ratios during composting and digestion of source-separated organic waste in full-scale plants. *Environmental Pollution*, *148*(2), 520–528. https://doi.org/10.1016/j.envpol.2006.11.021

Blasioli, S., Braschi, I., & Gessa, C. E. (2011). The Fate of Herbicides in Soil, Herbicides and Environment, Andreas Kortekamp (Ed.), Intech Book.

Brimo, K., Ouvrard, S., Houot, S., Lafolie, F., & Garnier, P. (2017). Modelling the fate of PAH added with composts in amended soil according to the origin of the exogenous organic matter. *Science of the Total Environment, 616–617*, 658–668. https://doi.org/10.1016/j.scitotenv.2017.10.269

Bunke, D., & Moritz, S. (2014).*c. 1 Discussion paper " Pollution of tomorrow ." 603437*, 0–35.

Capozzi, F., Adamo, P., Spagnuolo, V., Giordano, S., Biologia, D., Federico, N., & Cintia, V. (2021). Field comparison between moss and lichen PAHs uptake abilities based on deposition fluxes and diagnostic ratios. *Ecological Indicators*, *120*, 106954. https://doi.org/10.1016/j.ecolind.2020.106954

Cerda, A., Artola, A., Font, X., Barrena, R., Gea, T., & Sánchez, A. (2018). Composting of food wastes: Status and challenges. *Bioresource Technology*, *248*, 57–67. https://doi.org/10.1016/j.biortech.2017.06.133

Crohn, D. M., Chaganti, V. N., & Reddy, N. (2013). Composts as post-fire erosion control treatments and their effect on runoff water quality. *Transactions of the ASABE*, *56*(2), 423-435. https://doi.org/10.13031/2013.42692

Chang, B. V., Fan, S. N., Tsai, Y. C., Chung, Y. L., Tu, P. X., & Yang, C. W. (2018). Removal of emerging contaminants using spent mushroom compost. *Science of the Total Environment*, *634*, 922–933. https://doi.org/10.1016/j.scitotenv.2018.03.366

Chen, C., Pankow, C. A., Oh, M., Heath, L. S., Zhang, L., Du, P., Xia, K., & Pruden, A. (2019). Effect of antibiotic use and composting on antibiotic resistance gene abundance and resistome risks of soils receiving manure-derived amendments. *Environment International*, *128*, 233–243. https://doi.org/10.1016/j.envint.2019.04.043

Chen, H. R., Rairat, T., Loh, S. H., Wu, Y. C., Vickroy, T. W., & Chou, C. C. (2017). Assessment of veterinary drugs in plants using pharmacokinetic approaches: The absorption, distribution and elimination of tetracycline and sulfamethoxazole in ephemeral vegetables. *Plos one*, *12*(8), e0183087. 1-16.

Chen, M., Xu, P., Zeng, G., Yang, C., Huang, D., & Zhang, J. (2015). Bioremediation of soils contaminated with polycyclic aromatic hydrocarbons, petroleum, pesticides, chlorophenols and heavy metals by composting: Applications, microbes and future research needs. *Biotechnology Advances*, *33*(6), 745–755. https://doi.org/10.1016/j.biotechadv.2015.05.003

Chen, X., Zeng, D., Xu, Y., & Fan, X. (2018). Perceptions, risk attitude and organic fertilizer investment: Evidence from rice and banana farmers in Guangxi, China. *Sustainability*, *10*(10), 3715.https://doi.org/10.3390/su10103715

Cheng, J., & Deming, T. J. (2011). Ecotoxicology of Synthetic Pyrethroids. *Springer-*

Verlag Berlin Heidelberg, *310*, 1–26. https://doi.org/10.1007/128

Chiti, T., Perugini, L., Vespertino, D., & Valentini, R. (2016). Effect of selective logging on soil organic carbon dynamics in tropical forests in central and western Africa. *Plant and soil*, *399*(1), 283-294. https://doi.org/10.1007/s11104-015-2697-9

Chung, H. S., Lee, Y. J., Rahman, M. M., Abd El-Aty, A. M., Lee, H. S., Kabir, M. H., ... & Shim, J. H. (2017). Uptake of the veterinary antibiotics chlortetracycline, enrofloxacin, and sulphathiazole from soil by radish. *Science of the total Environment*, *605*, 322-331. https://doi.org/10.1016/j.scitotenv.2017.06.231

Ciesielczuk, T., Kusza, G., Poluszyńska, J., & Kochanowska, K. (2014). Pollution of flooded arable soils with heavy metals and polycyclic aromatic hydrocarbons (PAHs). *Water, Air, and Soil Pollution*, *225*(10), 0–11. https://doi.org/10.1007/s11270-014-2145-0

Cobbinah, P. B., Addaney, M., & Agyeman, K. O. (2017). Locating the role of urbanites in solid waste management in Ghana. *Environmental Development*, *24*, 9–21. https://doi.org/10.1016/j.envdev.2017.06.004

Cobbinah, P. B., Poku-Boansi, M., & Peprah, C. (2017). Urban environmental problems in Ghana. *Environmental Development*, *23*(May), 33–46. https://doi.org/10.1016/j.envdev.2017.05.001

Coelho-ravagnani, C. D. F., Corgosinho, F. C., La, F., Ziegler, F., Marques, C., Prado, M., Laviano, A., & Mota, F. (2020). *Dietary recommendations during the COVID-19 pandemic*. *0*(0), 1–14. https://doi.org/10.1093/nutrit/nuaa067

Coleman, J. O. D., Blake-Kalff, M. M. A., & Davies, T. G. E. (1997). Detoxification of xenobiotics by plants: Chemical modification and vacuolar compartmentation. *Trends in Plant Science*, *2*(4), 144–151. https://doi.org/10.1016/S1360-1385(97)01019-4

Danciulescu, V., Bucur, E., Pascu, L. F., Vasile, A., & Bratu, M. (2015). Correlations between noise level and pollutants concentration in order to assess the level of air pollution induced by heavy traffic. *Journal of Environmental Protection and Ecology*, *16*(3), 815–823.

Dang, Q., Zhao, X., Yang, T., Gong, T., He, X., Tan, W., & Xi, B. (2022). Coordination of bacterial biomarkers with the dominant microbes enhances triclosan biodegradation in soil amended with food waste compost and cow dung compost.

Science of the Total Environment, *824*, 153837. https://doi.org/10.1016/j.scitotenv.2022.153837

Dantas, R. F. (2005). Ozonation of Emergent Contaminants. In *Chemical Engineering*.

De Feo, G., Ferrara, C., Iannone, V., & Parente, P. (2019). Improving the efficacy of municipal solid waste collection with a communicative approach based on easily understandable indicators. *Science of the Total Environment*, *651*, 2380–2390. https://doi.org/10.1016/j.scitotenv.2018.10.161

Deemter, D., Oller, I., Amat, A. M., & Malato, S. (2021). Effect of salinity on preconcentration of contaminants of emerging concern by nano filtration: Application of solar photo-Fenton as a tertiary treatment. *Science of the Total Environment*, *756*, 143593. https://doi.org/10.1016/j.scitotenv.2020.143593

Desiraju, R. (2015). *History of Composting*. *October*. https://doi.org/10.13140/RG.2.1.1408.8402

Di Gilio, A., Palmisani, J., Trizio, L., Saracino, G., Giua, R., & de Gennaro, G. (2020). Total p-PAH levels nearby a complex industrial area: A tailored monitoring experiment to assess the impact of emission sources. *Atmosphere*, *11*(5), 1–13. https://doi.org/10.3390/ATMOS11050469

Djouaka, R., Soglo, M. F., Kusimo, M. O., Adéoti, R., Talom, A., Zeukeng, F., ... & Mahuku, G. (2018). The rapid degradation of lambda-cyhalothrin makes treated vegetables relatively safe for consumption. *International journal of environmental research and public health*, *15*(7), 1536. https://doi.org/10.3390/ijerph15071536

EPA USA. (2008). Polycyclic aromatic hydrocarbons. In *Encyclopedia of Earth Sciences Series*. https://doi.org/10.1007/978-94-017-8801-4_25

EPA USA. (2016). EPA’s priority pollutants: where they come from±where they’re going. In *In AIChE Symp. Ser., Water* (Vol. 77, Issue 209).

European Commission. (2018). *Chapter 7 Solid waste management*. Waste Management and Pollution. ec.europa.eu/echo/files/evaluation/watsan2005/annex

F, A. (2017). Unlocking the Potential of Soil Organic Carbon: In *The Proceedings of the Global Symposium on Soil Organic Carbon 2017*.

FAO. (2017). Global Soil Organic Carbon. In *Intergovernmental Technical Panel on Soils*. https://doi.org/10.1029/2008GB003327;

FAO. (2020). *Agriculture Sector in Ghana Review* (Vol. 20, Issue August). https://itrade.gov.il/ghana/files/2020/05/Agriculture-Sector-Review.pdf

Farrell, M., & Jones, D. L. (2009). Critical evaluation of municipal solid waste composting and potential compost markets. *Bioresource Technology*, *100*(19), 4301–4310. https://doi.org/10.1016/j.biortech.2009.04.029

Fogel, S., Lancione, R. L., & Sewall, A. E. (1982). Enhanced biodegradation of methoxychlor in soil under sequential environmental conditions. *Applied and Environmental Microbiology*, *44*(1), 113–120. https://doi.org/10.1128/aem.44.1.113-120.1982

Forján, R., Asensio, V., Vila, A. R., & Covelo, E. F. (2016). Contributions of a compost-biochar mixture to the metal sorption capacity of a mine tailing. *Environmental Science and Pollution Research*, *23*(3), 2595-2602. https://doi.org/10.1007/s11356-015-5489-0

Forján, R., Lores, I., Sierra, C., Baragaño, D., Gallego, J. L. R., & Peláez, A. I. (2020). Bioaugmentation treatment of a PAH-polluted soil in a slurry bioreactor. *Applied Sciences (Switzerland)*, *10*(8). https://doi.org/10.3390/APP10082837

Ghana. (2012). *National environmental policy*.

Ghana, G. of. (1999). *ENVIRONMENTAL SANITATION POLICY* (Issue May 1999).

Ghana Statistical Service. (2014). *Ghana*.

Godfrey, L. (2017). *Historical Review of Waste Management and Recycling in South Africa*. 1–11. https://doi.org/10.3390/resources6040057

Gogoi, A., Mazumder, P., Tyagi, V. K., Chaminda, G. T., An, A. K., & Kumar, M. (2018). Occurrence and fate of emerging contaminants in water environment: a review. *Groundwater for Sustainable Development*, *6*, 169-180. https://doi.org/10.1016/j.gsd.2017.12.009

Milinković, M., Lalević, B., Jovičić-Petrović, J., Golubović-Ćurguz, V., Kljujev, I., & Raičević, V. (2019). Biopotential of compost and compost products derived from horticultural waste—effect on plant growth and plant pathogens' suppression. *Process Safety and Environmental Protection*, *121*, 299-306. https://doi.org/10.1016/j.psep.2018.09.024

Gondek, M., Weindorf, D. C., Thiel, C., & Kleinheinz, G. (2020). Soluble Salts in Compost and Their Effects on Soil and Plants: A Review. *Compost Science and Utilization*, *28*(2), 59–75. https://doi.org/10.1080/1065657X.2020.1772906

Gong, Q., Chen, P., Shi, R., Gao, Y., Zheng, S. A., Xu, Y., ... & Zheng, X. (2019). Health assessment of trace metal concentrations in organic fertilizer in Northern China. *International journal of environmental research and public health*, *16*(6), 1031. https://doi.org/10.3390/ijerph16061031

Goswami, K., Choudhury, H. K., & Saikia, J. (2012). Forest Policy and Economics Factors influencing farmers' adoption of slash and burn agriculture in North East India.

Forest Policy and Economics, *15*, 146–151. https://doi.org/10.1016/j.forpol.2011.11.005

Grau, F., Drechsel, N., Haering, V., Trautz, D., Weerakkody, W., Drechsel, P., Marschner, B., Dissanayake, D., & Sinnathamby, V. (2017). Impact of Fecal Sludge and Municipal Solid Waste Co-Compost on Crop Growth of Raphanus Sativus L. and Capsicum annum L. under Stress Conditions. *Resources*, *6*(3), 26. https://doi.org/10.3390/resources6030026

Gunnell, D., Knipe, D., Chang, S. Sen, Pearson, M., Konradsen, F., Lee, W. J., & Eddleston, M. (2017). Prevention of suicide with regulations aimed at restricting access to highly hazardous pesticides: a systematic review of the international evidence. *The Lancet Global Health*, *5*(10), e1026–e1037. https://doi.org/10.1016/S2214-109X(17)30299-1

.

Gupta, N., Yadav, K. K., & Kumar, V. (2015). A review on current status of municipal solid waste management in India. *Journal of environmental sciences*, *37*, 206-217. https://doi.org/10.1016/j.jes.2015.01.034

Gworek, B., Klimczak, K., Kijeńska, M., & Gozdowski, D. (2016). Comparison of PAHs uptake by selected Monocotyledones and Dicotyledones from municipal and industrial sewage sludge. *Environmental Science and Pollution Research*, *23*(19), 19461-19470.https://doi.org/10.1007/s11356-016-7130-2

Haritash, A. K., & Kaushik, C. P. (2009). Biodegradation aspects of Polycyclic Aromatic Hydrocarbons (PAHs): A review. *Journal of Hazardous Materials*, *169*(1–3), 1–15. https://doi.org/10.1016/j.jhazmat.2009.03.137

Rahman, M. H. A., Sadi, T., Ahmad, A. A., Masri, I. N., Yusoff, M. M., Kamaruddin, H., ... & Malek, R. A. (2020). Inventory and composting of yard waste in Serdang, Selangor, Malaysia. *Heliyon*, *6*(7), e04486.https://doi.org/10.1016/j.heliyon.2020.e04486

Bandaw, T., & Herago, T. (2017). Review on abattoir waste management. *Global Veterinaria*, *19*(2), 517-524.https://doi.org/10.5829/idosi.gv.2017.517.524

Hettiarachchi, L. G., Jayathillake, N., Fernando, S., & Gunawardena, S. (2019). Effects of compost particle size, moisture content and binding agents on co-compost pellet properties. *International Journal of Agricultural and Biological Engineering*, *12*(4), 184-191.https://doi.org/10.25165/j.ijabe.20191204.4354

Hoffmann, U., Hoffmann, T., Jurasinski, G., Glatzel, S., & Kuhn, N. J. (2014). Assessing the spatial variability of soil organic carbon stocks in an alpine setting (Grindelwald, Swiss Alps). *Geoderma*, *232–234*, 270–283.

https://doi.org/10.1016/j.geoderma.2014.04.038

Hoornwerg, D., & Bhada-Tata, P. (2012). A Global Review of Solid Waste Management. *Washington, District of Columbia: Urban Development & Local Government Unit World Bank*.https://doi.org/10.1016/S1002-0160(12)60038-1

Horská, T., Kocourek, F., Stará, J., Holý, K., Mráz, P., Krátký, F., ... & Hajšlová, J. (2020). Evaluation of pesticide residue dynamics in lettuce, onion, leek, carrot and parsley. *Foods*, *9*(5), 680. https://doi.org/10.3390/foods9050680

Houtman, C. J. (2010). *Emerging contaminants in surface waters and their relevance for the production of drinking water in Europe*. *8168*. https://doi.org/10.1080/1943815X.2010.511648

Hu, Z., Liu, Y., Chen, G., Gui, X., Chen, T., & Zhan, X. (2011). Characterization of organic matter degradation during composting of manure-straw mixtures spiked with tetracyclines. *Bioresource Technology*, *102*(15), 7329–7334. https://doi.org/10.1016/j.biortech.2011.05.003

Huang, B., Chen, F., Shen, Y., Qian, K., Wang, Y., Sun, C., Zhao, X., Cui, B., Gao, F., Zeng, Z., & Cui, H. (2018). Advances in targeted pesticides with environmentally responsive controlled release by nanotechnology. *Nanomaterials*, *8*(2). 102 https://doi.org/10.3390/nano8020102

Sabki, M. H., Lee, C. T., Bong, C. P., & Klemes, J. J. (2018). A review on the economic feasibility of composting for organic waste management in Asian countries. *Chemical Engineering Transactions*, *70*, 49-54.https://doi.org/10.3303/CET1870009

Idris, A. M., Said, T. O., Sahlabji, T., & El-zahhar, A. (2020). *Monitoring and health risk assessment of some pesticides and organic*. *May*.

Asiri, H. F., Idris, A. M., Said, T. O., Sahlabji, T., Alghamdi, M. M., El-Zahhar, A. A., & El Nemr, A. (2020). Monitoring and health risk assessment of some pesticides and organic pollutants in fruit and vegetables consumed in Asir Region, Saudi Arabia. *Fresenius environmental bulletin*, *29*(1), 615-625.

Imoro, Z. A., Larbi, J., & Duwiejuah, A. B. (2019). Pesticide availability and usage by farmers in the Northern Region of Ghana. *Journal of Health and Pollution*, *9*(23), 1–8. https://doi.org/10.5696/2156-9614-9.23.190906

Jakovljević, I., Štrukil, Z. S., Godec, R., Bešlić, I., Davila, S., Lovrić, M., & Pehnec, G. (2020). Pollution sources and carcinogenic risk of PAHs in pm1 particle fraction in an urban area. *International Journal of Environmental Research and Public Health*, *17*(24), 1–21. https://doi.org/10.3390/ijerph17249587

Jcu, R. (2017). *Jenberu, Getachew Agegnehu (2017) Biochar, compost and biochar-*

compost: effects on crop performance, soil quality and greenhouse gas emissions in tropical agricultural soils. PhD thesis, James Cook University.

Jenberu, G. A. (2017). *Biochar, compost and biochar-compost: Effects on crop performance, soil quality and greenhouse gas emissions in tropical agricultural soils* (Doctoral dissertation, James Cook University).

Folefack, A. J. J. (2015). The determinants for the adoption of compost from household waste for crop production by farmers living nearby Yaoundé, Cameroon: descriptive and logit model approaches of analysis. *International Journal of Biological and Chemical Sciences*, *9*(1), 308-328.. *9*(1), 308–328. https://doi.org/10,4314/ijbcs.v9i1.28

Jin, X., Liu, Y., Qiao, X., Guo, R., Liu, C., Wang, X., & Zhao, X. (2019). Risk assessment of organochlorine pesticides in drinking water source of the Yangtze River. *Ecotoxicology and Environmental Safety*, *182*. 109390. https://doi.org/10.1016/j.ecoenv.2019.109390

ERGUVEN, G., & KANAT, G. (2020). Importance of solid waste management on composting, problems and proposed solutions: The case of Turkey. *European Journal of Science and Technology*, (19), 66-71. https://doi.org/10.31590/ejosat.672413

Kassie, M., Zikhali, P., Manjur, K., & Edwards, S. (2009, August). Adoption of sustainable agriculture practices: Evidence from a semi-arid region of Ethiopia. In *Natural Resources Forum* (Vol. 33, No. 3, pp. 189-198). Oxford, UK: Blackwell Publishing Ltd. https://doi.org/10.1111/j.1477-8947.2009.01224.x

Kathi, S., & Khan, A. B. (2011). Phytoremediation approaches to PAH contaminated soil. *Indian Journal of Science and Technology*, *4*(1), 56-63.https://doi.org/10.17485/ijst/2011/v4i1/29935

Kaushal, J., Khatri, M., & Arya, S. K. (2021). A treatise on Organophosphate pesticide pollution: Current strategies and advancements in their environmental degradation and elimination. *Ecotoxicology and Environmental Safety*, *207*, 111483. https://doi.org/10.1016/j.ecoenv.2020.111483

Keenum, I., Williams, R. K., Ray, P., Garner, E. D., Knowlton, K. F., & Pruden, A. (2021). Combined effects of composting and antibiotic administration on cattle manure–borne antibiotic resistance genes. *Microbiome*, *9*(1), 1–16. https://doi.org/10.1186/s40168-021-01006-z

Keerthanan, S., Jayasinghe, C., Biswas, J. K., & Vithanage, M. (2021). Pharmaceutical and Personal Care Products (PPCPs) in the environment: Plant uptake, translocation, bioaccumulation, and human health risks. *Critical Reviews in Environmental Science and Technology*, *51*(12), 1221–1258. https://doi.org/10.1080/10643389.2020.1753634

Kelley, A., Wilkie, A. C., & Maltais-Landry, G. (2020). Food-based composts provide more soil fertility benefits than cow manure-based composts in sandy soils. *Agriculture*, *10*(3), 69. https://doi.org/10.3390/agriculture10030069.

Kelova, M. E., Ali, A. M., Eich-Greatorex, S., Dörsch, P., Kallenborn, R., & Jenssen, P. D. (2021). Correction to: Small-scale on-site treatment of fecal matter: comparison of treatments for resource recovery and sanitization. *Environmental Science and Pollution Research*, *28*(45), 63965-63967.https://doi.org/10.1007/s11356-021-13658-3

Komakech, A. J. (2014). *Urban waste management and the environmental impact of organic waste treatment systems in Kampala, Uganda* (Vol. 2014, No. 2014: 77).

Kopeća, M., Smreczakb, B., Ukalska-Jarugab, A., Mierzwa-Herszteka, M., & Gondeka, K. (2017). Changes of PAHs and C humic fractions in composts with sewage sludge and biochar amendment. *Desalin. Water Treat.*, *97*, 234-243.https://doi.org/10.5004/dwt.2017.21629

Kristak, L., Kubovský, I., & Réh, R. (2021). New challenges in wood and wood-based materials. *Polymers*, *13*(15), 2538.

Kudłak, B., Szczepańska, N., Owczarek, K., Mazerska, Z., & Namieśnik, J. (2015). Endocrine disrupting compounds–problems and challenges. *Emerg Pollut Environ Curr Furth Implications*, *169*.https://doi.org/10.5772/60410

Kupper, T., Bucheli, T. D., Brändli, R. C., Ortelli, D., & Edder, P. (2008). Dissipation of pesticides during composting and anaerobic digestion of source-separated organic waste at full-scale plants. *Bioresource Technology*, *99*, 7988–7994. https://doi.org/10.1016/j.biortech.2008.03.052

Lalander, C., Senecal, J., Gros Calvo, M., Ahrens, L., Josefsson, S., Wiberg, K., & Vinnerås, B. (2016). Fate of pharmaceuticals and pesticides in fly larvae composting. *Science of the Total Environment*, *565*, 279–286. https://doi.org/10.1016/j.scitotenv.2016.04.147

Langdon, K. A., Chandra, A., Bowles, K., Symons, A., Pablo, F., & Osborne, K. (2019). A preliminary ecological and human health risk assessment for organic contaminants in composted municipal solid waste generated in New South Wales, Australia. *Waste Management*, *100*, 199–207. https://doi.org/10.1016/j.wasman.2019.09.001

Lee-smith, D., & Lee-smith, D. (2013). *Which way for UPA in Africa ? 4813*. https://doi.org/10.1080/13604813.2012.754177

Lei, M., Zhang, L., Lei, J., Zong, L., Li, J., Wu, Z., & Wang, Z. (2015). Overview of emerging contaminants and associated human health effects. *BioMed Research International*, *2015*.

Pereira, J. C. V., Serbent, M. P., & Skoronski, E. (2021). Application of immobilized mycelium-based pellets for the removal of organochlorine compounds: a review. *Water Science and Technology*, *83*(8), 1781-1796. https://doi.org/10.2166/wst.2011.079

Létondor, C., Pascal-Lorber, S., & Laurent, F. (2015). Uptake and distribution of chlordecone in radish: different contamination routes in edible roots. *Chemosphere*, *118*, 20-28. https://doi.org/10.1016/j.chemosphere.2014.03.102

Li, X., Zhang, C., Li, Y., & Zhi, Q. (2016). The Status of Municipal Solid Waste Incineration (MSWI) in China and its Clean Development. *Energy Procedia*, *104*, 498–503. https://doi.org/10.1016/j.egypro.2016.12.084

Li, Y., Yan, H., & Yu, X. (2019). Uptake and accumulation of di-n-butyl phthalate in six leafy vegetables under hydroponic conditions. *Food Production, Processing and Nutrition*, *1*(1), 1–7. https://doi.org/10.1186/s43014-019-0009-0

Lin, C., Cheruiyot, N. K., Bui, X. T., & Ngo, H. H. (2022). Composting and its application in bioremediation of organic contaminants. *Bioengineered*, *13*(1), 1073–1089. https://doi.org/10.1080/21655979.2021.2017624

Liu, B., Li, Y., Zhang, X., Feng, C., Gao, M., & Shen, Q. (2015). Effects of composting process on the dissipation of extractable sulfonamides in swine manure. *Bioresource Technology*, *175*, 284–290. https://doi.org/10.1016/j.biortech.2014.10.098

Lohri, C. R., Camenzind, E. J., & Zurbrügg, C. (2014). Financial sustainability in municipal solid waste management – Costs and revenues in Bahir Dar, Ethiopia. *Waste Management*, *34*(2), 542–552. https://doi.org/10.1016/j.wasman.2013.10.014

Long, T. B., Blok, V., & Coninx, I. (2016). Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europ: evidence from the Netherlands. *Journal of Cleaner Production, 112*, 9–21. https://doi.org/10.1016/j.jclepro.2015.06.044

Loos, R., Marinov, D., Sanseverino, I., Napierska, D., & Lettieri, T. (2018). Review of the 1st Watch List under the Water Framework Directive and recommendations for the 2nd Watch List. *Luxembourg: Publications Office of the European Union*. https://doi.org/10.2760/614367

Lorenz, K., & Lal, R. (2016). Environmental impact of organic agriculture. *Advances in Agronomy*, *139*, 99-152. https://doi.org/10.1016/bs.agron.2016.05.003

Lü, H., Chen, X. H., Mo, C. H., Huang, Y. H., He, M. Y., Li, Y. W., Feng, N. X., Katsoyiannis, A., & Cai, Q. Y. (2021). Occurrence and dissipation mechanism of organic pollutants during the composting of sewage sludge: A critical review. *Bioresource Technology*, *328*, 124847. https://doi.org/10.1016/j.biortech.2021.124847

Lupton, S. (2017). Markets for waste and waste e derived fertilizers; An empirical survey. *Journal of Rural Studies*, *55*, 83–99. https://doi.org/10.1016/j.jrurstud.2017.07.017

Xu, J., Tang, C., & He, J. (2010). Molecular environmental soil science at the interfaces in the Earth's critical zone. *Journal of Soils and Sediments*, *10*(5), 797-798. https://doi.org/10.1007/978-3-642-05297-2

Manirakiza, N., Şeker, C., & Negiş, H. (2021). Effects of Woody Compost and Biochar Amendments on Biochemical Properties of the Wind Erosion Afflicted a Calcareous and Alkaline Sandy Clay Loam Soil. *Communications in Soil Science and Plant Analysis*, *00*(00), 1–12. https://doi.org/10.1080/00103624.2020.1862148

Martín-Pozo, L., de Alarcón-Gómez, B., Rodríguez-Gómez, R., García-Córcoles, M. T., Çipa, M., & Zafra-Gómez, A. (2019). Analytical methods for the determination of emerging contaminants in sewage sludge samples. A review. *Talanta*, *192*, 508-533.https://doi.org/10.1016/j.talanta.2018.09.056

Martínez Blanco, J. (2014). *Sustainability assessment of municipal compost use in horticulture using a life cycle approach*. Universitat Autònoma de Barcelona,.http://hdl.handle.net/10803/51440

Massé, D. I., Saady, N. M. C., & Gilbert, Y. (2014). Potential of biological processes to eliminate antibiotics in livestock manure: An overview. *Animals*, *4*(2), 146–163. https://doi.org/10.3390/ani4020146

Massone, C. G., Santos, A. A., Ferreira, P. G., & Carreira, R. S. (2021). A baseline evaluation of PAH body burden in sardines from the southern Brazilian shelf. *Marine Pollution Bulletin*, *163*, 111949.https://doi.org/10.1016/j.marpolbul.2020.111949

Matsui, N., & Cornelius, C. (2017). Household survey on the compost use and its constraints in smallholder farming of Malawi northern region. *J. Plant. Nutr. Soil Sci*, *19*, 1-9.https://doi.org/10.9734/IJPSS/2017/36570

McGowin, A. E., Adom, K. K., & Obubuafo, A. K. (2001). Screening of compost for PAHs and pesticides using static subcritical water extraction. *Chemosphere*, *45*(6-7), 857-864.MDH. (2014). *Guidance for Evaluating the Cancer Potency of Polycyclic Aromatic Hydrocarbon (PAH) Mixtures in Environmental Samples*. 1–13. http://www.health.state.mn.us/divs/eh/risk/guidance/pahmemo.html

Medyńska-Juraszek, A., Bednik, M., & Chohura, P. (2020). Assessing the influence of compost and biochar amendments on the mobility and uptake of heavy metals by green leafy vegetables. *International Journal of Environmental Research and Public Health*, *17*(21), 1–16. https://doi.org/10.3390/ijerph17217861

Meena, A. L., Karwal, M., Dutta, D., & Mishra, R. P. (2021). Composting: phases and factors responsible for efficient and improved composting. *Agriculture and Food: e-Newsletter*, *1*, 85-90.https://doi.org/10.13140/RG.2.2.13546.95689

Mensah, A. K., Mahiri, I. O., Owusu, O., Mireku, O. D., Wireko, I., & Kissi, E. A. (2015).

Environmental impacts of mining: a study of mining communities in Ghana. *Applied Ecology and Environmental Sciences*, *3*(3), 81-94.

Mensah, A. K., & Frimpong, K. A. (2018). Biochar and/or Compost Applications Improve Soil Properties, Growth, and Yield of Maize Grown in Acidic Rainforest and Coastal Savannah Soils in Ghana. *Hindawi International Journal of Agronomy*, *2018*.

Michal, J., Eva, C., Igor, C., Markéta, S., Jana, Ž., & Pavel, V. (2018). Endocrine disruptive compounds and male reproduction. *Medical Journal of Cell Biology*, *6*(4), 131–134. https://doi.org/10.2478/acb-2018-0021

Michelini, L., Meggio, F., Reichel, R., Thiele-Bruhn, S., Pitacco, A., Scattolin, L., ... & Ghisi, R. (2015). Sulfadiazine uptake and effects in common hazel (Corylus avellana L.). *Environmental Science and Pollution Research*, *22*(17), 13362-13371.https://doi.org/10.1007/s11356-015-4560-1

Miezah, K., Obiri-danso, K., Kádár, Z., Fei-baffoe, B., & Mensah, M. Y. (2015). Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. *Waste Management*, *46*, 15–27.

Mirabelli, M. C., Wing, S., Marshall, S. W., & Wilcosky, T. C. (2006). Asthma symptoms among adolescents who attend public schools that are located near confined swine feeding operations. *Pediatrics*, *118*(1), e66-e75.https://doi.org/10.1542/peds.2005-2812

Mishra, A. K., Kshama, S., Kailash, S., Shalini, S., Md, S., & Ali, S. (2014). Carbon sequestered through biomass and soil organic carbon dynamics in Jatropha curcas L. *Ecology Environment and Conservation*, *20*(2), 561-565.

Mishra, E. A. (2020). *A Report on Plastic Waste Problem & Management*. *November*, 0–4.

Mu, L., Liang, Y., Xue, Q., Chen, C., & Lin, X. (2014). Using the DNDC model to compare soil organic carbon dynamics under different crop rotation and fertilizer strategies. *Spanish Journal of Agricultural Research*, *12*(1), 265–276. https://doi.org/10.5424/sjar/2014121-4895

Muscolo, A., Papalia, T., Settineri, G., Mallamaci, C., & Jeske-Kaczanowska, A. (2018). Are raw materials or composting conditions and time that most influence the maturity and/or quality of composts? Comparison of obtained composts on soil properties. *Journal of Cleaner Production*, *195*, 93–101. https://doi.org/10.1016/j.jclepro.2018.05.204

Mustafa-Msukwa, A. K., Mutimba, J. K., Masangano, C., & Edriss, A. K. (2011). An assessment of the adoption of compost manure by smallholder farmers in Balaka District, Malawi. *South African Journal of Agricultural Extension*, *39*(1), 17-25.

Muvvala, S. S., & Subbaraya, S. (2020). *A Brief Review on Soil Organic Carbon*. *April*.

Naidu, R., & Wong, M. H. (2013). Science of the Total Environment. *Science of the Total Environment, The*, *463–464*, 1077–1078. https://doi.org/10.1016/j.scitotenv.2013.05.085

Nartey, E. G., Amoah, P., Ofosu-Budu, G. K., Muspratt, A., & Pradhan, S. kumar. (2017). Effects of co-composting of faecal sludge and agricultural wastes on tomato transplant and growth. *International Journal of Recycling of Organic Waste in Agriculture*, *6*(1), 23–36. https://doi.org/10.1007/s40093-016-0149-z

Cook, R. C. (1966). World population prospects. *Ohio St. LJ*, *27*, 634.

NEPC. (2013). National Environment Protection (Assessment of Site Contamination) Amendment Measure 2013 (Cth). *Federal Register of Legislative Instruments*, *6*(1). https://lms.uwa.edu.au/bbcswebdav/pid-1195771-dt-content-rid-16965649_1/courses/ENVT3361_SEM-1_2019/Guidelines Reports ENVT3361/NEPM 2014 VOL02.pdf

Neugebauer, M., Sołowiej, P., Piechocki, J., Czekała, W., & Janczak, D. (2017). The influence of the C: N ratio on the composting rate. *International Journal of Smart Grid and Clean Energy*, *6*(1), 54-60.https://doi.org/10.12720/sgce.6.1.54-60

Niemuth, N. J., & Klaper, R. D. (2015). Chemosphere Emerging wastewater contaminant metformin causes intersex and reduced fecundity in fish. *Chemosphere*, *135*, 38–45. https://doi.org/10.1016/j.chemosphere.2015.03.060

Nigam, R., Singh, J., Singh, R., Kumar, A., & Agarwal, Y. K. (2016). *Modern approaches in pest and disease management* (Vol. 4, Issue 1).

Nigussie, A., Kuyper, T. W., & Neergaard, A. De. (2015). Agricultural waste utilisation strategies and demand for urban waste compost : Evidence from smallholder farmers in Ethiopia. *Waste Management*, *44*, 82–93. https://doi.org/10.1016/j.wasman.2015.07.038

NWAKWASI, L. N., Okoro, B. C., Osuagwu, J. C., Nwachukwu, A. N., & Agunwamba, J. C. (2019). Modeling Soil Organic Carbon in Crude Oil Contaminated Soil in the Niger Delta. *European Journal of Engineering and Technology Research*, *4*(3), 93-96.

Nygård, K., Werner-Johansen, Ø., Rønsen, S., Caugant, D. A., Simonsen, Ø., Kanestrøm, A., ... & Aavitsland, P. (2008). An outbreak of legionnaires disease caused by long-distance spread from an industrial air scrubber in Sarpsborg, Norway. *Clinical Infectious Diseases*, *46*(1), 61-69. https://doi.org/10.1086/524016

Obuobie, E., Keraita, B., Danso, G., Amoah, P., Cofie, O. O., Raschid-Sally, L., & Drechsel, P. (2006). Irrigated urban vegetable production in Ghana. *Characteristics, Benefits and Risks.*

Accra, CSIR-INSTI, Printing Division.

Okere, U., & Semple, K. (2012). Biodegradation of PAHs in 'pristine'soils from different climatic regions. *J Bioremed Biodegrad S*, *1*(2), 1-11.https://doi.org/10.4172/2155-6199.s1-006

Babasola, O. J., Olaoye, I. J., Alalade, O. A., Matanmi, B. M., & Olorunfemi, O. D. (2018). Factors affecting the use of organic fertilizer among vegetable farmers in Kwara State, Nigeria. *Tanzania Journal of Agricultural Sciences*, *16*(1).

Sundukov, Y. N. (2006). First record of the ground beetle Trechoblemus postilenatus (Coleoptera, Carabidae) in Primorskii krai. *Far Eastern Entomologist*, (165), 16-16.https://doi.org/10.1002/tox

Olutona, G. O., & Aderemi, M. A. (2019). Organochlorine pesticide residue and heavy metals in leguminous food crops from selected markets in Ibadan, Nigeria. *Legume Science*, *1*(1), 1–9. https://doi.org/10.1002/leg3.3

Omar, T. F. T., Zaharin, A., Yusoff, F., & Mustafa, S. (2019). Occurrence and level of emerging organic contaminant in fish and mollusk from Klang River estuary, Malaysia and assessment on human health risk. *Environmental Pollution*, *248*, 763–773. https://doi.org/10.1016/j.envpol.2019.02.060

Omer, A. (2020). *Anaerobic Degradation of Polycyclic Aromatic Hydrocarbons (PAHs) by an Enriched Bacterial Consortium Isolated from Riverbank Sediments Contaminated with PAHs. December*.

Ondarts, M., Hort, C., Sochard, S., Platel, V., Moynault, L., & Seby, F. (2012). Evaluation of compost and a mixture of compost and activated carbon as biofilter media for the treatment of indoor air pollution. *Environmental technology*, *33*(3), 273-284.https://doi.org/10.1080/09593330.2011.570793

Oteng-Ababio, M., Arguello, J. E. M., & Gabbay, O. (2013). Solid waste management in African cities: Sorting the facts from the fads in Accra, Ghana. *Habitat International*, *39*, 96-104.https://doi.org/10.1016/j.habitatint.2012.10.010

Owusu-Nimo, F., Mantey, K., Nyarko, B., Appiah-Effah, E., & Aubyn, A. (2018). *Spatial distribution patterns of illegal artisanal small scale gold mining (Galamsey) operations in Ghana: A focus on the Western RegionNo Title*.

Owusu, P. A., Banadda, N., Zziwa, A., Seay, J., & Kiggundu, N. (2018). Reverse engineering of plastic waste into useful fuel products. *Journal of Analytical and Applied Pyrolysis*, *130*, 285-293.https://doi.org/10.1016/j.jaap.2017.12.020

Owusu, P. A., Banadda, N., Zziwa, A., Seay, J., & Kiggundu, N. (2018). Reverse engineering of plastic waste into useful fuel products. *Journal of Analytical and Applied Pyrolysis*, *130*, 285-293.https://doi.org/10.1016/j.geoderma.2019.114008

Oxford, E. (2019). *The Global Chemical Industry : Catalyzing Growth and Addressing*

Our World's Sustainability Challenges (Issue March).

Economics, O. (2019). The global chemical industry: Catalyzing growth and addressing our world's sustainability challenges. *Report for ICCA*.

Ozaki, N., Nakazato, A., Nakashima, K., Kindaichi, T., & Ohashi, A. (2017). Loading and removal of PAHs, fragrance compounds, triclosan and toxicity by composting process from sewage sludge. *Science of the Total Environment*, *605–606*, 860–866. https://doi.org/10.1016/j.scitotenv.2017.06.165

Ozturk I., Demir I., Altinbas M., Arikan O.A., Ciftci T., Cakmak I., Ozturk L., Yildiz S., K. A. (2015). *Composting Handbook (Technical book series- 1) ISTAC-TUBITAK INSTABUL TURKEY*.

Pacios, O., Blasco, L., Bleriot, I., Fernandez-Garcia, L., Bardanca, Mónica González Ambroa, A., López, M., Bou, G., & Tomas, M. (2020). Strategies to Combat Multidrug-Resistant and. *Antibiotics*, *9*(65), 1–20.

Pal, A., Gin, K. Y., Lin, A. Y., & Reinhard, M. (2010). Science of the Total Environment Impacts of emerging organic contaminants on freshwater resources : Review of recent occurrences , sources , fate and effects. *Science of the Total Environment*, *T 408*(24), 6062–6069. https://doi.org/10.1016/j.scitotenv.2010.09.026

Pampuro, N., Caffaro, F., & Cavallo, E. (2018). Reuse of animal manure: A case study on stakeholders' perceptions about pelletized compost in Northwestern Italy. *Sustainability*, *10*(6), 2028.https://doi.org/10.3390/su10062028

Pandyaswargo, A. H., & Premakumara, D. G. J. (2014). Financial sustainability of modern composting: the economically optimal scale for municipal waste composting plant in developing Asia. *International Journal of Recycling of Organic Waste in Agriculture*, *3*(3). https://doi.org/10.1007/s40093-014-0066-y

Paradelo, R., Villada, A., & Barral, M. T. (2020). Heavy metal uptake of lettuce and ryegrass from urban waste composts. *International Journal of Environmental Research and Public Health*, *17*(8), 1–10. https://doi.org/10.3390/ijerph17082887

Partey, S. T., Zougmoré, R. B., Ouédraogo, M., & Campbell, B. M. (2018). Developing climate-smart agriculture to face climate variability in West Africa: Challenges and lessons learnt. *Journal of Cleaner Production*, *187*, 285–295. https://doi.org/10.1016/j.jclepro.2018.03.199

Paz, S., Ayalon, O., & Haj, A. (2013). The potential conflict between traditional perceptions and environmental behavior: compost use by Muslim farmers. *Environment, development and sustainability*, *15*(4), 967-978. https://doi.org/10.1007/s10668-012-9421-1

Montanarella, L., Pennock, D., Mckenzie, N., Alavipanah, S. K., Alegre, J., Alshankiti, A., ... & Zhang, G. L. (2015). The Status of the World's Soil Resources (Technical Summary).

Pereira, L. (2014). Persistent organic chemicals of emerging environmental concern. In *Environmental deterioration and human health* (pp. 163-213). Springer, Dordrecht. https://doi.org/10.1007/978-94-007-7890-0

Petrie, B., Barden, R., & Kasprzyk-Hordern, B. (2015). A review on emerging contaminants in wastewaters and the environment: Current knowledge, understudied areas and recommendations for future monitoring. *Water Research*, *72*(0), 3–27. https://doi.org/10.1016/j.watres.2014.08.053

PHE Centre for Radiation, C. and E. H. (2018). *Polycyclic aromatic hydrocarbons (Benzo[a]pyrene) - Toxicological Overview*. *August 2018*, 10. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/737017/PAH_TO_PHE_240818.pdf%0Ahttps://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/341371/PAHs_Toxicological_Overvi

Plana, R. (2015). *Handbook for compost marketing*. 1–44.

Poluszyńska, J., Jarosz-Krzemińska, E., & Helios-Rybicka, E. (2017). Studying the effects of two various methods of composting on the degradation levels of polycyclic aromatic hydrocarbons (PAHs) in sewage sludge. *Water, Air, & Soil Pollution*, *228*(8), 1-10. https://doi.org/10.1007/s11270-017-3481-7

Pramanik, M. M. A. (2013). *Prospects and Challenges of Urban and Peri-Urban Agriculture of Dhaka City*.

Pullagurala, V. L. R., Rawat, S., Adisa, I. O., Hernandez-Viezcas, J. A., Peralta-Videa, J. R., & Gardea-Torresdey, J. L. (2018). Plant uptake and translocation of contaminants of emerging concern in soil. *Science of the Total Environment*, *636*, 1585–1596. https://doi.org/10.1016/j.scitotenv.2018.04.375

Rather, I. A., Koh, W. Y., Paek, W. K., & Lim, J. (2017). The sources of chemical contaminants in food and their health implications. *Frontiers in Pharmacology*, *8*. https://doi.org/10.3389/fphar.2017.00830

Rathi, B. S., Kumar, P. S., & Show, P. L. (2021). A review on effective removal of emerging contaminants from aquatic systems: current trends and scope for further research. *Journal of Hazardous Materials*, *409*, 124413.https://doi.org/10.1016/j.jhazmat.2020.124413

Reis, F. C. Dos, Tornisielo, V. L., Cason, J. B., Dias, A. C. R., Freitas, M., Sotomayor, J. F., Barroso, A. A. M., & Filho, R. V. (2015). Uptake, translocation, and control of trumpet flower (Tecoma stans) with aminocyclopyrachlor. *Journal of Environmental Science and Health - Part B Pesticides, Food Contaminants, and Agricultural Wastes*, *50*(10), 727–733. https://doi.org/10.1080/03601234.2015.1048106

Rempel, A., Gutkoski, J. P., Nazari, M. T., Biolchi, G. N., Cavanhi, V. A. F., Treichel, H., & Colla, L. M. (2021). Current advances in microalgae-based bioremediation and other technologies for emerging contaminants treatment. *Science of the Total Environment*, *772*, 144918. https://doi.org/10.1016/j.scitotenv.2020.144918

Zhu, X., Risse, L. M., Mccutcheon, S. C., Tollner, E. W., Rasmussen, T. C., & West, L. T. (2010). Laboratory investigation of rill erosion on compost blankets under concentrated flow conditions. *Transactions of the ASABE*, *53*(4), 1077-1086. https://doi.org/10.13031/2013.32598

Robertson, S., Douglas, P., Jarvis, D., & Marczylo, E. (2019). Bioaerosol exposure from composting facilities and health outcomes in workers and in the community: A systematic review update. *International journal of hygiene and environmental health*, *222*(3), 364-386. https://doi.org/10.1016/j.ijheh.2019.02.006

Sądej, W., & Namiotko, A. (2010). Content of polycyclic aromatic hydrocarbons in soil fertilized with composted Municipal waste. *Polish Journal of Environmental Studies*, *19*(5), 999–1005.

Samwine, T., Wu, P., Xu, L., Shen, Y., Appiah, E., & Yaoqi, W. (2017). Challenges and prospects of solid waste management in Ghana. *International Journal of Environmental Monitoring and Analysis*, *5*(4), 96-102. https://doi.org/10.11648/j.ijema.20170504.11

Sánchez, Ó. J., Ospina, D. A., & Montoya, S. (2017). Compost supplementation with nutrients and microorganisms in composting process. *Waste Management*, *69*(26), 136–153. https://doi.org/10.1016/j.wasman.2017.08.012

Šašek, V., Bhatt, M., Cajthaml, T., Malachová, K., & Lednická, D. (2003). Compost-mediated removal of polycyclic aromatic hydrocarbons from contaminated soil. *Archives of Environmental Contamination and Toxicology*, *44*(3), 336–342. https://doi.org/10.1007/s00244-002-2037-y

Sauvé, S., & Desrosiers, M. (2014). A review of what is an emerging contaminant. *Chemistry Central Journal*, *8*(1), 1-7.https://doi.org/10.1186/1752-153X-8-15

Sayara, T., Basheer-Salimia, R., Hawamde, F., & Sánchez, A. (2020). Recycling of Organic Wastes through Composting: Process Performance and Compost Application in Agriculture. *Agronomy*, *10*(11), 1838. https://doi.org/10.3390/agronomy10111838

Scarlat, N., Motola, V., Dallemand, J. F., Monforti-Ferrario, F., & Mofor, L. (2015). Evaluation of energy potential of municipal solid waste from African urban areas. *Renewable and*

Sustainable Energy Reviews, *50*, 1269-1286.https://doi.org/10.1016/j.rser.2015.05.067

Shehu, Z., Nyakairu, G. W. A., Tebandeke, E., & Odume, O. N. (2022). Overview of African water resources contamination by contaminants of emerging concern. *Science of the Total Environment*, *852*(August), 158303. https://doi.org/10.1016/j.scitotenv.2022.158303

Shelukindo, H. B., Semu, E., Msanya, B. M., Singh, B. R., & Munishi, P. K. (2014). Soil organic carbon stocks in the dominant soils of the Miombo woodland ecosystem of Kitonga Forest Reserve, Iringa, Tanzania.

Siedt, M., Schäffer, A., Smith, K. E. C., Nabel, M., Roß-Nickoll, M., & van Dongen, J. T. (2021). Comparing straw, compost, and biochar regarding their suitability as agricultural soil amendments to affect soil structure, nutrient leaching, microbial communities, and the fate of pesticides. *Science of the Total Environment*, *751*, 141607. https://doi.org/10.1016/j.scitotenv.2020.141607

Siles-Castellano, A. B., López-González, J. A., Jurado, M. M., Estrella-González, M. J., Suárez-Estrella, F., & López, M. J. (2021). Compost Quality and Sanitation on Industrial Scale Composting of Municipal Solid Waste and Sewage Sludge. *Applied Sciences*, *11*(16), 7525. https://doi.org/10.3390/app11167525

Silpa, K., Yao, L., Bhada-Tata, P. and Van Woerden, F. (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development Series. Washington, DC: World Bank.*

Snow, D. D., Cassada, D. A., Biswas, S., Malakar, A., D'Alessio, M., Marshall, A. H. L., & Sallach, J. B. (2020). Detection, occurrence, and fate of emerging contaminants in agricultural environments (2020). *Water Environment Research*, *92*(10), 1741–1750. https://doi.org/10.1002/wer.1429

Soliman, M., Potlakayala, S., Millar, D., Weeden, H., Bogush, D., Deguchi, M., & Rudrabhatla, S. (2019). Comparing A Review of Heavy Metal Uptake and Their Toxicity on Plant and Human Health. *Int J Plant Anim Environ Sci*, *9*(3), 182–189. https://doi.org/10.26502/ijpaes.004

Song, B., Manu, M. K., Li, D., Wang, C., Varjani, S., Ladumor, N., Michael, L., Xu, Y., & Wong, J. W. C. (2021). Food waste digestate composting: Feedstock optimization with sawdust and mature compost. *Bioresource Technology*, *341*, 125759. https://doi.org/10.1016/j.biortech.2021.125759

Soni, A., Patil, D., & Argade, K. (2016). Municipal Solid Waste Management. *Procedia Environmental Sciences*, *35*, 119–126. https://doi.org/10.1016/j.proenv.2016.07.057

Sotamenou, J., & Parrot, L. (2013). Sustainable urban agriculture and the adoption of composts in Cameroon. *International journal of agricultural sustainability*, *11*(3), 282-295.https://doi.org/10.1080/14735903.2013.811858

Stacey, N. E., Lewis, R. W., Davenport, J. R., & Sullivan, T. S. (2019). Composted biosolids for golf course turfgrass management : Impacts on the soil microbiome and nutrient cycling. *Applied Soil Ecology*, *144*, 31–41. https://doi.org/10.1016/j.apsoil.2019.06.006

Stockholm Convention. (2001). *Restrictions on Persistant Organic Pollutants*. *14*(1), 121~128.

Stoeva, K., & Alriksson, S. (2017). Influence of recycling programmes on waste separation behaviour. *Waste Management*, *68*, 732–741. https://doi.org/10.1016/j.wasman.2017.06.005

Sturini, M., Speltini, A., Maraschi, F., Profumo, A., Pretali, L., Irastorza, E. A., ... & Albini, A. (2012). Photolytic and photocatalytic degradation of fluoroquinolones in untreated river water under natural sunlight. *Applied Catalysis B: Environmental*, *119*, 32-39.https://doi.org/10.1016/j.apcatb.2012.02.008

Suk, H., Lee, Y., El-aty, A. M. A., Sol, H., Kabir, H., Woo, S., Park, B., Kim, J., Hac, F., Nahar, N., Shin, H., & Shim, J. (2017). Uptake of the veterinary antibiotics chlortetracycline , enrofloxacin, and sulphathiazole from soil by radish. *Science of the Total Environment*, *606*, 322–331. https://doi.org/10.1016/j.scitotenv.2017.06.231

Sun, Q., Li, Y., Li, M., Ashfaq, M., Lv, M., Wang, H., Hu, A., & Yu, C. P. (2016). PPCPs in Jiulong River estuary (China): Spatiotemporal distributions, fate, and their use as chemical markers of wastewater. *Chemosphere*, *150*(86), 596–604. https://doi.org/10.1016/j.chemosphere.2016.02.036

Supaporn, P., Kobayashi, T., & Supawadee, C. (2013). Factors affecting farmers' decisions on utilization of rice straw compost in Northeastern Thailand. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *114*(1), 21-27.

Survey, G. L. S. (2017). *The Ghana Living Standards Survey - Mian Report*.

Swami, S. (2019). Composting Technology for Organic Crop Production. *Sifonoforos*, *1*, 12–14.

Syoku-An. (2006). *Method as specified by Multi-Residue Method for Agricultural Chemicals by GC/MS as released by the Department of Food Safety, Ministry of Health, Labour and Welfare, Japan. 1129001*, 1–8.

Taheran, M., Naghdi, M., Brar, S. K., Verma, M., & Surampalli, R. Y. (2018). Emerging contaminants: Here today, there tomorrow! *Environmental Nanotechnology*, *Monitoring & Management*, *10*(May), 122–126. https://doi.org/10.1016/j.enmm.2018.05.010

Tang, Y., Li, Y., Zhan, L., Wu, D., Zhang, S., Pang, R., & Xie, B. (2022). Removal of emerging contaminants (bisphenol A and antibiotics) from kitchen wastewater by alkali-modified biochar. *Science of the Total Environment*, *805*. https://doi.org/10.1016/j.scitotenv.2021.150158

Tasho, R. P., & Cho, J. Y. (2016). Veterinary antibiotics in animal waste, its distribution in soil and uptake by plants: A review. *Science of the Total Environment*, *563–564*(3), 366–376. https://doi.org/10.1016/j.scitotenv.2016.04.140

Tey, Y. S., Li, E., Bruwer, J., Abdullah, A. M., Brindal, M., Radam, A., ... & Darham, S. (2014). The relative importance of factors influencing the adoption of sustainable agricultural practices: A factor approach for Malaysian vegetable farmers. *Sustainability science*, *9*(1), 17-29.https://doi.org/10.1007/s11625-013-0219-3

Thi, N. B. D., Kumar, G., & Lin, C.-Y. (2015). An overview of food waste management in developing countries: Current status and future perspective. *Journal of Environmental Management*, *157*, 220–229. https://doi.org/10.1016/j.jenvman.2015.04.022

Thompson, L. A., & Darwish, W. S. (2019). Environmental Chemical Contaminants in Food: Review of a Global Problem. *Journal of Toxicology*, *2019*. https://doi.org/10.1155/2019/2345283

Tian, H., Lu, C., Yang, J., Banger, K., Huntzinger, D. N., Schwalm, C. R., Michalak, A. M., Cook, R., Ciais, P., Hayes, D., Huang, M., Ito, A., Jain, A. K., Lei, H., Mao, J., Pan, S., Post, W. M., Peng, S., Poulter, B., … Zeng, N. (2015). The role of women in agriculture. In *Global Biogeochemical Cycles* (Vol. 29, Issue 6). https://doi.org/10.1002/2014GB005021

Tibu, C., Annang, T. Y., Solomon, N., & Yirenya-Tawiah, D. (2019). Effect of the composting process on physicochemical properties and concentration of heavy metals in market waste with additive materials in the Ga West Municipality, Ghana. *International Journal of Recycling of Organic Waste in Agriculture*, *8*(4), 393–403. https://doi.org/10.1007/s40093-019-0266-6

Tomczyk, B., Siatecka, A., Jędruchniewicz, K., Sochacka, A., Bogusz, A., & Oleszczuk, P. (2020). Polycyclic aromatic hydrocarbons (PAHs) prsistence, bioavailability and toxicity in sewage sludge-or sewage sludge-derived biochar-amended soil. *Science of The Total Environment*, *747*, 141123.https://doi.org/10.1016/j.scitotenv.2020.141123

Tomocsik, A., Makadi, M., OROSZ, V., ARANYOS, T., DEMETER, I., MÉSZÁROS, J.,

& FÜLEKY, G. (2016). Effect of Sewage Sludge Compost Treatment on Crop Yield. *Agrofor*, *1*(2), 4–12. https://doi.org/10.7251/agreng1602005t

Tousova, Z., Oswald, P., Slobodnik, J., Blaha, L., Muz, M., Hu, M., Brack, W., Krauss, M., Di Paolo, C., Tarcai, Z., Seiler, T. B., Hollert, H., Koprivica, S., Ahel, M., Schollée, J. E., Hollender, J., Suter, M. J. F., Hidasi, A. O., Schirmer, K., … Schulze, T. (2017). European demonstration program on the effect-based and chemical identification and monitoring of organic pollutants in European surface waters. *Science of the Total Environment*, *601–602*, 1849–1868. https://doi.org/10.1016/j.scitotenv.2017.06.032

Tubeileh, A. M., & Stephenson, G. T. (2020). Current Plant Biology Soil amendment by composted plant wastes reduces the Verticillium dahliae abundance and changes soil chemical properties in a bell pepper cropping system. *Current Plant Biology*, *22*(April), 100148. https://doi.org/10.1016/j.cpb.2020.100148

Takele, B., & Berihun, T. (2014). Rational veterinary drug use: Its significance in public health. *Journal of Veterinary Medicine and Animal Health*, *6*(12), 302-308. https://doi.org/10.5897/JVMAH2014.

UN. (2015). Transforming Our World: The 2030 Agenda for Sustainable Development - A/RES/70/1. In *United Nations General Assembly - 70th Session* (Vol. 16301, Issue October). https://doi.org/10.1007/s13398-014-0173-7.2

UNEP. (2020). *UNEP promotes environmentally sound practices globally and in its own activities*.

United Nations. (2012). *Outcome document of the United Nations Conference on Sustainable Development*.

US EPA Ecotox. (2007). *ECOTOXicology Knowledgebase System*.

Uyizeye, O. C., Thiet, R. K., & Knorr, M. A. (2019). Effects of community-accessible biochar and compost on diesel-contaminated soil. *Bioremediation Journal*, *23*(2), 107–117. https://doi.org/10.1080/10889868.2019.1603139

Vaddella, V., Pandey, P., Cao, W., Biswas, S., Chiu, C., Zheng, Y., ... & Buyuksonmez, F. (2018). Assessment of pathogen inactivation under sub-composting temperature in lab-scale compost piles. *Journal of Food Research*, *7*(3).https://doi.org/10.5539/jfr.v7n3p64

Van der Wurff, A. W. G., Fuchs, J. G., Raviv, M., & Termorshuizen, A. J. (2016). Compost types, feedstocks and composting methods. *Handbook for Composting and Compost Use in Organic Horticulture*, *82*(6), 29–43. http://dx.doi.org/10.18174/375218%0Ahttp://dx.doi.org/10.18174/375218%0Ahttp:/

/library.wur.nl/WebQuery/wurpubs/499425

Van Epps, A., & Blaney, L. (2016). Antibiotic Residues in Animal Waste: Occurrence and Degradation in Conventional Agricultural Waste Management Practices. *Current Pollution Reports*, *2*(3), 135–155. https://doi.org/10.1007/s40726-016-0037-1

Varjani, S., Pandey, A., & Upasani, V. N. (2020). Oilfield waste treatment using novel hydrocarbon utilizing bacterial consortium — A microcosm approach. *Science of the Total Environment*, *745*, 141043. https://doi.org/10.1016/j.scitotenv.2020.141043

Verdonck, O. (2008). Compost specifications. *Acta Horticulturae*, *469*, 169–177. https://doi.org/10.17660/actahortic.1998.469.16

Viaene, J., Lancker, J. Van, Vandecasteele, B., Willekens, K., Bijttebier, J., Ruysschaert, G., Neve, S. De, & Reubens, B. (2016). Opportunities and barriers to on-farm composting and compost application : A case study from northwestern Europe. *Waste Management*, *48*, 181–192. https://doi.org/10.1016/j.wasman.2015.09.021

Vigneswaran, S., Kandasamy, J., & Johir, M. A. H. (2016). Sustainable Operation of Composting in Solid Waste Management. *Procedia Environmental Sciences*, *35*, 408–415. https://doi.org/10.1016/j.proenv.2016.07.022

Vigoroso, L., Pampuro, N., Bagagiolo, G., & Cavallo, E. (2021). Factors influencing adoption of compost made from organic fraction of municipal solid waste and purchasing pattern: A survey of italian professional and hobbyist users. *Agronomy*, *11*(6). https://doi.org/10.3390/AGRONOMY11061262

Vijgen, J., Weber, R., Lichtensteiger, W., & Schlumpf, M. (2018). The legacy of pesticides and POPs stockpiles—a threat to health and the environment. *Environmental Science and Pollution Research*, *25*(32), 31793–31798. https://doi.org/10.1007/s11356-018-3188-3

Vodyanitskii, Y. N., Mineev, V. G., & Shoba, S. A. (2014). Role of zero-valent iron in the degradation of organochlorine substances in groundwater. *Moscow University Soil Science Bulletin*, *69*(4), 175–183. https://doi.org/10.3103/s0147687414040085

Wang, A., Hu, J., Huang, X., Li, X., Zhou, G., & Yan, Z. (2016). Comparative transcriptome analysis reveals heat-responsive genes in Chinese cabbage (Brassica rapa ssp. chinensis). *Frontiers in plant science*, *7*, 939. https://doi.org/10.3389/fpls.2016.00939

Wang, H., Cheng, Z., Yuan, H., Zhu, N., Lou, Z., & Otieno, P. (2020). Occurrence of banned and commonly used pesticide residues in concentrated leachate: Implications for ecological risk assessment. *Science of the Total Environment*, *710*, 136287.

https://doi.org/10.1016/j.scitotenv.2019.136287

Wang, L., Zhang, S., Wang, L., Zhang, W., Shi, X., Lu, X., Li, X., & Li, X. (2018). Concentration and risk evaluation of polycyclic aromatic hydrocarbons in urban soil in the typical semi-arid city of Xi'an in Northwest China. *International Journal of Environmental Research and Public Health*, *15*(4). https://doi.org/10.3390/ijerph15040607

Waste, A., & Outlook, M. (2018). *State of solid waste management in Africa*.

Wee, S. Y., & Aris, A. Z. (2017). Endocrine disrupting compounds in drinking water supply system and human health risk implication. *Environment International*, *106*, 207–233. https://doi.org/10.1016/j.envint.2017.05.004

Wei, Y., Li, J., Shi, D., Liu, G., Zhao, Y., & Shimaoka, T. (2017). Environmental challenges impeding the composting of biodegradable municipal solid waste: A critical review. *Resources, Conservation and Recycling*, *122*, 51–65. https://doi.org/10.1016/j.resconrec.2017.01.024

WHO. (2018). *Evaluation of certain veterinary drug residues in food*.

Marrs, T. Pesticide residues in food-2002-Joint FAO/WHO Meeting on Pesticide Residues.

Wireman, M., & Expert, N. G. (2012). *Transport and Fate of Contaminants in the Subsurface Natural Ground-Water Quality*.

Wlodarczyk-Makula, M. (2005). The loads of PAHs in wastewater and sewage sludge of municipal treatment plant. *Polycyclic Aromatic Compounds*, *25*(2), 183–194. https://doi.org/10.1080/10406630590930743

Xiong, Z. Q., Wang, G. X., Huo, Z. C., Yan, L., Gao, Y. M., Wang, Y. J., ... & Wang, W. D. (2017). Effect of aeration rates on the composting processes and Nitrogen loss during composting. *Applied Environmental Biotechnology*, *2*(2), 20-27.

Yañez-ocampo, G., Wong-villarreal, A., Del, P., Fuente, J. L., & Vaca-paulín, R. (2016). Composting of Soils Polluted with Pesticides : A Microbial Approach and Methods for Monitoring. *JSM Environmental Science & Ecology*, *4*, 1032.

Yang, Y., Ashworth, A. J., Willett, C., Cook, K., Upadhyay, A., Owens, P. R., Ricke, S. C., DeBruyn, J. M., & Moore, P. A. (2019). Review of Antibiotic Resistance, Ecology, Dissemination, and Mitigation in U.S. Broiler Poultry Systems. *Frontiers in Microbiology*, *10*, 1–10. https://doi.org/10.3389/fmicb.2019.02639

Yuan, Y., Jia, H., Xu, D. Y., & Wang, J. (2023). Novel method in emerging environmental contaminants detection: Fiber optic sensors based on microfluidic chips. *Science of the Total Environment*, *857*(October 2022), 159563.

https://doi.org/10.1016/j.scitotenv.2022.159563

Jing, Yulin, Yuhu Zhang, Ihnsup Han, Peng Wang, Qiwen Mei, and Yunjie Huang. "Effects of different straw biochars on soil organic carbon, nitrogen, available phosphorus, and enzyme activity in paddy soil." *Scientific Reports* 10, no. 1 (2020): 1-12. https://doi.org/10.1038/s41598-020-65796-2

Zhang, Jingdong, Zhu, L., Li, F., Liu, C., & Yang, Z. (2017). *Heavy metals and metalloid distribution in different organs and health risk assessment for edible tissues of fish captured from Honghu Lake*. *8*(60), 101672–101685.

Zhang, Juan, Zhang, J., & Fan, S. (2018). *Influence of PAH speciation in soils on vegetative uptake of PAHs using successive extraction Influence of PAH speciation in soils on vegetative uptake of PAHs using successive extraction*. *April*. https://doi.org/10.1016/j.jhazmat.2016.08.024

Zhang, M., He, L. Y., Liu, Y. S., Zhao, J. L., Liu, W. R., Zhang, J. N., Chen, J., He, L. K., Zhang, Q. Q., & Ying, G. G. (2019). Fate of veterinary antibiotics during animal manure composting. *Science of the Total Environment*, *650*, 1363–1370. https://doi.org/10.1016/j.scitotenv.2018.09.147

Zhang, S., Yao, H., Lu, Y., Yu, X., Wang, J., Sun, S., Liu, M., Li, D., Li, Y., & Zhang, D. (2017). Uptake and translocation of polycyclic aromatic hydrocarbons (PAHs) and heavy metals by maize from soil irrigated with wastewater. *Scientific Reports*, *June*, 1–11. https://doi.org/10.1038/s41598-017-12437-w

Zhang, Y., Li, T., Wu, H., Bei, S., & Zhang, J. (2019). *Maize yield and soil fertility with combined use of compost and inorganic sustainability Effect of Different Fertilization Practices on Soil Microbial Community in a Wheat – Maize Rotation System*. *January 2016*. https://doi.org/10.1016/j.still.2015.08.006

Zheng, X., Aborisade, M. A., Liu, S., Lu, S., Oba, B. T., Xu, X., Cheng, X., He, M., Song, Y., & Ding, H. (2020). The history and prediction of composting technology: A patent mining. *Journal of Cleaner Production*, *276*, 124232. https://doi.org/10.1016/j.jclepro.2020.124232

Zhou, Y., Wu, J., Wang, B., Duan, L., Zhang, Y., Zhao, W., Wang, F., Sui, Q., Chen, Z., Xu, D., Li, Q., & Yu, G. (2020). Occurrence, source and ecotoxicological risk assessment of pesticides in surface water of Wujin District (northwest of Taihu Lake), China. *Environmental Pollution*, *265*, 114953. https://doi.org/10.1016/j.envpol.2020.114953

Zhu, X., Wang, Y., Zhang, Y., & Chen, B. (2018). Reduced bioavailability and plant uptake of polycyclic aromatic hydrocarbons from soil slurry amended with biochars pyrolyzed under various temperatures. *Environmental Science and Pollution Research*, *25*(17), 16991-17001.https://doi.org/10.1007/s11356-018-1874-9

ANNEXES

ANNEX 1A: Results of Soils PAH analysis from the Ghana Atomic Energy Commission Soil (mg/kg)

Acenaphthylene	0.113
Fluoranthene	0.023
Indeno[1,2,3-c,d]pyrene	0.030
Pyrene	0.0690
Naphthalene	ND
Fluorene	0.0028
Acenaphthene	0.083
Benz[a]anthracene	0.023
Dibenzo[a,h]anthracene	0.083
Benzo[a]pyrene	0.006
Benzo[g,h,i,]perylene	0.026
Chrysene	0.034
Benzo[k]fluoranthene	ND
Benzo[b]fluoranthene	0.046
Anthracene	0.070
Phenanthrene	0.020

ANNEX 1B; Results of some agronomic Parameter of Lettuce and Carrot

Lettuce

	MWMW	SSMW	MAW	Control
Plant Height	14.4	15.3	15.6	13.7
No. of leaves per plant	6.0	6.0	6.0	6.0
Length of Leaf (cm)	10.2	11.4	13.2	10.0
With of leaf (cm)	6.2	6.2	363	6.0

Carrot

	MWMW	SSMW	MAW	Control
Weight of carrot (g)	120	118	114	110
Diameter (cm)	3.4	3.0	4.0	2.9
Length (cm)	20.3	18.4	19.4	16.9

ANNEX 2A: Questionnaire for farmer's interview

UNIVERSITY OF GHANA

INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES

RESPONDENT'S ASSURANCE

I am researching about socio-cultural and attitude of farmers to the use of compost. It is part of a thesis titled: Compost Quality; Composition, Quantification, Uptake and Translocation of Emerging Contaminants. Please, I want to assure you that this survey is for research purposes only. All information shall be kept confidential. I will hold all your resources in strict confidence and present all findings in aggregates, and no statements obtained will be attributed directly to you.

Showed we continue the interview? Yes/No

If no, Discontinue the survey

Date:	Locality:	Serial No:

BIO-DATA

Gender: Male ☐ Female ☐
Farm Ownership: Farm Owner ☐ Farm Worker☐
Age: 18-20 ☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ 60-69 ☐ 70+ ☐
Educational Level: None ☐ Primary ☐ JHS/Middle ☐ Secondary☐ Tertiary ☐ Vocational ☐ Other ☐ (Specify)…………………………………………………………
Religion: Christian ☐ Muslim ☐ Traditionalist ☐ Other ☐ (Specify)………………………………………………………………
Marital Status: Single ☐ Married ☐ Divorced/Separated ☐ Widowed ☐
Are you head of Household **Yes** ☐ **No**☐
Household Size: **1 – 4**☐ **5 – 9**☐ **10- 14** ☐ **15-19** ☐ **>20**☐
Number of children (if any): None ☐ 1-3 ☐ 4-6 ☐ 7-9 ☐ 10 and above ☐
Are you engaged in other business activities: **Yes**☐ **No**☐ If yes specify Plot Size …………………………………………………………………………..

Association/Farmer Based organisation	**Yes**	**No**
Please names ………………………………………………………………..		
Income:		

1. How long have you lived here?...

2. What was your previous work?..

3. Do you use compost on your crops? Yes / No

If no, jump to Question 7

If Yes

4. The sources of the compost, you know? Please provide names.

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………..

5. What is the amount of compost you use?

…………………………………………………………………………………………

6. When was the last time you used compost on your farms?

…………………………………………………………………………………………

Go to Question 11

7. Do you know about compost use on crops? Yes / No

Do you have argic extension officers in this community Yes/ No, Don't know

If yes, how many times they have visited you during the past year

……………………………………………………………………………………………

What are the pieces of information that you receive from the officer

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………….

Does he talk to you about the importance of compost on crops? Yes/ No

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………..

Are there compost shops in this area Yes/ No

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………..

7. Where do you get information on farming

a. Own Experience b extension officers c farm organizations

friends e Radio

8. Have you ever used organic compost on your farm? Yes/ No

(Note Q8 is for respondents not using compost)

	1	2	3	4	5
Compost is good for the soil amendment.					
Compost gives essential elements to the land					
Compost harms the environment					
Compost causes odour problems					
Compost use can cause problems for human health					
Compost use can cause vegetable contamination					
Compost brings pest to vegetable					
Compost gives low-quality foods					
Working with compost is difficult					
The use of compost helps solve waste issues					

9. When was the last time you used organic fertilizer

………………………………………………………………………………………………..

10. Why did you stop using compost?

……………………………………………………………………………………………….

……………………………………………………………………………………………….

………………………………………………………………………………………………..

11. Are there any challenges with the use of compost? Yes/No

What are some of the challenges?

a…………………………………………………………………………………………….

b…………………………………………………………………………………………….

c…………………………………………………………………………………………….

d…………………………………………………………………………………………

e…………………………………………………………………………………………

f…………………………………………………………………………………………

12. If compost cost is a challenge, would you use compost if the government subsidized the

cost?...……

Yes/No

13. If yes, how much subsidy do you expect?

……………………………………………………………………………………...

14. Are there any social challenges with the use of compost?...................................Yes/No

If yes, please list the challenges barriers?..

a…………………………………………………………………………………………

b…………………………………………………………………………………………

c…………………………………………………………………………………………

d…………………………………………………………………………………………

e…………………………………………………………………………………………

f…………………………………………………………………………………………

15. Do you know of cultural barriers or taboos issues regarding compost use? Yes/No

If yes, please list the challenges?

a…………………………………………………………………………………………

b…………………………………………………………………………………………

c……………………………………………………………………………………….

d………………………………………………………………………………………

e………………………………………………………………………………………

f……………………………………………………………………………………….

g………………………………………………………………………………………

16. Are there any religious barriers (taboos) to use (in accepting) compost? Yes/No

If yes, please list the taboos

a……………………………………………………………………………………….

b……………………………………………………………………………………….

c……………………………………………………………………………………….

d………………………………………………………………………………………

e………………………………………………………………………………………

f……………………………………………………………………………………….

g………………………………………………………………………………………

17 Are you concerned about your health in the use of compost? Yes/No

If yes, what are some of the health issues?

a……………………………………………………………………………………….

b……………………………………………………………………………………….

c……………………………………………………………………………………….

d………………………………………………………………………………………

e………………………………………………………………………………………

f……………………………………………………………………………………….

g…………………………………………………………………………………………

18. what must we do to promote compost use?

a…………………………………………………………………………………………

b…………………………………………………………………………………………

c…………………………………………………………………………………………

d…………………………………………………………………………………………

e…………………………………………………………………………………………

f…………………………………………………………………………………………

g…………………………………………………………………………………………

19. What can you do as an individual to promote the use of compost?

21. Considering the benefits of compost to the environment, are you prepared to use compost on your crops?

20. How do you sell your products?

a…………………………………………………………………………………………

b…………………………………………………………………………………………

c…………………………………………………………………………………………

d…………………………………………………………………………………………

e…………………………………………………………………………………………

f…………………………………………………………………………………………

g…………………………………………………………………………………………

21. Any challenges when using compost on crops to the use of compost

Odour……………………………………………………………………………………

Unavailability in required quantity…………………………………………………….

Source of Compost and the farms ……………………………………….……………

Crop death when there is rain failure ………………………………………………..……

The quality of the compost is low…..……………………………………………..…

Mockery from other farmers…………………………………………………………

Compost use throughout the year……………………………………………………..

Increased weeds infestation ……………………………………………………………..

Use of the compost requires expensive work on the farm……………………………….

Need to wear protective clothing ……………………………………………………..…

Lack of means to spread sludge evenly on the field ……………………………………

22. Any precaution is taken when using compost

a no precaution ………………………………………………………………………………..

b. safety boots…………………………………………………………………………………

c safety boots and gloves……………..…………………………………………………

d nose mask………………….…………………………………………………………………

f. others ……….……………………………………………………………………………

23. For those currently using compost or have used compost before

What is the crop yield compared to if artificial fertilizer is used compared to compost?

24. What is the quality of the production of compost is used compared to artificial fertilizer.

25. Do you premium prices with your crops if you use compost and not artificial fertilizers?

Yes/No

27. If yes, what is the difference in the price?

…………………………………………………………………………………………

…………………………………………………………………………………………

28. What is the distance between the facility and the farms? (For Current Compost user)

…………………………………………………………………………………………

…………………………………………………………………………………………

29. Please, do you have any comments to share with the team?

…………………………………………………………………………………………

…………………………………………………………………………………………

Thank you for your attention.

Signature of the Enumerator.

ANNEX 2B: Questionnaire for Key Personnel Interview

UNIVERSITY OF GHANA

INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES

RESPONDENTS ASSURANCE

I am researching about socio-cultural and attitude of farmers to the use of compost. It is part of a thesis titled: Compost Quality; Composition, Quantification, Uptake and Translocation of Emerging Contaminants. Please, I want to assure you that this survey is for research purposes only. All information shall be kept confidential. I will hold all your resources in strict confidence and present all findings in aggregates, and no statements obtained will be attributed directly to you.

Focus Group

Discussion checklist

First, thank you all for attending to my invitation. My name is Maxwell Kogbe from the Univesity of Ghana, IESS and my assistant is.............................. We are here because I am researching socio-cultural and attitudes to the use of compost as fertilizer. It is part of a thesis that borders on the quality of compost on the market. This discussion is confidential. When I write my report, I will not mention any name. Please participate freely. I value your views and your precious time. Before we start, if there is any question, please let me know.

General information:

Location ....

No. of participants in FGD, Total: .... Male: .... Female

As an introduction, let’s go around to introduce ourselves and ask us any questions.

Q 1: Do you use fertilizer

Q2; Do you know about compost? Yes/No

What type

Q3: What are the fertilizers you use in your vegetables/?

Compost, chicken manure, chemical fertiliser cow dung, pig manure

Q4: What do you know about compost use?

Raw material, source, price, advantages and disadvantages

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

Question 5: Have you ever used compost on your crops or home?

If yes, please provide me with the names, source and price?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

Question 6: why do you choose that type?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

Question 7: Any idea about feedstock concerning making compost?

What is the composition of the compost

………………………………………………………………………………………….

………………………………………………………………………………………….

…………………………………………………………………………………………..

Q 8: Why do you use (not use) compost in your farms)?

Deliberate on the ideas

Q 9: Any problem with compost use?

Q10: How can we solve the challenges with compost use

Q11: How is compost sold on the market?

Q 12: How can the use be improved?

Q 13: How can the current marketability of compost be increased?

Q 14: Please Provide me with those who produce compost.

Q 15: What are the prices of compost and other organic fertilizers?

Q 16: what do you think is the right price for compost?

Q 17: Are there problems with the pricing. Yes/NO

Would you use compost if the price is low? Yes/No

If yes, how do you want to buy compost?

…………………………………………………………………………………………

…………………………………………………………………………………………

Q 18: Are there any cultural, religious and social barriers in accepting compost? Yes/No

If yes, please, what the challenges are?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

Q 19: Anyone with any health concerns regarding compost use? Yes/No

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

Q 20: Please, is there any question for our team?

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………...

Q21: Please is there any specific comment

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………...

Thank you all for a fruitful discussion

Date: …………………………

Signature of the Investigator

Name:.....................................

ANNEX 2C: Checklist for Focus Group Discussion Guide

UNIVERSITY OF GHANA

INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES

RESPONDENT'S ASSURANCE

I am researching about socio-cultural and attitude of farmers to the use of compost. It is part of a thesis titled: Compost Quality; Composition, Quantification, Uptake and Translocation of Emerging Contaminants. Please, I want to assure you that this survey is for research purposes only. All information shall be kept confidential. I will hold all your resources in strict confidence and present all findings in aggregates, and no statements obtained will be attributed directly to you.

Guide to Key Informant Informants

General information:

Position……………………………………………………………………………………..

Organization:..

1. How long have you been working with the organisation.

……………………………………………………………………………………………..

2. Please give me your experiences working with your organisation and pro- agro policies?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………...

3. Please tell me what you know about compost use?

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………...

4. Precisely what the composting feedstock are for compost?

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………...

5. Tell me about the process of composting?

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………...

6. What are the merits and demerits of compost?

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………..

7. Please tell me about the challenges with compost adoption.

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………...

8. Are there any challenges with current policies regarding compost use.

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………………...

9. Please any health-related issues regarding compost use.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

10. Tell me about the challenges with compost.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

11. Do you know those involved in compost production?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

12. how can we improve on compost adoption?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

11. Do you know how to fix the price?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

13. Is the price of compost realistic?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………...

14. Pricesesly, do you play any role in adoption promotion?

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………...

Any general comment from you

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………...

Thank you.

Date:

Signature of Investigator

ANNEX 3 Analysis of the variance of contaminants from three composting facilities

Annex 3a Analysis of variance for Pesticide residues

Methoxychlor

Analysis of variance
Variate: Concentration_g_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	12.1589	6.0795	7.89	
Block.*Units* stratum					
Sources	5	6422.1057	1284.4211	1666.96	<.001
Residual	154	118.6598	0.7705		
Total	161	6552.9245			

Beta HCH

Analysis of variance
Variate: Concentration_g_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	3.436	1.718	0.37	
Block.*Units* stratum					
Sources	5	1762.567	352.513	75.06	0.011
Residual	154	723.222	4.696		
Total	161	2489.225			

Delta HCH

Analysis of variance
Variate: Concentration_g_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	178.500	89.250	11.88	
Block.*Units* stratum					
Sources	5	8876.620	1775.324	236.27	0.131
Residual	154	1157.169	7.514		
Total	161	10212.290			

Analysis of variance for Pesticide residues (Continued)

Gamma HCH

Analysis of variance
Variate: Concentration_g_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	12.075	6.038	1.46	
Block.*Units* stratum					
Sources	5	4345.295	869.059	209.95	<.001
Residual	154	637.462	4.139		
Total	161	4994.833			

Cyfluthrin

Analysis of variance
Variate: Concentration_g_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.3140	0.1570	0.22	
Block.*Units* stratum					
Sources	5	5538.9461	1107.7892	1536.52	0.130
Residual	154	111.0300	0.7210		
Total	161	5650.2900			

Lambda-cyhalothrin

Analysis of variance
Variate: Concentration_g_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	5.151	2.575	1.42	
Block.*Units* stratum					
Sources	5	4844.649	968.930	532.68	<.001
Residual	154	280.120	1.819		
Total	161	5129.920			

Analysis of variance for Pesticide residues (Continued)

Chlorpyrifos

```
Analysis of variance
Variate: Concentration_g_kg
Source of variation          d.f.        s.s.        m.s.      v.r.    F pr.
Block stratum                   2       12.00        6.00      0.32
Block.*Units* stratum
Sources                         5    22522.71     4504.54    242.87    0.101
Residual                      154     2856.27       18.55
Total                         161    25390.98
```

Glyphosate

```
Analysis of variance
Variate: Concentration_g_kg
Source of variation          d.f.        s.s.        m.s.      v.r.    F pr.
Block stratum                   2       70.13       35.06      1.61
Block.*Units* stratum
Sources                         5    54309.55    10861.91    497.86    <.001
Residual                      154     3359.88       21.82
Total          161       57739.56
```

Atrazine

```
Analysis of variance
Variate: Concentration_g_kg
Source of variation          d.f.        s.s.        m.s.      v.r.    F pr.
Block stratum                   2      35.144      17.572      3.50
Block.*Units* stratum
Sources                         5    5705.097    1141.019    227.49    <.001
Residual                      154     772.423       5.016
```

Triclopyr

```
Analysis of variance
Variate: Concentration_g_kg
Source of variation          d.f.        s.s.        m.s.      v.r.    F pr.
Block stratum                   2      24.249      12.124      2.91
Block.*Units* stratum
Sources                         5    1306.396     261.279     62.64    <.001
Residual                      154     642.309       4.171
Total          161       1972.954
```

Annexe 3b Analysis of variance for PAH residues

```
Acenaphthene
Analysis of variance
Variate: Acenaphthene_Concentration_g_kg
Source of variation       d.f.     s.s.     m.s.     v.r.      F pr.
Block stratum  2          6.566   3.283   0.79
Block.*Units* stratum
Sources        5    4028.760        805.752          194.62           <.001
Residual       154          637.588          4.140
Total          161          4672.914
```

```
Acenaphthylene
Analysis of variance
Variate: Acenaphthylene_Concentration_g_k
Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.
Block stratum  2          2.32     1.16     0.11
Block.*Units* stratum
Sources        5    1137.91          227.58           20.86  <.001
Residual       154          1679.91          10.91
Total          161          2820.14
```

```
Anthracene
 Analysis of variance
Variate: Anthracene_Concentration_g_kg
Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.
Block stratum  2          50.51   25.26   1.79
Block.*Units* stratum
Sources        5    89.49   17.90   1.27     0.280
Residual       154          2173.20          14.11
Total          161          2313.21
```

```
Benzo_a_Antracene
Analysis of variance
Variate: Benzo_a_anthracene_Concentration
Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.
Block stratum  2          363.0   181.5   1.31
Block.*Units* stratum
Sources        5   10478.5          2095.7           15.15  <.001
Residual       154           21299.3          138.3
Total          161           32140.8
```

```
Benzo_a_pyrene
 Analysis of variance
Variate: Benzo_a_pyrene_Concentration_g_k
Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.
Block stratum  2          10.57   5.29     0.25
Block.*Units* stratum
Sources        5   6084.02          1216.80          57.93  <.001
Residual       154           3234.88          21.01
Total          161           9329.48
```

```
 Benzo_g_h_i_perylene
 Analysis of variance
 Source of variation     d.f.      s.s.      m.s.     v.r.      F pr.
 Block stratum  2          58.50   29.25   1.23
 Block.*Units* stratum
 Sources        5   79676.45        15935.29        672.13          <.001
 Residual       154           3651.13          23.71
 Total          161           83386.09
```

```
Benzo_b_fluoranthene
Analysis of variance
Variate: Benzo_b_fluoranthene_Concentration
Source of variation     d.f.      s.s.      m.s.      v.r.      F pr.
Block stratum  2          15.541           7.770   6.02
Block.*Units* stratum
Sources        5   20776.558      4155.312        3217.03         <.001
Residual       154          198.916          1.292
Total          161          20991.015
```

```
Benzo_g_h_i_perylene
Analysis of variance
Variate: Benzo_g_h_i_perylene_Concentration
Source of variation     d.f.      s.s.      m.s.      v.r.      F pr.
Block stratum  2          58.50   29.25   1.23
Block.*Units* stratum
Sources        5   79676.45       15935.29        672.13          <.001
Residual       154          3651.13          23.71
Total          161          83386.09
```

```
Chrysene
Analysis of variance
Variate: Chrysene_Concentration_g_kg
Source of variation     d.f.      s.s.      m.s.      v.r.      F pr.
Block stratum  2          328.46           164.23           10.69
Block.*Units* stratum
Sources        5   2114.64          422.93           27.53  <.001
Residual       154          2365.78          15.36
Total          161          4808.88
```

```
Fluoranthene
Analysis of variance
Variate: Fluoranthene_Concentration_g_kg
Source of variation     d.f.      s.s.      m.s.      v.r.      F pr.
Block stratum  2          3.989   1.995   0.20
Block.*Units* stratum
Sources        5   4256.565       851.313         85.69  <.001
Residual       154          1529.895         9.934
Total          161          5790.450
```

Fluorene

```
 Analysis of variance
Variate: Fluorene_Concentration_g_kg
Source of variation     d.f.      s.s.       m.s.      v.r.       F pr.
Block stratum  2          146.45            73.22   3.63
Block.*Units* stratum
Sources        5    1577.93           315.59            15.66  <.001
Residual       154            3103.20           20.15
Total          161            4827.58
```

Indeno_1_2_3_c_d_pyrene

```
Analysis of variance
Variate: Indeno_1_2_3_c_d_pyrene_Concentr
Source of variation     d.f.      s.s.       m.s.      v.r.       F pr.
Block stratum  2          32.43   16.21   0.63
Block.*Units* stratum
Sources        5    22270.44         4454.09          172.80          <.001
Residual       154            3969.55           25.78
Total          161            26272.42
```

Phenanthrene

```
Analysis of variance
Variate: Phenanthrene_Concentration_g_kg
Source of variation     d.f.      s.s.       m.s.      v.r.       F pr.
Block stratum  2          403.24            201.62            9.73
Block.*Units* stratum
Sources        5    6784.43          1356.89          65.46  <.001
Residual       154            3192.29           20.73
Total          161            10379.95
```

Pyrene

```
Analysis of variance
Variate: Pyrene_Concentration_g_kg
Source of variation     d.f.      s.s.       m.s.      v.r.       F pr.
Block stratum  2          25.35   12.68   1.12
Block.*Units* stratum
Sources        5    11836.49         2367.30          210.01          <.001
Residual       154            1735.92           11.27
Total          161            13597.77
```

Annex 3c Analysis of variance for Antimicrobial Drug Residues

Sulfadiazine

```
Analysis of variance
Variate: Concentration_g_kg
Source of variation          d.f.        s.s.        m.s.     v.r.    F pr.
Block stratum                   2      4.0064      2.0032     4.04
Block.*Units* stratum
Sources                         5   6690.4349   1338.0870  2696.08    <.001
Residual                      154     76.4314      0.4963
Total                         161   6770.8727
```

Amoxicillin

```
Analysis of variance
Variate: Concentration_g_kg
Source of variation          d.f.        s.s.        m.s.     v.r.    F pr.
Block stratum                   2      74.164      37.082     4.75
Block.*Units* stratum
Sources                         5   33741.610    6748.322   863.59    <.001
Residual                      154    1203.401       7.814
Total                         161   35019.175
```

Danofloxcin

```
Analysis of variance
Variate: Concentration_g_kg
Source of variation          d.f.        s.s.        m.s.     v.r.    F pr.
Block stratum                   2       67.48       33.74     0.78
Block.*Units* stratum
Sources                         5   120423.51    24084.70   553.53    <.001
Residual                      154     6700.66       43.51
Total          161          127191.65
```

Amprolium HCL

```
Analysis of variance
Variate: Concentration_g_kg
Source of variation          d.f.        s.s.        m.s.     v.r.   F pr.
Block stratum                   2      376.21      188.11    10.13
Block.*Units* stratum
Sources                         5    35071.52     7014.30   377.71  <.001
Residual                      154     2859.89       18.57
Total                         161    38307.62
```

Ciprofloxacin

```
Analysis of variance
Variate: Concentration_g_kg
Source of variation          d.f.        s.s.        m.s.     v.r.   F pr.
Block stratum                   2       46.21       23.11     1.52
Block.*Units* stratum
Sources                         5   233770.67    46754.13  3082.78  <.001
Residual                      154     2335.60       15.17
Total          161          236152.48
```

Case Processing Summary

Unweighted Cases		N	Per cent
Selected Cases	Included in Analysis	349	99.7
	Missing Cases	1	.3
	Total	350	100.0
Unselected Cases		0	.0
Total		350	100.0

a. If weight is in effect, see the classification table for the total number of cases.

Classification Table^{a,b}

	Observed		Predicted		
			Compost Use		Percentage Correct
			0	1	
Step 0	Compost Use	0	275	0	100.0
		1	74	0	.0
	Overall Percentage				78.8

a. Constant is included in the model.

b. The cut value is .500

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	Householdsize	6.600	1	.010
		Householdsize_Location	22.358	1	.000
		Householdsize_Education	.239	1	.625
		Householdsize_Sex	.144	1	.704
		Householdsize_Proximity	24.868	1	.000
		Householdsize_Extension_Parttime	15.995	1	.000
		Training_Sex	24.706	1	.000
		Training_Location	67.799	1	.000
		Training_Education	13.149	1	.000
		Training_Proximity	72.295	1	.000
		Training_Extension_Parttime	.006	1	.940
	Overall Statistics		82.840	11	.000

Variables not in the Equation[a]

			Score	df	Sig.
Step 0	Variables	AGE	2.490	1	.115
		Location	15.451	1	.000
		Training	47.223	1	.000
		Education	.028	1	.867
		ExtensionOfficers	.234	1	.629
		Part Time	.001	1	.970
		Parttimeworker	15.756	1	.000
		Proximity	18.051	1	.000
		Percapitalincome	11.259	1	.001
		Age_Sex	2.378	1	.123
		Age_Location	12.503	1	.000
		Age_Training	48.033	1	.000
		Age_Education	.096	1	.757
		Age_Proximity	14.698	1	.000
		Age_Extension_Partime	16.179	1	.000
		Percapitalincome_Sex	.305	1	.581
		Percapitalincome_Location	14.778	1	.000
		Percapitalincome_Training	58.922	1	.000
		Percapitalincome_Education	.382	1	.536
		Percapitalincome_Proximity	16.667	1	.000
		Percapitalincome_Extension_Extention Parttime	8.974	1	.003
		Location_Sex_Education_Proximity_Extension Parttime	.015	1	.902

a. Residual Chi-Squares are not computed because of redundancies.

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	88.212	22	.000
	Block	88.212	22	.000
	Model	88.212	22	.000

Classification Table

	Observed		Predicted		
			Compost Use		Percentage Correct
			0	1	
Step 1	Compost Use	0	269	6	97.8
		1	50	24	32.4
	Overall Percentage				84.0

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	AGE	-.133	.146	.827	1	.363	.875
	Location	102.943	98.115	1.101	1	.294	5.099E+044
	Training	-18.760	11.623	2.605	1	.107	.000
	Education	-2.410	4.531	.283	1	.595	.090
	ExtensionOfficers	1.019	.839	1.476	1	.224	2.771
	ExtentionOfficers	.135	.582	.054	1	.817	1.144
	Parttimeworker	.275	.814	.114	1	.736	1.317
	Proximity	-4.591	4.675	.964	1	.326	.010
	Percapitalincome	.001	.001	1.108	1	.293	1.001
	Age_Sex	.053	.037	1.999	1	.157	1.054
	Age_Location	.561	2.528	1.027	1	.311	.077
	Age_Training	.311	.219	2.005	1	.157	1.364
	Age_Education	.044	.087	.258	1	.611	1.045
	Age_Proximity	.116	.121	.922	1	.337	1.123
	Age_Extension_Partime	-.102	.032	9.780	1	.002	.903
	Percapitalincome_Sex	-.001	.000	2.614	1	.106	.999
	Percapitalincome_Location	.005	.008	.316	1	.574	1.005
	Percapitalincome_Training	.002	.001	3.923	1	.048	1.002
	Percapitalincome_Education	.000	.000	.007	1	.936	1.000

Classification Table

	Observed		Predicted		
			Compost Use		Percentage Correct
			0	1	
Step 1	Compost Use	0	272	3	98.9
		1	52	22	29.7
	Overall Percentage				84.2

a. The cut value is .500

	Percapitalincome_Proximity	.000	.000	.303	1	.582	1.000
	Percapitalincome_Extension_Parttime	.001	.000	7.525	1	.006	1.001
	Location_Sex_Education_Proximity_Extension_Parttime	-.006	.052	.012	1	.912	.994
	Constant	1.025	6.510	.025	1	.875	2.788

a. Variable(s) entered on step 1: AGE, Location, Training, Education, ExtensionOfficers, Officers, Parttimeworker, Proximity, Percapitalincome, Age_Sex, Age_Location, Age_Training, Age_Education, Age_Proximity, Age_Extension_Partime, Percapitalincome_Sex, Percapitalincome_Location, Percapitalincome_Training, Percapitalincome_Education, Percapitalincome_Proximity, Percapitalincome_Extension__Parttime, Location_Sex_Education_Proximity_Extension_Parttime.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Householdsize	.026	.172	.023	1	.881	1.026
	Householdsize_Location	-.233	.651	.128	1	.720	.792
	Householdsize_Education	-.020	.056	.127	1	.722	.980
	Householdsize_Sex	-.035	.073	.227	1	.634	.966
	Householdsize_Proximity	.016	.031	.262	1	.609	1.016
	Householdsize_Extension_Parttime	-.129	.072	3.240	1	.072	.879
	Training_Sex	-1.837	1.661	1.223	1	.269	.159
	Training_Location	-32.083	26.849	1.428	1	.232	.000
	Training_Education	1.145	1.351	.718	1	.397	3.142
	Training_Proximity	1.694	1.297	1.707	1	.191	5.443
	Training_Extension_Parttime	-.021	1.642	.000	1	.990	.979
	Constant	-1.796	.799	5.055	1	.025	.166

a. Variable(s) entered on step 1: Household size, Householdsize_Location, Householdsize_Education, Householdsize_Sex, Householdsize_Proximity, Householdsize_Extension_Parttime, Training_Sex, Training_Location, Training_Education, Training_Proximity, Training_ExtensionParttime.

UNIVERSITY OF GHANA
ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES (ECBAS)
P. O. Box LG 1195, Legon, Accra, Ghana

23rd August, 2021.

ETHICAL CLEARANCE
(UG-ECBAS 026/19-20)

Title of Protocol: EMERGING CONTAMINANTS AND COMPOST QUALITY: ASSESSING THE FACTORS INFLUENCING COMPOST ADOPTION

Student Investigator: MAXWELL KOGBE

Your protocol for an amendment was presented to the University of Ghana Ethics Committee for Basic and Applied Sciences (ECBAS) for a full board review and the following actions have been taken subject to the conditions and explanation provided below:

On Agenda for: An Amendment

UG- ECBAS Action: Approved

Expiry Date: 13/08/2022

Reporting: Annually

APPROVED
23 AUG 2021

Signature of Chairperson
Professor Daniel Bruce Sarpong

UNIVERSITY OF GHANA
ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES (ECBAS)

P. O. BOX LG 1195, Legon-Accra

Ref. No: ECBAS 026/19-20

30th January, 2020.

Mr. Maxwell Kogbe
Institute of Environmental
and Sanitation Studies
University of Ghana
Legon, Accra

Dear Mr. Kogbe

ECBAS 026/19-20: COMPOST QUALITY; COMPOSITION, QUANTIFICATION, UPTAKE AND TRANSLOCATION OF EMERGING CONTAMINANTS

This is to inform you that the above reference study has been presented to the Ethics Committee for Basic and Applied Sciences for a full board review and the following actions taken subject to the conditions and explanation provided below:

Expiry Date:	04/01/21
On Agenda for:	Initial Submission
Date of Submission:	05/11/2019
ECBAS Action:	Approved
Reporting:	Quarterly

Please accept my congratulations.

Yours sincerely,

Professor Daniel Bruce Sarpong
ECBAS Chairperson

ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES
APPROVED
30 JAN 2020
UNIVERSITY OF GHANA