

Justice Kofi Debrah

Improper Medical Waste Management in Ghana: Environmental Sustainability and
Public Health

Universidade Fernando Pessoa

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Public Health

Thesis presented to the University Fernando Pessoa
as part of the requirements for obtaining the degree
of Doctor in Ecology and Environmental Health,
under the supervision of Professor Maria Alzira
Pimenta Dinis.

ABSTRACT

Improper Medical Waste Management in Ghana: Environmental Sustainability and Public Health

(Under the supervision of Professor Maria Alzira Pimenta Dinis)

Handling, managing, and disposal of waste, especially biomedical waste (BMW), in healthcare facilities (HF), present significant challenges to Governments in sub-Saharan Africa. BMW is mixed with domestic waste and disposed into landfills in most developing countries. However, in recent times, efforts have been made to handle adequately and manage BMW for proper disposal due to its hazardous nature and the impact it poses to the environment and public health to move towards the achievement of some United Nations (UN) Agenda 2030, Sustainable Development Goals (SDGs).

In Ghana, the government, non-governmental agencies, and individual entrepreneurs provide the infrastructure of HF, such as the buildings and medical equipment, while neglecting the proper handling of BMW, thereby affecting SDGs 3, 6, 13 to 15. Therefore, to address and analyse improper management practices of BMW, from generation to disposal, and its impact on the environment and human health in Ghana, Africa, a research study was conducted in six selected HF in Greater Accra and Eastern Regions of Ghana from March 2021 to April 2022. This thesis, resulting from that assessment, aims to evaluate the nature of BMW from the point of generation through transportation and disposal, determining the knowledge and practices of healthcare practitioners and BMW handlers towards handling and managing BMW and the associated potential effects on the environment and public health. In addition, it will appraise the content of bottom ash (BA) from the incinerator for the presence of oxides and heavy metals.

A mixed methodological approach, integrating a qualitative and quantitative study, comprising descriptive and systematic review research design, was used to accomplish the objectives of the chapters in this doctoral thesis through questionnaires, observation, interviews, and laboratory work. The participants for this thesis were selected using a

convenience sampling technique to assess the understanding and practice of BMW management in Ghana. The data collected in this thesis were analysed using IBM Statistical Package for the Social Science (SPSS) version 27, and the chemical compositions of the BA were also analysed using X-ray fluorescence spectrometry (XRF) and atomic absorption spectroscopy (AAS).

The results of work done in this thesis reveal a significant shortcoming in handling and managing BMW in Ghana, in relation to segregation, collection, transportation, and treatment/disposal methods in most HF. 11.41 tonnes of BMW are generated, with 49.1% being infectious and an average infectious BMW rate between 0.23 to 2.34 kg/bed/day. Thus, BMW generators, collectors and handlers do ineffective segregation, do not disinfect BMW containers, have inadequate means of transportation for BMW, and lack proper personal protective equipment (PPE). Eighty-seven percent (87%) of studied HF needs more procedural knowledge of handling liquid BMW, and 82.2% lack knowledge of handling expired blood. Also, 95% of patients from the studied HF have unused out-of-date medicine at home and disposed of in waste bins. In addition, 33% of the studied HF has no medical technology to process the waste, while 33% use an incinerator to handle BMW. Nonetheless, both BMW and incinerated BA from BMW are disposed of in open spaces or landfills. The BA has a high concentration of heavy metal ions such as Fe, Zn, Ti, Pb, Cr, and other oxides that affect the environmental and human health and could negatively impact the achievement of UN SDGs 3, 6, 13 to 15 by 2030.

Therefore, tools and logistics must be provided by the Ministry of Health, Ghana, and Ghana Health Service for proper handling of BMW for environmental sustainability in Ghana and SSA in general. Furthermore, BMW circularity needs to be implemented to transform generated waste for other innovative purposes like using plastics from HF for artifacts and pavement blocks for roads and houses, and BA for binding materials in construction. At the same time, regular training will ensure requisite skills and knowledge for improving practice in handling BMW and reducing the risks associated with environmental pollution, which threatens public health. This thesis will also guide HF in Ghana and other SSA countries in proper management of BMW and BA, which will contribute to preserve environmental and human health regarding the achievement of the UN 2030 SDGs. In the context of this thesis, the attainment of these SDGs specifically includes good healthy living (SDG 3), clean water and hygienic conditions

(SDG 6), reducing bad climatic conditions (SDG 13), decreasing pollution for a better life in water (SDG 14) and on land (SDG 15), protecting the environment in Ghana.

Additionally, the main findings of this thesis, translated into a significant volume of publications in indexed SCOPUS/WoS journals and SCOPUS chapters from 2021 to 2023, are already spreading evidence-based knowledge and are expected to assist the policymakers at various HF and other stakeholders such as Ministry of Health and Ghana Health Service for decision-making in BMW management in Ghana and SSA countries, with emphasizes of the meaningfulness of the research work carried out.

RESUMO

Gestão Inadequada de Resíduos Médicos no Gana: Sustentabilidade Ambiental e Saúde Pública

(Sob a orientação da Professora Doutora Maria Alzira Pimenta Dinis)

O manuseamento, gestão e eliminação de resíduos, especialmente resíduos biomédicos (RBM), nas instalações de saúde (IS), apresentam-se como desafios significativos para os governos da África Subsaariana. Os RBM são misturados com resíduos domésticos e depositados em aterros em grande parte dos países em desenvolvimento. Contudo, recentemente, têm sido feitos esforços para tratar adequadamente e gerir os RBM para uma deposição adequada devido à sua natureza perigosa e ao impacto que representam para o ambiente e a saúde pública, a fim de progredir no alcance de alguns dos Objetivos de Desenvolvimento Sustentável (ODS) da Agenda 2030 das Nações Unidas (ONU).

No Gana, governos, agências não governamentais e empresários individuais fornecem as infraestruturas de IS, tais como os edifícios e o equipamento médico, negligenciando ao mesmo tempo o manuseamento adequado da RBM, comprometendo, assim, os ODSs 3, 6, 13 a 15. Portanto, para abordar e analisar as práticas de gestão inadequadas dos RBM, desde a sua geração até à sua deposição, bem como o seu impacto no ambiente e na saúde humana, no Gana, África, foi realizado um estudo de investigação em seis IS selecionadas na Grande Acra e nas regiões orientais do Gana, entre março de 2021 a abril de 2022. Esta tese, resultante dessa avaliação, visa avaliar a natureza dos RBM desde a sua geração até ao transporte e tratamento, determinando os conhecimentos e as práticas dos profissionais de saúde e dos atores associados aos RBM em relação ao seus manuseamento e gestão e o efeito potencial associado sobre o ambiente e a saúde pública. Além disso, avaliará ainda o conteúdo de cinzas de fundo (CF) do incinerador quanto à presença de óxidos e metais pesados.

Foi utilizada uma abordagem metodológica mista, constituída por um estudo qualitativo e quantitativo, compreendendo uma conceção de investigação descritiva e de revisão

sistemática para alcançar os objetivos desta tese de doutoramento através de questionários, observação, entrevistas e trabalho laboratorial. Os participantes para esta tese foram selecionados utilizando uma técnica de amostragem amostra de conveniência para avaliar a compreensão e a prática da gestão dos RBM no Gana. Os dados recolhidos foram analisados utilizando o pacote estatístico IBM para as Ciências Sociais (SPSS) versão 27, e as composições químicas das CF foram também analisadas utilizando espectrometria de fluorescência de raios X (XRF) e espectroscopia de absorção atômica (EAA).

Os resultados desta tese revelaram uma falha significativa no manuseamento e gestão dos RBM no Gana, em relação à separação, recolha, transporte, e métodos de tratamento na maioria das IS. Os resultados indicaram que são geradas 11,41 toneladas de RBM, sendo 49,1% desta consideradas infecciosas e uma taxa média infecciosa de RBM que varia entre 0,23 a 2,34 kg/cama/dia. Assim, aqueles que produzem, recolhem e manipulam os RBM fazem uma separação ineficaz, não desinfetam os contentores dos RBM, têm meios de transporte inadequados para os mesmos e carecem de equipamento de proteção pessoal (EPP) adequado. 87% das IS estudadas necessitam de mais conhecimentos processuais de manuseamento de RBM líquidos e 82,2% carecem de conhecimentos de manuseamento de sangue expirado. Além disso, 95% dos pacientes das IS estudadas têm medicamentos desatualizados não utilizados em casa que são depositados em contentores de lixo. 33% das IS estudados também não possuem tecnologia médica para processar os resíduos, enquanto 33% utilizam um incinerador para manusear os RBM. No entanto, tanto os RBM como o CF incineradas dos mesmos são depositados em espaços abertos ou aterros sanitários. As CF têm uma alta concentração de iões de metais pesados como Fe, Zn, Ti, Pb, Cr, e outros óxidos que afetam o ambiente e a saúde humana e podem ter um impacto negativo nos ODSs 3, 6, 13 a 15 até 2030.

Por conseguinte, as ferramentas e a logística devem ser fornecidas pelo Ministério da Saúde, Gana e o Serviço de Saúde do Gana para um manuseamento adequado dos RBM e para a sustentabilidade ambiental no Gana e na África Subsariana em geral. Além disso, a circularidade dos RBM deve ser praticada para transformar os resíduos que são gerados para outros fins inovadores como a utilização de plásticos de IS para artefactos e blocos de pavimento para estradas e casas, bem como as CF para materiais ligados à construção. Ao mesmo tempo, a formação regular assegurará as competências e conhecimentos

necessários para melhorar a prática no manuseamento dos RBM e reduzir os riscos associados à poluição ambiental, que ameaça a saúde pública. Esta tese orientará também as IS no Gana e noutros países da África Subsariana na gestão adequada dos RBM e das CF, o que contribuirá para preservar o ambiente e a saúde humana no que diz respeito à realização dos ODS da Agenda 2030. A realização destes ODS inclui uma boa vida saudável (ODS 3), água limpa e condições de higiene (ODS 6), redução das más condições climáticas (ODS 13), e diminuição da poluição para uma vida melhor na água (ODS 14) e na terra (ODS 15), o que poderá contribuir para a proteção do meio ambiente no Gana.

Além disso, as principais conclusões desta tese, traduzidas num volume significativo de publicações em revistas e capítulos indexados na SCOPUS/WoS desde 2021 a 2023, já estão a difundir conhecimentos baseados em evidência e espera-se que ajudem os decisores políticos em várias IS e outras partes interessadas, tais como o Ministério da Saúde e o Serviço de Saúde do Gana para a tomada de decisões na gestão dos RBM tanto no Gana como na África Subsariana, com ênfase no significado do trabalho de investigação realizado.

RÉSUMÉ

Gestion inadéquate des déchets médicaux au Ghana : durabilité environnementale et santé publique

(Sous la direction de la Professeure Maria Alzira Pimenta Dinis)

La manipulation, la gestion et l'élimination des déchets, en particulier des déchets biomédicaux (DBM), dans les établissements de santé (ES) sont des défis importants pour les gouvernements en Afrique subsaharienne. Les DBM sont mélangés aux déchets domestiques et éliminés dans des décharges dans la plupart des pays en développement. Cependant, ces derniers temps, des efforts ont été faits pour une manipulation et une gestion adéquates des DBM en vue d'une disposition appropriée en raison de leur caractère dangereux et de l'impact qu'ils ont sur l'environnement et la santé publique, afin de progresser vers la réalisation de certains objectifs de développement durable (ODD) de l'Agenda 2030 des Nations Unies (NU).

Au Ghana, les gouvernements, les agences non gouvernementales et les entrepreneurs individuels fournissent les infrastructures des ES, telles que les bâtiments et les équipements médicaux, tout en négligeant la gestion adéquate des DBM, affectant ainsi les ODD 3, 6, 13 à 15. Par conséquent, pour aborder et analyser les pratiques de gestion inappropriées des DBM, de génération à disposition, et son impact sur l'environnement et la santé humaine, au Ghana, en Afrique, une étude de recherche a été menée dans six ES sélectionnés des régions du Grand Accra et de l'Est du Ghana, de mars 2021 à avril 2022. Cette thèse, résultant de cette évaluation, vise à évaluer la nature des DBM depuis le point de leur génération jusqu'au transport et au traitement, en déterminant les connaissances et les pratiques des praticiens de la santé et des gestionnaires de DBM en matière de manipulation et de gestion des DBM et de leur impact potentiel sur l'environnement et la santé publique. En outre, elle évalue la teneur en cendres de fond (CD) de l'incinérateur pour la présence d'oxydes et de métaux lourds.

Une approche méthodologique mixte, composée d'études qualitatives et quantitatives comprenant des recherches descriptives et systématiques, a été utilisée pour atteindre les objectifs des chapitres de cette thèse de doctorat à travers des questionnaires, des observations, des entretiens et des travaux de laboratoire. Les participants pour cette thèse

ont été sélectionnés en utilisant une technique d'échantillonnage commodité pour évaluer la compréhension et la pratique de la gestion des déchets biomédicaux au Ghana. Les données collectées pour cette thèse ont été analysées à l'aide du logiciel IBM Statistical Package for the Social Science (SPSS) version 27, et les compositions chimiques des CD ont également été analysées à l'aide de la spectrométrie de fluorescence des rayons X (XRF) et de la spectrométrie d'absorption atomique (AAS).

Les résultats de cette thèse ont révélé une lacune significative dans la gestion des DBM au Ghana, en ce qui concerne la ségrégation, la collecte, le transport et les méthodes de traitement dans la plupart des ES. Les résultats ont indiqué que 11,41 tonnes de BMW sont générées, dont 49,1% sont infectieuses, avec un taux moyen d'infectiosité compris entre 0,23 et 2,34 kg/lit/jour. Ainsi, les générateurs, collecteurs et manipulateurs de DBM effectuent une ségrégation inefficace, ne désinfectent pas les conteneurs de DBM, disposent de moyens de transport inadéquats pour la DBM et ne disposent pas d'un équipement de protection individuelle adéquat. 87% des ES étudiées ont besoin d'une connaissance procédurale plus poussée pour manipuler les DBM liquides, et 82,2% ne connaissent pas la manipulation du sang expiré. De plus, 95% des patients des ES étudiées ont des médicaments non utilisés et périmés à la maison, qu'ils jettent dans les poubelles. De plus, 33% des ES étudiées ne disposent pas de technologie médicale pour traiter les déchets, tandis que 33% utilisent un incinérateur pour manipuler les DBM. Néanmoins, à la fois les DBM et les CD incinérées sont jetées dans des espaces ouverts ou des décharges. Les CD contiennent une forte concentration d'ions de métaux lourds tels que Fe, Zn, Ti, Pb, Cr et d'autres oxydes qui affectent la santé environnementale et humaine et pourraient avoir un impact négatif sur la réalisation des ODD de l'ONU 3, 6, 13 à 15 d'ici 2030.

Par conséquent, le Ministère de la Santé du Ghana et le Service de Santé du Ghana doivent fournir des outils et des moyens logistiques pour assurer une gestion appropriée des BMW en vue de garantir la durabilité environnementale au Ghana et en Afrique subsaharienne en général. De plus, la circularité DBM doit être pratiquée pour transformer les déchets générés à d'autres fins innovantes comme l'utilisation de plastiques de ES pour les artefacts et les pavés pour les routes et les maisons, et CD pour les matériaux de liaison dans la construction. En outre, une formation régulière permettra d'acquérir les compétences et les connaissances nécessaires pour améliorer la gestion des DBM et

réduire les risques associés à la pollution environnementale, ce qui menace la santé publique. Cette thèse guidera également les établissements de santé au Ghana et dans d'autres pays d'Afrique subsaharienne dans la gestion adéquate des DBM et des CD, contribuant ainsi à préserver la santé environnementale et humaine dans le cadre de la réalisation des ODD des Nations unies à l'horizon 2030. La réalisation de ces ODD comprend une vie saine et de qualité (ODD 3), de l'eau propre et des conditions d'hygiène (ODD 6), la réduction des mauvaises conditions climatiques (ODD 13), la diminution de la pollution pour une vie meilleure dans l'eau (ODD 14) et sur la terre (ODD 15), qui pourraient protéger l'environnement du Ghana.

De plus, les principales conclusions de cette thèse, traduites en un volume important de publications dans des revues et des livres indexés SCOPUS/WoS depuis 2021 à 2023, diffusent déjà des connaissances fondées sur des preuves et devraient aider les décideurs dans les différents ES et les autres parties prenantes, telles que le Ministère de la Santé et les Services de Santé du Ghana, dans la prise de décisions en matière de gestion de DBM au Ghana et dans les pays de la SSA, soulignant ainsi l'importance de la recherche effectuée.

DEDICATION

I dedicate this Thesis to my father, Rev. Thomas Yaw Mensah, and mother, Margret Yaa Mensah, for investing in my education and enabling me to achieve this dream. Also, to my mother-in-law Felicia Danso, my sisters Eunice and Abigail Mensah, my brothers, my wife Linda Adu Debrah, and my wonderful children Maame Gyankromah Debrah, Nana Dansowaa Debrah, and Papa Mensah Debrah.

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INTRODUCTION

Management of biomedical waste (BMW) became noticeable after United Nations Conference on Environment and Development (UNCED) in 1992, held in Brazil. BMW management has become one of the essential topics for discussion by governments, scientific researchers, and other non-governmental organizations due to its potential occupational hazards, environmental impacts, and public health implications (Mochungong, 2011).

The growing affluence in sub-Saharan Africa (SSA) countries by human activities has increased the generation of BMW, which requires special attention and skills to dispose of and manage due to the risks and threat it poses to the environment and public health (Debrah et al., 2021b). However, BMW is poorly managed in developing countries, especially the SSA countries, because of rapid population growth, an increase of healthcare facilities (HF) (Ara et al., 2022; Khatib, 2011; Kwikiriza et al., 2019; Wafula et al., 2019), and a lack of technological treatment facilities before disposal of BMW (Debrah et al., 2022), indicated in Figure 1, negatively influencing United Nations (UN) 2030 Sustainable Development Goals (SDGs) in Table 1. According to the World Health Organization (WHO, 2018), BMW from HF comprises 15 % of infectious waste (e.g., pharmaceuticals and pathological waste, sharps, contaminated blood, human tissues, chemicals, and radioactive materials, and effluents from mortuaries). The remaining 85% of non-hazardous waste come from stores, offices, and kitchens.



(a)



(b)






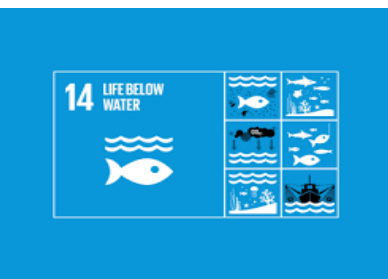

(c)



(d)

Figure 1. Disposal of BMW through (a) dumping in an open space, (b) BMW dumped a short distance from the HF, (c) burning of BMW in a pit, and (d) ashes of BMW left after burning in the pit.

Table 1: Poor handling of biomedical waste in developing countries and affected SDGs.

BMW handling issues	BMW Poor handling implications	Involved SDGs
<p>Poor segregation of BMW Burning of BMW Dumping of BMW in uncontrollable landfill</p>	<p>Transmissions of parasitic and other infectious diseases, for example, hepatitis, candida, cholera, typhoid, and HIV</p>	
<p>Unsegregated BMW Dumping of BMW in an open space</p>	<p>BMW litters the land and water bodies, resulting in land and water pollution</p>	
<p>Burning of BMW with incinerator or open. BMW disposed of in landfills and decomposed.</p>	<p>The burning and decomposition of BMW emit gases such as CH₄, N₂O, H₂S, NH₃, and other particulate matter that contributes to the depletion of the ozone layer.</p>	
<p>Leachate of chemicals from incinerated BMW contains heavy metals like Pb, Hg, Ni, Cr, Zn, Cu, Ti, and Fe. Leaching of chemicals from the decomposed BMW enters underground and surface waters</p>	<p>Heavy metals leached into water bodies are consumed by fishes and other aquatic organisms, thereby affecting reproductively, and disrupting the food chain.</p>	
<p>The indiscriminate dumping of BMW in spaces and release of heavy metals from bottom ash (BA) of incinerated BMW</p>	<p>The heavy metals affect life on land by causing stunted growth in plants. It can cause cancer and heart diseases in humans, which reduces the life expectancy rate on earth.</p>	

Studies conducted in developing countries indicate that BMW is generally handled and disposed of as waste in an open landfill or using an incinerator (Agbere et al., 2021; Borowy, 2020; Coker et al., 2009; Hassan et al., 2008; Karungamye et al., 2022), has necessitated proper management for ecological stability. For example, in Pakistan, an estimated 30-40% of hazardous BMW is produced (Nosheen et al., 2022), and 50.4% of infectious BMW in India (Thind et al., 2021). Other countries within SSA, including Ethiopia, generates 48% infectious BMW (Gebremeskel et al., 2021) and an average of 50% infectious BMW is found in Tanzania (Manyele & Lyasenga, 2010; Mwaria. et al., 2021). The infectious BMW could transmit pathological diseases (Das et al., 2021; Subramanian et al., 2021) such as cholera, typhoid, hepatitis, polio, among others (Gerba & Pepper, 2019; Nichols et al., 2018) if not adequately managed, and could pose a severe threat to the environment and public health affecting the achievement of UN 2030, SDGs 3, 6, 13 to 15 (Debrah et al., 2021a; Debrah et al., 2022; Filho et al., 2022) as indicated in Figure 2.

In Ghana, research on waste management has been directed toward domestic waste, the challenges of waste management, institutional arrangement, and technological options (Anomanyo, 2004; Kanhai et al., 2021). Nevertheless, more needs to be done on BMW management, in Ghana (Bamfo-Tanor & Owusu-Agyei, 2013; Odonkor & Mahami, 2020). Wilson et al. (2006) study on BMW management in Korle-Bu and Komfo-Anokye Teaching Hospitals, the two largest teaching hospitals in Ghana, revealed that BMW management practices were not in conformity with the Ghana Environmental Protection Agency guidelines, and that is expected to negatively affect the ecological system and prevent the actualization of the UN 2030 SDGs agenda, especially given the vast volume of BMW generation resulting from the current dynamic population size, different kinds of disease outbreaks, and the spread of accessible HF in Ghana and the world in general.

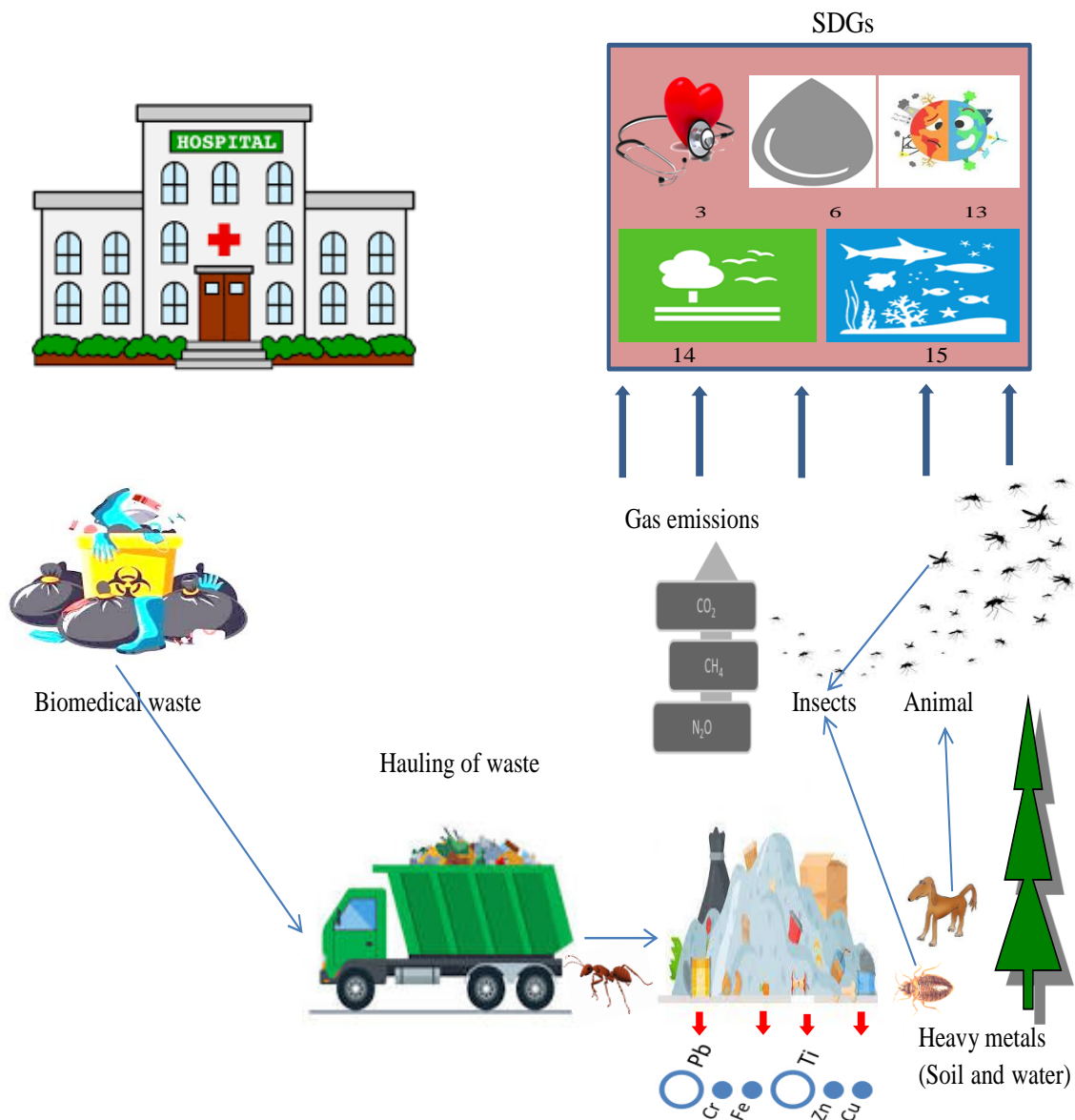


Figure 2. Relationship between improper handling of BMW and SDGs in SSA Countries.

The improper handling and disposal of BMW exposes the environment to toxic emissions from the decomposition and burning of BMW, through emission of CH₄, CO₂, N₂O, and NH₃, odour from the foul stench, and the conducive environment created for the vermin to breed. Most developing countries are making all the necessary effort to ensure proper BMW management (Datta et al., 2018; Rajan et al., 2019). However, despite all the steps to provide adequate sanitation and proper BMW management, several issues, such as unregulated BMW treatment, disposal, and transportation of non-segregated BMW due to inadequate knowledge, are linked to several public health threats. Given that, this

doctoral research aimed to examine and explore the environmental and public health impacts of improper BMW management practices, from generation through transportation to disposal, in Ghana, Africa.

This research aimed to investigate the process and nature of medical waste in Ghana by assessing how BMW is generated, collected, and transported. It also examined how BMW is stored temporally, handled, and disposed of and assessed the knowledge and practices of BMW generators and handlers towards BMW management associated with its potential environmental and public health effects. The study further analysed the oxides and inorganic metal content in the BA produced from BMW incinerators and its possible effect on human health and the environment, preventing the realisation of UN SDGs 3, 6, 13 to 15 by 2030 through the following research questions:

1. What is the nature of BMW collected, temporarily stored, and transported from the six HF in Ghana?
2. How does the BMW generated at the HF managed?
3. What is the contribution of improper BMW management to the environmental and public health burden in Ghana?
4. How important are BMW incinerators and other disposal choices for BMW to the health of susceptible populations within a particulate area?

The above aims, objectives and research questions are further illustrated in Figure 3.

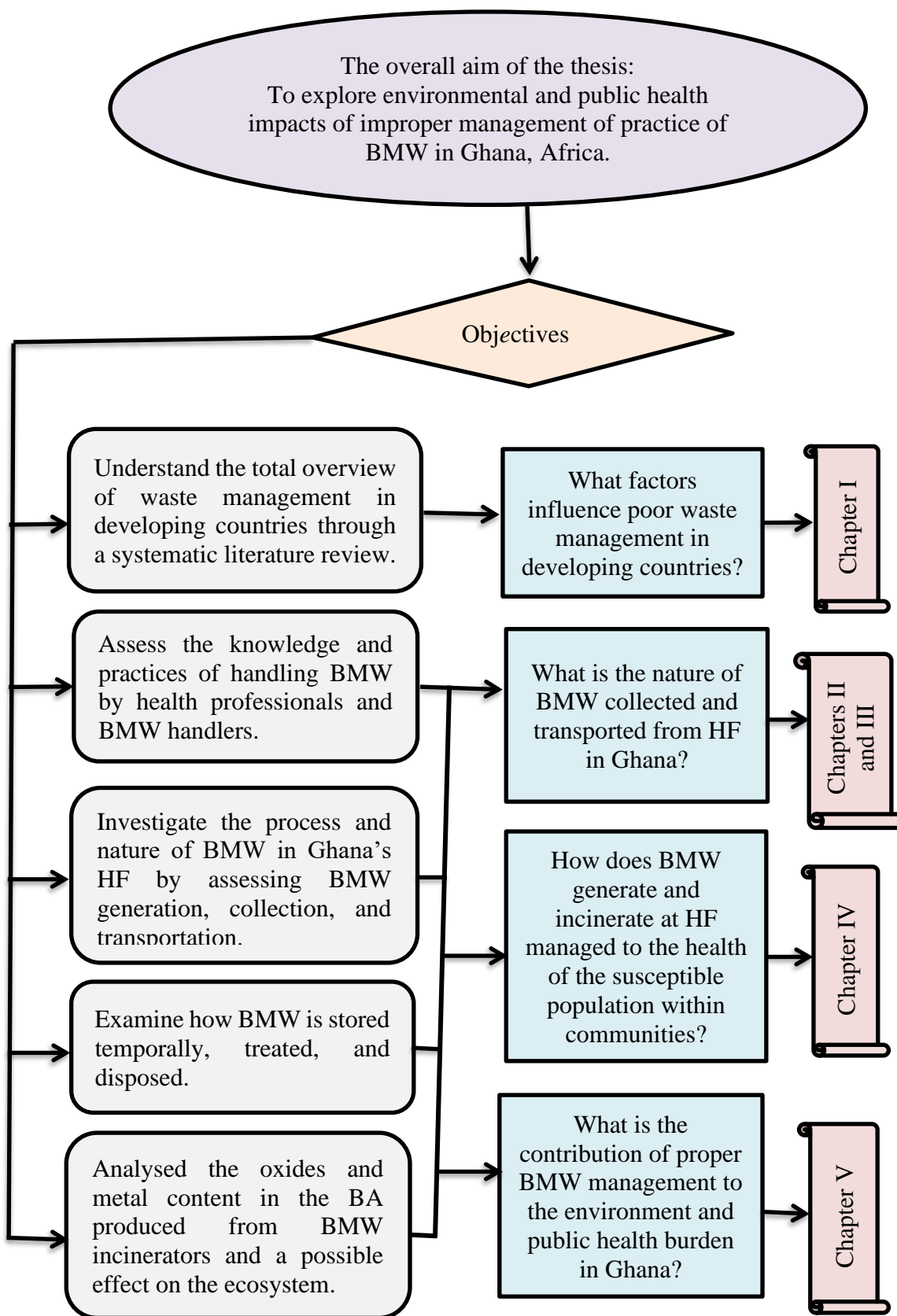


Figure 3. Overview of aim, objectives and research questions of thesis and connection to chapters.

To address the aim and respond to the research questions of this thesis, one-year research (March 2021 to March 2022) was carried out in six selected HF in Eastern and Greater Accra regions in Ghana. A mixed approach, a combination of the quantitative and qualitative methods (Maanen, 2007), was used to analyse the objectives, as shown in Figure 4. The qualitative approach evaluates the nature and assessment of knowledge and practices through critical observation, interviews, and text analysis. At the same time, the quantitative method focuses on the treatment of data obtained from questionnaires and laboratory analytical instruments such as X-ray fluorescence spectrometry (XRF) and atomic absorption spectroscopy (AAS).

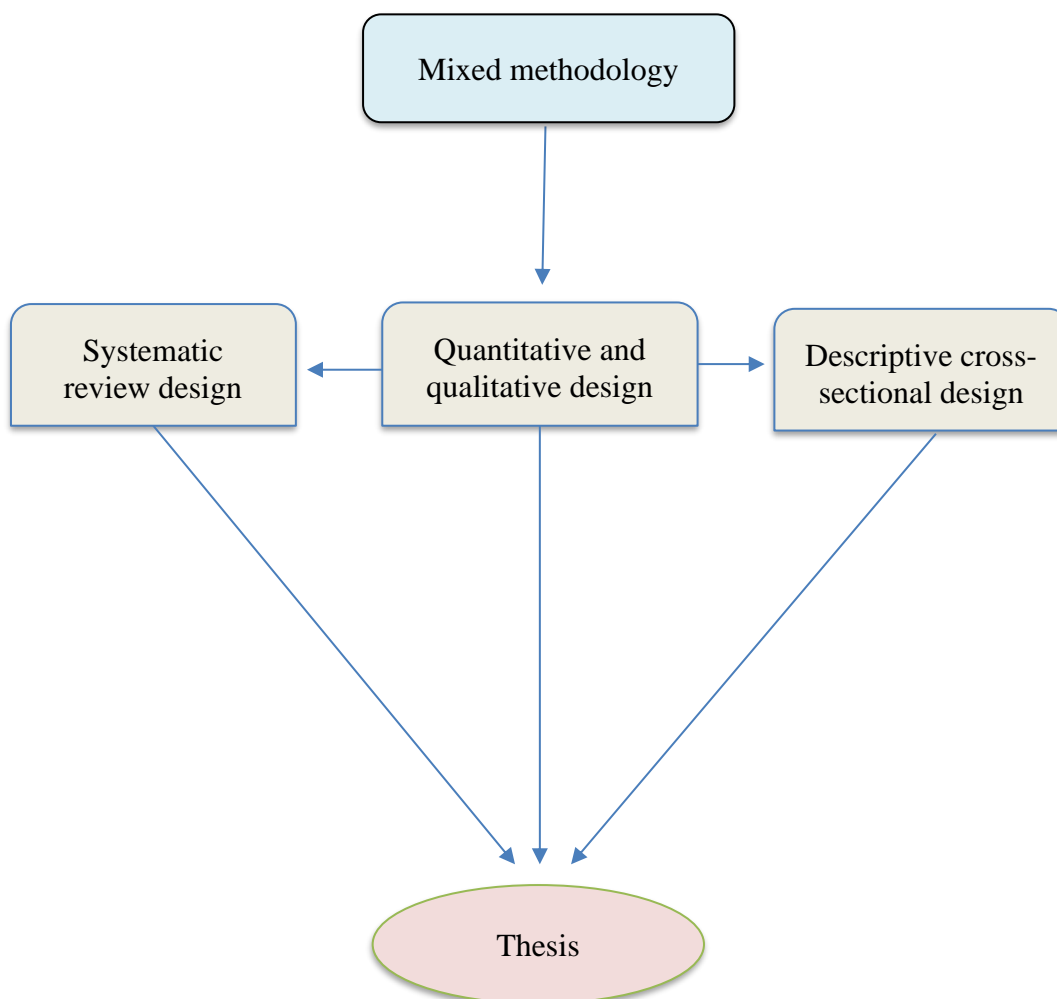


Figure 4. Mixed method approach used for the chapters.

The findings of this research thesis have been published in SCOPUS indexed articles and book chapters, in order to spread knowledge associated with evidence-based intervention for the scientific world and policymakers, especially in Ghana, while simultaneously contributing to solving similar problems in other developing countries. These selected published articles and book chapters have been compiled, organized, and integrated into five different chapters in the thesis as shown in Table 2.

Table 2: Some publications resulting from the research work within this thesis.

Chapter	Title	Reference
I	Raising Awareness on Solid Waste Management through Formal Education for Sustainability: A Developing Countries Evidence Review	Debrah et al. (2021b)
II	Assessment of biomedical waste handling in Ghana	Debrah et al. (2022c)
III	Sustainable Pharmaceutical Waste Management: Pharmacist and Patient Perception in Ghanaian Hospitals	Debrah et al. (2022d)
IV	Managing medical waste in Ghana-the reality	Debrah et al. (2021c)
V	Chemical characteristics of bottom ash from biomedical waste incinerators in Ghana	Debrah and Dinis (2023)

The first research chapter, entitled "Raising Awareness on Solid Waste Management through Formal Education for Sustainability: A Developing Countries Evidence Review," (**Debrah** et al., 2021b), presents a systematic review of solid waste management in developing countries. This study identifies a lack of environmental knowledge,

awareness, and attitudes toward good practices for sustainable solid waste management in developing countries due to teachers' lack of understanding of ecological sustainability leading to sustainable development.

The second chapter, entitled "Assessment of biomedical waste in Ghana," (**Debrah** et al., 2022c) evaluates the knowledge and practice of BMW by healthcare professionals (BMW generators) and BMW handlers for proper waste management towards SDGs 3, 6, and 13 achievements.

Although BMW is generated in HF, pharmaceutical waste types of BMW are found in homes in Ghana. Given this, the third chapter of this thesis entitled "Sustainable Pharmaceutical Waste Management: Pharmacist and Patients Perception in Ghanaian Hospitals" (**Debrah** et al., 2022d), published in the Handbook of Sustainability Science in the Future: Policies, Technologies, and Education by 2050, by Springer Nature, seek to analyse the perception of handling of pharmaceutical waste products generation by pharmacists in HF and patients in various homes in Ghana for environmental sustainability and public health.

The fourth chapter entitled "Managing medical waste in Ghana-the reality," (**Debrah** et al., 2021c) estimates and quantity of BMW generated in the select HF. Moreover, it determines the factors that influence the generation of BMW. It also shows how the generated BMW is handled, which determines the achievement of UN SDGs 3 and 6 by 2030.

Finally, the fifth chapter, titled "Chemical characteristics of bottom ash from biomedical waste incinerators in Ghana," (**Debrah** and Dinis, 2023), published by Environmental Monitoring and Assessment, Springer Nature, analyses the content of heavy metals and oxide in the generated BA in select HF. The chapter deals with the possible effects of heavy metals and oxides on the environment and public health and their impact on SDGs 3, 6, 13 to 15.

Though this thesis comprehends five selected chapters, other relevant indexed publications were developed side by side with the general aim of the doctoral program to enhance the development of scientific knowledge in the context of BMW. Selected

publications have been chosen to be integrated into this thesis to deepen the understanding of waste management sustainability for public health.

Experimental work developed in this thesis research was approved by the Ghana Health Service Ethics Review Committee (GHSERC), reference GHS-SEC.002/11/20, per guidelines and strict COVID-19 protocol. During the research, a design consent form was issued to participants and also translated into the local language for those who could not comprehend English. The confidentiality of respondents' data was assured, with names being excluded from the questionnaires.

CHAPTER I - Raising Awareness on Solid Waste Management through Formal Education for Sustainability: A Developing Countries Evidence Review

This chapter investigates the causes of the poor solid waste management problem in developing countries. It identifies the gap for a broader understanding of awareness creation, which raises environmental sustainability and public health issues in developing countries. This review revealed that students have low environmental knowledge within developing countries. This low level of knowledge is due to a lack of teachers' practical experience in waste management and the absence of modern-day practical environmental educational curricula.

In this review article, the first author participated in the conceptualization, development of methodology, validation, formal analysis, investigation, data curation, and the writing and editing of the manuscript. The complete citation of the publication is presented below:

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Review

Raising Awareness on Solid Waste Management through Formal Education for Sustainability: A Developing Countries Evidence Review

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Abstract: Solid Waste Management (SWM) is a multifaceted problem comprising political, socio-economic, institutional, and environmental aspects. Due to exponential urban growth, it has become one of the most significant issues faced by urban spaces in developing countries. The gap in environmental knowledge among the youth and the old within developing countries contribute to ecological issues or waste management problems, resulting in unsustainable development, with important consequences in low-income countries. For that matter, a systematic review was conducted aiming to identify and analyse environmental knowledge, awareness, attitudes, and practice studies on SWM from 2010 to 2019 in developing countries. The evidence suggests that students at both secondary and tertiary levels have positive environmental attitudes, and high awareness of environmental issues, but there is a lack of practical education of teachers to guide students to put SWM into practice. Student's low environmental knowledge is related to a deficiency in teachers' practical experience in SWM for environmental sustainability. A relationship between teachers' and students' knowledge and attitudes towards SWM, as well as differences in awareness, attitude, and practices of SWM linked with education and age, were also found. This review also revealed that the lack of environmental education in most developing countries is caused by fragilities in practical environmental curricula of teachers to respond to modern-day environmental issues for sustainable development and cleaner production (CP). To bridge the knowledge gap between the youth and older people in SWM, environmental sustainability education should be integrated into schools at all levels within developing countries.

Keywords: solid waste management (SWM); environmental awareness; environmental education; environmental sustainability



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1. Introduction

Solid waste management (SWM) is a critical environmental problem with direct effects on both environment, e.g., air, water, and soil, and public health. The increase in waste generation across the world greatly complicates proper waste management activities [1,2]. Any non-liquid waste created by individuals, households, small businesses, or institutions outside of the waste generated within cities is referred to as solid waste (SW) and the uncontrolled disposal of SW may affect public health and the environment [3]. It is known that the collection rates of SW may vary significantly from one country to another. According to Hoornweg and Bhada-Tata [4], less than 50% of waste generated is collected in low-income countries: 50% to 80% is collected in middle-income countries, and more than 90% is collected in high-income countries. However, hardly anywhere is 100% collected. The rapid growth in urban populations, economies, and power consumption in developing countries, combined with the failure of institutional authorities responsible

for city planning, roadworks, SWM, and the environment to execute their core functional duties, has led to rampant SW generation [5–8].

SWM plays a vital role in minimizing the impacts faced by municipal and rural areas due to increasing urbanization [9]. It has become a major environmental challenge in developing countries due to the economic growth and the acceleration of consumption, which caused an expansion in SW generation. SWM systems in most cities of lower-middle-income countries are underachieving their goals, underperforming, and originating adverse sustainability effects in urban growth and development [10–13].

Nonetheless, since waste management is gradually considered a “basic human right” [14], there is a rising demand to improve SWM in cities in the developing world due to the rural-to-urban surge of migration. This need is linked to at least 12 of the 17 Sustainable Development Goals (SDGs) [14,15]. The increase in waste creation has caused a severe shortage of landfills and higher costs for waste management [16]. SWM is directly related to the circular economy, which are two basic concepts that have a crucial role in the 2030 Agenda, especially in SDG for sustainable cities and communities (SDG 11), responsible consumption and production (SDG 12), and life below water (SDG 14) [17]. The Stockholm Environment Institute’s latest report, commissioned by the European Environment Agency [18], identified that, among the targets with the most substantial synergistic potential to make progress on SDGs implementation, is SDG target 12.4, which aims toward responsible management of chemicals and waste.

Most of the low/middle-income countries are unable to provide effective SWM collection services because of resource constraints, lack of facilities including vehicles, infrastructure, improper route planning, lack of technical know-how, and inadequate environmental education and awareness [19–23]. A study by Ikhlayel [24] reported that waste management is a complex sustainability issue that requires a clear vision and integrative approach in addressing its intrinsic association with many environmental and economic drives.

To sustain SW or environmental issues in developing countries, formal education for sustainable development is essential at all levels of education, able to trigger a whole societal transformation. For better environmental sustainability or waste management sustainability education, teachers with the right knowledge, attitude, skills, and innovation, are required. Accordingly, this study will review how formal environmental education in schools can help sustain SWM toward cleaner production (CP) in low/middle-income countries. As far as it is known, no similar systematic review has been made in this field, in the context of developing countries. A result from a search in the ScienceDirect database (2000–2020) reveals that 391 review papers have been produced in this area. However, none of these studies have associated the formal education and SWM practices in developing countries. Thus, it is expected that this review can complement the determination of decision-makers and solid waste management providers that aim to improve management system schemes in developing countries. Furthermore, this review aims to contribute to determining which factors need to be investigated further in future research in SWM, which are created in developing countries.

2. Literature Review

2.1. Solid Waste Management—Courses and Effects of Poor Management of SWM in Developing Countries

Waste is an unavoidable, unwanted material resulting from human activity [25]. It is generated from every human and animal habitat. It is considered as refuse of useless or worthless stuff, material to be discarded, or material that has no longer been used for any purpose by people within a specific locality, and can be classified into a solid, liquid, or gas. SW comprises sludge, garbage, refuse, and other solid materials that are discarded. It also includes SW from mining, agricultural, electronic, industrial, and municipal waste, which consists of household and commercial activities.

The pool of these different, unwanted, solid materials by cities from different types of household activities is known as SWM [26], representing a severe environmental problem in developing countries. It is expected that the cost of waste management in developing

countries will increase, which is a major source of concern. Scarlat et al. [27] indicated that 125 million tons per year of SWM were generated in Africa in 2012. The waste amount is expected to grow to 244 million tons per year by 2025 [28]. Due to the fast-growing economy, through industrialization and population growth, waste generation is projected to double or triple in most of the developing countries by 2050 [28]. Inappropriate management of waste in the municipalities of developing countries has led to polluted cities. Some of the problems associated with polluted environments include leachate, which contaminates both land and surface waters, with emission of methane (CH₄) and other gases. Lee et al. [29] found that more than 800 tons of carbon dioxide waste are released to the atmosphere yearly. Poor management of waste practice causes blocked drains, floods, transmitted infections via the breeding of vectors, and escalates respiratory issues through floating particles that result from the burning of waste [28,30]. In most studies reviewed, it has been acknowledged that rapid population growth (urbanization), inadequate human resources, lack of facilities such as vehicles and infrastructure, improper route planning, weak organizational structure, insufficient budget, weak legislation, lack of enforcement, low public awareness, corruption, conflict, political instability, and lack of political will [20,22,31], as well as other activities resulting from lack of government regulation, are the underlying problems affecting SWM in most developing countries. The main difficulty facing proper management of SWM is that one-third to two-thirds of SW generated is not collected [31–33]. This amount of uncollected waste pollutes the soil, water, and atmosphere, and the negative impact of the pollutants represent a significant health risk to animals, plants, and the human population [34].

The absence of an effective and comprehensive legislative framework governing the SW sector, coupled with inadequate enforcement mechanisms, creates gaps in SWM. A study from Khateeb et al. [35] has also shown that some of the developing countries without financial resources are lacking human and organizational capacities. As an example, most developing countries do not have monitoring mechanisms to check the waste that is generated to enhance planning at the various local, district, regional, and country-level holistically [36–38]. In recent times, modernized technological devices such as geographic information systems (GIS), radio-frequency identification (RFID), and international systems for mobile/general radio packet services have been developed to monitor the collection of bins and trucks [39]. However, this technology is virtually absent in all developing countries because of its high cost. This a very important aspect of the entire technology issue related to SWM to be considered in developing countries.

Although some of the developing countries have the infrastructures and the needed facilities for proper collection, transportation, and discarding of SW, the institutions needed to build human capacities, and public awareness in the management of SW are not encouraging aspects of SWM, able to be handled by most developing countries [40]. SWM can be sustained with the support of formal education and awareness. For Ardoin et al. [41], environmental education is more than the unidirectional transfer of information, enhancing environmental attitudes, awareness, knowledge, and skills for an affirmative environmental action. The sustainability of SW can be achieved through effective environmental education both at school and outside school. Most of the authors involved in SWM studies reported that segregation of waste, which serves as a conduit for the sustainability of SWM, is not well practised or not done in most of the developing countries [11,42–44]. In municipalities where sorting was partially practised, gender and age were the predictive factors of this behaviour, i.e., it was observed that females appeared to be more active in waste separation than males, according to Sarbassov et al. [45]. The study of the same authors further indicated that two-thirds of sorted waste in the developing countries is done by the elderly (50 years and above), and no separation or a small amount is done by the age range of 5–17 years, while almost one-third of the segregated waste is done by people within the ages of 18–39. A report by the statistical department of South Africa [46] also highlights that young adults aged 18–24 years displayed far lower percentages of sorting than those aged 65 years and older. In Bogota (Colombia), Padilla and Trujillo [47] realised that older heads

of families demonstrate good environmental behaviour when it comes to the sorting of waste from source. In sustaining and managing SW within developing countries, attitude changes toward waste management and enhanced knowledge in the segregation of waste from the source are essential to reduce landfill problems. The sustainability of SWM can be realised in lower/middle-income countries through rigorous formal environmental education at all school levels, to close the gap in waste awareness between the elderly and the youth. SWM leads to the first hypothesis in this study.

Hypothesis 1: *The lack of teachers' practical environmental knowledge influences waste management.*

2.2. Teachers' Knowledge of Solid Waste Management

Education is one of the essential tools to create awareness among people, particularly in developing countries. According to Singhirunnusorn et al. [48], waste separation slightly improves with age. The elderly practice more waste segregation than the young. Other studies conducted within developing countries also indicate that most older generations are willing to sort out their waste [49–51] because they may become more aware of environmental consequences and value the planet. Environmental education is, thus, essential to bridge the gap in knowledge of the young and old in waste management segregation and waste sustainability in developing countries. For UNESCO [52], people's awareness about the environment and its accompanying challenges can be increased through environmental education. It develops the specified skills and expertise necessary to deal with the environmental challenges and promote attitudes, motivations, and commitments to form decisions and take responsible actions. The United States Environmental Protection Agency (EPA) [53] considers that environmental education comprises more than only information about the environment. It rather enhances critical thinking, contributing to solving problems, and allowing effective decision-making skills. Moreover, it increases public awareness, knowledge of environmental issues, and enables individuals to provide facts or opinions on environmental matters, aiming to take responsible decisions.

Environmental knowledge is a term used to describe concepts and behaviour patterns related to the environment [54]. Olsen et al. [55] believe that teachers are the primary keys to develop skills of knowledge in students using education to sustain human life, sustainable environmental behaviour, and achieve sustainable development. The upsurge in environmental knowledge raises the awareness of environmental problems, which may likely allow individuals to take action to protect the environment [56]. However, to solve the problem concerning waste management or environmental issues, the teacher's SWM knowledge is essential with particular emphasis in developing countries. Therefore, and through formal education, teachers may provide students with a knowledge base and a clear understanding of emerging environmental problems [57,58]. However, misinformation of students might come from incorrect opinions passed along by their teachers [59] with important future consequences.

A study conducted by Martínez-Borreguero et al. [60] indicates that teachers in developing countries lack practical knowledge of waste and understanding of what they teach. This is because most of the country's tertiary institutions that educate the teachers do not have a regulated curriculum for waste management. Studies by Galarpe and Heyasa [61] and Ifegbesan [62] indicate that teachers in developing countries have negative waste management practices because they have limited waste management knowledge and awareness. The awareness and knowledge of waste management or environmental issues depend on the teachers' area of specialization or qualification, and the kind of institution attended, coupled with the personal teaching experience [16,62], which is meaningful in developing countries.

Teacher's knowledge and awareness are very important when designed to promote sustainable education or environmental sustainability goals. According to Fien [63] and Sibbel [64], environmental education encourages sustainable lifestyles and discourages students' unsustainable lifestyles by providing them all the obligatory tools for widespread

positive societal effects. A study conducted by Colombo and Alves [65] indicated that sustainability could be joined to education through training programs. The contribution of teachers, students, and communities can have a positive impact on the cost of waste operations, and the investment in technology can ensure long-term benefits on the environment and sustainable development and CP in developing countries [66].

Due to the absence of viable environmental knowledge, most of the developing countries have seen their environment destroyed. The nonexistence of practical knowledge of SWM or environmental knowledge by most teachers within developing countries negatively influences students' knowledge environment and attitude toward SWM.

These considerations lead to the second and third hypotheses.

Hypothesis 2: *The lack of teachers' knowledge influences students' SWM knowledge and awareness.*

Hypothesis 3: *Students' environmental attitudes influence SWM.*

2.3. Students' Knowledge and Awareness of Solid Waste Management

Being aware of natural cycles is a huge step toward developing nature connectedness. This will be the first stage to raise environmental awareness. According to Anija-Obi [67], environmental education is a field of study that seeks to promote among citizens, not only awareness and understanding of the environment, but the relationship of man with the environment and mandatory actions of responsibility to allow survival, while improving the life quality standard. Students' SWM knowledge and awareness is important for waste sustainability in most developing countries. Some researchers have shown that early childhood experiences affect children's cognitive and emotional benefits and influence the development of lasting environmental attitudes and behaviours [68–70]. A study by Evans et al. [68] indicates that children understand the ecological and human impacts on the environment from environmental problems awareness.

Research by Tikka et al. [71] indicates that education influences environmental awareness and attitude. Most students in the developing countries do not have the practical knowledge to enable the practice of correct waste management in their schools and, at home, to impact their family's knowledge due to the lack of teachers' knowledge. Environmental education in recent years has been taught in the curriculum levels of education in most of the developing countries, but the practical knowledge from teachers to students is minimal. As a result, this has created gaps that lead to lower standards in managing waste for sustainability in most developing countries. A case study by Panko and Sharma [72] indicated that submerging students into practicalities of environmental education, i.e., waste management, enhance a profound understanding of the broader principle of knowledge and attitudes to be acquired. Sustainable and effective waste management can be accomplished within developing countries when a conscious effort is put into developing the curriculum levels of education and teachers, giving the necessary training in practically imparting knowledge and creating awareness in students. For developing countries to achieve 12 of the 17 SDGs (Sustainable Development Goals) of the 2030 agenda, waste management, accomplished through environmental education, must be practically oriented [15,73]. For SW sustainability, developing countries' governments must enforce waste segregation at all levels of schools for better behavioural and attitudinal change and bridge the knowledge gap between the old and the youth in the management of waste.

2.4. Environmental Attitude—Students' Attitudes Towards Solid Waste Management

Environmental attitudes refer to people's favourable or unfavourable feelings regarding some characteristics of the physical environment. Fabio and Kenny [74] believe that people's attitudes toward the environment and the type of concern they develop toward it are associated with the degree to which they view themselves as being interconnected with nature. This will have consequences in the sustainability level to be achieved in the entire country.

Studies have shown that environmental attitudes of children are formed roughly at the age of twelve [70,75–77]. That is why children should be taught with a positive attitude toward SWM, through environmental education, which will teach children to respect the environment and its resources. For that matter, the environmental attitudes of young people must be critical as they ultimately play a direct role in providing knowledge-based solutions to emerging environmental problems [78,79]. Meanwhile, if school environmental programs are directed at students, and they are formulated appropriately, they can impact the environmental knowledge, attitudes, and behaviour on adults, i.e., parents, teachers, and local community members, through the process of intergenerational influence [80,81]. A study conducted on environmental knowledge and attitudes also shows that students can develop high levels of understanding and positive attitudes, thanks to their families, teachers, school curriculum, and through reading studies and information regarding the environment [79]. In that case, teachers' mental attitude in environmental education toward waste management is vital in teaching students in the context of developing countries.

A positive attitude toward environmental education can reduce the disparity in waste management between the youth and the aged in developing countries. Every school generates waste from routine activities such as classwork, sweeping, serving food, and bush cutting. It is expected that, as part of the learning process, waste management activities in schools will involve students by building the right attitudes toward waste management in developing countries.

3. Understanding Cleaner Production for Sustainable Transformation

The willingness to understand the environment through education is one of the important key steps in finding lasting solutions to environmental problems such as SW, pollution, degradation, deforestation, energy, and others, caused by mankind and compromising sustainable development and CP.

CP is an environmental preventive approach to waste reduction and energy efficiency aiming business profitability [82]. Hence, understanding waste minimization sustainability requires a new attitude, additional knowledge, and skills from students and academics. According to Abdul-wahab [83] and Katherine et al. [84], integration of CP into the environment curricula is an important strategy for the understanding of nature, technology, and economy, from the university to the lower level of education, so important in developing countries.

In developing countries, the level of awareness of CP programs among professionals, companies, and stakeholders is low [85,86]. This is because students, employees, and public authorities are not trained toward sustainable CP. Universities that bear the responsibility of training for transformational changes in CP techniques such as technology, waste use, operation practices, materials input, and packaging [87,88], are not resourced enough to create awareness, knowledge, technologies, and tools to achieve a future environment within the developing countries [89]. Therefore, if students in the developing countries are educated effectively on CP, the cost of managing waste disposal, raw materials, and energy will reduce, which will positively affect the environment and significantly influence the economic savings in most of these countries [90,91]. Therefore, CP should be introducing gradually at all levels of education for better awareness, considering that a late positive environmental attitudinal change is difficult to achieve.

4. Sustainable Waste Management Gap Bridging

Educating students on environmental sustainability remains necessary for a healthy and stronger environment. A study conducted by Agut et al. [92] reports that, to achieve sustainable living, early environmental education is necessary. This is because children build their own identities at a primary age [93]. Given that sustainability education in the primary parts of students' life, it is crucial to equip or build them with the kind of knowledge, attitudes, awareness, and skills to protect the socio-economic environments of both present and future generational leaders [94]. A study in the United States showed

a significant relationship between age and waste source separation. More than 62.5% of urban waste separation aiming sustainability is done by older people [95]. Research in other parts of the world also indicates that the older age groups tend to sort and manage household SW by themselves, whereas the younger residents allow waste management services to perform the separation [50,96]. To bridge the knowledge gap between the youth and older people in managing waste to achieve environmental sustainability, formal environmental education is necessary for early childhood education, which will lead to greener waste practices and to CP. This formal education must be practically oriented up to university levels with the teacher as the pivot for implementation of sustainability learning.

5. Barriers to SWM Sustainability in Schools

Implementation of SWM sustainability in schools within the developing countries encounters several major barriers. Some of these challenges include the lack of resources, absence of qualified administrators or trained teachers, logistics, and the nonexistence of students' commitment, interest, and sustainability awareness.

The lack of resources affects time and money. Schools and institutions within the developing countries lack the funds [97,98] to support significant and meaningful sustainable interventions. This is because the institutions and governments in most developing countries do not prioritize sustainability activities. Hence, schools are deprived of the required funds for effective practice.

Another barrier for SWM sustainability implementation in school is the absence of teachers and administrators to support sustainability. According to Herrera et al. [99] and McIntosh et al. [98], sustainability cannot fully be implemented in schools and institutions unless administrators and teachers work hard to promote it. Due to the lack of specialized teachers for effective teaching of sustainability in the developing countries, the practice of SWM sustainability leading to CP, will be delayed. The logistical barrier also affects the implementation of SWM sustainability in school. Most schools in developing countries do not have access to any tools and materials, such as data tracking systems, bin sorters, and other items necessary to improve an effective SWM.

Lastly, there is a lack of commitment from teachers and experts to engage and create a sense of awareness, knowledge, and attitude toward students' interest in sustainability [100], which is one of the main barriers in developing countries. Because the change in attitude is difficult, leaders in developing countries' institutions or schools must work toward sustainable development by introducing citizens to sensitizing environmental research and promoting sustainability activities.

6. Materials and Methods

6.1. Type of Study

A systematic review of the scientific literature was conducted, selecting relevant studies in the field. The systematic review was performed according to Khan et al. [101] guidelines. This review aims to give a contribution to the following research hypotheses.

Hypothesis 1: *The lack of teachers' practical environmental knowledge influences waste management.*

Hypothesis 2: *The lack of teachers' knowledge influences students' SWM knowledge and awareness.*

Hypothesis 3: *Students' environmental attitudes influence SWM.*

6.2. Search Strategy

A search was performed to find studies in multidisciplinary databases such as Scopus, Emerald Publishing (CFT1), Medline/PubMed, Springer, ERIC, and Google Scholar content aggregator. The syntax used to search for the articles was "solid waste management" AND "Teacher knowledge" AND "attitude" AND "environmental awareness" AND "formal education."

6.3. Selection of Studies

The combination of syntaxes such as SWM, environmental awareness, environmental education, environmental sustainability, and students' attitudes toward waste and other additional search terms resulted in a significant number of findings. To choose appropriate studies for this review, the study obeyed the following criteria. The inclusion criteria were: articles published between 2010 and 2019, containing empirical data, published in peer-reviewed scientific journals, focused on knowledge, awareness, attitude, and practice, involving students at all levels, and studies focused on developing countries. The countries were considered as developing because they either have less than 0.800 human development index (HDI) in the United Nations Human Development [102]. Although Malaysia has an HDI value of 0.804 [102], it is considered as a developing country due to low gross domestic product (GDP) per capita income (below 25,000 USD) and due to the low level of industrialization, when compared with countries classified as developed [103]. Philippe Ithurbide [104] also considers Malaysia as a non-developed country due to regular sharp depreciation of its currency, which led to an increase of debts for the country. To remove duplicates from the studies, a rigorous literature screening process was performed using Mendeley bibliographic software and also by manually further analysing the various articles identified by the software.

6.4. Data Collection and Analysis

The study variables were country, year, size of the sample, data collection methods and findings and variable factors that consisted of knowledge, attitudes, practices, awareness, gender, and age for which the extraction was completed on the Microsoft Excel 2019 spreadsheet.

7. Results

The preliminary search finding identified 17,821 articles. This search was then reduced to 128 when the main used keywords were combined together. After applying the inclusion criteria of the studies developed in developing countries and the removal of duplicates, 37 studies remained. Through a laborious literature screening procedure, 23 of the studies that focused on teachers' and students' knowledge, awareness, and attitude towards SWM in developing countries, were selected. The reviewed studies were conducted in Kenya, Ghana, Nigeria, India, South Africa, Philippines and Malaysia, China, Vietnam, Bangladesh, Ethiopia, Nepal, and Indonesia. These studies consisted of teachers ($n = 110$), students ($n = 9970$), and community members ($n = 512$) with a total of 10,592 individuals. Self-administered questionnaires were used in each studied article to collect data. Articles were analysed systematically, and detailed information on the articles are presented in Tables 1 and 2.

The summary of the analysed studies presented in Table 1 indicates that 22 studies were conducted in schools, except for the study of Shewasinad et al., and Twumasi [110,115], which surveyed their community. The variables presented in Table 1 can be grouped into three main dimensions. These are psychological variables, i.e., attitude, behaviour, situational variable, i.e., knowledge, awareness, age, gender, and participation variable, i.e., practice and communication.

The summary of the analysed studies presented in Table 2 also indicates the findings of the articles and the challenges.

Improper Medical Waste Management in Ghana: Environmental Sustainability and Public Health

Table 1. Summary of the analysed studies.

Study	Country	Variables That May Influence and Determine Sustainable Waste Management/Environment	Method to Collect Data/Sample Size
Madrigal & Oracion [105]	Philippines	Awareness, attitude	survey/563
Ahmad et al. [106]	Malaysia	Knowledge, attitude, practice, communication	survey/895
Paghasian [107]	Philippines	Awareness, practice	survey/253
Adeolu & Enesi [108]	Nigeria	Attitude, practice, knowledge, age	survey/400
Gustria & Fauzi [109]	Indonesia	Awareness of student	mix-method/65
Shewasinad et al. [110]	Ethiopia	Attitude, knowledge, practice	survey/392
Licy et al. [111]	India	Attitude, practice, knowledge	survey/300
He et al. [112]	China	Knowledge, attitude, behaviour	survey/223
Phan Hoang & Kato [113]	Vietnam	SW knowledge	survey/247
Karpudewan et al. [114]	Malaysia	Knowledge, awareness	survey/110
Twumasi [115]	Ghana	Awareness, practice	survey/120
Boiyo et al. [116]	Kenya	Attitude, behaviour	survey/164
Aduku [117]	Ghana	Attitude	survey/400
Niekerk [118]	South Africa	Awareness, knowledge, practice	survey/815
Sultana et al. [79]	Bangladesh	Knowledge, attitude	survey/300
Dung et al. [119]	Nigeria	Knowledge, attitude	survey/1800
Kalsum & Isa [120]	Malaysia	Awareness, behaviour	survey/186
Pavliukh [121]	Turkey	Awareness, sensitivity	survey/212
Abdullahi & Tuna [122]	Nigeria	knowledge	survey/470
Ifegbesan et al. [123]	Nigeria	Awareness, age, agenda	mix-method/840
Varoglu et al. [124]	Turkey	Awareness, attitude, behaviour, illiteracy	survey/335
Müderrişoğlu & Altanlar [125]	Turkey	Attitudes, behaviour	survey/507
Singh et al. [126]	Nepal	Awareness, knowledge, attitude, practice	survey/434
Liao & Li [127]	China	Knowledge, behaviour	survey/562

Table 2. Synthesis of the analysed study's objectives and main findings.

Study	Summary of Objective and Findings of Research Articles
Madrigal & Oracion [105]	Madrigal conducted a study in SW awareness, attitude, and practice with 563 students and employees of Catholic higher education in the Philippines and concluded that the respondents had high SWM awareness, attitude, and practice. There was a significant difference in awareness, attitude, and practice when it comes to status and religion, but significantly related in terms of age and education.
Ahmad et al. [106]	A study was conducted to determine the relationship between students' environmental knowledge, attitude, communication, and practice of the 895 higher level institution students. The study revealed that students were knowledgeable about the environment, but the knowledge did not lead to practice. For environmental sustainability, the study showed a weak relationship between students' knowledge, attitude, and practice. The study also suggested social media and families as another means of spreading environmental practice information. The school did not have materials for waste sorting practice.
Paghasian [107]	253 students were randomly selected to investigate the significant relationship between SWM awareness and practice. The study indicated that awareness was high, and there was a good practice concerning separation, reduction, and recycle. SWM awareness had no influence on the practices of disposal but affected the student practices on sorting, recycle, reduce, and reuse.
Adeolu & Enesi [108]	This study aimed at investigating the knowledge, attitude, and practices of 358 students in the secondary school in Ibadan, Nigeria, toward waste management. The results showed that students' knowledge, attitude, and practice of waste management were moderate. The study indicated a high number of improper disposal of waste at every space. The results showed that gender and age significantly influence knowledge, awareness, and practice of waste management.
Gustria & Fauzi [109]	A study was conducted to measure environmental literacy on knowledge, awareness, and concern with 66 selected senior high students in Indonesia. The study indicated that 80% of the students were considered as having inadequate environmental literacy. The lack of understanding was due to limited information and inappropriate lesson plans for the study.
Shewasinad et al. [110]	A total of 392 Kometa kebele community members were randomly selected to assess knowledge, practice, and attitude toward waste disposal management in South West Ethiopia. The results indicated that the majority of people have good knowledge, a positive attitude, and good practice toward waste management. Most of the respondents were married and also female.
Licy et al. [111]	A study was conducted to assess waste management practice information among school children in Kerala. Using a well-structured questionnaire, 300 students were randomly selected for the studies. The result showed that high school students are more aware of waste when compared to high secondary students. The results also indicated a significant difference between awareness and practice. The study revealed the need for massive awareness of waste practice from the beginning of school as well as the urgent need to rectify the knowledge and practice gap in waste management.

Table 2. *Cont.*

Study	Summary of Objective and Findings of Research Articles
He et al. [112]	The study was conducted to determine environmental awareness in two regions of contrasting levels of economic development and environmental problems in China. The data obtained from the university results showed that all the students sampled had low levels of environmental knowledge but a positive attitude and were also environmentally-friendly. A student growing up in developed and less-developed settings had significantly different levels of environmental awareness.
Phan Hoang & Kato [113]	In January 2014, a survey of 247 students was conducted in DA Nang city. Two elementary school students' knowledge of SWM were assessed. The results in February 2015 indicated that 96% of the student developed an absolute interest in SWM activities. The study also resulted in a change in student knowledge after environmental education for a year.
Karpudewan et al. [114]	A survey was conducted to investigate the level of awareness and understanding of traditional environmental concepts and sustainable development concepts among pre-service teachers. The result of the 110 pre-service teachers indicated that knowledge of sustainable development and awareness was low, when compared with the understanding of traditional environmental concepts. The study confirmed a sustainability knowledge gap in sustainable development knowledge.
Twumasi [115]	The objective of the study was to find information about waste management practice within a community in Ghana. In the survey, 120 people were randomly selected to respond to a well-designed questionnaire. The results indicated that most people were aware of SWM but never put it into practice. People's attitudes toward a social commitment to waste participation were weak. The researcher noticed that e-waste awareness was absent in the community and it was necessary to rectify the knowledge and practice gap.
Boiyo et al. [116]	A study was conducted with 320 students who were randomly selected to determine the relationship between attitudes and environmental participation in the urban area of Nairobi. The result showed that attitude and level of environmental participation did not influence each other. The study also revealed a positive connection between attitude and ecological behaviour.
Aduku [117]	This research was conducted to examine the attitude and knowledge of junior high school toward an environmental condition in public schools in the Ga West metropolis of Ghana. A total of 400 students was used for the research. According to the result, students have a poor attitude toward sanitation and different environmental behaviour within each school studied. The research found a gap in knowledge of sanitation by the student.
Niekerk [118]	This study examined 815 students' level of SWM awareness, knowledge, and practice. The study used descriptive statistics to analyse it. The results indicated that students were aware of concerns of waste management practice in their schools and the communities, but had poor waste management practice with negative impacts on the country. The study indicated that waste management practice activities were minimal in schools and the environment. The research indicated that students were the key agent of change toward a more sustainable future. Therefore, young people should be engaged to improve their knowledge of environmental issues.
Sultana et al. [79]	This study used 300 students from both public and private schools to assess the environmental knowledge and attitude in the Tangail district from January to April 2015. The study revealed that the level of environmental knowledge depends on the program offered in schools. Student attitude toward the environment is higher in public schools, when compared with private schools. With gender, environmental knowledge and attitude had a substantial difference. The students from an urban area have higher environmental knowledge while the rural student has a better environmental attitude. The study also showed that students' environmental awareness is influenced by parents' educational level. In conclusion, the students' level of understanding and positive attitude may be achieved from families, media, teachers, and reading.
Dung et al. [119]	This study was conducted to assess the knowledge and attitude of students' toward SWM. A sample size of 1,800 colleges of education students of the North Central zone of Nigeria was used. The finding indicated that students had low knowledge and a positive attitude toward SWM. A significant relationship was found between students' knowledge and attitude toward SWM. Gender has no major influence on knowledge and attitude toward SWM.
Kalsum & Isa [120]	A total of 186 university academic staffs were surveyed to determine the connections between knowledge, attitude, behaviour, and level of awareness to the principles of a sustainable campus. The result indicated that the staff have a high awareness level about principles of a sustainable campus, but a weak correlation between awareness and behaviour.
Pavliukh [121]	A study was conducted to determine environmental sensitivity and awareness of university students. A survey that was applied to 212 students indicated that environmental awareness and behaviour were lower even though courses on environmental issues were taken. The study concluded that environmental knowledge does not influence awareness and behaviour.
Abdullahi & Tuna [122]	In this study, 470 students were surveyed from secondary schools, universities, and colleges in Nigeria, to investigate students' knowledge and perceptions. The results revealed that the knowledge of environmental issues was not satisfactory, but perception toward the environment was good.

Table 2. *Cont.*

Study	Summary of Objective and Findings of Research Articles
Ifegbesan et al. [123]	A study was conducted to determine the practice of SWM in public secondary school. The results showed an overall positive level of awareness, attitude, and practices of teachers toward SWM, but the practice was better in some schools, when compared to others.
Varoglu et al. [124]	Environmental literacy, attitudes, awareness, and behaviour studies were conducted among 335 middle school students in Eskişehir to determine the effects of purchasing good environmental products. The study showed that environmental illiteracy has no major effect on the attitude and purchase of environmental products, while awareness has a positive effect on a pro-environmental attitude toward environmentally-friendly purchased products. The results also showed that students develop positive attitudes toward the environment through awareness. In addition, a positive environmental attitude leads to pro-environmental behaviour and adaptation of environmentally-friendly products.
Müderrisoğlu & Altanlar [125]	A study was conducted with 507 undergraduate students from the Abant Yzzet Baysal University toward attitudinal and environmental behaviour issues. The findings reported that university students were aware of the importance of waste management. The findings further indicated that the department area and gender have affected students' environmental attitudes and behaviour.
Singh et al. [126]	Studies were conducted to assess the awareness, knowledge, attitude, and practice regarding medical waste management. A total of 434 undergraduate dental students in five different institutions was used in Nepal. According to the results, the students had a positive attitude. Knowledge of biomedical waste was high and more than 50% of the students are unaware of government guidelines on biomedical waste. In terms of medical waste disposal, there is a lack of strict protocols since not all students are aware of disposal techniques.
Liao & Li [127]	In this investigation, 562 students were used to explore the understanding of Chinese high students' motivation toward the separation of SW on campus. The Theory of Planned Behaviour including environmental education and knowledge was used for the explanation of waste separation. The results indicated that environmental education is essential for students to acquire knowledge and a positive attitude toward the separation of SW on campus. Knowledge was the best predictor in student's separation behaviour.

7.1. The Variables Behind Solid Waste Management

The analysis of the variable from Table 1 and the summary results of Table 2 will take into account the three previously designed theoretical hypotheses, H1 to H3.

7.1.1. Attitude Variable

Attitude is a set of values and feelings acquired to motivate and contribute to environmental development and protection [128]. According to Ahmad et al. [106] (p.285), "knowledge forms attitude, and both knowledge and attitude are the building blocks for practice." The same study describes that attitude is measured through students' awareness and beliefs. The way to measure attitudes is by focusing on a person's assessment of whether the participation in the data was positive or negative.

Attitude is a critical element that influences SWM participation in schools and communities within developing countries. This is because positive attitudes toward SWM might increase the likelihood of involvement in waste management. The review showed that students had a high attitude toward waste management [105,109,112,116,119,125,126,128], which confirmed the third hypothesis. However, other studies found the opposite [115,117], which results in indiscriminate disposal of waste that undermines the environmental health status of schools and residents. In the study to determine environmental attitude and ecological behaviour, it was found that there was no significant correlation between attitude and the level of participation in environmental activities [106,116].

SWM in schools and communities seems to be low, despite high or positive attitudes in developing countries, due to some of the following barriers. The lack of teachers with practical and specialized knowledge to teach and train students with the right approach to manage waste, and the lack of funds to buy adequate technological facilities to manage waste is considered to be the biggest barriers to SWM awareness. Attitude can influence the participants of SWM studies in schools, universities, and communities within developing countries.

7.1.2. Knowledge Variable

Environmental knowledge is considered as one's capacity to recognize symbols, concepts, and behavioural patterns related to environmental protection [54,129]. An increase in knowledge will enhance the concerns of people's awareness and attitudes toward the environment [130,131]. Karpudewan et al. [114] stated that knowledge determines the attitudes and behaviour of an individual and should "... convince people to carry their intention to change, by giving a lot of attention to attitudes, subjective norms and perceived behaviour control." (p.118). However, a change in perspective does not necessarily result in a behavioural change [132,133]. The lack of environmental knowledge may hamper the adoption of pro-environmental behaviour [134] or lead to wrong environmental decisions [135].

Knowledge is considered extrinsic in this context in which one can gain or acquire through an external source, such as in schools and universities. Most of the analysed studies [108,112–114,119,122] found low knowledge of SWM, while others [79,106,110,126] indicated a high knowledge level of SWM or environmental education. However, and as seen by the analysed results, knowledge does not necessarily lead to practice. Ahmad et al. [106] found that students with vast SWM knowledge had fragile practice, which supports the first hypothesis that the lack of teachers' practical environmental knowledge influences waste management. Hence, there is a gap between knowledge and practice of waste management among students [126] in developing countries.

7.1.3. Solid Waste Management Awareness Variable

Awareness, which can be defined as the perception or knowledge of an event, is accepted as the initial step, performing a requisite function in probable behavioural change and successful education, particularly when related to environmental issues [115,136].

It has been shown that the students' awareness of environmental problems and solutions can be increased through education [137]. For example, several studies [107,111,120,128] have shown a high SWM awareness. However, it is expected that SWM activities on the schools' campus should involve students as a part of their learning process, considering there is a significant difference between awareness and practice [111]. The cited studies confirm the second hypothesis, which states that the lack of teachers' knowledge influences students' SWM knowledge and awareness. The appropriate skills and awareness obtained through the correctly guided environmental study would assist in changing human behaviour toward the environment [106], which is very important in developing countries. For Pavliukh [121], environmental knowledge does not always influence awareness and behaviour. That is why students must be early motivated to participate in environmental protection activities and plans [138].

7.1.4. Solid Waste Management Students' Age Variable

Age is considered to be one of the essential variables concerning environmental education. According to Adeolu and Enesi [108] and Madrigal and Oracion [105], awareness, attitude, and practice were significantly related to age in SWM. This means that older age managed waste well. Students with a higher level of education managed the waste better than the lower level. Hence, the SWM knowledge of a university student cannot be compared with secondary and primary school students.

8. Discussion

This review allows us to conclude that there is generally an SWM positive attitude and high awareness. This should mean that an SWM positive attitude and perception must influence the practice or participation of the SWM in schools [139,140], which may lead to environmental or SW sustainability. A study conducted by Arı and Yılmaz [141] to examine the effects of ecological literacy, environmental awareness, and environmental attitudes among middle school students found differences. The study indicated that environmental literacy did not have a statistically significant impact on environmental attitudes. In most of

the developing countries, SWM practice has no corresponding effect with high awareness and no correlation or influence on attitudes toward waste participation or practice for sustainability, and these findings are extremely alarming. Studies conducted by Babaei et al. [50] and Yildiz et al. [142] indicate that awareness and attitude toward SWM problems or environmental issues do not change spontaneously. The change in a positive attitude toward SWM or environmental issues can occur through practical education, change of perception, social responsibility, and incentives or motivation through students'/teachers' rewards. According to Zsóka et al. [143], there is a correlation between environmental knowledge and awareness of environmental issues. This implies that knowledge and attitude may regulate the course of one's environmental action. Hence, students' environmental knowledge and environmental attitudes may lead to environmental participation for CP and environmental sustainability. However, it was also found that having a good level of attitude toward SWM could not be reflected in practices, as the study of Ahmad stated [106]. This evidence is not new and previous studies have also demonstrated, such as the study of Tatlonghari and Jamias [144].

Second, these review findings highlight an opposite position: profound knowledge of SWM or low environmental knowledge by students about waste management or environmental issues. Low education can lead to a possible change in attitudes toward environmental anxiety and awareness of sustainability. People with more education tend not only to be more concerned about the environment but also to be engaged in actions that promote and support political decisions designed to protect the environment. This is vital to start a movement to push governments toward the type of binding agreement needed to reduce greenhouse gases and control emission levels, dramatically affecting the global environment and climate change. However, behavioural change does not necessarily affect attitudinal change [145]. Hence, a lack of environmental knowledge or poor SWM knowledge may discourage the adaptation of a pro-environmental behavioural change [146]. The correlation between environmental knowledge and environmental attitude is significantly positive [147]. The deficiency of students' environmental awareness from various educational institutions in developing countries is due to a lack of practically oriented sustainable environmental knowledge by teachers to impact technical expertise to the student, encouraging the attitudinal change toward sustainability. This implies that environmental knowledge is the key to a clean environment and global environmental sustainability. Hence, students' environmental knowledge in developing countries can be enhanced when teachers are equipped with the necessary information, aiming to achieve a better sustainable environmental education.

Moreover, this review article revealed a significant difference in SWM's awareness, attitude, and practices, when linked to education and age. It was found that the understanding of SWM or environmental issues, awareness of the environmental problems, and attitudes toward environmental sustainability issues were associated with the students' educational level, age, and the geographical location of the studies. Younger participants, due to less experience in the field and less education, may be less open to receiving information about SWM, when compared to older age. However, the same result was achieved about environmental attitude. This suggests that higher environmental awareness, environmental attitude, and practices committed toward environmental issues related to environmental sustainability are important to achieve overall sustainability [105,108,148,149].

This review also revealed that the lower level of students' environmental knowledge or SWM knowledge is a result of a lack of the teacher's knowledge in SWM or environmental education. According to Jafer [57], teachers must provide students with knowledge based on a clear understanding of environmental problems for sustainable development. This implies that a lack of environmental knowledge among teachers strongly affects the implementation of environmental education at all school levels. The few students with a good understanding of SWM had a weak relationship between knowledge and sustainable environmental practice [106].

This study sought to establish that teachers' environmental knowledge influences how waste is practised and managed in schools, which is in agreement with the second hypothesis. Most teachers in developing countries lack practical environmental knowledge to impact positive environmental education in students, which will contribute to enhance environmental sustainability. It must be highlighted that the developing countries do not have the facilities and technologies for practical studies of sustainable waste management.

Analysing the results found in this study, it can also be concluded that teachers play essential roles in environmental education and sustainability, and these roles help to transform schools and society as a whole [148], specifically in the context of developing countries. The absence of adequate environmental education in most developing countries is caused by a lack of effectiveness and need serving curricula to respond to current environmental issues for sustainable development. According to Musthofiyah and Lailiyah [149], environmental problems can be solved by developing curricula activities within schools that could bring a positive impact on the environment. However, the lack of teachers' environmental knowledge influences the students' understanding of environmental sustainability. Salas-Zapata et al. [150] considered sustainability as the integration of environmental principles in human activities. Teachers' education has a significant role in the processes of sustainability, according to Nousheen et al. [151]. The author of the same study found that most students showed positive attitudes and awareness of environmental issues, active participation, or the practice of environmental education, which leads to environmental sustainability programs, such as conservation and protection of the environment as well as recycling, which are not always available in developing countries.

This review findings have also clarified some open problems and challenges of SWM or environmental issues that may affect and prevent implementation of SWM sustainability or environmental sustainability in schools within developing countries. Some of the barriers are the lack/inexistence of finance to promote sustainability, absence of trained teachers in sustainability issues, and the nonexistence of knowledge, awareness, practice, and interest of sustainability to achieve overall sustainable development. This suggests that SWM sustainability or environmental sustainability barriers can be overcome in schools when governments and other agencies are able to financially support sustainability projects in schools, train teachers to improve on sustainability knowledge, aiming to enhance the cleaner production effectiveness. Schools in developing countries are formulating curricula to promote sustainability through practice, awareness, and involvement, leading to sustainable development and cleaner and greener production.

To be able to achieve future sustainability in developing countries, teachers' education in sustainable development is the most important factor for upcoming generational leaders. Hence, teachers' knowledge, awareness, and attitude toward sustainable development should be enhanced through sustainable training such as workshops, research, conferences, and other capacity building information that can be practically transferred to students for now and for future sustainability. Financial constraints on financing activities and policies related to environmental sustainability for sustainable development and CP at all levels of the school must be a focus within developing countries. Stakeholders, governments, and other agencies must invest in schools' sustainable development for students for now and for future sustainable practice and participate in sustainable development activities for cleaner and greener production. This review is also able to positively contribute to improve managerial implications within sustainable development in developing countries by providing a synthesis of the current evidence in this topic, which can then be used at a local government and municipal level. Several studies have demonstrated that SWM managers make better decisions when inserted into an integrated framework [152,153].

9. Conclusions

Waste management related to overall environmental issues is a significant problem in most developing countries. This review article found that waste sustainability or environmental sustainability could be achieved in developing countries when environmental attitude, environmental awareness, and environmental knowledge are connected or communicated from teachers to students through formal education. Other conclusions able to be drawn from this article indicate that a high level of awareness and positive attitudes of students toward the environment did not influence the participation of environmental issues, which is contrary to the third hypothesis that states that positive student attitude affect SWM. Environmental knowledge and attitude levels were shown to be inconsistent with the students' practice level, which was lower. However, this third hypothesis can be supported and changes accomplished through practical education, motivation, or incentives, and social responsibility of teachers to students for environmental sustainability. The absence of students' environmental knowledge may impact behaviour and environmental, attitudinal change, which will affect overall sustainability in developing countries. The correlation between environmental education and environmental knowledge of students is essential in developing countries, aiming to achieve CP and environmental sustainability. Formal education will help create awareness for efficient and effective sustainable development, which is essential in developing countries.

The research further indicates that there is a significant difference between awareness, attitude, and practice when it comes to education and age. Age and education are directly proportional to environmental attitude, knowledge, and practice when it comes to environmental sustainability issues. According to the review's results, the lack of teachers' environmental knowledge influences the knowledge of environmental issues, which positively supports the previous first and second hypotheses, i.e., that lack of teachers' practical environmental knowledge influences waste management sustainability, automatically impacting students' SWM knowledge and awareness or environmental issues. Within this study, the reviewed articles show that students with either high or low knowledge in SWM or environmental issues have a fragile practice in terms of sustainability. However, teachers' core obligations are to teach and provide students with environmental knowledge based on clear understanding of sustainability issues. Hence, the lack of teachers' environmental knowledge will negatively impact the students' level of environmental issues toward achieving sustainability aiming CP. Teachers' knowledge is essential for sustainable development of students and it is the key to a sustainable future in the context of developing countries. Lastly, it can be concluded from the results that the absence of environmental education in most of the studied developing countries is due to the deficiency of up-to-date environmental curricula to respond to current environmental issues.

From this review, a link can be established with the main social and environmental challenges that world societies, and the developing countries in particular, are facing. It would be a big step if the priority of these nations was to fight the existing environmental problems, triggered in part by climate change and also by demographic pressure. Although these populations are struggling to have their basic needs fulfilled, such as food, education, health, and habitation, environmental issues represent an enormous source of concern due to the consequences it has to these specific countries. Being aware that humans are part of a larger interdependent ecosystem, these disadvantaged conditions make these populations more vulnerable to environmental problems, such as those related to the reported ineffective SWM practices. The poor state of SWM and other known and acknowledged environmental and public health issues in the context of developing countries can be addressed by bridging the environmental knowledge gap through practically oriented environmental education in schools. Practical environmental knowledge through activity-based curricula at various tertiary institutions that train teachers, carrying out regular workshops and conferences with teachers, will positively contribute to develop teachers' curricula and shape the knowledge and attitudes of students toward global environmental sustainability in these countries.

Limitations are present in this systematic review. One of the limitations of this study is the possibility of environmental bias in the selected studies. Another limitation of this research work is based on the review of earlier studies conducted by different authors at a different time frame and locations as well as motivational factors. Hence, a generalization of results may be inaccurate.

Further studies aim to overcome some limitations, focusing on the student-teacher knowledge, attitude, and practice of environmental sustainability with unified standardized tools that make progress toward CP in developing countries, with important consequences in SWM.

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CHAPTER II - Assessment of biomedical waste handling in Ghana

This chapter assesses the knowledge of handling BMW in selected HF in Ghana in response to one of the thesis objectives which is to evaluate the knowledge and practices of handling BMW by health professionals and BMW handlers and investigate the process and nature of BMW in Ghana's HF by assessing BMW generation, collection, and transportation.

A structured self-administered questionnaire was set up to collect data from health professionals and waste collectors to determine the understanding of BMW and its impact on the environment and human health. This study allows to realise a knowledge gap in handling liquid BMW and human tissues. Only 13% of the participants indicated adequate procedural knowledge in handling the BMW with 17.8% demonstrating the ability in handling expired blood units.

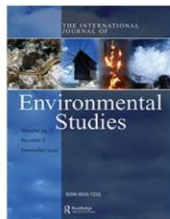
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Assessment of biomedical waste handling in Ghana

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ABSTRACT

This article reports a study in Greater Accra and Eastern Region, to assess knowledge and practices related to biomedical waste (BMW) handling and disposal in six health care facilities (HF) in Ghana. The results showed a significant knowledge gap in handling expired blood units, human tissue, and liquid BMW. Of the respondents, 87.0% revealed inadequate procedural knowledge in disposing of liquid BMW, with only 19.6% inspecting it; and 82.2% of the respondents demonstrated insufficient knowledge of handling expired blood units. Intensive training in handling of BMW is required to produce adequate understanding of procedural guidelines.

KEYWORDS

Biomedical; waste; knowledge; practices; management; Ghana

Introduction

Poor quality handling of biomedical waste (BMW) is an environmental and health problem in many sub-Saharan African (SSA) countries, including Ghana. BMW generation and the health services sector are interconnected. Human activities performed during and after healthcare delivery services have a severe impact on the environment and health [1–3].

The BMW generated from healthcare facilities (HF) is in solid and liquid states [1,4–6]. The BMW materials obtained from HF include, *inter alia*, syringes, razors, needles, radioactive materials, chemicals reagents, dressings, disposable plastics, and surgical devices [7,8]. BMW is produced during patients' diagnosis, treatment, immunisation, and in research activities [9]. The World Health Organization (WHO) [8] has categorised BMW as the second most hazardous waste to handle, especially in developing countries [10]. Studies by Aung et al. [11], Mol et al. [12], and Olaniyi et al. [13] provide evidence that poorly handled BMW culminating in the ever-increasing volumes of waste generation coupled with weaker waste handling practices, have exposed health professionals and individuals within HF to serious health risks. Examples of a few of the infectious BMW diseases include: hepatitis B virus (HBV), hepatitis C virus (HCV) [14], human immunodeficiency virus/acquired immunodeficiency syndromes (HIV/AIDS) [15], and over other 30 highly infectious transmitted blood-borne pathogens [16,17]. The WHO [18] estimated that 16 billion injections are administered globally yearly. This is currently required to

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increase because of coronavirus disease of 2019 (COVID-19) vaccinations. A study conducted by Pepin et al. [19] estimated that blood-borne microorganism transmission by use of unsafe injections was about 1.6 million HBV, 315,000 HCV, and 33,800 HIV. Numbers are expected to increase rapidly if not managed adequately, with most affected individuals living in developing countries [20]. This situation is likely to be aggravated by the continuing unprecedented surge of the COVID-19 pandemic, which has contributed to 12 billion doses of injections for vaccination up to July 2022 [21]. These injections have the potential to increase the transmission of pathogenic diseases through the risk of infection caused by syringes when mishandled [22].

In the face of existing and new health challenges such as HBV, HCV, HIV, and COVID-19, developing countries, Ghana included, need to work hard in handling BMW to achieve SDG12, target 12.5, which aims to reduce waste generation consequences through recycling, prevention, reduction, and reuse by 2030. This would benefit both the environment and human health. Achieving SDG12 target 12.5 requires adequate knowledge of BMW, resources, i.e. infrastructure and technology for proper management by health personnel who generate and handle the BMW, and training to incorporate efficient waste management practices in SSA HF everyday health engagement activities [23,24].

In most SSA countries, the BMW types of equipment and infrastructural facilities to handle this specific type of waste do not match the much-needed expansion of modern BMW materials and policy regulations [25–28] to handle BMW effectively. Other factors include increasing population [29], HF accessibility [30], and the outbreak of COVID-19 pandemic disease [27], which, coupled with improper segregation of BMW, have all contributed to the increasing quantities of BMW [31,32].

Poorly handled BMW has resulted in more than 15% of BMW-based infections in developing countries, as estimated by WHO [8]. The groups of people most impacted by this infectious waste are BMW generators (nurses, physicians, pharmacists) BMW handlers (waste collectors and sweepers), patients and the general public [33–35]. In addition, evidence shows that infectious BMW is a source of growth of various microorganisms that increase the magnitude of microbial transmissions [36–38].

For example, in the hospitals of Addis Ababa, Ethiopia, more than 41% of generated BMW was infectious [39]. Similarly, a study on six HF in Eastern and Greater Accra HF in Ghana indicated approximately 49.1% of infectious waste generation [38]. Likewise, in Kumasi, Ashanti Region, Ghana, Oduro-Kwarteng et al. [40] reported that infectious BMW generation from the Kumasi hospitals is about 49.6%. This highly infectious BMW results from a lack of knowledge that hinders efficient waste handling practices [41].

Studies conducted in SSA countries exhibit inadequate knowledge of the preventive measures that should be implemented in BMW management [42–44]. The lack of awareness and non-compliance of BMW management [41,45,46] have threatened almost 50% of the developing countries' population with public health risks [47]. Existing research shows that a high level of knowledge, attitudes, and practices about BMW has resulted in the proper handling of BMW [48–50]. It is therefore pertinent to improve the training for self-protection above all of health workers in generating BMW and sweepers handling BMW in HF for disposal.

Not much attention is paid to BMW management in Ghana, and there is a lack of research on the level of knowledge of BMW generators and handlers. This creates an

alarming deficit in the capacity of people associated with BMW [51]. The knowledge produced through research is valuable for any organisation aiming to adopt sustainable BMW management practices [52,53]. Accordingly, the main objective of this paper is to assess and present knowledge of handling BMW by the BMW generators and handlers in the selected six HF in Ghana.

Materials and methods

Study design

A descriptive cross-sectional study was conducted from January to June 2021, using a purposive sampling technique to identify the participants in the studied HF. This is located in the Greater Accra and Eastern Region of Ghana and within 4 out of 258 metropolitan, municipal, and district assemblies (MMDAs) in Ghana, as shown in Figure 1.

The study was conducted in the Greater Accra Region and Eastern Region of Ghana because of the high surge of HIV in expecting mothers in these MMDAs [54–56]. Given this problem, it was crucial to assess the knowledge of generators and handlers responsible for adequately handling BMW.

Study sampling

A purposive sampling method [57–60] was used to select participants for this study since the objective was only to assess the knowledge and practice of BMW generators and handlers. These included health professionals such as pharmacists, nurses, and physicians and non-health workers such as waste handlers.

The sample size for the study at various HF could not be clearly defined because the BMW handlers were not regular staff. Instead, they were recruited by a third-party company, and supervised by the senior environmental health officer and public health nursing officer in the HF. In view of this, the least sample size for the studied HF was considered as 384 using Watson [61] and Cochran [62] expression as the targeted sample size.

$$n = Z^2pq/e^2$$

where,

n = expected sample size for the survey

Z = 1.96 for a confidence level (α) of 95%

p = the estimated proportion of the population (reported effect caused by BMW is assumed to be 50%, with q being $p-1$)

e = the desired precision (margin of error of 5%, equivalent to 0.0025)

With $n = 384.16$

Data collection

A structured self-administered questionnaire was developed for data collection from participants as recommended by Deress et al. [43], Olaifa et al. [63], Bakobie et al. [64], and Mochungong [65]. The survey questionnaire was classified into two major sections:

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Figure 1. Ghana region of research and the metropolitan, municipal, and district assemblies of the studied healthcare facilities.

sociodemographic characteristics of the participants and specific questions, relevant to assess the level of knowledge about BMW handling.

The questionnaire was pre-tested through a pilot study by 21 BMW generators consisting of 3 physicians, 2 pharmacists, 14 nurses, 2 laboratory assistants, and 6 BMW handlers in the HF. The piloted responses were assessed for clarity of questions, and any identified ambiguity was removed.

Four hundred and fifty (450) questionnaires were distributed to the administrators of the six HF. In addition, each Head of Department in the HF was given questionnaires and was responsible for distributing to the staff that either generated BMW or handlers of BMW who were willing to participate in the study.

The second part of the survey questionnaire, seeking information about the level of knowledge of BMW handling for environmental sustainability, was scored 1 to 3 with the response options from the participant as 'Yes', 'No', and 'I do not know', respectively. During the pre-test, the authors of this study realised that the BMW generators, such as physicians, pharmacists, and some nurses, were pressed for time because of regular patient overload. Hence, closed-ended questions requiring less time for response were used for easy participation. In Ghana, the doctor-to-patient ratio of 1:7374 and the nurse-to-patient ratio of 1:505 is relatively high [66]. Therefore, some of the closed-ended questions were followed with open-ended questions to seek a deeper understanding of BMW. The responses were coded. According to Fraser et al. [67] and Glazier et al. [68], coding responses reduce information into a form, which in turn, aids in organising and interpreting data.

Data analysis

The data collected from the structured questionnaires were analysed using IBM Statistical Package for the Social Sciences (SPSS) version 27. Descriptive statistics such as frequency, percentage, mean, and standard deviation (*SD*) were calculated. Since the study aimed to determine the level of knowledge of BMW from BMW generators and BMW handlers, the participants' total knowledge score was calculated from the close-ended questions. Therefore, the overall knowledge mean score was calculated by dividing the total sum of the knowledge score by the total number of participants (393). Knowledge scores above or equal to the mean score were considered adequate knowledge, while those below mean score showed inadequate knowledge, as recommended by Deress et al. [43].

Ethical considerations

This research was approved by the Ghana Health Service Ethics Review Committee (GHSERC), reference GHS-SEC.002/11/20. Permission was also sought from and granted by the Eastern Regional Health Directorates (ERDH) to assess the knowledge of BMW among the BMW generators and handlers in the selected HF in Ghana, reference number ERDH 133612021. Written informed consent was granted by each study participant prior to completing the questionnaire. In ascertaining maximum voluntary participation, utmost confidentiality of individual information, with names excluded in the questionnaires, was assured.

Results

Socio-demographic profile

Three hundred and ninety-three (393) BMW generators and handlers from six selected HF participated in the study. Most of the respondents were female (69.2%), with a gender

ratio (female to male) of 69.2%:28.2%. Concerning age, the mean age of the study participants was 39.20 ± 9.62 years. 222 (56.5%) participants were in the age range of 36–45 years, and 8 (2.0%) of the participants fell within the age range of 26–35 years. At the education level, 257 (65.4%) had completed their first degree, with 37 (9.4%) having diplomas. 27 (6.9%) hold master's, 21 (5.3%) are physicians and 4 (1.0%) have doctorates. The majority of the respondents 231 (58.8%) were single, with 157 (39.9%) married, 0.8% divorced and 2 (0.5%) windows(er). In response to the professional category, more than half of the participants, 275 (69.9%) were nurses, 46 (11.7%) medical laboratory officers, 20 (5.1%) physicians were considered BMW generators, and 27 (6.9%) BMW handlers. The majority of the participating professionals, 225 (57.5%), worked at the district HF (Table 1).

Level of knowledge in handling BMW by respondents

Table 2 illustrates the respondents' responses regarding the knowledge and practices of handling BMW. A mean score of 6.06 was obtained for the 13 close-ended, knowledge-related BMW questions. Based on the mean scores, 60.6% of the BMW generators and

Table 1. Demographic profile of BMW generators and handlers ($n = 393$).

Variable		<i>n</i>	%
Gender	Female	272	69.2
	Male	111	28.2
	Prefer not to say	10	2.6
Age (years)	less than 25	79	20.1
	26 - 35	8	2.0
	36 - 45	222	56.5
	46 - 55	54	13.7
	above 55	30	7.6
Education level	Basic to high school	47	12.0
	Diploma	37	9.4
	Graduate	257	65.4
	Masters	27	6.9
	Physicians	21	5.3
Marital status	PhD (Doctorate)	4	1.0
	Single	231	58.8
	Married	157	39.9
	Separated/divorced	3	0.8
Workplace	Widower	2	0.5
	District	226	57.5
	Polyclinic	3	0.8
	Specialist	3	0.8
	General hospital	73	18.6
Profession	Regional hospital	88	22.4
	Nurse	275	69.9
	Waste handlers	27	6.9
	Medical laboratory	46	11.7
	Dental Surgery Assistant	6	1.5
	Phlebotomist	3	0.8
	Physician Assistant	8	2.1
	House Officer	6	1.5
	Physicians	20	5.1
	Anaesthesia	2	0.5

n: sample size, %: percentage.

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Table 2. Level of knowledge of BMW generators and handlers ($n = 393$).

Question	<i>n</i>	%
Can you identify medical waste?		
No	53	9.7
Yes	318	80.9
I don't know	22	5.6
Is there a standard operating procedure for disposing of liquid waste?		
No	121	30.8
Yes	165	42.0
I don't know	107	27.2
Is there inspection on how liquid wastes are deposited?		
No	115	29.3
Yes	143	36.4
I don't know	135	34.4
Do you know the colour coding for medical waste?		
No	48	12.2
Yes	326	83.0
I don't know	19	4.8
Do you follow colour coding for medical waste?		
No	66	16.8
Yes	300	76.3
I don't know	17	6.9
Does your facility follow the Ghana health service colour coding waste disposal practice?		
No	64	16.3
Yes	262	66.7
I don't know	67	17.0
Do you sort (segregate or separate) medical waste during collection?		
No	86	21.9
Yes	269	68.4
I don't know	38	9.7
Do you know the disposal procedure for expired blood units and by-products at waste?		
No	229	58.3
Yes	70	17.8
I don't know	94	23.9
Do you know the disposal method for human tissues?		
No	198	50.4
Yes	142	36.1
I don't know	53	13.5
Does the medical centre have a person(s) designated for liquid waste disposal?		
No	128	32.6
Yes	137	34.9
I don't know	115	29.3
Is liquid waste treated prior to disposal?		
No	135	34.4
Yes	121	30.8
I don't know	125	31.8
Is there a procedure for liquid waste disposal in your outfit?		
No	162	45.0
Yes	51	13.0
I don't know	165	42.0
Is there an inspection of how liquid wastes are disposed of?		
No	154	39.2
Yes	77	19.6
I don't know	162	41.2
Total	393	100

n: sample size, %: percentage.

handlers from the studied HF had adequate knowledge about BMW. Although in general the workers' responses show sufficient knowledge of BMW, responses to specific questions indicate inadequate knowledge of BMW.

The respondents' knowledge about liquid BMW and tissue waste handling were limited. Only 13.0% of the participants had procedural knowledge of disposal of liquid BMW, with 77 (19.6%) participants indicating that liquid BMW was properly inspected before discarding. Furthermore, 30.8% of the respondents showed awareness that liquid BMW is correctly handled before disposal. On the other hand, a minority of respondents, 17.8% and 36.1%, understood and practised correct removal methods of expired blood units and human tissue, respectively (Table 2).

In seeking a further detailed understanding of the respondents on BMW, a few open-ended questions were included and presented in Table 3. Only 23.1% of the study participants responded to the open-ended questionnaires, probably because health personnel were overloaded at the HF. The responses in Table 3 show that 121 (62.1%) out of 195 respondents identified BMW through the container colour coding, with 14 (7.2%) using the source of generated waste to recognise the kind of BMW. Furthermore, only 76 participants responded to the question on the operating procedure for handling the liquid BMW. Of these respondents, only 47 (61.9%) of the participants chlorinated liquid BMW, with 21 (27.6%) of the participants' reporting untreated liquid BMW in the HF before discarding it into pits, sewages, and containers.

Knowledge level between BMW generators and handlers

Table 4 shows the level of knowledge of BMW by both generators and handlers. Although the level of knowledge for the liquid BMW by BMW generators was comparatively better than BMW handlers, the BMW generators did not have adequate knowledge in handling the liquid BMW. However, both BMW handlers and generators showed adequate knowledge of BMW identification and colour coding. The result revealed that 26 (96.3%) BMW handlers knew BMW's colour coding, when compared to the 300 BMW generators (82.0%). The BMW generators and handlers within the studied HF could, however, identify BMW.

Discussion

Developing countries need to intensify adequate segregation and education in handling BMW. This will minimise BMW, especially in the face of emergent viruses, to reduce the health risks associated with the BMW generation. BMW handling is a recognised global, environmental and health challenge [69,70], with Ghana being no exception [71,72]. BMW generators and handlers in HF are closely associated with the problems of environmental protection because of the nature of their work. Therefore, the present study aimed to assess BMW generators and handlers' knowledge of handling BMW and associated practices at various HF.

The study resulted in a response score of 60.6% for adequate BMW knowledge, which is better than the 56.8% and 45.5% scores obtained in Ethiopia [43,73], respectively, 57.3% in Cyprus [74], and 13% score in India [75]. But, better knowledge score results, 71.5% and 96%, were obtained from BMW studies conducted by Wafula et al. [10] in Uganda, and Ajmal & Ajmal [76] in India, respectively. The knowledge score in handling BMW can be attributed to differences in the level of professionalism, type of educational training, and the kind of logistic infrastructures in various countries [77].

Table 3. Level of knowledge demonstrated by the respondents in BMW.

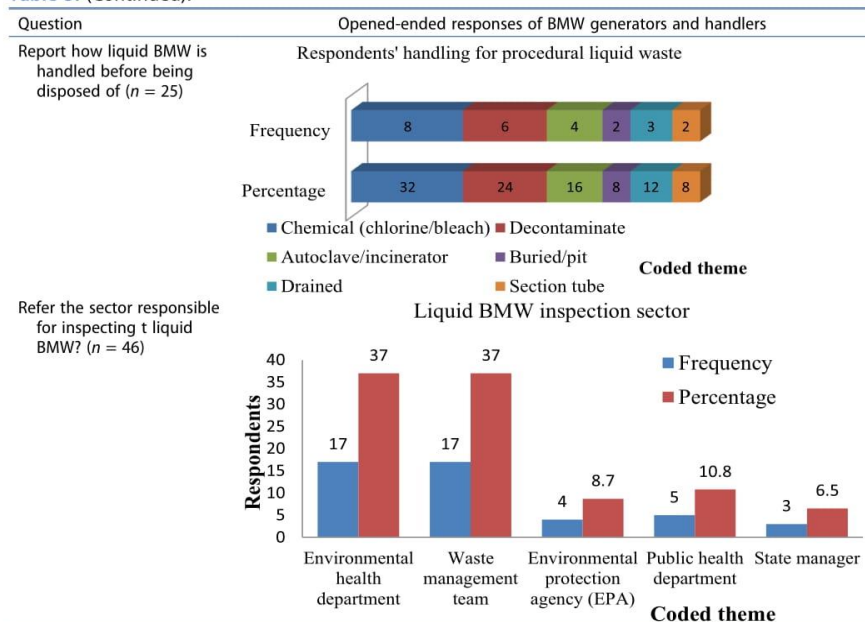
Question	Opened-ended responses of BMW generators and handlers																								
Report the criteria used to identify biomedical waste (n = 195)	<p style="text-align: center;">BMW criteria identification</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <caption>BMW criteria identification data</caption> <thead> <tr> <th>Coded theme</th> <th>Frequency</th> <th>Percentage</th> </tr> </thead> <tbody> <tr> <td>Colour coding</td> <td>121</td> <td>62.1</td> </tr> <tr> <td>Waste content</td> <td>60</td> <td>30.7</td> </tr> <tr> <td>Department</td> <td>14</td> <td>7.2</td> </tr> </tbody> </table>	Coded theme	Frequency	Percentage	Colour coding	121	62.1	Waste content	60	30.7	Department	14	7.2												
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Report the operating procedure for handling of liquid BMW in the HF (n = 76)	<p style="text-align: center;">Standard procedure to handle liquid BMW</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <caption>Standard procedure to handle liquid BMW data</caption> <thead> <tr> <th>Coded theme</th> <th>Frequency</th> <th>Percentage</th> </tr> </thead> <tbody> <tr> <td>Chlorinated</td> <td>47</td> <td>61.9</td> </tr> <tr> <td>Untreated</td> <td>21</td> <td>27.6</td> </tr> <tr> <td>Container</td> <td>8</td> <td>10.5</td> </tr> </tbody> </table>	Coded theme	Frequency	Percentage	Chlorinated	47	61.9	Untreated	21	27.6	Container	8	10.5												
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Container	8	10.5																							
Report the kind of waste deposited in the following colours: black, yellow, red, white and other colours	<p> “Black - general waste, yellow - sharps, red - highly infectious waste, brown - pharmaceutical and chemical containers” “General, infectious, body tissues, brown is for hazardous” “Black for general waste, yellow for infectious waste” “Black- general waste, yellow-infectious, safety box-sharp” “Black - general waste” “Yellow- medical waste” “Red - highly infectious” “Red for infectious waste, black for normal waste” </p>																								
Report how expired blood unit is handled in your HF (n = 42)	<p style="text-align: center;">Respondents' handling of expired blood-units</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <caption>Respondents' handling of expired blood-units data</caption> <thead> <tr> <th>Coded theme</th> <th>Frequency</th> <th>Percentage</th> </tr> </thead> <tbody> <tr> <td>Drain/sewage</td> <td>4</td> <td>9.5</td> </tr> <tr> <td>Incinerator</td> <td>7</td> <td>16.7</td> </tr> <tr> <td>Autoclave</td> <td>5</td> <td>11.9</td> </tr> <tr> <td>Pit</td> <td>2</td> <td>4.7</td> </tr> <tr> <td>Bin</td> <td>7</td> <td>15.7</td> </tr> <tr> <td>Chemical</td> <td>13</td> <td>31</td> </tr> <tr> <td>Return to source</td> <td>4</td> <td>9.5</td> </tr> </tbody> </table>	Coded theme	Frequency	Percentage	Drain/sewage	4	9.5	Incinerator	7	16.7	Autoclave	5	11.9	Pit	2	4.7	Bin	7	15.7	Chemical	13	31	Return to source	4	9.5
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Return to source	4	9.5																							

(Continued)

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Table 3. (Continued).



Note: BMW: biomedical waste; *n*: sample size.

Table 4. Comparison of the knowledge of BMW between BMW generators and BMW handlers.

Questions	Adequate knowledge ($\geq 60.6\%$)	
	BMW generators (<i>n</i> = 366) (%)	BMW handlers (<i>n</i> = 27) (%)
Can you identify medical waste?	298 (81.4)	20 (74.1)
Is there a standard operating procedure for disposing of liquid waste?	160 (43.7)	5 (18.5)
Is there an inspection of how liquid wastes are deposited?	135 (36.8)	8 (29.6)
Do you know the colour coding for medical waste?	300 (82.0)	26 (96.3)
Do you follow colour coding for medical waste?	283 (77.3)	17 (63.0)
Does your facility follow the Ghana health service colour coding waste disposal practice?	147 (40.2)	15 (55.6)
Do you sort (segregate or separate) medical waste during generation or collection?	254 (69.4)	15 (55.6)
Do you know the disposal procedure for expired blood units and by-products at waste?	67 (18.3)	3 (11.1)
Do you know the disposal method for human tissues?	141 (38.5)	1 (3.7)
Does the medical centre have a person(s) designated for liquid waste disposal?	131 (35.8)	6 (22.2)
Is liquid waste treated prior to disposal?	119 (32.5)	2 (7.4)
Is there a procedure for liquid waste disposal in your outfit?	51 (14.0)	0.0
Is there an inspection of how liquid wastes are deposited?	75 (20.5)	2 (7.4)

n: sample size, %: percentage, BMW: biomedical waste.

Safe handling of BMW requires adequate knowledge to identify and classify the waste for proper handling in HF. A majority of this study's participants, 318 (80.0%) identified BMW. This is comparatively higher than similar studies that have reported 52.4% in

Ghana who could identify BMW [78] and 56.8% in Debre Markos town hospitals in Northwest Ethiopia [73], respectively. Furthermore, the majority of the participants in this study, 326 (83.0%), know the colour coding for BMW, which is more than the 60.5% obtained by Vishal et al. [79], but less than 94% of the participants with adequate knowledge in colour coding [80], in India. In the present study, 76.3% of the respondents followed colour coding, with 66.7% adhering to BMW's colour coding policy recommended by the HF. Moreover, 68.4% of BMW generators and handlers participated in segregation of BMW before disposal. Similarly, a study conducted by Deress et al. [43] in Debre Markos town health facility, Ethiopia, reported that 80% of the participants had adequate knowledge to follow colour coding for BMW segregation, which is slightly above the figures in the current study.

Therefore, the findings of this study revealed that although a majority of the participants had adequate knowledge to identify BMW and understood colour coding, they could not practise the required high standard segregation within the HF. Previous studies in developing countries have reported the lack of financial investment in resource facilities, inadequate training of staff, and absence of policy and regulation enforcement by authorities to be the reasons for the low segregation of BMW [11,81].

Concerning liquid BMW, this study's results showed that only a minority (13.0%) of the respondents could handle liquid BMW. Simultaneously, most of the BMW generators and handlers of this study lack the knowledge to handle liquid BMW. This result is contrary to a study conducted by Bakobie et al. [64], to assess liquid BMW in Tamale Metropolis, Ghana. Those authors found that 46.7% of respondents knew how to handle liquid BMW because of regular training received by the BMW generators and handlers. The lack of knowledge of liquid BMW in HF in this study can be attributed to the absence of personnel nominated to teach the handling of BMW and create awareness amongst BMW generators and handlers. Only 34.9% of the respondents reported that they had been trained in handling liquid BMW in the HF.

In ensuring that liquid BMW becomes non-infectious, it is essential to have a standardised procedure in handling BMW prior to disposal, if necessary. In this study, 42.0% of the participants believe that it is important to know how to handle liquid BMW in the HF, with 30.8% properly practising the liquid BMW. The findings of this study contrast with the results obtained in South Africa by Olaifa et al. [63] in handling liquid BMW. In the same Olaifa et al. [63] study, 54% of the participants reported being supervised on the handling of BMW, prior to disposal. But the present study indicates that most of the research HF participants lacked adequate knowledge to handle liquid BMW before practising safety disposal.

The findings of this study agree with those of Asfar et al. [82] and Williams [83] who reported that untreated liquid BMW was discarded into drains. According to Chisholm et al. [84] and Prem Ananth et al. [85], inadequate knowledge in handling liquid BMW results from a lack of policies and legislation by governments in HF. The present study further reported that only 13.0% of respondents knew their HF had a specified procedure for disposal of liquid BMW. This figure is lower than the one found by Ahmed et al. [86] for participants in their study in Sudan, 25%, i.e., almost twice the result obtained in this study.

The lack of designated personnel in the HF in this study led to poor or inadequate disposal of BMW. This study's results indicate that 19.6% of the

participants inspected liquid BMW, but 80.4% of the participants did not. This is contrary to another study conducted in Ghana, where 77% of the participants testified that liquid BMW was inspected before disposal [64]. This discrepancy in two studies carried out in Ghana suggests that the more positive outcome should be further scrutinised.

Finally, the results in the present study showed that only 17.8% of the participants knew the procedures for handling expired blood units, and 63.9% did not know how to dispose of human tissue, which is a significant knowledge gap. Ghana is only one of many SSA countries, including South Africa [63] and Tanzania [87] which have shown inadequate knowledge of safe methods for disposing of expired blood and human tissue by BMW generators and handlers. Collected evidence shows that there is a general problem of BMW in Africa, related to applying standards and training. According to Christyraj et al. [88], a large volume of BMW in HF is generated because of mishandling of BMW, resulting from inadequate knowledge and practice of handling BMW by respondents [41,89].

This study shows that there is a lack of knowledge, designated personnel, and procedural handling of liquid BMW that needs to be confronted in HF in Ghana. Improper handling of BMW results in environmental pollution and the encouragement of various types of insects and rodents [34,90,91]. Furthermore, the poor handling of BMW by generators and handlers contributes to contamination of aquatic bodies and soil, and transmission of diseases like cholera and typhoid [92,93], with severe consequences for the environment and public health [34,38,84,94].

Conclusions and policy recommendations

Unregulated BMW in developing countries is a serious environmental and human health challenge. It must be confronted with appropriate and urgent action at institutional level. Proper handling of BMW requires adequate knowledge for practice from its generators and handlers. A descriptive cross-sectional analysis was undertaken using a purposive sampling technique in distributing the questionnaire to BMW generators and handlers in selected HF in Ghana to assess the level of knowledge in handling BMW within four months, from March to June 2021. A higher number of response was obtained from nurses who were single, with a gender ratio (female to male) of 69.2:28.2 and held first-degree certificates with a mean age of 39.20 ± 9.62 . The study reveals a dangerous lack of appropriate knowledge and action in handling BMW. The HF enquiry showed that 87.0% of the respondents had no procedural knowledge of handling liquid BMW, 82.2% lacked knowledge of handling expired blood, and 63.9% lacked knowledge of handling human tissue.

Consequently, it is recommended that there should be regular and intensive training for waste generators and handlers to improve their knowledge in handling BMW, especially the liquid BMW and human tissue. HF procedural guidelines for handling liquid BMW should be reinforced to reduce the negative impact that BMW has on the environment and human health, compromising the sustainability efforts of BMW practices in developing countries, particularly in Ghana.

Limitations and future studies

One major limitation of the present study is the inability to access the exact sample number of BMW generators and handlers at each studied HF. Another limitation is that the participants did not respond to open-ended questionnaires about detailed knowledge of handling BMW, probably because of work overload.

It is advisable for the methodology of this study to be applied consistently in other African countries. It is suggested that medical associations and nursing regulatory bodies throughout the continent should be invited to consider conducting, country by country, an assessment on the pattern of this study. Once the results have been considered by all the countries, some general improvement may be attainable.

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CHAPTER III - Sustainable Pharmaceutical Waste Management: Pharmacist and Patient Perception in Ghanaian Hospitals

This chapter focuses on the pharmaceutical waste (PW) management part of BMW generated by both HF and various homes, and its significant effect on individual households within Ghana, due to the current abuse of expired pharmaceutical products in SSA countries. It does not restrict the knowledge and attitude of handling and management of PW by the BMW generators such as physicians, nurses, pharmacists, laboratory technicians, and especially pharmacists. It also investigates patients using medications at home. The result from this chapter indicates inadequate knowledge and a lack of logistics in segregating PW in HF and households. The unsegregated PW in HF and expired or unused medication in the home is disposed of in landfills, burry, and openly burnt, affecting ecological sustainability and human health. This could avert the realisation of UN SDG 3 (good health), SDG 6 (clean water and sanitation), SDG 13 (good climatic condition), SDG 14 (better life below water), and SDG 15 (good life on land).

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Sustainable Pharmaceutical Waste Management: Pharmacist and Patient Perception in Ghanaian Hospitals

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1

Abstract

Pharmaceutical waste (PW) is known to be a health problem in developing countries, being harmful to human beings, animals, and the environment, with a high potential for the transmissibility of diseases. This study aims to address the implementation of strategies in the hospital context in Ghana, Africa, regarding the proper pharmaceutical waste management and the relationship with the environment and public health from both pharmacists and patients. Based on a questionnaire and observation, a cross-sectional exploratory-descriptive study with quantitative and qualitative approaches (mixed method) was carried out in selected hospitals in Ghana. A total of 111 responses were received, with 23 (76.7% rate response) being the professional pharmacists and 88 (60.7% rate response) from patients. The survey used random sampling, and the data collected were analyzed using SPSS version 27. The result shows that most of the participants were aware of what constitutes PW and had social awareness of PW. The majority of both types of respondents do not segregate PW, resulting in poor disposal. Unsegregated PW from the professionals was due to a lack of logistics like color-coding. The problems associated with PW in Ghana will be better managed through continued education and awareness at all levels to promote waste segregation.

Keywords

Pharmaceutical waste management · Developing countries · Pharmacists · Patients · Ghana · Africa

1 Introduction

Like any other human activity, the provision of Medicare generates waste that needs to be managed and disposed of safely to minimize the risks it poses to health workers, patients, and the community. The waste generated in various Medicare facilities is dangerous, posing a threat to public health when poorly managed (Blenkharn 2015), resulting in significant environmental problems in developing countries (Debrah et al. 2021a). The exponential population growth, an increase of Medicare centers, and the lack of disposal treatment facilities and technology (Khatib 2011) in developing countries are the main factors of poor medical waste. According to World Health Organization (WHO 2014), medical waste from Medicare facilities comprises 10–25% of hazardous waste, such as pharmaceuticals waste (PW), e.g., out-of-date or unused drugs. Others include pathological waste, sharps, swabs, bandages, disposable medical devices, chemicals and radioactive materials, wastewater, and effluents from mortuaries, requiring special management treatment.

The PW, which consists of out-of-date and unused discarded medicinal drugs, contaminated chemical sludge, and others, is obtained through pharmaceutical

products generated from the medical centers, manufacturing plants, and personal care products (Kadam et al. 2016; Jaseem et al. 2018). Though pharmaceutical products are essential to protect people's life (Balachandar and Chinnaiyan 2019), they can lead to health hazards and ecological risks (Debrah et al. 2021b) and pose serious management challenges at households and hospitals. According to Mikulic (2021), about \$1.27 trillion US dollars (USD) were spent on medication globally only in 2020 and it is expected to increase to 1.6 trillion by 2025. According to Aitken and Kleinrock (2015) and Komilis (2016), a projected amount of 4.5 trillion doses of estimated medication were expected within the globe in 2020. However, the same study further indicated that the doses could increase if there is a high population and drive market forces in developing countries like China, India, Brazil, and Indonesia. The average use of medication in those countries was expected to exceed one use of medicine per day (Aitken and Kleinrock 2015).

In Africa, the pharmaceutical market size is estimated to reach USD 45 billion in 2020 (African Pharmaceuticals Market 2016). Still, the rapid economic growth, urbanization, and the increased incidence of chronic disease resulting from unhealthy lifestyles lead to increasing Medicare spending, which is expected to rise to USD 160.7 billion by 2024 (Goldstein Research 2021). Around 70–90% of the pharmaceutical's drugs used are imported into the Africa continent (Conway et al. 2019), contributing to illegal drug use and serious health problems. In Africa, pharmaceutical products are not given only by dispensers, pharmacists, and specialists, but by people who do not know the components of pharmaceuticals products. The unused pharmaceuticals or medications from Medicare centers and households result in the expiration of drugs, dosage changes (Bain 2010; Azmi Hassali and Shakeel 2020), out-of-date cosmetic products, and other personal pharmaceutical products (Ejeromedoghene et al. 2021), generating hazardous PW. This PW enters the environment because most people in developing countries do not segregate PW.

Waste managing in developing countries is a challenge that requires education and awareness (Debrah et al. 2021a). A study by Ngwuluka et al. (2011) in Nigeria showed that 91.20% of the respondents believed PW was not segregate, hence poorly managed. The same study further reported that more than 58% of the health and safety personnel did not know how to manage PW. The poorly managed PW contributed by the absence of knowledge and awareness of the effects of PW in the environment and health. Improper management of PW can affect the environment and public health. Human body excretion (Daughton and Ruhoy 2009; Bungau et al. 2018), water sinks, and household trash to the landfills (Bashaar et al. 2017) are examples of PW contamination.

This study aims to assess how PW is managed in both the hospital and patient's household in Ghana, Africa, and whether actions affect the environment and public health. The study also aims to propose solutions to mitigate environmental health issues caused by the poor PW management in Africa.

2 Management of Pharmaceutical Waste in Ghana, Africa

2.1 Policy

In Ghana and sub-Saharan Africa, PW in medical centers is generated from new dosages from the hospital, patient medications, and out-of-date drugs accumulated from hospital dispensaries stores. It also occurs when the patient supply ends, by death, leaving the medicines behind (American Society of Consultant Pharmacists 2009; Alshemari et al. 2020). Hence, managing PW has become a significant challenge due to the lack of specific legislation to regulate the management of PW in Africa. In Ghana, there is no defined legislation on PW. The 2020 health policy guideline ensures that various medical centers managed their PW and adheres to the by-laws and regulations of the different agencies of the government. The agencies include the Ministry of Local Government and Rural Development, Environmental Protection Agency, Metropolitan, Municipal, and District Assemblies Ministry of Sanitation and Water Resources, ensuring a safe environment and good public health (MoH 2020).

2.2 Pharmaceutical Waste at Medical Facilities

According to MoH (2020), the guidance and policy of all PW generated from any Medicare center need to be segregated and have an appropriate color coding. A study conducted in Ghana by Sasu et al. (2011) at six hospital facilities indicated that PW is not segregated from other medical waste. Also, another study by Asante et al. (2014) on medical waste segregation revealed that 83% of hospitals in greater Accra in Ghana do not also sort PW. The chemical compounds from unsegregated and poorly managed PW, which are found in rivers and land, cause risk to human health and other ecological systems (Praveena et al. 2018; O'Flynn et al. 2021). Hence, proper treatment and disposal of PW are essential for environmental sustainability. Considering this, the 2020 policy guideline for MoH of Ghana indicates that PW must be disposed of and treated by WHO standards. The standardized way of treating all medical waste includes incineration at 800–1200 degrees Celsius, by microwaving, steam treatment, or advanced autoclave (MoH 2020; WHO 2018).

In Ghana and most of Sub-Saharan Africa, PW is mainly sent to both the landfills and individual dump sites included in the hospitals (Asante et al. 2014), which were not designed for hazardous waste. Most of the Medicare centers that have autoclaves and incinerators are not standardized. The majority of the incinerators operate below the required temperature and are not equipped with an air pollution control system (Honest et al. 2020; Wang et al. 2020; Liang et al. 2021), polluting the environment and affecting public health in Ghanaian and other sub-Saharan African countries.

2.3 Household Pharmaceutical Waste Management

PW at homes is generated when pharmaceuticals medication are unused or out-of-date (Dar et al. 2019). In most developing countries, including Ghana, unused

medication is kept mainly by individuals for future use without a prescription by health personnel, which enhanced self-medication and drug abuse (Marwa et al. 2021). A survey conducted in Ghana by Sasu et al. (2011) indicates that more than half of the respondents kept their medication bought over the counter and reused when symptoms of the disease or similar one occurred. Still, the same study further indicated that unused pharmaceuticals are disposed of by burning, flushing, tossing them into domestic waste bins, flushing with waste, or indiscriminate dumping. This attitude in Ghana is virtually common in many sub-Saharan Africa and other countries in the world (Rogowska et al. 2019; Begum et al. 2021; Marwa et al. 2021). The study further indicated that more than half of the household respondents believes that PW affects the environment (Insani et al. 2020) and that is why implementing strategies to manage PW properly is essential. Studies by Owens (2015) and Sokač et al. (2017) detected that PW finds its way in surface water, groundwater, and food, impacting both human and environmental health. In Lebanon, pharmaceutical chemicals were found in treated drinking water (Massoud et al. 2016). Proper PW management is, therefore, necessary to prevent pollution and minimize the ecosystem risks.

To correctly manage PW in sub-Saharan Africa, including Ghana, requires social innovation and social level players. A social innovator creates, develops, and implements ideas and technologies to meet people's social needs (European Commission 2013; Eskiyörük 2021). At the social level, people invest in the business models and in the innovator's ideas to drive a societal change (Gandhi and Raina 2018; Farinha et al. 2020). That is also intended in the PW management in Ghana, Africa, for environmental and health sustainability and social development.

3 Material and Methods

3.1 Study Area

The study was conducted in six metropolitan, municipal, and district assemblies within two regions in Ghana. The two regions, Greater Accra and Eastern, were selected for the study because they have the highest human immunodeficiency virus (HIV) prevalence among pregnant women in Ghana (Ghana Health Service 2016). Also, the recent surge of HIV in some of the selected assemblies and their surroundings (Kyeremeh-Atuahene 2019; Quartey 2020) was considered in this selection. During 1999–2013, greater Accra has had the highest death of cholera outbreak with selected areas and their surrounding within the eastern region being the hotspot (UNICEF 2013). Considering the problems associated with these two regions and the Medicare facilities in the selected metropolitan and municipal district assemblies, it is essential to assess how PW is managed within the facilities and the household communities. Furthermore, it is important to implement strategies and innovative ideas or proper PW management in the region.

3.2 Method

A mixed-method approach was adopted with a cross-sectional design in this study. In the mixed-method design, the researchers combine the elements of both quantitative and qualitative approaches (Almalki 2016) to eliminate the inherent bias in data sources (Johnson et al. 2007; Jimenez et al. 2018). The research was categorized into two parts. The qualitative approach was based on a careful and critical observation with a systematic walk through the entire hospital work, then checking the temporary storage points, and the disposal and final treatment. Finally, the quantitative approach of the research involves administering structured questionnaires to the selected pharmaceutical professionals and patients at dispensaries at the hospital for medications.

3.3 Instruments

A structured survey was designed to assess the understanding of PW management by the respondents. The survey was divided into two groups: Survey A was applied to professional pharmacists and technicians who work at the pharmacy departments of the six research facilities; Survey B dealt with only patients collecting their medications at the pharmacy departments of the various hospital facilities within a period. A pilot survey was conducted and shared with three pharmacists and eleven patients who visited the pharmacy department of the clinic to ensure that all relevant issues were considered and to check redundancies or similar items, as well as to assess the writing and sequence of questions. The survey questionnaire was divided into two sections: The first section deals with the sociodemographic part of the respondent (e.g., occupation, age, area of work, qualification, position, gender, years of work); the second part of the questionnaire includes specific issues relating the PW effects and how to manage the waste. The questionnaires were hosted on a Google Forms link and distributed to the participants either by WhatsApp or email.

3.4 Study Sampling

The samples for the study were collected through a random sampling method in six selected medical centers. The samples were picked from pharmacists and technicians from four government hospitals, a faith-based hospital, and a public-private hospital, and patients who visited the pharmacy departments for medication. A total of 175 respondents have been selected: 30 participants were professional pharmacists and technicians (Survey A), and 145 participants were patients who were taking their drugs in the hospital at the time of study (Survey B). One hundred and eleven (111) completed responses were received from the randomly selected samples within March to June 2021. Out of the 111 responses, Survey A comprised 23 responses (response rate = 76.7%), and Survey B comprised 88 responses (response rate = 60.7%). According to Fincham (2008), a high response rate of about 60% must be an expected goal for a researcher. This is because a reasonable response rate does

reduce sampling bias (Meterko et al. 2015). In this study case, this condition has been reached.

3.5 Ethical Issues

Ethical approval for this study was given by the Ghana Health Service Ethics Review Committee (GHSERC 2015), reference GHS-SEC 002/11/20. A GHSERC letter was first sent to the Eastern Regional health Directorates (ERDH), then resulting in a study introductory letter with the reference ERDH 133612021 to the selected hospitals in their region for the research. During the research, participants were assured of the confidentiality of their data, with names excluded in the questionnaires. Consent forms were designed with all information translated to the local language for those who did not understand English. Also, the GHSERC (2015) protocols and COVID-19 Ghana Health Service protocols were strictly followed during the research.

4 Results

4.1 Pharmacists' Perception

Demographic data obtained from the pharmacists' respondents is shown in Fig. 1. A total of 65% of the 23 respondents were male, and 35% were female, with a mean age of 35.2 years. Only one respondent (4.3%) is below 24 years with 13% above 50 years. Figure 1 also indicates that 43.5% of the professionals are graduates, with 30.4% holding master's degrees. More than 95% of the survey respondents work at the hospital, with the majority being in the government sector (78.3%). A total of 70% of the respondents are pharmacists, 30% are pharmacy technicians, 43.5% are working for less than 5 years, and 8.7% are above 20 years. 52.2% of the respondents are senior staff with only one casual worker.

Table 1 and Table 2 include data from closed and opened-ended responses from professional pharmacists. In Tables 1, 69.6% of the respondents know what constitutes PW, with 73.9% not having a routine of segregating waste at the facility. Though 69.6% believe there is a protocol for disposing of pharmaceutical waste, 30.4% have not seen any protocol for disposing of PW. The responses reveal that 73.9% cannot access the public health policy guidelines on managing PW at the facility. Only 34.8% have undergone some training in managing PW waste, but the remaining 65.2% report no training on PW.

4.2 Patients' Perception

Figure 2 describes the demographic of the patients. More than 53% of respondents who visited the pharmacy department for medication were male, with 46.6% been

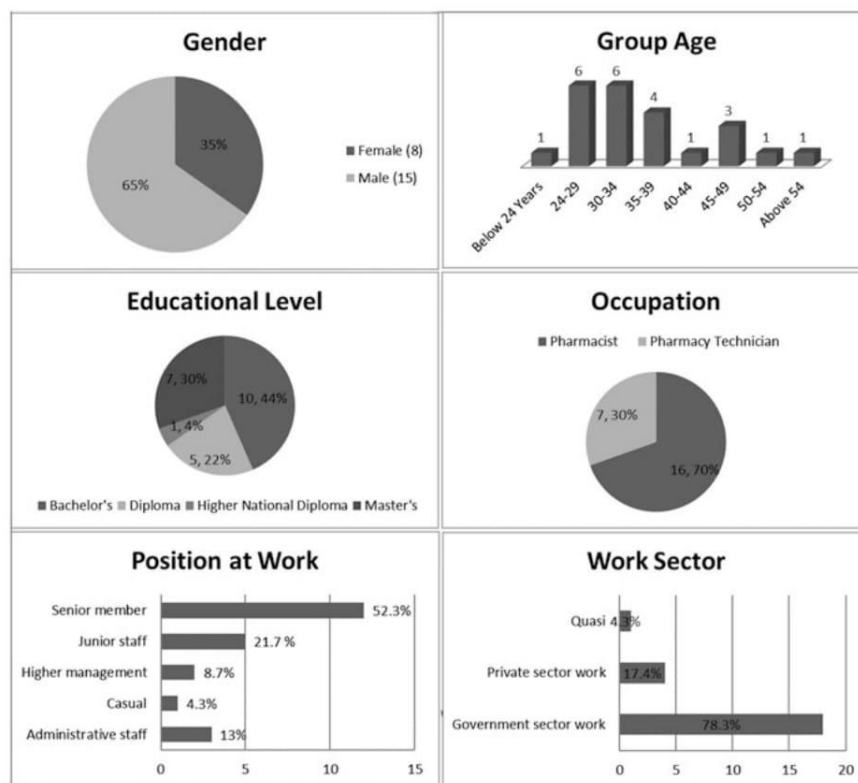


Fig. 1 Demographic profile of professional pharmacists and technicians ($n = 23$)

female. Among the respondents, only 2.3% were above 60 years, and the majority of the attendees receiving medication were aged 24–29 years (27.3%). The data from Fig. 2 also indicates that 50% of the respondents are graduate, with only 2% without education. The data shows that 46% of the patients work in the government sector.

Table 3 and Fig. 3 represent the closed-ended responses for patients who visited the pharmacy department for medication. From Tables 3, 60.2% are aware of the PW constituents, with only 31.8% segregating the PW. More than 87% have either unused or out-of-date drugs in their houses, with 95.5% never returning the medication to the hospitals for disposal.

The method of PW's disposal is shown in Fig. 3 which indicated that 71.6% place PW in the domestic waste bins, with 13.6% disposing of it by open burning.

Table 4 The responses of opened-ended questions from the patients at various hospital facilities for medication give a clear idea of how PW are segregated and disposed of in households.

Table 1 Knowledge of pharmaceutical waste management by professional pharmacists and technicians ($n = 23$)

Question	<i>n</i>	%
Are you aware of what constitutes pharmaceutical waste?		
Yes	16	69.6
No	7	30.4
Do you have a routine of separating/segregating pharmaceutical waste at your facility?		
Yes	6	21.1
No	17	73.9
Do you know if there is a protocol for the disposal of pharmaceutical waste in your facility?		
Yes	16	69.6
No	7	30.4
Do you have access to or knowledge about a public health policy guideline on pharmaceutical waste management at your facility?		
Yes	6	26.1
No	17	73.9
Have you been trained in pharmaceutical waste management practices in your facility?		
Yes	8	34.8
No	15	65.2
Total	23	100

4.3 Assessment of Medicare Facilities Regarding PW Management Practices

Table 5 represents the medical solid waste disposal process, including PW at the selected facilities. Each facility has a group of people managing the generated waste. It was observed that only facilities A and F segregated waste into coded containers for disposal. Within facility E, no proper segregation was done. Hence, both infectious and noninfectious waste were incinerated together. Facilities B and D have no containers to segregate waste, and the waste generated is sent to the dumping site around the hospital for disposal. It was also found that facility C has built a new incinerator but not yet ready for use. Instead, waste was collected and sent to landfills by a waste management company.

5 Discussion

Understanding PW, the handling of PW, and its disposal and the effect on the environment, such as the associated risks to water, food chain, wildlife, climate change, and communities, has become a significant issue and concern in Ghana, not forgetting in other African countries. Pharmacists play a vital role because they are responsible for all medications before it reaches consumers; therefore, this study is conducted to discover the existing knowledge of PW management. In addition, we

Table 2 Opened-ended response of professional pharmacist and technicians ($n = 23$)

Question	Example of statements
What constitutes pharmaceutical waste?	“Unused or an out-of-date item from pharmaceutical products.” “Unwanted pharmaceutical or drugs”
	“Waste generated during the process of using pharmaceutical products”
	“Damaged out-of-date and unused medicines”
	“Any medicinal product and its packaging that is not fit for consumption”
	“Waste from production, out-of-date and obsolete medicines, etc. drugs, excipients”
	“Pharmaceutical waste is pharmaceutical manufacturer products that are either out-of-date, contaminated or can’t be used for their purpose anymore”
	“Waste is an item that is not needed”
	“Pharmaceutical waste is pharmaceutical manufacturer products that are either out-of-date, contaminated or can’t be used for their purpose anymore”
How is your routine of separating/ segregating pharmaceutical waste at your facility?	“All capsules are put into one container and liquids into another bin”
	“Color coding of bins are used for such purposes”
	“To differentiate medical waste from general waste we check for expiry or contaminated drugs every week”
	“Pharmaceutical waste is separated from usable stock and stored in a room reserved for that purpose awaiting disposal in accordance to the waste disposal guidelines of the Ghana Health Service”
	“There are waste bins allotted for pharmaceutical waste only”
	“All out-of-date meds are sent to the pharmacy store for onward disposal”
	“There’s a designated room for those drugs”
	“Routine stock taking helps and if there’s out-of-date or unused drug over time, a particular team from stores management puts the out-of-date drugs together for disposal”
	“They are gathered together and the appropriate authority is called upon to dispose them”
Can you explain the protocol for the disposal of pharmaceutical waste in your facility?	“We use brown color coded bin for pharmaceutical waste, black for non-infectious products”
	“Pharmaceutical waste is separated from biohazardous waste.”
	“The Ghana Health Service with Stakeholders has developed guidelines for the disposal of Pharmaceutical waste”

(continued)

Table 2 (continued)

Question	Example of statements
	“Segregation, auditing of Out-of-date medicines by a team and disposal”
	“Done in collaboration with the FDA”
	“Disposal procedures as outlined in the logistics management of public sector health commodities in Ghana document”
	“The various waste is gathered and the Food and Drugs”
	“Authority is called upon to come for them for proper disposal”
	“It is being dispose of on daily bases by train labor”
	“Paper and rubber materials are sent to the facility refinery” “Out-of-date pharmaceuticals are compiled, reported to regional FDA who come every quarterly to dispose them off”
	“Burning and burial method”
Which are the guidelines on pharmaceutical waste management available at your facility?	The waste disposal guidelines adopted by the Ghana Health Service”
	“Infection prevention and control guidelines (a chapter is devoted to Waste Management)”
	“Document as stated above”
	“SOP for waste management”
	“Policy of infection prevention”

also included the patient’s perception, aiming to improve its management with some degree of social innovation.

The research data showed that 65% of the respondents are male, with a mean age of 35.2, completing their first degree in pharmacy. This study also found that 69.6% of the pharmacist know what constitutes PW, similar to a study conducted in Brazil (Marques et al. 2015) and Nepal (Paudel et al. 2019). We can suggest that pharmacist in developing countries is knowledgeable on the matter of PW constituents. However, the experts’ knowledge on PW composition was not translated into the segregation of the waste in practice. This might be due to lack of policies direction and inability to properly enforce regulations in managing PW. Furthermore, it is observed that most of the facilities in this study do not have logistics, such as color coding containers required for the segregation. As a result, only 26.1% of respondents do separate PW, while 73.9% do not, which is in agreement with the studies from Nepal (Paudel et al. 2019) and Ghana (Odonkor and Mahami 2020), reporting the lack of segregation of medical waste including PW by professional pharmacists. This is a common problem among hospitals in Africa continent due to the financial constraints to address the appropriate logistics in managing PW.

Despite each hospital operates under the ministry of health regulations and policy guidelines, being monitored by the Ghana health service, it was observed that each

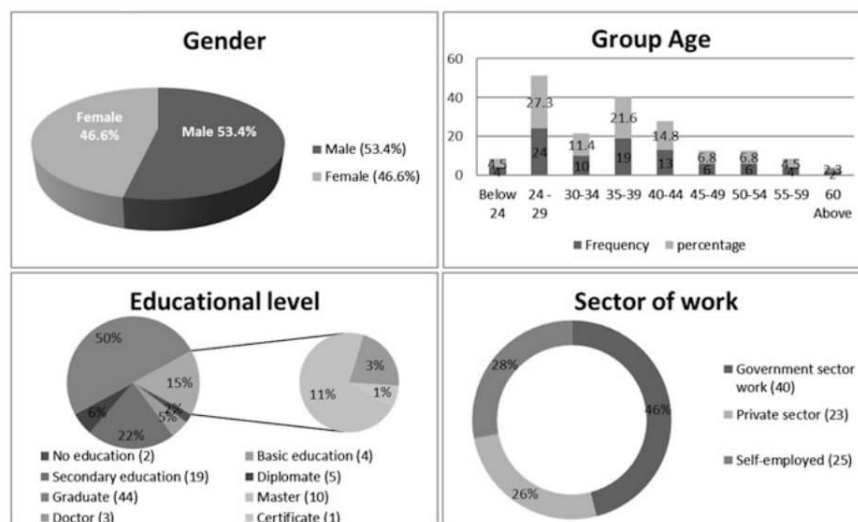


Fig. 2 Demographic profile of patients who received the medication at the pharmacy department ($n = 88$)

Table 3 Closed-ended response by the patients who received medical care at the hospital facilities before going home ($n = 88$)

Question	<i>n</i>	%
Do you know the constitution of pharmaceutical waste?		
Yes	53	60.2
No	35	39.8
Do you try to separate/segregate pharmaceutical waste from all other waste in your home? *		
Yes	28	31.8
No	60	68.2
Do you have unused medication at home?		
Yes	77	87.5
No	11	12.5
Have you already returned unused pharmaceutical products to the facility that issued them for disposal? *		
Yes	4	4.5
No	84	95.5
Total	23	100

one has its own management body, responsible for the daily management. Therefore, hospitals have their protocols in managing and disposing of all kinds of waste, including the PW. For that matter, 69.6% of the pharmacists were aware of the protocol to dispose of the PW, but were not aware of the main MoH (2006) public policy guidelines to manage medical waste, including PW. About 73% of the

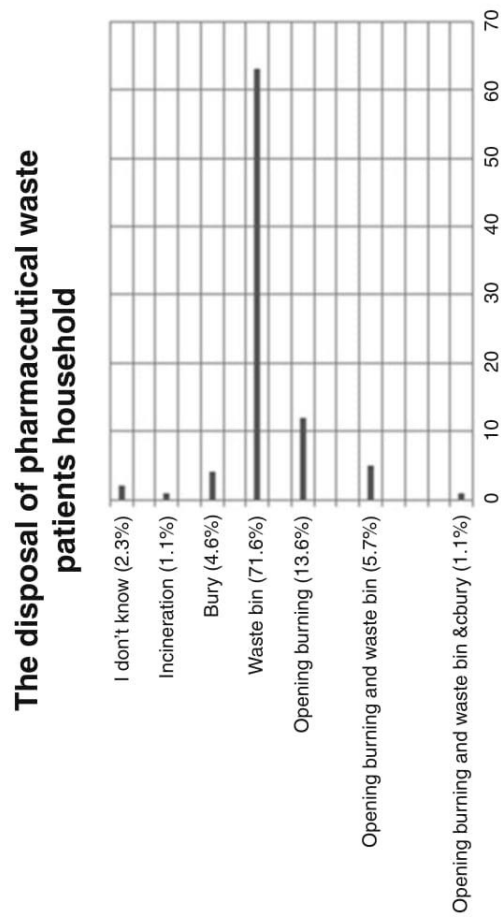


Fig. 3 Disposal of pharmaceutical waste in households (n = 88)

Table 4 Opened-ended response by patients at the pharmacy department ($n = 88$)

Question	Example of statements
How do you perform the separation of pharmaceutical waste from all other waste in your home?	“Putting them in separate waste bins”
	“Store plastic separately while all other waste is put together”
	“By putting them in secret bins”
	“I have two bins which I use to separate the waste”
	“Put some in plastic and papers”
	“I have two ways bins”
	“In separate waste bins”
	“I separate the plastics from the cans and burn the plastics and dispose the cans to any waste management company”
	“Waist segregation”
	“I have two bins which I use to separate the wastes”
	“In different waste bins”
	“Separate plastic from cans”
	“I have different waste bin”
	“Separating the cans from the plastic in different waste bin”
	“I have two waste bins”
	“I have two bins which I used to separate the waste”
	“I have to bins which I used to separate the waste”
	“Putting them in separate dustbin”
	“I have two bins which are used to separate the waste”
	“By putting them in separate bins”
	“I have two waste bins”
	“By putting the in separate bins”
	“In different waste bins”
“In different waste bin”	
“I separate the plastic from the cans when the plastic and dispose the cans to any waste management”	
“Store plastic separately falls other waste are put together”.	
“Store plastics separately while all other wastes are put together”	
When you returned unused pharmaceutical products to the facility that issued them for disposal, please clarify whether the establishment has received and what procedures have been adopted	“No”
	“It was Rejected by the establishment”
	“Never done before”
	“Never return medicine before”

Table 5 Assessment of Medicare facilities

Facilities	Coded containers	Treatment method	Remarks
A	Yes	Autoclave	Pharmaceutical waste is segregated from the source of generation into coded containers as the mandated ministry of health protocol. Infectious wastes are treated in autoclave
B	None	None	The waste is not segregated due to the absence of coded containers. As a result, medical waste, including PW, is burnt within the hospital premises
C	Yes	Incinerator	Waste is put together at a common point for the collection. There is no proper segregation of PW. All wastes collected are sent to landfills by a waste management company. Though the management facility has acquired a new incinerator, it was not operational when collecting this data
D	None	None	The facility has no coded container to segregate PW waste generated. In addition, the facility has no treatment plant. Hence, all waste is sent to a dumping site closer to the hospital for burning
E	Yes	Incinerator	Though the facility has coded containers, waste generated is not segregated from the source. Hence, all waste from the facility and every department is incinerated
F	Yes	Incinerator	Waste is segregated with coded plastic bags. Hence, the infectious waste is incinerated

pharmacist respondents do not have any knowledge or existence of a public health policy to manage PW, which aligns with the World Health Organization (WHO 2018) to ensure adequate sanitation and hygiene services in all health facilities. Through critical observation, it was realized that two of the medical centers disposed of medical waste, including the PW, by burning them. This is attributed to the lack of a treatment plant to dispose of the PW, as done in most developing countries (Gudeta and Desta 2020; Begum et al. 2021).

The segregation of waste is one of the significant issues in developing countries currently. One reason for the nonsegregation of PW by the pharmacists' respondents is the lack of waste management training and logistics for disposal. The study results indicate that about 65% of the professional pharmacists have not received any training in PW practice, similar to a study conducted by Esayas et al. (2021), with almost 70% of the health professionals, including the pharmacist, not trained in PW, contributing to improper PW management. The lack of training in managing PW could result from budget constrains in different health facilities in Africa.

Concerning patients, 53% of respondents were male, with the majority of respondents (75.1%) between 24 to 44 years. Most of the respondents were graduates who work in the government sector. However, due to the educational background of respondents, 60% expressed knowledge about what is a PW but the non-segregation is the issue. Because of that, the study's findings indicate that 68.2% of the patients

respondents do not segregate their PW at home before disposal, similar to the study of Paudel et al. (2019). However, in a study conducted in Malaysia by Ariffin and Zakili (2019), it was found but which that 78% of the household respondent segregate PW waste. This study further indicates that about 71% of the people dispose of the PW into waste bins, followed by about 13% who burn it. Disposing of PW in a waste bin in households is found in other countries in Africa such as Ethiopia (Teni et al. 2017) and Nigeria (Banwat et al. 2016). Other countries outside Africa with the same practices include Lebanon (Massoud et al. 2016), India (Manocha et al. 2020), Serbia (Kusturica et al. 2012), and Hong Kong (Chung and Brooks 2019), which is detrimental to the environment and public health. In addition, this research further showed that about 87% of the respondents who have unused medication in their household have not returned them to the pharmacy, which is a significant problem in most countries alike in developing countries. Furthermore, 95.5% have never returned their medication to the pharmacist for disposal. Only 4.5% of the patients returned the unused pharmaceutical products to the facility, a finding which is similar to other studies conducted in Saudi Arabia (Sarah and Lamyaa 2016) and Zambia (Martin et al. 2020). The nonacceptance of PW by professionals is justified by no existing law professionals mandate to collect PW from outside their facilities.

The study also showed that both the pharmacists and the household patients know what constitutes PW and are educated. They did not segregate PW for disposal, which could occur due to a lack of practical education. A changed attitude towards segregation and managing PW through practical or instructional education, social responsibilities, motivation through social initiatives, rewards, and formal and informal education (Debrah et al. 2021b; Shaaban et al. 2018) will contribute to reduce waste segregation problem including PW for proper disposal. Therefore, education and some level of social initiative should be set as a platform for collecting unused medicine from households by introducing a reward or motivation to the system to individuals who return unused or out-of-date drugs effectively, as done in countries like Portugal (Castro et al. 2021), Saudi Arabia (Alghadeer and Al-arifi 2021), and Sweden (Persson et al. 2009). Hence, education should contribute to return unused and out-of-date medication, assisted by policies and regulations to enforce all pharmacists and dispensaries to accept out-of-date medicines. At the same time, education through social awareness would also contribute to a mentality change by patients and the entire society, being more conscious of environmental and health problems results from improper waste disposal (Kinrys et al. 2018).

Finally, because the disposal of PW is of particular importance in developing countries, requiring adequate facilities, tolls, logistics, equipment, and professionals, additionally to the effort made by governments, it will be important that society as a whole can be mobilized in developing community awareness to this problem.

6 Conclusions

PW management has implications for the environment and public health. This cross-sectional observational study applied to pharmacists ($n = 23$) and patients ($n = 88$) at six selected hospitals in Ghana, Africa, has allowed obtaining an overview of how PW management is practiced at the hospitals and households. To the authors' knowledge, this is the first study on the subject in Ghana. Even though the two surveys on pharmacists and patients show some general knowledge towards the constituents of PW, still no segregation is done by either pharmacists or patients. Therefore, there is an absolute need to educate people in developing countries on the essence of segregation for proper disposal. The reason is that practical education will help change the attitude towards the importance of handling PW and returning unused and out-of-date medication for appropriate disposal. This is highlighted by the fact that more than 95% of patient respondents have some unused and out-of-date drugs at home and PW are disposed of in waste bins. Therefore, for effective management of PW, there should be direct policies to regulate unused and out-of-date medication in households.

Finally, a social level investment for innovation in Africa, assisted by modern technological logistics for disposal of PW, as well as introducing a reward system for returned unused and out-of-date medications in households will contribute to change and safeguard the environment and human health in developing countries, such as Ghana. To reduce unused and out-of-date medications in developing countries, innovative social programs assisted by adequate legal regulation are necessary to help return no longer used or expired medication. PW can be better managed through innovatively social initiatives assisted by technological ideas and solutions to help overcome the current social problems involving PW management in household and Medicare centers in Africa.

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CHAPTER IV - Managing medical waste in Ghana - the reality

This chapter reports on the estimated amount of BMW generated by selected HF in Ghana and the factors influencing the BMW generations and threatening the ecosystem and human health. This quantitative approach revealed the failings in handling and managing BMW and the parameters influencing the generation of BMW in the investigated HF. Segregation of BMW is not correctly practiced with BMW from HF uncontrollably combusted in open burning and dumping, which could negatively affect human health (SDG 3), hygienic environment (SDG 6), climate change (SDG 13), better life in water (SDG 14) and healthy life on land (SDG 15). This study is expected to help HF managers in Ghana plan and budget for the management of BMW.

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ARTICLE



Managing medical waste in Ghana – the reality

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ABSTRACT

This study estimates the Medical Waste (MW) generated and the handling process in six Healthcare Facilities (HF) in Ghana, Sub-Saharan Africa (SSA), and identifies the associated parameters. The data were collected by field work and MW collection, identification and weighing. The results indicate that the average rate of infectious MW ranged from 0.23 to 2.34 kg/bed/day ($M = 0.95$ kg/bed/day), and 0.24 to 1.68 kg/bed/day for non-infectious MW ($M = 0.56$ kg/bed/day). An amount of 11.41 tonnes of MW were estimated in the six HF in Greater Accra and Eastern Region in Ghana, comprising 49.1% infectious MW. The results suggest that the number of outpatients/day and the size of HF are the main predictors for the MW generation. The study shows that the segregation of MW is not correctly practised in the studied HF since 33% used the uncontrolled combustion process of open burning and dumping to handle 0.99 tonnes (8.7%) of MW.

KEYWORDS

Waste; hazardous; disposal; hospital; health; Ghana

Introduction

Managing waste materials is a problem in developing countries [1], including medical waste (MW), with a regulatory framework that needs to be observed in each case [2]. According to Anne and Selin [3], MW is highly regulated from generation to final disposal, but the process needs to be monitored to ensure full compliance within the Healthcare Facilities (HF) [4].

MW includes solid and liquid waste materials generated from HF [5] such as hospitals, health research institutions, health clinics, nursing homes, veterinary clinics, blood banks, mortuaries, autopsy centres, or diagnostics centres, among others [6–8]. All the waste generated from HF is classified into non-hazardous (non-infectious) and hazardous MW. According to the World Health Organization (WHO) [9], MW from all HF should consist of 85% non-hazardous (non-infectious or domestic) MW and 15% hazardous waste, with the infectious MW comprising 10% infectious and 5% chemical and radioactive waste. WHO [9] classifies hazardous MW in seven categories; Figure 1. The components of the classified hazardous MW or the by-products include syringes,

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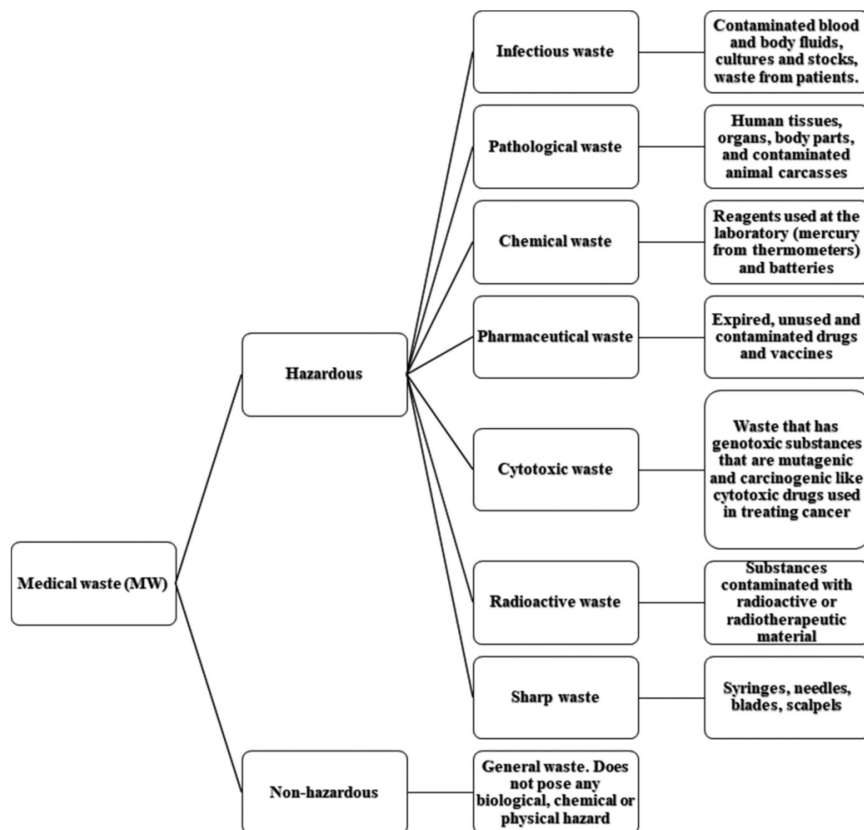


Figure 1. Examples of medical waste categorisation adapted from WHO [9].

blood samples, needles, tissues, body parts, razors, scalpels, chemical solutions, faecal samples, radioactive materials, surgical devices, heavy metals, and batteries [5,10]. The recent trend of increased generated MW in developing countries is a result of improved access to medical services, population growth [11], and economic expansion leading to a higher gross domestic product (GDP) [12,13]. Improper management of MW promotes the growth of harmful microorganisms [14], which harms the environment and public health [15,16]. Therefore, proper management of MW reduces the risk associated with released pathogens, toxic exposure of pollutants, chemical burning and sharp inflictions [9], affecting human health, fauna, flora and the environment as a whole.

Proper MW management can be promoted through colour-coding of containers, appropriate segregation, handling, storage, and transporting the waste for treatment and disposal, which are significant concerns in Africa and Sub-Saharan Africa (SSA) in particular [17]. A proper MW management process ensures that MW is segregated as hazardous (infectious) and non-hazardous (non-infectious) for adequate handling. Acceptable waste management methods reduce public health risk diseases like anthrax

[18], hepatitis [19] or cholera [20,21], and also keep chemical toxics from being released to the environment [22]. Although 15% of MW is expected to be infectious in most developing countries, including Ghana [9,23], the estimated infectious MW in HF in SSA is mostly more than 30% [9].

Most MW generated in HF constitutes non-infectious or general MW [24]. Collected infectious MW should be handled with appropriate technologies, including microwave, incinerator, plasma pyrolysis or autoclave [25], to reduce the contagious effect on humans and protect the environment. MW treatment methods such as autoclaving and incineration must be regulated within the required temperature range to reduce the microbial load for safe handling and disposal. There should be a general idea of recycling and reusing material where possible [26]. Owing to financial constraints, the recycling and reuse of MW are not common in most developing countries [27]. If correctly segregated, MW can be recycled and reused, assisting in sustainable growth and creating employment in SSA countries, while simultaneously protecting the environment.

The amount of estimated MW generated in HF is determined by the country's economic power, facility size, and regulations for adequate MW management [12,28,29]. Some studies have addressed the composition of MW in both the developed and developing countries by estimating both the infectious and non-infectious MW in HF in kg/bed/day or kg/patient/day. For example, in a study conducted in Italy, an amount of 4 kg/bed/day of infectious MW was estimated to be generated in HF [30]. An amount of 3.6 kg/bed/day infectious MW was reported in Greece HF [31]. Canada and the United States of America showed a range of 8.2–8.4 kg/bed/day estimated infectious MW [32]. Within the SSA, a case study conducted in two Nigerian hospitals estimated the ranged of infectious MW from 0.01 to 3.98 kg/bed/day [33], and in the city of Hawassi, Ethiopia, the median quantity of infectious MW generated in HF was estimated to be between 1.48 and 8.19 kg/bed/day [34]. A survey conducted by Asante [35] in 120 hospitals in greater Accra, Ghana, found the average weighted MW to be 1.2 kg/bed/day for a sample of 6,851 beds. Amfo-Out and Doo reported 0.58 kg/bed/day of infectious MW in the Tetteh Quarshie Memorial Hospital at Akuapem-Mampong, Eastern Region of Ghana [36], and Oduro-Kwarteng et al found a range of 0.72 to 2.92 kg/bed/day generated infectious MW in Kumasi hospitals in Ghana [2]. When compared to the values reported for developed countries, these low values from developing countries suggest low economic power, small facility sizes, and poor regulation for adequate MW management. These conditions do not show movement towards the Millennium Development Goals.

Although the amount of MW produced at any HF varies with the country and its laws [37], the estimated infectious MW produced from HF of the world's low-income countries is about 0.2 kg/bed/day [9]. SSA countries cannot meet this figure when managing MW because regulations and procedures such as collection, handling, segregation and transportation of MW are not strictly implemented, generating infectious MW above the WHO [9] recommended value of 0.2 kg/bed/day.

As far as the authors are aware, no studies have yet focused on parameters affecting MW generation for future MW budget guidelines and proper MW planning in HF in Ghana. Therefore, to achieve a better understanding, this study aims to estimate the

amount of MW generated in six selected HF in Ghana. Through a multivariate linear regression model, it also seeks to identify the associated parameters that affect the amount of MW generated at the studied HF.

Material and methods

Study location and time frame

The study was conducted in the Eastern and Greater Accra part of Ghana, in six HF located in 4 of Ghana's metropolitan, municipal and districts assemblies (MMDAs). [Figure 2](#) shows a Ghana map that indicates the Eastern and Greater Accra and the MMDAs where the six HF are located. The six studied HF consist of a regional hospital (RH), which also serves as a referral centre, a general hospital (GH), two government district hospitals (GDH₁ and GDH₂), a mission hospital (MH), and a public-private hospital (PPH), according to designations used in Ghana hospitals [2,38]. The study was developed from March to May 2021, during the coronavirus COVID-19 pandemic. The research was conducted in the selected MMDAs because of the high prevalence of the Human Immunodeficiency Virus (HIV) in surrounding areas [39,40].

Sampling and methodology

Both quantitative and qualitative research designs [41] were used in this study. In the quantitative approach, all the MW generated from the HF was weighed with a highly standardised electronic Camry weighing platform scale (TCS-150-JC11), maximum capacity of 150 kg/130 lb, minimum of 1000 g/2.2 lb, and an accuracy of 50 g/0.1 lb. Then, the systematic observation technique was used as a qualitative tool to check how MW was handled after weighing and to assess the potential effects on the environment.

Within the March to May 2021 3 months duration, the study was divided into two stages. During the first stage, a period of 2 months was used to determine the weight of MW generated from the six selected HF. Then, in each HF, the researchers spent ten continuous days, i.e. from morning to evening, measuring the generated MW, including the incinerator bottom ashes produced in GH and PPH before disposal. The measured MW was first collected from the generation source, moved to a storage point and later transported to the treatment site for measurement. For HF without the technological handling equipment (MH, GDH₁ and GDH₂), MW was measured at the disposal sites. The remaining monthly period was used to study the activities of the sites of the HF, where MW was either burnt or dumped (GDH₁ and GDH₂).

According to WHO [9], the MW samples collected were categorised as hazardous (infectious) MW and non-hazardous (non-infectious or general) MW, and the quantity of MW was estimated. Therefore, it was possible to confirm that the weighted MW from the HF were not segregated by type, as required by the Ghana health service [42], except in the case of sharps, which were separated by all the studied HF.

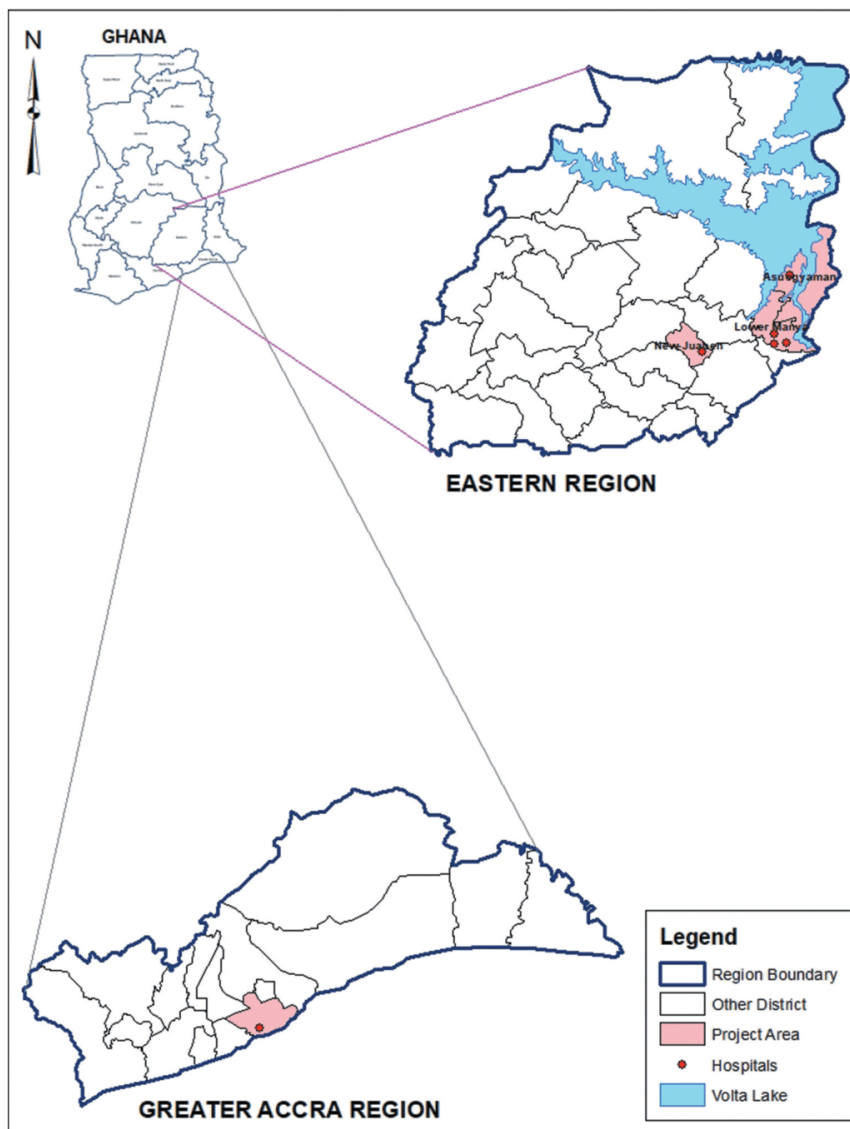


Figure 2. Ghana map indicating the location of Greater Accra and Eastern Region used to carry out this study.

Data analysis

An estimated daily MW, which resulted in a week weighted MW generated, was calculated per day for infectious and non-infectious MW in all the HF using IBM statistical package for social sciences (SPSS) version 27. In addition, the estimated MW generated in kg/day/bed was also assessed. The assessment process used in this study is similar to a study conducted to quantify MW generation in kg/bed/day in different HF in Vietnam [43] and Iran [44], respectively. Multivariate linear regression was used to assess the variables associated with the MW generation within the six HF facilities to obtain a correlation matrix among the different variables. Some of the effective parameters associated with MW generation were estimated as infectious MW in kg/bed/day, hospital sizes or type of hospital, and the number of outpatients/day. The methodological procedures to assess the HF in this study were designed following previous studies recommendations by Cheng et al. [45], Idowu et al. [33], Ansari et al. [12] and Tesfahun et al. [46] in determining the influential factors of MW generation, such as infectious MW, number of patients, national health insurance and bed capacity in other developing countries.

Ethical clearance

The Ghana Health Service Ethics Review Committee (GHSERC) issued ethical approval for this study, reference GHS-SEC 002/11/20. Further permission was obtained from Eastern Regional Health Directorates (ERDH), reference ERDH 133612021. The COVID-19 Ghana Health Service protocols were strictly followed, including the required ethical protocol guidelines.

Results

Estimated medical waste production at the studied healthcare facilities

MW generated from the selected HF were categorised as infectious MW and non-infectious MW. From Table 1, an estimated amount of 11.42 tonnes of MW were weighed within a week for the selected HF. It consisted of an average value of 5.61 tonnes (49.1%) for infectious MW and 5.81 tonnes (50.9%) for non-infectious or general MW.

Table 1. Estimated amount of infectious and non-infectious medical wastes in the six selected HF.

Type	No. beds	Weighted infectious MW			Weighted non-infectious MW	
		kg/week (SD)	kg/bed/day (SD)	%	kg/week (SD)	kg/bed/day (SD)
RH	415	665.24 (71.598)	0.229 (0.181)	12.0	4880.13 (159.085)	1.678 (0.383)
PPH	55	892.80 (81.755)	2.319 (0.796)	89.1	181.60 (24.425)	0.472 (0.483)
GDH ₁	69	339.45 (20.551)	0.703 (0.298)	63.8	192.31 (21.989)	0.398 (0.319)
GDH ₂	109	302.67 (21.503)	0.397 (0.197)	54.0	258.20 (142.600)	0.338 (0.262)
GH	409	3184.40 (129.165)	1.112 (0.316)	82.4	678.95 (26.025)	0.237 (0.506)
MH	120	795.24 (39.741)	0.947 (0.331)	79.0	211.10 (8.000)	0.251 (0.066)
Total		6179.80	5.707		6402.29	1.374

SD: Standard deviation; No.: number, MW: medical waste, kg: kilogram, RH: regional hospital, PPH: public-private hospital, GDH₁: government district hospital one, GDH₂: government district hospital two, GH: general hospital, MH: mission hospital, HF: healthcare facilities

Among all the six HF assessed, the RH recorded 12% infectious MW, almost 7 times less than the GH (82.4%) infectious MW, meaning that the MW generated in RH were better segregated, when compared with GH. The generation of estimated infectious MW in kg/bed/day was very high, with the PPH corresponding to 2.319 kg/bed/day, followed by the GH with 1.112 kg/bed/day. The two GDH, i.e. GDH₁ and GDH₂, recorded 0.703 kg/bed/day and 0.397 kg/bed/day, respectively. The estimated infectious MW in RH or the referral hospital was recorded as 0.229 kg/bed/day, the least among the six researched HF.

Table 2 shows the number of patients that attended each facility within the week, and the estimated MW produced. Table 2 also indicates the weighted incinerator bottom ash obtained from combusting the infectious MW generated at some of the six assessed HF. From the data presented in Table 2, it can be observed that the quantity of MW increased with the number of patients, except for PPH, which did not follow that pattern. The highest weighted MW of 5.03 tonnes was recorded in RH, corresponding to a patients' attendance of 5,900 within the studied period, followed by 3.50 tonnes of MW, generated by 3,270 patients in GH. An estimated 0.93 tonnes of MW and 0.97 tonnes of MW were recorded in the MH and PPH, respectively, corresponding to 1,444 patients in MH and 978 patients in PPH, contributing to the weighted MW in the HF. The MW being combusted and presented in Table 2, was reduced to a minimum. The estimated MW in the incinerator reduced the waste to less than six times the original MW.

Parameters influencing MW

A high degree of correlation is confirmed through the value of R (0.999). Through R^2 , it is verified that the MW generation is explained in 99.8% by the model. On the other hand, the significance value found ($p < 0.005$) shows that the model significantly predicts MW generation, being well adjusted to the data. Furthermore, the Durbin–Watson test value (1.965) is within the range of 1.5 to 2.5, expressing the absence of autocorrelation.

Table 3 describes significant predictors regarding hospital size, the number of out-patients/day, and infectious MW in kg/bed/day with the amount of MW generated.

Handling of MW in HF

Table 4 indicates observations made in the HF for handling MW during the study. Three of the studied HF used technological treatment equipment such as incinerators and autoclaves to handle the MW before disposal. The other three had no specialised equipment. GH and PPH, representing 33.3% of the studied HF, treated infectious

Table 2. HF with the number of patients and the estimated MW.

Type	RH	GH	PPH	GDH ₁	GDH ₂	MH
No. of Patients	5900	3270	978	1163	641	1444
Estimated MW (tonnes)	5.03	3.50	0.97	0.51	0.48	0.91
Treated infectious MW (tonnes)	0.60	2.89	0.81	0.31	0.27	0.72
Estimated bottom ash (tonnes)		0.27	0.07			

Notes: MW: medical waste, RH: regional hospital, GH: general hospital, PPH: public-private hospital, GDH₁: government district hospital one, GDH₂: government district hospital two, MH: mission hospital

Table 3. Significant predictors regarding hospital size and number of outpatients/day.

Model 1	Unstandardised Coefficients			Standardised Coefficients			95.0% Confidence Interval for B	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	
(Constant)	-226.397	159.236		-1.422	0.291	-911.532	458.739	
Infectious MW (kg/bed/day)	260.516	89.061	0.092	2.925	0.100	-122.683	643.716	
No. of outpatients/day	5.237	0.536	0.670	9.763	0.010	2.929	7.545	
Hospital size	1576.061	264.032	0.387	5.969	0.027	440.023	2712.100	

Notes: $R = 0.999$; $R^2 = 0.998$; $R^2_a = 0.996$; $F = 438.262$; $p < 0.05$; Durbin-Watson = 1.965. R : correlation coefficient R^2_a : adjusted correlation coefficient; F : change statistics, No.: number, B: unstandardised coefficient, Sig.: significant value.

b. Parameters: Hospital size, Infectious MW (kg/bed/day), No. of outpatients/day

Table 4. Equipment used to handle medical waste in the studied HF.

HF	Equipment	Remarks
RH	Autoclave	MW is well segregated. The infectious MW is treated in an autoclave (steam steriliser) before disposal.
GH	Incinerator	MW is not properly segregated. The infectious MW is combusted in a controlled chamber. The bottom ash obtained from the incinerated after the burning is weighted before disposal.
PPH	Incinerator	MW waste is inadequately segregated. Infectious MW is burnt in a controlled chamber. The bottom ash generated after combustion is estimated before disposal.
GDH ₂	No treatment equipment	The infectious and the non-infectious MW are sent to a dumping site closer to the hospital for uncontrolled combustion (opened burning). MW waste is also not well segregated.
GDH ₁	No treatment equipment	MW is not segregated. Both infectious and non-infectious MW is dumped closer to the HF. This makes it possible for stray animals and other insects to access the generated MW.
MH	No treatment equipment	MW collected is sent to landfills by the waste management company for disposal. HF had a new incinerator but it was not in use during the observational period.

HF: healthcare facilities, RH: regional hospital, GH: general hospital, PPH: public-private hospital, GDH₁: government district hospital one, GDH₂: government district hospital two, MH: mission hospital.

MW with incinerator equipment. RH uses autoclave equipment to treat infectious MW generated in the HF. The remaining HF, namely GDH₁, GDH₂, and MH, representing 50% of all HFs, have no equipment for treating MW. Out of the 50% of the HF without the technological treatment equipment for waste treatment, 33% (GDH₁ and GDH₂) practise uncontrolled open burning and dumping. MH dispose of the MW at landfills.

The use of technological equipment such as the autoclave and the incinerator in the treatment of the MW is intended to eliminate all pathogens and harmful microorganisms from the infectious MW and make it safe for handling and disposal. The presence of pathogens in the infectious MW could transmit diseases such as cholera, tetanus and skin infections [47]. Further, the toxic chemical content of MW could contaminate the environment [48,49]. In addition to eliminating pathogens from infectious MW, the incinerator also reduces the MW to ashes through the combustion process, drastically reducing the waste volume. Therefore, without technological equipment for the treatment of MW, the MW generated in HF, i.e. GDH₁, GDH₂, and MH, can represent a potential risk owing to the infectious content of MW for easy transmission of pathogens to people and the environment.

Uncontrolled MW disposal sites and impacts

Some HF lack appropriate technological treatment methods for handling MW, e.g. incineration, steam sterilisation (autoclave), or microwaving, and radiowaving. The researchers in this study found that the HF with no MW technology used uncontrolled methods of open burning and dumping. Both infectious MW and non-infectious MW were either burnt or dumped near the HF. In HF with uncontrolled MW handling, an estimated 0.51 tonnes (4.5%) and 0.48 tonnes (4.2%) MW were burnt and dumped within the studied week, respectively. The infectious and toxic chemical content in the MW could transmit diseases to the population and contaminate the environment. Additionally, with the exception of RH, none of the studied HF has a weighing scale to determine the produced MW.

Discussion

Managing MW is a subject of great concern in SSA, particularly in Ghana. According to Bucătaru et al. [50], any deficiencies in managing MW in HF could result in the release of harmful microorganisms into the environment and transmission of diseases. Hence, to contribute to current evidence on MW management in Ghana, the estimated waste generation in the six selected HF was assessed and discussed.

HF and medical waste production

A total 11.41 tonnes of MW were produced at the six assessed HF, consisting of an estimated amount of infectious MW of 5.61 tonnes and an amount of non-infectious MW estimated as 5.81 tonnes, representing 49.1% and 50.9%, respectively. These estimated infectious and non-infectious MW results were similar to those obtained in the study conducted by Oduro-Kwarteng et al. [2] in Kumasi, Ghana, in seven HF, where 50.35% of the total generated MW was non-infectious or general MW and 49.65% represented infectious MW. A study by Debere et al. [51] in hospitals in Addis Ababa, Ethiopia, reported that generated infectious MW exceeded 41%. The 49.1% infectious MW and 50.9% general or non-infectious MW values obtained in the current study far exceed the WHO [9] recommended categorisation of 15% infectious MW and below 85% of non-infectious or general MW, respectively. The high values of the estimated infectious MW in almost all the six assessed HF result from HF that do not segregate the generated MW. The results in the present study confirm those obtained by Padmanabhan & Barik [52] on the classification and quantification of infectious MW in developing countries. The same authors reported that MW is often not separated into infectious and non-infectious MW in low-income and middle-income countries, resulting in a higher quantity of infectious MW than the 15% WHO [9] level for developing countries. In the current study, the infectious MW ranged from 0.23 to 2.34 kg/bed/day in the six studied HF ($M = 0.95$ kg/bed/day), similar to the study by Bendjoudi et al. [53], on Algeria, in which the average infectious MW was 0.96 kg/bed/day. The range of infectious MW production obtained in the current study falls within the estimated infectious MW of specific African countries such as Nigeria, Libya, Ethiopia, Tunisia, Cameroon, Morocco, Sudan, Tanzania, Egypt and Mauritius [29].

This study showed that RH produced the lowest average infectious MW of 0.23 kg/bed/day among the six studied HF. This estimated infectious MW complies with the reported amount of infectious MW from middle and low-income countries [9,52], corresponding to only 4% of the entire infectious MW generated in kg/bed/day and 12% from the total MW generated in the six studied HF. In the researched HF, PPH produced an estimated infectious MW of 2.32 kg/bed/day (40.6%), followed by GH (1.11 kg/bed/day) representing 19.5%. Moreover, the two GDH, i.e. GDH₁ and GDH₂, generated 0.70 kg/bed/day and 0.40 kg/bed/day infectious MW, respectively, with MH generating 0.95 kg/bed/day of the infectious MW, corresponding to 16.7% in the six HF.

Furthermore, this study indicated that GH had more infectious MW than the MH, GDH₁, and GDH₂, probably because the GH is a bigger HF with many specialist facilities and more patients. RH, with most specialist departments, serves as a referral centre for

GDH₁, GDH₂, PPH, MH, and other hospitals within Eastern Region, Ghana, and has the least infectious MW in kg/bed/day among the studied HF. The high estimated infectious MW generation by GDH₁, GDH₂, PPH, and MH in HF could result from the hospital's activities, which might be similar to RH and GH in HF. From the analysis of the MW generated, it can be stated that the smaller HF were not correctly managing MW. Accordingly, MW was not correctly segregated before disposal. This is common in most SSA countries [54]. The incorrect segregation of the MW in the HF could result from a lack of equipment such as coloured waste bins in most of the studied HF, as well as lack of environmental awareness. The non-segregated MW in HF could spread infectious disease to patients, waste handlers, health care staff and the general visitors in HF. Among the studied HF, GH and PPH used incineration technology to process MW before disposal. MW generated in those HF were not correctly segregated. Although total MW in RH corresponded to 5.03 tonnes, only 0.60 tonnes (12%) of infectious MW were treated using autoclave technology. At the same time, GH and PPH incinerated 2.88 (82.4%) and 0.81 tonnes (83.2%) of infectious MW using an incinerator technology, respectively, out of 3.50 tonnes of MW from GH and 0.97 tonnes of MW from PPH. In the studied HF, 66% of infectious MW generated were handled using incineration equipment. Thus, from this study, the volume of the infectious MW in GH and PPH was reduced to a range of 80% – 90% using the incinerator, which serves the purpose of minimising solid waste, including MW [55].

Size of the HF, number of outpatients/day, and infectious waste/bed/day

The generation of MW can be associated to interrelated factors such as infectious MW in kg/bed/day, the number of outpatients/day, and hospital size, as mentioned before. Table 3, representing the multivariate linear regression model applied to MW, shows the predicted parameters that influenced the estimated MW generated at the HF. The MW generated from the medical centres was significantly associated with the size of the HF, the number of outpatients/day at the HF, and non-significantly associated with the estimated infectious MW/bed/day. This is in agreement with a similar multiple linear regression study on MW management in HF in Lagos, Nigeria, by Idowu et al. [33], who found that the size of the HF and the number of patients contribute to the generated MW.

In the current study, the evidence makes clear that the number of outpatients/day contributed to the prediction of MW generated in the studied HF. The value of B, which is 5.237 (Table 3), indicates that for every unit increase of outpatient/day, the quantity of MW rises by 5.237 kg, with hospital size being held constant. Since the evidence suggested that hospital size contributed to the prediction of MW generation, the value of B (1576.061) (Table 3) explains that MW is estimated to increase by 1576.061 kg for every additional unit of hospital size, with the number of outpatients/day being held constant. Therefore, the increase in the number of outpatients and hospital size could increase the amount of MW generated. When the MW is not segregated at the source, the estimated infectious MW will also be increased. The analysis in Tables 2 and 3 establish the fact that there is a significant association between the estimated MW generated from the

HF, the number of outpatients/day, and the size of HF, as expected. Therefore, any HF could use these findings to predict the generated MW amounts and to plan guidelines for future MW disposal budgets, assisting in sustainable MW management practices in SSA.

Improper MW disposal and impacts on health and environment

Although MW is harmful, value can be added for recovery, which most HF within SSA, including Ghana, have not yet fully explored. In this study, 33.3% of the selected HF used incineration, and 16.7% used autoclaving in MW treatment. But, 50% of the HF practised open burning and dumping, which can negatively impact the environment and human health [56]. This uncontrolled combustion and dumping of MW can transmit diseases caused by microorganisms from the infectious MW and pollute the environment. This is the common practice in most developing countries, especially in SSA countries such as South Africa [57,58], Nigeria [59], Ethiopia [60] or Myanmar [61], in Asia. During the uncontrolled open burning of MW, air pollutants like carbon monoxide (CO), nitrogen dioxide (NO₂), and sulphur dioxide (SO₂) are released and mixed with other pollutants, with a risk of respiratory health problems [62,63]. It was also observed that the MW dumped at the open space near the studied HF served as a source for flies, rodents and all types of insects. In fact, dumping sites could result in foul odour, water and land pollution, and mosquito breeding points [64], if not properly managed. They can lead to parasitic infections, meningitis, skin infections, respiratory diseases and bacteraemia [9], common in developing countries. It also became clear that as people moved towards the untreated MW dumping site, they were exposed to irritants of skin and eyes.

Another observation during the study was the uncontrolled open burning and dumping of the MW included materials like polyethylene, polyester, wraps, covers, aprons and discarded nose-covers, that could affect public health and the environment. The burning and dumping of these materials release toxic chemicals carrying risks to heart and lung function when inhaled, and contaminating the soil. Since managing MW in developing countries, mostly within SSA, is challenging, the high capacity for cross-contamination and degradation of these materials could negatively impact human health [49].

The prominence of uncontrolled open dumping and burning of MW in the studied HF shows that need for segregation of MW at the source and potential recycling of some of it is not well understood in Ghana. This can be explained by lack of education and awareness, lack of financial resources and tolerance of existing poor management practices [65]. The problem of MW management in HF must be confronted. The Millennium Development Goals cannot be reached otherwise.

MW management recommendations

Proper waste management must address the whole cycle, from generation to disposal, to reduce the risk that this MW poses to the ecosystem and human health. This means waste prevention, minimisation, reuse, recycling, recovery and disposal, which will help protect the environment and human health. This study has indicated a high estimated ratio of infectious MW, resulting from poor collection and inadequate segregation of waste at the source. Within the studied HF, MW must be segregated by the generators, correctly collected, stored, and then transported for treatment before final disposal, eventually at

landfills: the general outcome in SSA. As seen above, the multivariate regression analysis estimated that MW greatly depends on the number of outpatients/day and the type or size of the HF under study. Therefore, budget planners of MW management in HF could use these findings as a guide for adequate MW management planning in SSA, particularly in Ghana.

Although burning MW is less expensive, the air pollutants and ashes produced during the burning negatively impact the health of populations and the environment [66]. The improper management of the MW in SSA can be improved by introducing adequate waste treatment technology processes such as microwaving and steam sterilisation (i.e. autoclaving) or incinerators in the HF. These options are costly. They might require government or social entrepreneurs to help equip most of the facilities. The fundamental need for proper MW management in HF is correct segregation at source, observing the similarity characteristics, and the potential for cross-contamination between waste streams in order to facilitate recycling and reuse, followed by the use of proper handling technological equipment such as steam steriliser, microwave and modern incinerators.

Conclusions

MW from HF releases pathogens and toxic pollutants into the environment and could become a potential risk to the environment and public health, when not adequately managed. Hence, it is essential to know the main contributing factors of MW to estimate and manage it accurately from the generation point until disposal. This study found that 11.41 tonnes of MW generated from the six selected HF mainly depends on the number of outpatients/day and the size of the HF, the main parameters influencing MW generation at the studied HF. The RH and GH, large HF, contributed to 68.4% of the number of outpatients and about 73% of the estimated MW. Although the studied HF produced 49.1% infectious MW, most of this MW was generated within the HF using incinerators as the combustion method for the MW treatment before final disposal. This is because the HF with incinerators poorly segregated the MW, when compared with the HF with an autoclave. The 33% of the HF that had no MW technology to process the infectious MW before disposal, i.e. GDH₁ and GDH₂, resulted in uncontrolled waste, open burning and dumping of the MW close to the HF. Because of the environmental health problems such as skin infection, cholera, parasitic infection and spread of viral illnesses associated with improper management of MW, MW must be segregated appropriately, collected, transported, treated and disposed with appropriate technology.

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CHAPTER V - Chemical characteristics of bottom ash from biomedical waste incinerators in Ghana

This chapter sought to respond to the thesis objective by analysing the level of pollutants in the BA of the incinerated BMW using X-ray fluorescence spectrometry (XRF) and atomic absorption spectroscopy (AAS) techniques to determine heavy metals and the oxides in the ash. Due to the hazardous nature of heavy metals in the analysed BA samples resulting from improper handling of BMW, BA must be appropriately disposed of to prevent leachate of heavy metal ions from reducing its effect on the environment and public health towards the accomplishment of UN 2030 SDGs. These SDGs include improved health (SDG 3), clean sanitation (SDG 6), better climate change (SDG 13), healthy life in water (SDG 14) and good life on land (SDG 15).

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Chemical characteristics of bottom ash from biomedical waste incinerators in Ghana

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Abstract Biomedical waste (BMW) incineration is the most used alternative disposal method in developing countries, such as Ghana. The improper disposal of incinerator-generated bottom ash (BA) is a significant concern due to the hazardous nature of waste. A study was conducted at Tema Hospital (TGH) and Asuogyaman Hospital (VRAH) incinerator sites. The BA samples were sent to the Council for Scientific and Industrial Research, Institute of Industrial Research, Ghana. The BA samples were weighed with fisher analytical balance, ground, and sieved with standard grade meshes of 120, 100, and 80 to determine the BA particle size distribution. The chemical composition and heavy metals were analysed using X-ray fluorescence spectrometry (XRF) and atomic absorption spectroscopy (AAS) techniques. The results indicated the chemical composition of the analysed BA samples was CaCO_3 (49.90%), CaO (27.96%) and MgCO_3 (6.02%) for TGH and CaCO_3 (48.30%), CaO (27.07%), and SiO_2 (6.10%) for VRAH, respectively. The mean concentration (M) (kg m^{-3}) and standard deviation (SD) for

TGH in the BA were 7.082 ± 0.478 (Ti), 4.657 ± 0.127 (Zn) and 4.271 ± 1.263 (Fe), while that of VRAH consisted of 10.469 ± 1.588 (Ti), 7.896 ± 2.154 (Fe) and 4.389 ± 0.371 (Zn). Therefore, the heavy metals' mean concentration at the BA is above the WHO permissible limits of soil, i.e., 0.056 kg m^{-3} (Ti), 0.085 kg m^{-3} (Pb), 0.100 kg m^{-3} (Cr) and 0.036 kg m^{-3} (Cu). Furthermore, the heavy metal mean concentrations of TGH and VRAH present in the BA analysed samples were ranked in descending order: $\text{Ti} > \text{Zn} > \text{Fe}$ and $\text{Ti} > \text{Fe} > \text{Zn}$, respectively. It is therefore recommended that BA must be properly disposed of because of the hazardous nature of heavy metals present in the analysed samples, which are able to cause environmental and public health issues.

Keywords Biomedical waste (BMW) · Incinerator · Bottom ash (BA) · Heavy metal · Ghana

Introduction

The recent population growth and the outbreak of diseases such as the Ebola virus, severe acute respiratory syndrome (SARS), coronavirus disease of 2019 (COVID-19) and other illnesses (Bucătaru et al., 2021) have significantly increased medical activities globally. Unfortunately, medical activities have also contributed to the rising generation of biomedical waste (BMW), making it difficult to be managed (Olaniy et al., 2018; Chisholm et al., 2021), especially

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in developing countries such as Ghana (Debrah et al., 2022b, d, e). Improper handling of BMW contributes to the rising volume of infectious BMW. In sub-Saharan Africa (SSA), for instance, in Addis Ababa, Ethiopia, health facilities generate about 41% of infectious BMW (Debere et al., 2013). A study by Oli et al. (2016) also revealed that more than 40% of infectious BMW is generated in Southeast Nigeria health facilities. Infectious BMWs (49.1%) are generated in six selected healthcare facilities in Eastern and Greater Accra regions (Debrah et al., 2021a), and 49.6% infectious BMW is generated in health facilities in Kumasi (Oduro-Kwarteng et al., 2021), in Ghana. These values are higher than the recommended 15% limit by the World Health Organization (WHO, 2018), to 35–50% (Debere et al., 2013; Debrah et al., 2021a; Oduro-Kwarteng et al., 2021; Oli et al., 2016).

This could adversely affect the environment and public health through uncontrollable disposals, like dumping in the open space and pit burning (Debrah et al., 2021a, b, c; Debrah et al., 2022a, b, c, d, e, f; Leal Filho et al., 2022a), so common in Africa. The improper handling of BMW has hindered achieving of some of the sustainable development goals (SDGs) in most developing countries, specifically good health and well-being (SDG3), clean water and sanitation (SDG6) and climate action (SDG13) (Leal Filho et al., 2022b, c). It is the case in Ghana.

Considering the significant volume of infectious BMW produced by health facilities in SSA countries, the incineration method is currently used to minimize generated BMW and reduce the problems posed by BMW infectious waste (Awodele et al., 2016), negatively impacting the environment (Debrah et al., 2021a). Studies in developing countries have shown that incineration reduces the weight of BMW by more than 70% (Xiao et al., 2018; Zhao et al., 2010) and the volume by 90% (Debrah et al., 2021a; Xiao et al., 2018). After the incineration, significant combustion residues remain in the form of bottom ash (BA). Although BMW incineration disposal is widely used in SSA, its environmental impact has resulted in public health problems caused by gases being released (Rahman & Singh, 2019). A few epidemiological studies in developed countries have shown that incinerator workers/operators and residents closer to incinerators (< 10 km) present diseases related to their work environment. These include laryngeal cancer (Michelozza et al., 1998), gastric cancer (Dockery and Pope III 1994; Rapiti et al., 1997), liver cancers (Elliott

et al., 1996), and urinary mutagen (Landrigan et al., 1987). Other research also indicate that incinerator operators can present a significant level of mercury in their hair (Kurtitio et al., 1998), lead and cadmium in blood (Wrbitzky et al., 1995) and hexachlorobenzene in blood/urine (Angerer et al., 1992). These effects show why some industrialized nations, such as the United States of America (USA), Germany and the Netherlands, have prevented the usage of incinerators in the management of BMW (Abor & Bouwer, 2008). Instead, most countries have opted for the most acceptable alternative available technology to handle BMW, such as microwave, plasma pyrolysis and ionized autoclave, with minimum environmental and fewer health issues (Dharmaraj et al., 2021; Xu et al., 2020; Zhao et al., 2021; Zimmermann, 2018), representing less threat to the environment and human health (Zhao et al., 2021). In developing countries, especially in SSA, these alternative technologies to handle BMW are rare due to financial implications associated with its purchasing and management (Leal Filho et al. 2022d; Dinis et al., 2022; Debrah et al., 2022a). Although current modern incinerators operate within a temperature range of 850–1200 °C, BA containing metals that are non-biodegradable affects the entire ecosystem and human health (Dwivedi et al., 2019; Premkumar et al., 2018; Wei et al., 2021). Recent studies by Agnihotri and Kesari (2019), Tait et al. (2020), and Wallace et al. (2020) revealed that heavy metals such as Cd, Hg and Pb could cause chronic diseases like cancer and long-term neurological conditions, leading to possible morbidity (Bennett et al., 2001; Yang et al., 2020). Also, these and other heavy metals can leach through the soil and contaminate drinking water (Kapoor & Singh, 2021; Mukherjee et al., 2021), which is then absorbed by plants, animals, and other organisms in the food chain (Feng et al., 2020; Manzoor & Sharma, 2019; Sonone et al., 2020). Meanwhile, the accumulated heavy metals cause chronic and acute toxic effects in the various living beings in nature.

In Ghana, BMW disposal equipment has changed from the traditionally built container through open brick (De Montfort) to the current covered brick 6-regulator cylinder gas incinerator. Only a limited number of medical centres have this new 6-regulator cylinder gas incinerator equipment. However, few studies referring to incinerators have addressed the BMW BA in Ghana. For instance, a study by Amfo-Otu et al. (2015) showed that heavy metals such as Pb, Cd, Hg and Cr were found in the BA of a De Montfort-type incinerator, with a concentration of Pb

equal to 147.50 mg/kg. Also, a similar study by Adama et al. (2016) reported the release of Hg, Pb, Zn, Ag, Cr and Cd in the De Montfort incinerator. However, to this study authors' best knowledge, there is not yet a study in Ghana on particle size distribution, the main chemical composition and the concentrations of heavy metals residuals present in the 6-regulator cylinder gas incinerator involving BA.

Therefore, this study aims to assess and determine the significant elements in terms of chemical components found in the BA in two cases: the Tema Hospital (TGH) and the Asuogyaman Hospital (VRAH) in Ghana. The particle size distribution and the concentration of heavy metals present in the BMW BA were obtained from the 6-regulator cylinder gas incinerator in TGH in Greater Accra Region and VRAH in Easter Region, Ghana.

Materials and methods

The BA samples used in this study were collected from TGH and VRAH facilities, with bed capacities of 409 and 55 patients, respectively. TGH and VRAH generate an estimated amount of 1.10 kg/day and 2.30 kg/day of BMW infectious waste, representing an accumulated value of 3.20 tons and 0.90 tons per week, respectively. BAs (0.27 tons and 0.07 tons) were produced every week after the incineration of BMW from TGH and VRAH incinerators. The incinerators used in TGH and VRAH were constructed with bricks and covered with corrugated iron sheets. The walls of the incinerators are composed of three layers to reduce the heat transmissions

during the combustion process. In addition, fibres were placed between the walls and the covered corrugated iron sheets to prevent heat transfer. The incinerators have 2 chambers, a blower with six outlets and a front-loading window with 7 BA outlets. The two chambers operate within a temperature range of 800 ± 50 °C and 1100 ± 50 °C respectively, which is powered by gas from two gas cylinders with six regulators. Infectious BMWs collected from the various wards of TGH and VRAH are loaded directly into the incinerator by the operators and combusted continuously within 2–3 h with a maximum temperature of 800 °C. The BA generated from VRAH is hauled to the landfills, while the TGH is dumped close to the incinerator. Figure 1 shows the incinerators of TGH, VRAH.

Data sources and study period

Qualitative data on the incineration process of BMW in TGH and VRAH were obtained through critical observation and BA analyses. The time frame for the data collection was a month, i.e. March 2021. There was a daily check and observation of the waste type fed into the incinerators and how the BA was disposed of after incineration. In addition, the incinerated BAs were collected and sent to the Council for Scientific and Industrial Research-Institute of Industrial Research (CSIR-IIR), Ghana laboratory, for analysis.

Sampling preparation

Granulated BA samples (0.300 kg) were collected from the VRAH and TGH 6-regulator cylinder gas

Fig. 1 Six-cylinder gas incinerators: (a) front view and (b) cylinder regulators



incinerators every 9 days within March 2021. The collected BA also contained other coarse materials such as glasses, bricks, concretes and heavy metals (Ti, Fe and Cu), resulting from medical bottles and needles in the BMW or used in the construction of the incinerators. The hot BA samples were cooled at room temperature and then dried at 105 °C for 24 h, similar to Bakkali et al. (2013) procedure. Each dried BA sample was ground gradually using laboratory mortar and pestle into smaller particle sizes to allow the exchange between residue phases and the extraction solutions (Bakkali et al., 2013; Guérin, 2000). The grounded BA was sorted into sizes with shaker-fitted standardized grade meshes of 120, 100, and 80. However, within 20 min, the sampled BAs were sieved to the particle size below 125 µm, 125–150 µm and 150–180 µm and above 180 µm.

BA chemical composition

X-ray fluorescence spectrometry analysis

The elemental composition in the BA was determined using X-ray fluorescence (XRF) spectroscopy. Portions of the 0.300 kg prepared bottom ash sample of TGH and VRAH were pressed into a cake. The chemical components of the BA were qualitatively analysed using S2 Ranger Energy Dispersive equipment to determine the unknown elements.

Heavy metal analysis

Before heavy metals were analysed using the SP-IAA320 Atomic Absorption Spectrophotometer (AAS)

model, with a range of 190–900 nm and an accuracy level of $\leq \pm 0.5$ nm, the laboratory was thoroughly cleaned to eliminate possible contamination affecting the results. Dried sample (0.001 kg) was transferred into a round-bottom flask with 10 cm³ HNO₃, evaporated over 1 h on a hot plate. The residue obtained from the evaporated mixture was digested with concentrated HNO₃ and HClO₄ in the ratio of 3:1 for 10–15 min at 25 °C. The digested mixture was steadily heated at 300 °C for about 120 min on a hot plate until all HClO₄ gases evaporated. The mixture was allowed to cool at 25 °C and then filtered with Whatman No. 42 filter paper. The filtrate was kept in a 0.001 m³ well-labelled polyethylene bottle, ready to be analysed. The same procedure was carried out with estimated trace metals recorded and analysed with the ASS.

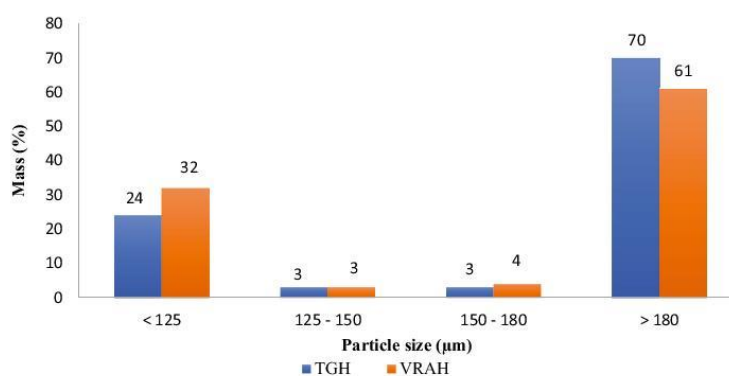
Results and discussion

Particle size distribution

The sieved particle size distribution of BA from TGH and VRAH is shown in Fig. 2. Most BA particles in this study were found above 180 µm and below 125 µm. This could result from the treatment of the sample, such as grinding or quantity of grounded sample on the sieve surface.

Figure 2 shows that the mass percentage of the particle size above 180 µm of VRAH is reduced by 9% of the total 70% TGH BA sample. The difference in the percentage might be due to the high content of the glass, ceramics, and other materials found in TGH BMW incinerated. The mass percentage content of

Fig. 2 BA samples particle size distribution in the VRAH and TGH incinerators



the BA particles decreases with the particle size, from 180 to 125 μm . Below 125 μm , VRAH mass percentage particles increased by 12% (34% of the VRAH mass samples and 24% TGH particle mass sample) due to the high content of the heavy metals present in VRAH BA. The particle size distribution of this study is similar to a study by Yu et al. (2013), which was carried out in China, but opposite to a study conducted by Bakkali et al. (2013) in Rabat, Morocco.

Chemical composition of BA samples analysed by XRF

XRF analysis is the main technique used to determine the status of BA elements of BMW. The composition of determinant elements depends on the toxicity of the waste in the incinerator (Bakalár et al., 2021; Li et al., 2004), furnace type, and gas velocity (Chang et al., 2009). Table 1 presents the chemical composition of the oxides obtained from XRF analysis samples of TGH and VRAH incinerators. The results obtained show that each BA analysed sample contains a higher percentage of CaCO_3 than all the remaining oxides. For TGH, the main BA elements consist of CaCO_3 (49.90%), CaO (27.96%), MgCO_3 (6.02%), MgO (2.87%), SO_3 (2.34%) and SO_4 (2.80%), while the main components of VRAH are constituted by CaCO_3

(48.30%), CaO (27.07%), SiO_2 (6.10%), MgCO_3 (6.12%), MgO (2.93%) and Al_2O_3 (3.74%). The high percentages of the oxides from TGH and VRAH BA samples show that most of the BMW incinerated include domestic waste, which emphasizes the need to proper segregation at the source.

Although BA contains CaCO_3 , its high content in this study, with a mean of 49%, may be due to the presence of papers in incinerating BMW (Chang et al., 2017). It could also be due to the presence of the marbles in constructing the incinerator (de Oliveira et al., 2021; Hashimoto et al., 2017; Krajewska, 2018) and possibly through the use of CaCO_3 dietary supplements in the form of medication by patients (Salomão et al., 2017; Zhai et al., 2018). According to Schabel et al. (2014), He and Liu (2017) and Indriati et al. (2020), CaCO_3 is used as a filler in paper production to ensure the brightness of the paper. The analysis of the BA from these researched hospitals indicated a silicon/calcium (Si/Ca) ratio of 8.64:55.03 and <0.3 , which is far less than a study conducted by Li et al. (2004) and Bakkali et al. (2013) in China and Morocco, with Si/Ca ratio of 3 and 5, respectively. Therefore, the Si/Ca ratio indicates the content of generated non-infectious waste within a BMW. This study's 0.3 Si/Ca ratio revealed that BMW generated from the TGH and VRAH was not adequately segregated.

The laboratory analysis from the TGH and VRAH incinerators showed mixed results of oxide compositions. This could be attributed to the size of the hospital, the area situated and the nature of activities performed by each hospital (Christiana & Anushree, 2021). In this study, the level of SO_4 and SO_3 in TGH BA was greater than that of VRAH, oppositely for K_2O . The content of SO_3 can be due to the presence of papers, food waste, plastics, leather mix, rubber, textile, wood, glass, ceramics and metals, which remains residual in BA (Kaiser, 1968). Nevertheless, a higher concentration of SO_3 in BA will be problematic since it converts into SO_4 at temperatures below 500 $^\circ\text{C}$, becoming corrosive (Hardman & Stacy, 1998; Jaworowski & Mack, 1979; Marier & Dibbs, 1974; Sarbassov et al., 2017).

BA heavy metal detection in TGH and VRAH incinerators

Heavy metals such as Zn, Pb, Cr, Ni, Cu and Cd are primarily used to manufacture or coat medical tools and photographic (Bakkali et al., 2013) due to their resistance to corrosion and antibacterial surface factor.

Table 1 BA content obtained by the X-ray fluorescence spectrometry

Incinerator chemical composition		
Oxides	TGH sample (%)	VRAH sample (%)
MgO	2.87	2.93
Al_2O_3	2.04	3.74
SiO_2	2.54	6.10
P_2O_5	1.14	1.01
SO_4	2.80	0.98
SO_3	2.34	0.81
K_2O	1.01	0.74
CaO	27.96	27.07
TiO_2	0.82	1.28
Fe_2O_3	0.42	0.83
MgCO_3	6.02	6.12
CaCO_3	49.90	48.30
Others	0.14	0.09

TGH Tema hospital, VRAH Asuogyaman hospital, % percentage

The results in Table 2 indicate the heavy metal concentration of the BA samples in TGH and VRAH. Even though TGH and VRAH BA samples showed different mean (*M*) and standard deviation (*SD*) concentrations, both had an amount of Ti, Cr, Mn, Fe, Ni, Cu, Zn and Pb. The mean concentrations of Ti, Fe and Cu heavy metals in VRAH BA were higher than in TGH BA, while Cr, Mn and Ni were opposite. The difference in the mean concentrations of the BAs from TGH and VRAH could be attributed to improper waste segregation, since coloured plastic materials in BMW contain heavy metals (Tufail, 2008). The results from the analysis for TGH and VRAH indicate that Ti has the highest value, $7.082 \pm 0.478 \text{ kg m}^{-3}$ and $10.469 \pm 1.588 \text{ kg m}^{-3}$. Ni has the least $0.030 \pm 0.021 \text{ kg m}^{-3}$ and $0.025 \pm 0.011 \text{ kg m}^{-3}$ for TGH and VRAH, respectively. The mean concentrations of TGH and VRAH heavy metals as ranked in order of descending are as follows: $\text{Ti} > \text{Zn} > \text{Fe} > \text{Cr} > \text{Pb} > \text{Mn} > \text{Cu} > \text{Ni}$ and $\text{Ti} > \text{Fe} > \text{Zn} > \text{Cu} > \text{Mn} > \text{Pb} > \text{Cr} > \text{Ni}$. Heavy metals such as Fe, Zn and Cu are essential to humans but become poisonous in high concentrations. Pb and Cr heavy metals are hazardous and have a high negative effect on humans (Tchounwou et al., 2012). The order raking of the heavy metals in TGH and

VRAH BA indicates that TGH BA is more toxic than VRAH.

This study allowed to obtain higher mean concentrations of Ti, Fe and Zn in TGH and VRAH, similar to a study conducted in China on pollutants of BMW BA (Zhao et al., 2010). The higher concentration of Ti, Fe and Zn in BA is because they are widely used as metal alloys in medical equipment (Dehghan-Manshadi et al., 2020; Hernández-Escobar et al., 2019; Kazemi et al., 2020). However, due to their high melting point, above the temperature used in incinerators, Ti and Fe tend to be present in BA.

Some metals found in BA could contain toxic contaminants that can be persistent in the environment (such as Pb, Ni, Cu and Cr) (Kumar et al., 2021; Thuy et al., 2021), negatively impacting it (Andreola et al., 2019; Lemly, 2018; Manzoor & Sharma, 2019; Yin et al., 2020). The mean concentration of Ti, Cr, Cu and Mn and Pb released from TGH BA and VRAH BA exceeded the WHO permissible limits of heavy metals in soil, including Fe from VRAH BA, as shown in Table 2. Due to its high content of heavy metals, the improper disposal of this BA could negatively impact the environment and public health. Each heavy metal has different properties and impacts, in terms of human health effects. As example, the exposure to high concentrations of Ti contained in BA samples could cause coughing, tightness and chest pains (Lenntech, 2022). Zn and Fe present in the BA may cause nausea, vomiting and anaemia (Kim et al., 2019; Njoku et al., 2020; Saria, 2016).

As seen by the results being presented, the disposal of BA resulting from BMW incineration needs to be properly addressed since the resulting BA can threaten ecosystems and humans. The heavy metal component in the BA can leach out into water bodies, groundwater and soil, polluting the environment and possibly causing cancer respiratory and other issues severely affecting human health (Mozhi et al., 2022; Munawar, 2018).

Table 2 Heavy metal concentration ($M \pm SD$) in BA samples from TGH and VRAH incinerator

Heavy metal	TGH $M \pm SD$ (kg m^{-3})	VRAH $M \pm SD$ (kg m^{-3})	WHO permissible value soil content ^b (kg m^{-3})
Ti	7.082 ± 0.478	10.469 ± 1.588	0.056
Cr	0.676 ± 0.162^a	0.169 ± 0.028	0.100
Mn	0.321 ± 0.033	0.265 ± 0.015	0.012
Fe	4.271 ± 1.263	7.896 ± 2.154	5.000
Ni	0.030 ± 0.021	0.025 ± 0.011	0.035
Cu	0.083 ± 0.005	0.292 ± 0.057^a	0.036
Zn	4.657 ± 0.127	4.389 ± 0.371	0.050
Pb	0.477 ± 0.020	0.243 ± 0.033	0.085

1Kg m^{-3} = 1000 ppm

BA bottom ash, TGH Tema hospital, VRAH Asuogyaman hospital, *M* mean concentration, *SD* standard deviation

^aValue: middle data

^bWHO permissible limit (International Programme on Chemical Safety 1982; Anjali et al., 2018; Osobamiro et al., 2019; Ullah et al., 2022)

Conclusions

When improperly handled and inadequately disposed, BMW generated from diagnostics centres, health-care centres, blood banks, research institutions and

laboratories are hazardous and negatively impact the environment and public health. In SSA countries in particular, and also in Ghana, BMW is primarily incinerated. Although this incineration process reduces the volume and weight of BMW, it also produces BA that contains heavy metals and oxides, toxic to human health and the environment. Departing from the analysis of the results from this study, involving XRF and ASS techniques, the results from this study using BA from two healthcare facilities in Ghana, i.e. TGH and VRAH, revealed that the BA generated by the BMW incinerators from both healthcare facilities contains high concentration of significant non-hazardous waste containing CaCO_3 , CaO , SiO_2 , MgCO_3 , MgO , SO_3 and Al_2O_3 in the incinerated BMW, resulting from materials used in the construction and domestic waste such as food waste, ceramics, plastics and papers. These values can be reduced if proper segregation is addressed prior to incineration. High concentrations of heavy metals, specifically Ti, Fe, Zn, Pb, Cu, Mn and Cr, were found in both incinerators, above WHO permissible soil limits, except Ni. In both TGH and VRAH incinerators, Ti heavy metal was the highest by-product in the BA, corresponding to $7.082 \pm 0.478 \text{ kg m}^{-3}$ and $10.469 \pm 1.588 \text{ kg m}^{-3}$, respectively, in TGH and VRAH. Ti is one of the most hazardous heavy metals, negatively impacting the environment and human health.

From the results obtained in this study, it is concluded that improper disposal of BA from incinerators may pollute the environment and water bodies through leachate, leading to possible health implications such as respiratory diseases and cancers, while also negatively impacting the environment. Ensuring proper disposal of BA through sanitary landfills may contribute to minimize the heavy metals and hazardous components in the environment, also protecting the human health. The advance of specific SDGs, such as SDG3, 6, and 13, strongly depend on actions aimed at contributing to better handling of waste in Africa. Accordingly, this study is of fundamental importance in Ghana, a developing country that needs to focus on environmental issues that also benefit human health. It represents a contribution to fulfil the gap of knowledge at this respect and the scarcity of studies in the SSA region.

Limitations and future studies

This study was conducted at a time when COVID-19 pandemic in Ghana was rising, and the selected hospitals were assigned as COVID-19 centres. The authors were unable to sort and classify BMW waste before being incinerated. Therefore, future studies must attempt to classify the types of BMW waste incinerated, as well as to analyse the percentage of limestone present in the BA of the incinerators, possibly used for binding materials.

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Data availability The datasets analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval All the authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the article is submitted.

Competing interests The authors declare no competing interests.

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DISCUSSION

Developing countries have significant challenges relating to several aspects of the UN SDGs by 2030 agenda, and proper handling and management of waste is of one of particular significance because it has implications in almost every SDG. The absence of infrastructure (Castellani et al., 2022; **Debrah** et al., 2022b; Kanwal et al., 2022), lack of enforcement regulations (Kouam & Asongu, 2022; Ogutu et al., 2021), and policy frameworks (Ghosh et al., 2022; Hannan et al., 2020) in waste management within developing countries is affecting the achievement of SDGs. Proper handling and managing of waste such as BMW through segregation, reduces and prevents waste generation (Adeobu et al., 2022; Dehal et al., 2022), minimises transmission of diseases, contributes to the quality of health SDG 3, prevents dumping waste in opened landfills, and improves water and sanitation SDG 6. Proper handling and managing of BMW again minimise leachate of heavy metals into water bodies and uncontrollable burning of waste to reduce the negative effect of climate change and the impact on earth SDG 13 to 15 and influence environmental sustainability and development. Therefore, this discussion highlights the relevant aspect of this thesis and how it contributes towards advancing the SDGs for sustainable development in SSA, with Ghana as the focus of the study.

Waste management, especially BMW, is a significant issue in SSA countries (**Debrah** et al., 2021b; Tirkolaei et al., 2021), with Ghana being no exception (Arimiyaw et al., 2021; **Debrah** et al., 2021a, 2022). Given that, one of the objectives of this thesis, is to investigate the nature and process of BMW management and practice and examine how BMW is stored temporally and disposed of in Ghana. Chapter four of this thesis draws attention to the fact that there are flaws or deficiencies in the handling of BMW from sorting through to storage, that is, segregation, collection, transportation and storage in the selected HF, which resulted in a rise in the volume of infectious BMW generation (Dharmaraj et al., 2021; Saini et al., 2022), hindering the achievement of SDGs 3, 6 and 13 by 2030. The six studied HF generated 11.42 tonnes of BMW between March to May

2021, of which 5.61 tonnes was infectious, with a rate of 0.95 kg/bed/day, exceeding the 0.2 kg/bed/day recommended by WHO (2018) for SSA countries. The poor handling process of BMW found in this study is similar to studies by Olaniyi et al. (2018) in South Africa, Agbere et al. (2021) in Togo and Akpan & Olukanni (2020) in Nigeria in SSA and Chand et al. (2021) in India, and Hani & Sarfaraz (2021) in Pakistan, Asia. This, therefore, poses a global threat to the environment and human health that could delay the achievement of SDGs 3, 6, 13 to 15.

To ensure this problem is minimised in Ghana and other SSA countries, this thesis suggests a holistic approach to BMW management, i.e., the provision of logistics and infrastructure in managing and handling BMW. This could transform BMW circularly (Antoniadou et al., 2021; Sharma et al., 2021) to achieve SDGs by 2030 and protect the environmental sustainability. It is noticed that the HF needs to have the appropriate logistics and equipment, such as bins and BMW disposal equipment, to properly handle and manage BMW generated for environmental preservation to accomplish SDGs 3 and 6. The lack of logistics in managing BMW found in this study is similar in countries like Kenya (Mbuvi et al., 2022), Nigeria (Ilesanmi et al., 2021), and Benin (Davou et al., 2022), hindering environmental sustainability due to lack of adequate investment by stakeholders and other entrepreneurs in the management of BMW (Debrah et al., 2022b; Dinis et al., 2022).

Chapters two and three in this thesis aim to analyse the objective that assesses knowledge and practices of handling BMW by health professionals and BMW handlers. These two chapters of this study reveal that health professionals in Ghana are unable to handle and manage the waste, i.e., BMW, due to insufficient knowledge, lack of waste awareness resulting in lack of education (SDG 4) (Alharbi et al., 2021; Debrah et al., 2021b; Kenny & Priyadarshini, 2021). Moreover, the lack of tools and logistics (Dang et al., 2021; Debrah et al., 2022b) poorly influence the management of BMW and negatively impacts health (SDG 3), water and environmental hygiene (SDG 6), Climate change (SDG 13), pollution in water (SDG 14) and pollution on land (SDG 15). Therefore, reducing BMW in HF for ecological stability and protection of human health depends on the knowledge, attitude, and practice of the BMW handlers (Krishnamoorthy et al., 2022; Nosheen et al.,

2022). Proper handling of BMW contribute to a better waste management process, contributing to the achievement of SDGs such as health and wellbeing (SDG 3), sanitation (SDG 6), climate action (SDG 13), life below water (SDG 14) and land (SDG 15). BMW generators, i.e., nurses, physicians, pharmacists, and laboratory, among others, and the BMW handlers in studied HF lack adequate knowledge in handling BMW to practice thorough segregation of BMW. This situation could cause cross-contamination of waste and affect ecological sustainability, resulting in nonattainment of UN agenda 2030 SDGs such as SDGs 3, 6, 13 to 15. The lack of knowledge is similar to the one reported in a review study conducted by Khan et al. (2019) on healthcare waste management in Asian countries where healthcare workers lacked knowledge, attitudes and practices of handling and management of BMW. Also, a study by Leonard et al. (2022) reported that improperly handled BMW was as a result of limited knowledge to practice segregation, which contributes to improper BMW management in developing countries. Studies have shown that poor management of BMW in the SSA countries results in the emissions of CH₄, CO, and other gases negatively affecting climate change, SDG 13 (Chand et al., 2020, 2021; Chisholm et al., 2021). This also transmits diseases (Zikhathile, & Atagana, 2018) and other blood diseases like HBV (Sharma et al., 2021; Souza-Silva et al., 2021), HCV (Homaeigohar et al., 2021; Souza-Silva et al., 2021), HIV/AIDs (Ebomah et al., 2022; Fuseini et al., 2021) and other blood borne pathogens (Sherine et al., 2020). Furthermore, it serves as a breeding source for insects such as cockroaches, and mites (Wankhede & Wanjari, 2021), which affect human health, SDG 3.

The results expressed in chapter three of this thesis further show that poor handling of BMW, like pharmaceutical waste, is not restricted to health professionals but also to patients who visit HF. Unused pharmaceutical products, for instance, medications, are not segregated. Patients disposed of unused medicines into waste bins, burning or burying them similar to studies conducted in Nigeria (Salim et al., 2022), South Africa (Magagula et al., 2022), and Tanzania (Marwa et al., 2021), posing environment and public health issues for non-attainment of UN, SDGs 3, 6, 13 to 15 by 2030. This thesis has filled a knowledge gap in handling and managing BMW, especially liquid BMW and unused pharmaceutical products by healthcare workers, waste handlers, and patients in Ghana, SSA. Therefore, education on appropriate handling of BMW and using drugs at home

must be encouraged. Also, the regulations and policies of BMW must be reviewed to fill the existing gap for better implication, to reduce the threat posed by the poor handling of BMW for a sustainable environment in Ghana and other SSA countries for the success of SDGs, especially SDGs 3 and 6. Furthermore, to minimize the abundant unused pharmaceutical medication, citizens should be incentivized to return unused drugs for a sustainable environment.

The handling of BMW, estimating the quantity and the parameters that influence BMW, understanding the management of BMW, and disposal of BA resulting from BMW incineration in chapter five of this thesis need to be appropriately addressed since it could negatively affect ecosystems and humans. For example, improper handling of BMW and poor disposal of BA could cause the leaching of heavy metals into water bodies, groundwater, and soil, polluting the environment and possibly causing respiratory cancer and other issues affecting human health (Mozhi et al., 2022; Munawer, 2018). Therefore, for sustainable BMW management to be realized in Ghana and the other SSA countries, BMW, which are improperly segregated and incinerated with the BA disposed of in landfills, must be transformed into valuable products for reuse, recycled, and repaired (circular economy) for sustainable development. It will ensure the achievement of SDGs, especially SDG 3, 6, 13 to 15, for sustainable development.

The results of this thesis research are of fundamental importance in Ghana, SSA countries, and other developing countries in fulfilling the scientific knowledge gap in handling and managing BMW. Therefore, the findings from this thesis which are published in SCOPUS and or /WoS indexed journals or book chapters are anticipated to assist government agencies such as Environmental Protection Agency (EPA Ghana), Ministry of Local Government, Decentralization and Rural Development, and Ministry of Environment Science and Technology that are involved in the management of BMW for policy direction in the attainment of UN SDGs, good health (SDG 3), healthy hygienic environment (SDG 6), good climatic condition (SDG 13), better life in water (SDG 14) and land (SDG 15) in Ghana by 2030.

CONCLUSIONS

BMW is hazardous and serves as a suitable medium for the growth of microorganisms and disease transmission. It consists of contaminated blood, unused medications, sharps, and human tissues from HF. Handling and managing BMW is essential to lower the negative impact on the environment and human health. The improper management of BMW in Ghana and the remaining SSA countries could be one of the main contributing factors toward the non-attainment of the UN 2030 agenda, SDGs 3, 6, and 13 to 15.

A mixed methodological approach was used to conduct a research in six selected HF in the Eastern and Greater Accra Regional part of Ghana, aiming to determine the process and nature of BMW handling and management using questionnaires, observations, weighing of BMW for experimental work, and laboratory analysis. The responses to this thesis research questions were assessed using quantitative, qualitative, descriptive, and systematic review research designs. The data were analysed using IBM Statistical Package for the Social Science (SPSS) version 27 and XRF and AAS for the BMW BA chemical composition.

In finding responses to the research questions in this thesis, it is found that although the Ministry of Health, Ghana, has all the policies and laws regulating BMW, Ghana Health Service should focus on its implementation process to lessen the shortcomings in BMW handling and management in the studied HF. This thesis allowed to understand that the segregation of waste, in general, is a significant environmental and health problem in Ghana and other developing countries. BMW is improperly segregated, collected, transported, and disposed of despite the hazardous nature of BMW per this thesis. The response to the research question number two, "how does the BMW generated at the HF managed", in chapter four of this thesis revealed that the selected and analyse HF generated 11.41 tonnes of BMW, with 49.1% being infectious. 50% of the studied HF had no technological equipment to handle BMW, with almost 33% uncontrollably

practicing open burning and dumping of BMW. The remaining HF uses specialized equipment, such as an autoclave and incinerator, for handling BMW.

Lack of proper understanding in handling BMW has resulted in an enormous volume of contagious BMW owing to improper handling of BMW. Chapters two and three in this thesis allows to find that there is a considerable knowledge gap in handling liquid BMW and human tissues by healthcare practitioners and waste handlers in Ghana. For example, 87% of the HF respondents needed knowledge of handling liquid BMW, while 63.9% did not know about handling human tissue. 71.6% of patients disposed of pharmaceutical waste in bins at home. Therefore, HF must reinforce regular training on handling BMW in HF to enhance proper BMW handling and ensure and reduce BMW's threat to the environment and human health.

In answering to the research question number three, "what is the contribution of BMW management to the environment and public health burden in Ghana", chapter five of this thesis, allow to recognise that BA generated from the poorly segregated BMW incinerator had a significant amount of CaCO_3 , CaO , and higher concentrations of Ti, Fe, Zn, Pb, Cu, and Cr, heavy metals, above WHO permissible soil limits. The improper handling of BMW and disposal of BA from BMW incinerators reported in this thesis could pollute the air, land, and water bodies through leachate and odours, resulting in skin diseases and cancer. In addition, it could also cause respiratory diseases and serve as a breeding ground for insects, which can negatively impact the ecosystem and hinder materialisation of SDGs 3, 6, and 13 to 15. Properly managing and handling BMW will protect the environment and human health for sustainable development.

Implication and recommendations

UN 2030, SDGs 3, 6, 13, to 15 agenda could be attained in Ghana and the remaining SSA countries if there is continuous training in the handling of BMW in HF and private sector participation in the management of BMW. The private sector must be encouraged to invest in appropriate technological equipment to handle BMW. This could prevent the traditional linear method of handling BMW to a circular economy where BMW is

transformed, reused, repaired, and recycled. The repair, reuse, and recycling of BMW will limit the use of raw materials in HF and predominately decrease the generation of BMW for disposal at landfills which could pose a risk to HF communities and society in general. This reduces possible transmission of diseases such as hepatitis, syphilis, tetanus, and HIV/AIDs through infectious medical equipment and trading used syringes and expired medication in communities. Furthermore, the technology and safe handling of BMW will cut down the contamination of the water supply with BMW, which could have exposed plants, humans, and wildlife in society to toxicities. The circularity of BMW could prevent biological threats in SSA countries since improper disposal of BMW could be a good ground for terrorist attacks.

This thesis will serve as a specific interventional study to help improve the management of BMW in HF toward achieving SDGs in Africa. The work carried out within the scope of this thesis is of particular interest to Ghana and other developing countries, where there is a need to access more scientific information focusing on the environmental and health issues involving waste. Additionally, the findings will be communicated to the Ministry of Health and Ghana's health service for possible policy decisions and shared with selected HF for internal policy directions to ensure a sustainable environment. Supervision of BMW will contribute to the protection of the environment and protect human health.

The published result of this thesis in the indexed SCOPUS/WoS journals and books is propagating evidence-based knowledge information on BMW to the scientific community of SSA and other developing countries.

Limitations and further studies

In exploring the environmental and public health impacts of the improper management practices of BMW, this thesis investigated the processes and nature of handling BMW. The oxides and inorganic metal content were analysed in the BA of incinerated BMW. The study presented in the chapters two to five of this thesis identified significant knowledge gaps in managing BMW and addressed limitations. The research was pursued in 2020/2021, during Ghana's rising COVID- 19 pandemic, and BMW was not sorted for

classification before incinerating. Additionally, most participants were not responding to open-ended questionnaires about detailed knowledge of managing and handling BMW, maybe due to given work overload. Therefore "experimental research on training in awareness and exposure of BMW management" should be conducted in all SSA countries due to the lack of adequate training in the management of BMW by healthcare workers, which is a threat to human health and the environment. This empirical research must consider the sortation and classification of BMW for proper disposal and incineration towards environmental sustainability. Also, practical research must be conducted in risk assessment to assess the low-level exposures of chronic diseases within the vicinity of BMW incinerators due to the hazardous nature of BMW BA and organic pollutants content. Since the world is moving toward a circular economy, further studies must investigate the high amount of limestone present in BAs of BMW incinerators for possible reuse as binding materials for sustainable development, thus contributing to the accomplishment of UN SDGs 3, 6 and 13 to 15 by 2030 in Ghana

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ADDITIONAL SCIENTIFIC PRODUCTION

Under the supervisor's guidance, Professor Maria Alzira Pimenta Dinis, several journals and book chapters are published and indexed in SCOPUS, related to the doctoral program's core aim, i.e., waste management, environmental health, and environmental sustainability towards SDG in SSA countries. Three of these publications are presented below in this thesis to share and impact the knowledge involving promoting proper waste management and public health issues in achieving SDGs for sustainable development within developing countries such as Ghana. Two of these publications are articles that identify the factors that hinder the management and handling of waste in Ghana and SSA countries and how some challenges have been successfully overcome with innovative ideas. For instance, generated plastic waste that pollutes the environment is shredded and mixed with sand to mould pavements blocks and are used for artifacts. While one is a book chapter publication addressing how food waste and faecal waste collected from markets and various homes are anaerobically digested into organic fertilizers, irrigation for farming activities, and household electricity promoting UN SDGs for possible achievement by 2030.

ENVIRONMENTAL WASTE SUSTAINABILITY: ORGANIC VALORISATION AND SOCIOECONOMIC BENEFITS TOWARDS SUSTAINABLE DEVELOPMENT IN GHANA⁶

This study showcases the use of organic waste products from communities in producing organic fertilizer and generating energy for the community and Ghana. The findings highlight some of the environmental benefits obtained from the production towards sustainable development and achievement of SDGs 3, 6, 7, 8, and 13 within Ashaiman, Ghana.

In this publication, the first author participated in the conceptualization, development of methodology, validation, formal analysis, investigation, data curation, and the writing and editing of the manuscript. The complete citation of the publication is presented below:

⁶**Debrah, J. K., Vidal, D. G., Dinis, M. A. P., (2022).** Environmental Waste Sustainability: Organic Valorisation and Socioeconomic Benefits towards Sustainable Development in Ghana. In: Leal Filho W., Vidal DG, Dinis MAP. DRC (ed) Sustainable Policies and Practices in Energy, Environment and Health Research. World Sustainability Series. Springer, Cham, pp 425–437.

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Environmental Waste Sustainability: Organic Valorisation and Socioeconomic Benefits Towards Sustainable Development in Ghana



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and Maria Alzira Pimenta Dinis 

1 Introduction

The inadequate Municipal Solid Waste Management (MSWM) has a significantly high impact on human health and the environment (Oliveira et al. 2020; Vidal et al. 2019). Around 2.01 billion tons of solid urban waste are generated globally and annually in the world, with approximately 46% of solid waste being collected in developing countries, contrasting with 90% collected in Europe, Central Asia, and North America. The waste generated is expected to increase to 3.40 billion tons by 2050 (Kaza et al. 2018). It is believed that more than 700 million households in urban communities' worldwide lack access to adequate sanitation (UNICEF 2015). Nations with inadequate environmental sanitation access suffer from diseases such as cholera, diarrhoea and reduce the quality of life or human well-being (WHO 2019). Within a sustainable waste management context, waste is collected, transported, and disposed of in a way that it does not negatively affect the environment and public health for future generations (Azzi 2017), oppositely to what happens in low-income countries, where MSWM is an urgent environmental and health problem (Debrah et al. 2021b).

In Sub-Saharan Africa, about 180 million tons of waste are generated (Ayeleru et al. 2020). The World Bank report shows that Sub-Saharan regional waste will rise to 269 million tons by 2030 and is also expected to increase to about 516 million tons by 2050 (Kaza et al. 2018), representing an estimated growth 91.8%.

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This projection is mainly justified by the fast-growing urbanization development programs in the Sub-Saharan region. Given the expected waste generation, conscious development must rely on an adequate waste management infrastructure within the sub-Saharan Africa region. Yeo et al. (2020) indicates that only about 44% of waste generated is collected, 60% being organic waste. The uncollected waste causes environmental and health problems (Debrah et al. 2021a) that need urgent and efficient solutions for a healthy and sustainable environment.

According to the UN Worldometers (2020-<https://www.worldometers.info/world-population/ghana-population/>), Ghana, located on the Gulf of Guinea coast in western Africa, is around 31,072,940 inhabitants, with 56.7% of the population concentrated in urban areas. The rise in population growth contributes to increased waste production in most developing countries, especially in Ghana. The study conducted by Miezah et al. (2015) indicated that 12,710 tons of solid waste were generated daily when the country's population was 27,043,093 inhabitants. Another study conducted by Bert (2019) reported that the total waste production in Ghana is approximately 22,500 tons/day, in a period in which the average population was estimated at 30 million. Using the average of 0.75 kg/person/day assumed by Bert (2019) compared to the 31,072,940 inhabitants of Ghana's population (<https://www.worldometers.info/world-population/ghana-population/2020>), it is estimated that 23,304 tons of waste are in fact generated daily.

Another issue impacting Ghana's environmental sustainability concerns the proper urban waste collection. About 70–80% of solid waste is not collected in urban centres in most developing countries (Kirama and Mayo 2016), including Ghana. Most of the waste that is not collected in Ghana is incinerated and ashes dumped into the environment, decomposing and originating toxic compounds contaminating the air and the drinking water, with negative consequences to public health (Al-Delaimy et al. 2014; Ziraba et al. 2016). The waste generated in all metropolitan, municipal, and district assemblies (MMDAs) in Ghana can undergo valorisation, resulting in economic benefits for sustainable development.

This study's main objective is to evaluate the organic waste generated in the Ashaiman community in Ghana and assess the waste-related environmental sustainability in this region. An analysis of how organic waste collected in the Ashaiman locality undergoes treatment in an anaerobic digester to produce organic fertilizer, wastewater irrigation, and biogas for electricity, boosting economic benefits, was performed in Safi Sana Ghana. This research also seeks to demonstrate that a healthy and sustainable environment is the better way to face the challenges associated with the Sustainable Development Goal (SDG) 6 of the 2030 Agenda implementation (UNDP 2015—<https://www.undp.org/content/undp/en/home/sustainable-development-goals.html>). Additionally, this study seeks to estimate the environmental impacts of locally produced organic fertilizers and the relevance of energy production from organic valorisation for farmers and households in the communities of Ashaiman in Ghana and their association with SDGs 3, 7, 8, and 13.

2 Theoretical Framework

In the developing world, organic waste composition collected from markets, restaurants, hotels, schools, and other sources is heterogeneous (Alibardia and Cossu 2015) with more biodegradability properties and higher moisture content (Alibardia and Cossu 2015; Lebersorger and Schneider 2011).

Several technologies are available for the treatment of organic waste in most developing countries. Dry anaerobic digestion (AD) is mainly used due to its low cost in construction and operation. In Ghana, a dry AD was made with a second-hand shipping container that produces 55–60% methane gas (CH₄) content from the organic waste (Lohri et al. 2013a). Though not enough to satisfy the needs, it can be used for energy production.

(i) Environmental waste management sustainability—Organic waste fertilizers and wastewater irrigation for agriculture

Organic waste is biodegradable (Alibardia and Cossu 2015), since it is able to be decomposed. However, in most developing countries, about 50–70% of urban city waste is composed by organic matter (NIUA 2015; Poletto et al. 2016), but much of this waste is just not collected in urban areas, which end up decomposing. According to Kaza et al. (2018), about 33% of organic waste remains in cities deposited in open dumps, with less than 7.7% of organic waste being recycled or reused. Non-collected organic waste in Ghana is gradually increasing due to an urban settlement with inadequate waste management infrastructures in reusing this type of waste. A survey conducted by Miezah et al. (2015) indicates that organic waste in Ghana totals, on average, 61%. The same study reports that the content of organic waste from districts and metropolitan areas is around 62 and 59%, respectively, depending on cities' developmental and economic activities in those regions within Ghana. In Ghana, most of the organic and municipal waste collected is transported to landfills for final disposal. Organic waste disposed of in landfills produces an estimated amount of CH₄ gas in the order of 68% (Gregory et al. 2014), which can be used to produce electricity. Some developed countries such as Germany and Sweden have banned the dumping of untreated organic waste in landfills to avoid the emission of CH₄ gas into the atmospheric environment, aiming to achieve a clean environment for climate mitigation. African countries need to progress in this direction but to be able to do this, requires deliberate effort by governments to invest in waste management facilities and mandatory policies to address the environmental issues.

The waste collected in the Ashaiman community, Ghana, is currently processed by AD to produce organic fertilizer, wastewater irrigation, and biogas energy to increase environmental sustainability.

(ii) Anaerobic digestion (AD)

AD is a worldwide recognized and scientifically acceptable technology used in generating energy from organic waste. It brings benefits to the environment, contributing to reducing energy crisis and natural resources sustainability

(Dennehy et al. 2017). In the UK, as in many other European countries, AD and composting are acceptable methods used to treat collected organic waste (WasteDataFlow 2017). In the United States of America, AD is mostly used in wastewater treatment plants and as a method for manure treatment (Eden 2019; Moriarty 2013; Wang et al. 2021).

AD and the composting process are somewhat similar. AD allows the treatment of sludge and organic waste without oxygen. The decomposition of AD resulting from organic matter is biogas, consisting of 60–70% CH₄, 30–40% carbon dioxide (CO₂), and other waste gases (Moriarty 2013). Biogas is capable of operating in almost all equipment destined for natural gas, a major advantage, particularly in the context of less developed countries. Greenhouse gas (GHG) emission reductions and reduced water pollution are some of the benefits derived using biogas as a renewable energy generation. With all the benefits of AD, this technology is rarely used in most developing countries, including Ghana (Kwabena Agyei Agyepong 2018), due to the high capital needed to construct and maintenance costs (GMI 2013), alongside operational challenges such as lack of appropriate technology and management experts (Lohri et al. 2013b), scarce in this region. The lack of consistent access to energy in developing countries leads to the use of traditional sources of energy such as firewood (Ram and Bahadur 2020; Surendra et al. 2013), which can be overcome by using AD technology applied to organic wastes. According to GMI (2013), the biogas produced by the AD system in the developing countries is used for cook stoves, reducing family expenses in purchasing fuel for cooking and also prevent deforestation, since forest wood serves as the primary source of energy for heating (Miguiiri et al. 2020; Yaseen et al. 2020). Developing countries also lack good business models for effective AD market penetration (Lohri et al. 2013b).

3 Materials and Methods

A cross-sectional case study with exploratory—descriptive methodology was carried out in Ashaiman community, Ghana, to determine the organic waste generated and transformed by Safi Sana Ghana (2020) company to produce organic fertilizer, biogas and wastewater irrigation for environmental sustainability. The company is presented as a case example aiming to illustrate how to contribute to sustainability within Ghanaian society.

3.1 Characterization of the Study Region

Ashaiman, Ghana, is the case study analysed in this work. It is a region located 41 m above sea level and has a total area dimension of 45 km². Its location is about 30 km from Accra's metropolitan centres and is projected to the north and east by

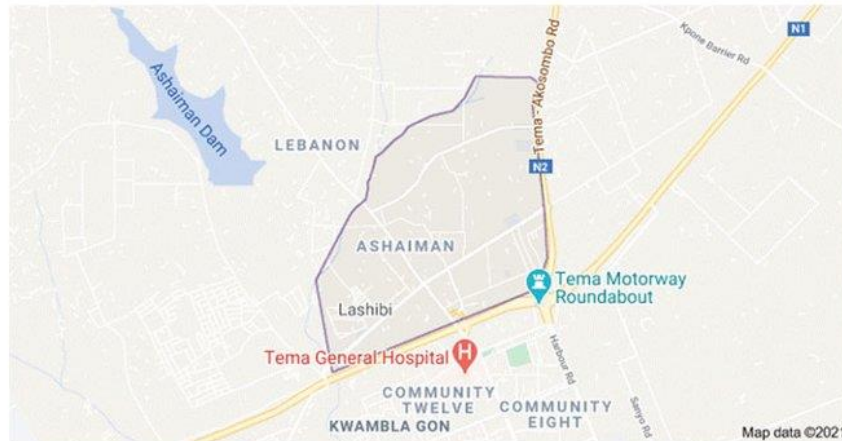


Fig. 1 Ashaiman Municipality location in Ghana. *Source* Illustration done in google.com map (<http://g.co/kgs/3QTfRg>)

Kpone Katamanso's municipality and south and west with Tema Metropolitan. Figure 1 represents the map of Ashaiman municipality, Ghana.

Ashaiman's average temperature is 26.7 °C, and annual rainfall is 827 mm (<https://en.climate-data.org/africa/ghana/greater-accra-region/ashaiman-688176>). The 2020 population census of Ashaiman municipality is estimated at 240,841 inhabitants, with a population density of 12,325/km². The population size was calculated using the 2010 population census by the Ghana statistic with a 2.35% load over 19.5 km². Demographic data for the region reveals a majority of 50.1% of female inhabitants. The municipality has almost a third (31.9%) of its total population of young people aged 0–14 years, indicating a large population pyramid with an inverted base since the elderly population comprises 2.4% of the total population (Ashaiman Municipal Assembly 2017). According to Fanta (2013), the municipality of Ashaiman attracts many rural migrants from all over Ghana, especially in the dry savannah regions, where climate change affects farmers (Nyantakyi-frimpong et al. 2016). 1.9% of the resident population are individuals from West African countries (Ghana Statistical Service 2014). Some of the migrants arriving in Ashaiman are also engaged in agricultural activities and waste collection in the municipalities.

4 Waste Generation in Ashaiman, Safi Sana Ghana Case Study

It is estimated that Ashaiman has more than 41,515 families, with about five members per family. The study further indicates that solid waste in 31,266 households is collected within the municipality for final disposal, with less than 1%

of families burying their waste as a final disposal method (Ashaiman Municipal Assembly 2017).

Ashaiman counties generate approximately 186 metric tons of solid waste per day (205 tons per day) (Tsigbe 2020). Miezah et al. (2015) indicate that 62% of all solid waste generated in all municipal communities comprises organic matter. Therefore, it is estimated that 127.1 tons of solid organic waste are produced in Ashaiman daily. These organic wastes are obtained in markets, cafeterias, school canteens, hotels, and individual residences. As examples of solid organic wastes from this region, fish wastes, smaller amounts of vegetables and fruits, and food wastes could be mainly mentioned.

Organic waste collected from Ashaiman municipality is transported to Safi Sana Ghana (2020) for treatment and reuse. The organic waste collected, mainly in markets and other places intended for food, is separated by trained personnel for later transportation to Safi Sana Ghana. About 25.42 tons per day (20%) of Ashaiman's classified organic waste collected in markets, restaurants, and slaughterhouses are mixed with about 20 tons of faecal waste from the Ashaiman locality to form a waste mix. The mixed waste is then treated in the double waste stream AD for the production of biogas. The treated waste is taken to drying beds to separate dry matter and water to produce organic fertilizer and wastewater irrigation. An estimated average of 2 tons of organic fertilizer and 20,000 L of wastewater irrigation is produced daily from solid and faecal organic waste in Safi Sana. The treated water obtained from the drying bed, in this process, is used as irrigation for the cultivation of seedlings and agricultural activities in the community. Figure 2 represents the stages of the organic waste transformation, contributing to environmental sustainability in Ghana.

The organic fertilizer resulting from the AD process is used to grow seedlings and is also applied to various land for agricultural purposes within Ghana. It is estimated that around 800,000 seedlings are produced annually by farmers in the community through Safi Sana's Ghana activities to increase agricultural production income in the community. Regarding the transformation of organic waste, biogas production is used to produce 2,200 kWh of electricity daily, as Safi Sana Ghana adds it to Ghana's national electricity grid for consumption (Safi Sana Ghana 2020).

5 Environmental Impacts and Benefits of Organic Waste Processing and Organic Waste Products Transformation Towards SDGs

Safi Sana Ghana (2020) closed-loop configuration's safety activities have no negative environmental impact associated with organic fertilizer, wastewater irrigation, and produce energy. It promotes and contributes to the region's environmental sustainability in focus and contributes to the safe management of liquid faecal waste in the municipality of Ashaiman, Ghana. About 20 tons of liquid waste from faecal

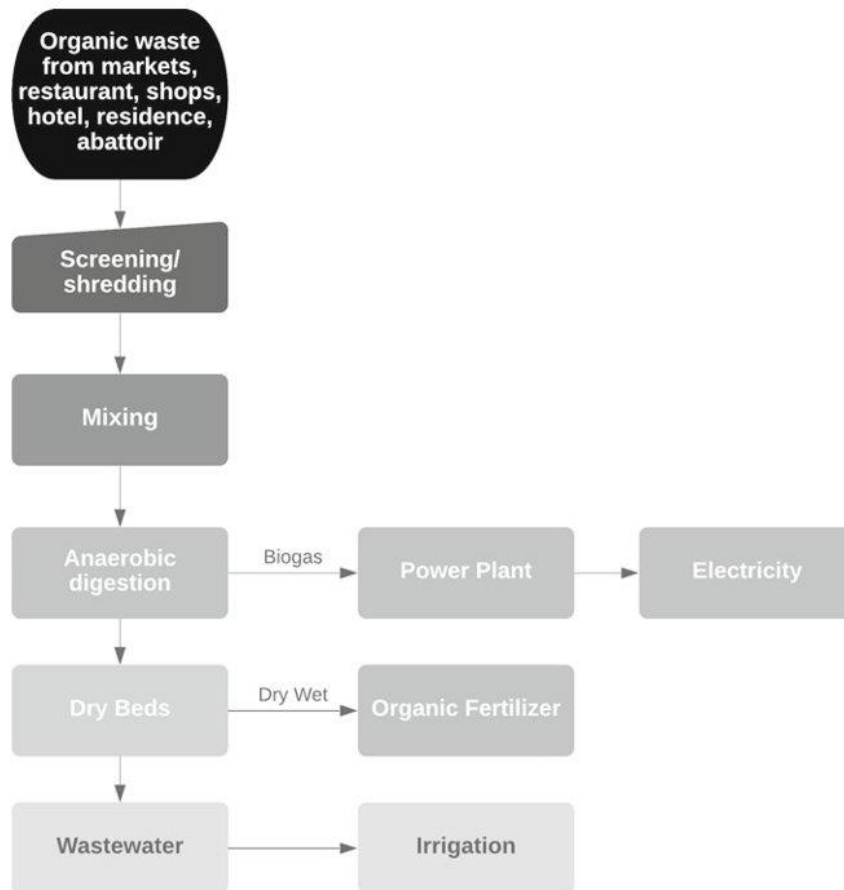


Fig. 2 Steps in the AD organic waste transformation to produce electricity, fertilizer, and wastewater irrigation in Safi Sana, Ashaiman, Ghana

sludge are treated daily, benefiting more than 40 thousand people in the localities. Although faecal waste treatment is carried out on-site, vacuum truck operators handle and manage liquid faecal waste from the siphon point to the final treatment stage. The treatment of liquid waste has helped reduce the enormous challenges associated with SDG 6 in the Ashaiman community. According to SDG 6 of UNDP (2015), addressing clean drinking water and sanitation, Ashaiman is successfully achieving the recommended goal, since the transformation of liquid faecal waste has reduced the negative impacts on public health, as well as the environmental impacts of sanitary waste in this community.

In turn, Safi Sana Ghana's waste transformation process equally promotes SDGs 3, 7, 8, and 13 related to the development of environmental sustainability in Ashaiman, Ghana. The residents of the region are trained/oriented on managing the

generation of their waste, segregating it for later treatment. During the training, public health education and health promotion, and hygiene care actions are carried out in the locality. Such qualified actions contribute to the operationalization of SDG 3, which provides for general hygiene and people's well-being.

One of the main goals in transforming organic waste in Ashaiman, Ghana, is energy production. The energy produced is characterized as clean and used to supply more than 500 families in Ghana. The power considered clean is added to the national electricity grid, compatible with what is recommended for reaching the goals recommended by the SDG 7.

The entire process of transformational production from organic waste requires human activities since it is not fully automated. According to the local policy, Safi Sana Ghana (2020), seeks to promote 90% of its workforce within the Ashaiman community. The company has as a goal the employability of 40% of female workers in its staff. Decent work brings economic relief and growth to people within the community. The economic growth resulting from the decent work offered to people in the municipality's community guarantees financial freedom, security, and stability, and this transformational change leads to SDG 8.

In the process of organic transformation, CH₄ and other gases are released in the AD (Ferdes et al. 2019), processed into biogas for electricity production. To minimize the emissions of CH₄ resulting from incomplete combustion, the biogas plants and processes must be operated effectively (Paolina et al. 2018). The operated biogas also reduces the emission of CO₂, Ammonia (NH₃), and other GHG, which are some of the contributing factors of climate change from SDG 13. The Safi Sana facility, ensures that the SDG13 goal is achieved by recovering slaughter and organic waste, other major factors of climate change. Organic waste's indiscriminate disposal becomes harmful to the environment when left to be decomposed, causing all kinds of pathogenic diseases which may be prevented through the AD process (Kasap et al. 2012).

The fertilizer produced by the transformation of organic waste is used to enrich the soil fertility (nutrient) and soil texture by increasing plant production in the community and reducing the use of excess land or big farmland for the small yield of plant or food (Al Seadi et al. 2018; Ma et al. 2021; Mezzullo et al. 2013). The organic fertilizer's texture or moisture content reduces soil erosion, ensures water conservation in farming land within the farming community and reduces the greenhouse effect. According to Brempong et al. (2019), organic fertilizer's moist content produced traps the temperature-raising carbon content in the soil, thus preventing the greenhouse effect for climate mitigation. The organic fertilizer produced is added to soil to prevent environmental degradation and promote the ecosystem's recovery by improving the soil's water quality. This activity enhances environmental restoration, vital for biodiversity. It is important to note that biogas digesters control odour, improve waste handling, and ensures that pathogens and worms are destroyed. The digesters also prevent leaching and thus safeguard underground water. A summary of the main environmental impacts of organic waste transformation within AD is presented in Table 1.

Table 1 Environmental impacts of organic waste transformation towards SDG in Ashaiman community, Ghana, adapted from Kubanza and Simateel (2020)

SDG	Action	Organic waste, positive environmental impacts in Ashaiman municipality
3	To ensure the health and well-being of people in the municipality	Promote good health and public hygiene through education
6	To ensure access to clean water (providing clean water) and sanitation	Promote and support clean water and environmental sanitation within the community through waste transformation and sustainability
7	To ensure access to affordable, reliable, sustainable, and modern clean energy for all	The biogas obtained from the organic transformation is a clean fuel powering home in the community, Ghana
8	To promote, sustain, and ensures decent work and economic growth	Some of the people in the communities are now employed through the activities of the waste transformation
13	To take urgent action and combat climate change and its impacts	In the organic waste transformation, biogas reduces CO ₂ , NH ₃ , and other GHG emissions, which impact climate change

6 Conclusions

Waste is a major problem in developing countries and Ghana is no exception. This is also justified by the high capital needed to invest in the construction and appropriate technology needed to transform waste. In Ashaiman communities, Ghana, organic waste transformation is essential due to the lack of engineered or inadequate landfills to manage waste and the huge volume of uncollected waste generated, specifically organic waste. Safi Sana company role in the community is presented as an example of a company contributing to sustainable development in Ghana, within the context of AD technology.

It is estimated that 127.1 tons of organic waste obtained from 205 tons of solid waste are generated daily in Ashaiman municipality, Ghana. The organic waste transformation activities within the municipality result in environmental sustainability, contributing to local economies, promoting hygiene and health. The education and training on hygienic conditions to the waste segregation and collectors ensure that the people's health and well-being in the Ashaiman localities are paramount by the Safi Sana operators towards achieving SDG 3.

The transformation of faecal and organic waste through the AD process reduces the negative impacts on public health and the environmental impact of sanitary waste in this community. These activities promote, support, and ensure clean water and environmental sanitation within the community to progress in SDG 6. The biogas produced during AD serves as a clean, renewable, and cheap energy source and is obtained from organic transformational activities. This electricity power used in the Ghanaian communities is affordable, reliable, sustainable, and clean, progress towards SDG 7.

The entire process of organic waste transformation for environmental sustainability creates jobs and enhances the people's economic growth, so important in developing countries. More than 90% of local people are employed in Ashaiman, Ghana, working in the process of organic valorisation, i.e., collection of organic waste, transportation, sorting, AD operation, and so on, a contribution to SDG 8, work for a decent living and economic opportunities. Through AD, the organic waste transformation in the Ashaiman locality reduces the emission of CH₄, CO₂, and other GHG released to the atmosphere for positive climatic change and environmental restoration towards SDG 13.

Apart from the organic fertilizer for farmers in crop yield and the energy for household electricity consumption obtained during the transformation of the organic waste, organic waste disposal at the landfills and GHG emission is also reduced because most of the organic wastes undergo AD.

Grounded on the organic waste transformation process, SDGs 3, 7, 8, and 13 have shown to be implemented in the Ashaiman community, Ghana.

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**BARRIERS AND CHALLENGES TO WASTE MANAGEMENT HINDERING
THE CIRCULAR ECONOMY IN SUB-SAHARAN AFRICA⁷**

This review article outlines the issues associated with SSA countries practicing a linear method of waste management instead of a circular economy and its related implication on the environment and public health for ecological preservation. A compelling solution to the challenges was also provided for possible circularity within SSA.

The first author participated in this publication conceptualization, methodology development, validation, formal analysis, investigation, data curation, and the writing and editing of the manuscript. The complete citation of the publication is presented below:

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Review

Barriers and Challenges to Waste Management Hindering the Circular Economy in Sub-Saharan Africa

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Abstract: More and more, waste generated in most parts of the Western world has been recycled and transformed into new circularity products. However, managing waste within Sub-Saharan Africa (SSA), such as in Ghana, has become a challenge due to the continued practice of the old traditional linear waste economy, that is, the taking, making and disposing methods of management, representing a threat to global environmental sustainability. Despite the need to revise current linear waste management (WM) in order to turn to the circular economy (CE) model, which consists of the concept of renew, remake and share, to advance sustainable development, a number of factors restrict the CE realization in practice, specifically in developing countries. An integrative methodology was used in this article to identify some of the challenges that hinder the achievement of CE in SSA countries. The results revealed the absence of educational programs and public awareness of waste management activities. The findings also highlight the lack of political will, funding and national policies on WM as some of the most significant issues. The study contributes to further encouraging policymakers and policy implementers, entrepreneurs and relevant interested groups to commit resources to sustainable WM services aiming to advancing CE in SSA countries.

Keywords: waste management (WM); circular economy (CE); Sub-Saharan Africa (SSA); sustainability



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1. Introduction

In recent years, waste management (WM) has become an issue in developed and developing countries [1], especially in the Sub-Saharan Africa (SSA) region [2–5]. The high volume of waste generated in SSA is attributed to rapid population growth and industrialization [6,7]. As shown in Figure 1, about 1.09 billion people were living in Africa in 2012 [8], producing about 125 million tons of waste [9], an increase resulting from the estimated growth rate by Tabutin [10], anticipating population growth to Africa, already in 1991, growth trend confirmed by the United Nations [11].

The volume of waste by SSA countries increased by 55 million tons from 2012 to 2019 [12], resulting in a population size of approximately 1.31 billion in 2019, while in 2025, the SSA waste is expected to increase to 244 billion tons, with an anticipated population size of about 1.50 billion [10–12], as shown in the Figure 2. According to the Water and Sanitation Program (WSP) 2012 report [13], improper waste disposal costs Ghana USD 290 million annually, equivalent to 1.6% of the country's gross domestic product (GDP) and USD 3 billion in Nigeria, representing 1.3% of GDP yearly. According to the same report, Zambia, Liberia, Madagascar and Kenya spend USD 195 million, 17.5 million, 103 million and 324 million, respectively, annually on indiscriminate waste disposal, representing a range of 0.9% to 2% of each country's GDP.

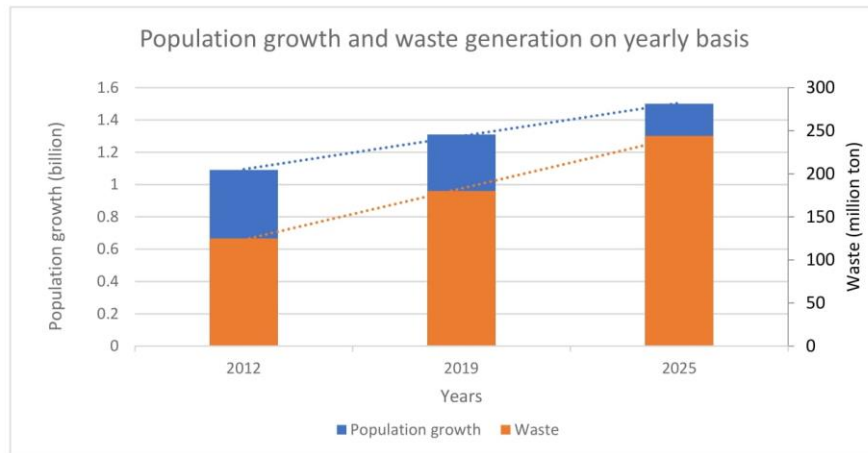


Figure 1. Anticipated trend of population growth and waste generation from 2012 to 2025 within SSA, data from Tieso [8], Scarlet et al. [9], Tabutin [10], United Nations [11] and Ayeleru et al. [12].

It should be recognized that there are efforts being made to deal with the challenges of WM in SSA through various development international partners. For instance, Galan [14] indicated that the United Nation’s Environment Programme (UNEP), in collaboration with the Global Environment Facility, Government of Nigeria, is promoting CE through recycling to minimize waste generation. Specifically, the partnership supports self-sustaining CE approaches for the electronics WM in Nigeria. The objective of this action is to address the challenges represented by the current electronic waste management practices which affect the environment and human health. The project was to process half a million tons of electronic waste annually. In addition, it aims to encourage electronic producers to assume responsibility for their products’ end-of-life and support related regulations and legislation.

In Ghana, Zoomlion Ghana Limited [15], a private WM company backed by the Ghanaian Government and the Hungarian Government, built a composting and recycling plant to enhance WM services to protect the environment, as well as to contribute to CE. In Kenya, the Ministry of Environment and Natural Resources have started a project named nationally appropriate mitigation action—CE municipal solid WM approach for urban areas in 2017 [16]. The essence is to move away from the huge volumes of wastes from the disposal sites, towards recycling. Similarly, South Africa has a CE guideline for a development project in partnership with UNEP [17] This was for the South African government to focus on CE for sustainable consumption and production.

Waste generated is grouped into decomposable either chemically or biologically, i.e., organics, partially degradable, for example, sludge [18], and non-degradable, i.e., electronic, metal, and plastics [19]. However, waste in SSA has a large composition of organic (57%) and other partially degradable contents of 22% [20] as shown in Figure 3. This type of waste can undergo anaerobic and aerobic decomposition [21,22]. Therefore, when waste is improperly managed, it has a negative influence on both human health and the environment by serving as grounds for infections and emitting gases, among many other diverse types of pollution [23–25].



Figure 2. SSA countries.

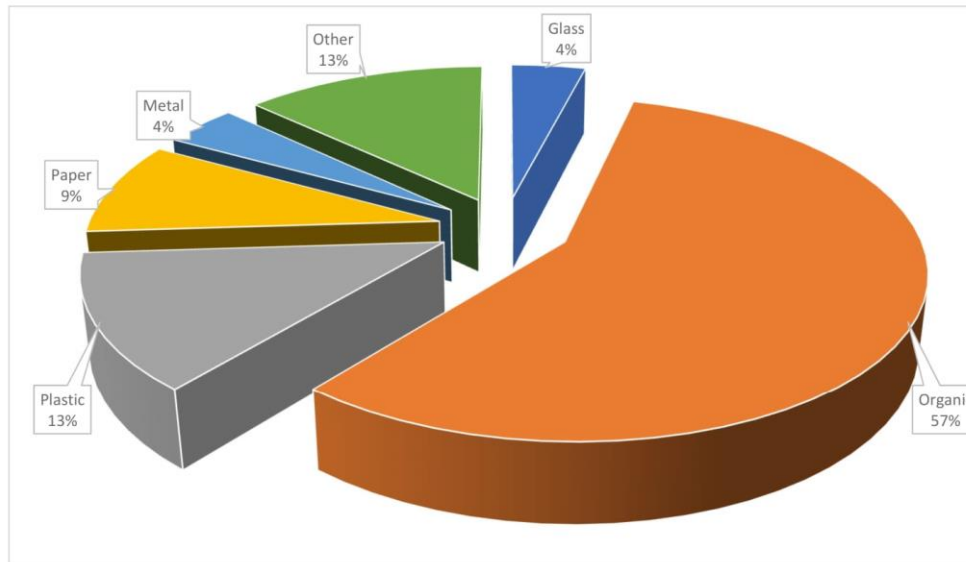


Figure 3. Waste composition in SSA, data from United Nations [20], Hoornweg and Bhada-Tata [26].

Though waste is considered a valuable resource [2,27–30] within the SSA region, countries like Somalia, Congo, Sudan, and Zimbabwe primarily practice WM linearly, i.e., take–make–dispose [31], while some of the countries such as Ghana, Nigeria, South Africa, Ethiopia, Kenya, Rwanda, Namibia, and Ivory Coast, among others, either fully or partially practice recycling [28] and some form of CE. Because of the linear material flow economy and the partial WM recycling practice, the SSA countries cannot fully recover waste materials and give them useful purposes. Hence, these countries cannot retrieve valuable resources from their waste and re-introduce them into the local economy. It, therefore, becomes challenging to enhance the growth of the local economy. Furthermore, the recovery of valuables such as plastics for recycling and organic components for composting from the waste, contributes to the reduction of the volumes to be disposed of. It also helps to break the chain of disease transmission which aids in the strengthening of public health [32]. It also, contributes to advance sustainable development goals (SDGs), good health and well-being for humans at all ages (SDG, 3), clean water and sanitation (SDG 6), sustainable cities and communities (SDG11) and responsible consumption and production (SDG 12) [33,34]. The CE strategy provides support to become closer to what other developed nations in the world are currently practicing [35].

The CE concept is considered a better efficiency to enhance sustainable WM [36], under which waste materials are transformed into new products. This is the best alternative way of transitioning from the traditional linear waste flow economy [37,38] towards the CE [39]. Therefore, the current linear model and the partial recycling of managing waste in some SSA countries needs to move towards material circularity, which will ensure the sustainable growth of the economy through optimization of resources, reduction of raw material consumption and recovering waste materials through recycling for second life [40–42], moving from the linear economy model built on a *take–make–consume–throw-away* pattern, as illustrated by Soysa [43]. In this way, waste materials could be managed more efficiently in a CE by reusing items and resources, while encouraging the use of renewable resources through sustainable ecological practices.

The CE is an economic model aiming to sustainably produce goods and services by reducing resource consumption and waste generation through recovered materials, water and energy production [44]. Studies by Kalmykova et al. [45], Ekins et al. [46] and Allen et al. [47] have shown that the CE will contribute to reducing the pressure on the environment and improve the safety of the supply of raw materials as well as increase the competitiveness among industry players, inspiring innovation and enhancing economic growth [48]. One of the best strategies to ensure sustainable WM is to adopt the CE business model [49]. This requires appropriate technology and simple tools and equipment to be used by well-trained personnel for the results to be attained.

Though CE is not fully practiced in some SSA countries, there is recognition of its potential to contribute to economic growth [50]. Therefore, governments, private organizations, and other social groups must implement the CE for sustainable development. Given that, this paper focuses on the barriers and challenges to WM practices hindering the realization of CE in SSA countries. An integrative methodological approach consisting of peer-reviewed journals and press releases from the internationally recognized organizations was used to collect data for analysis, from 2018 to 2021. The results are discussed based on the barriers and challenges associated with the transitioning from the traditional WM to a CE within SSA. This study points out specific recommendations for the possible operationalization of the CE implementation within a sustainable WM context in SSA, where this topic assumes a crucial importance. The results will be vital in helping SSA countries to develop CE policies and guidelines for the WM sector of the economy, including local government planning, education and research, thus moving closer to advancing the SDGs, specifically SDG's 3, 6 and 11 [51]. The study will also help policymakers, policy implementers, private entrepreneurs, researchers, non-governmental organizations (NGO's), and other social bodies in SSA to promote policies and standard frameworks for CE in order to advance sustainable development in this region.

The novelty of this study approach is evident within the existing and practiced traditional linear economy concept of WM, which needs to move towards CE, where waste materials are transformed and new goods and services are produced, contributing to overall sustainable development in the SSA. Therefore, raising awareness on this specific topic is essential in addressing the scope of sustainability in SSA countries, such as Ghana, supporting the reduction of consumption patterns, as pointed out by Romero-Hernández and Romero [52].

2. Methodology

An integrative research approach, suggested by Romero-Hernández and Romero [52] and Debrah et al. [53], was used in this study, as shown in Figure 4. Secondary data was obtained from existing primary data studies intending to solve issues of WM through CE for a greater level of awareness. For this purpose, an expert-driven literature review was performed [54]. The data collected was critically reviewed in order to generate new knowledge for a better assessment of the problems and barriers in this respect [53,55].

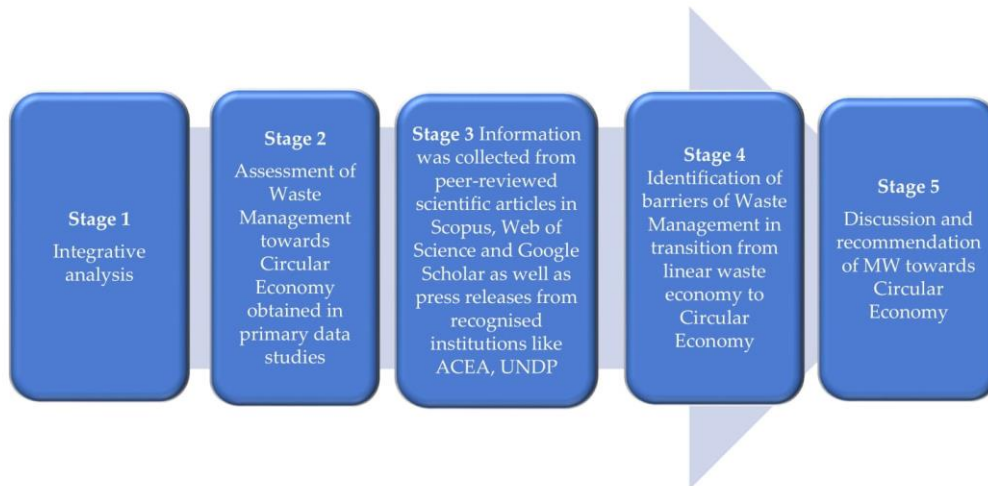


Figure 4. Integrative approach used in this study, adapted from Filho et al. [56].

To recognize the problems associated with the implementation of CE in SSA, mentioned above, secondary data was collected from WM companies, government agencies, and press releases from recognized institutions such as the Africa Circular Economy Alliance (ACEA) [57].

In order to revise the literature on the topic, information was also collected from publications in databases such as Scopus, Web of Science and Google Scholar. The syntax for the search of the article was ‘Challenges’, AND ‘waste management’, AND ‘circular economy’, AND ‘Sub-Saharan Africa’. In determining the appropriate content for this study, the publications were restricted to 2018–2021. Other inclusion criteria were peer-reviewed scientific articles, journals written in English, aimed at government policies, CE funding, and WM awareness at all levels. The studies mainly focused on SSA. An initial search for the published articles and book chapters identified 124,000 publications. The combination of all keywords reduced the search articles to 127. Fifteen (15) articles remained after considering the inclusion criteria and removing duplicates, using ZOTERO bibliographic software. After the rigorous screening, six articles were linked to issues related to CE in SSA, as shown in Figure 5, based on Panigrahi and Dubey [58] and Yu et al. [59] methodology.

A summary of the studied articles by Ali et al. [60] in Ghana, Owebor et al. [61] in Nigeria, Mmerekhi [62] in Botswana, Ayeleru et al. [12], Ijoma et al. [63] and Somé [64] indicates law enforcement, political will, and funding as the major issues for WM within SSA.

The study used integrative analysis to understand the following:

- The policies and regulations of CEs in SSA;
- The support and funds to practice CE;
- The human resource in WM towards CE;
- The awareness about WM towards CE.

This study should provide a clear understanding of existing issues that create a gap between MW and the CE in SSA, for better-informed knowledge and recommendations assisting decision-makers and research in SSA in order to advance sustainable development.

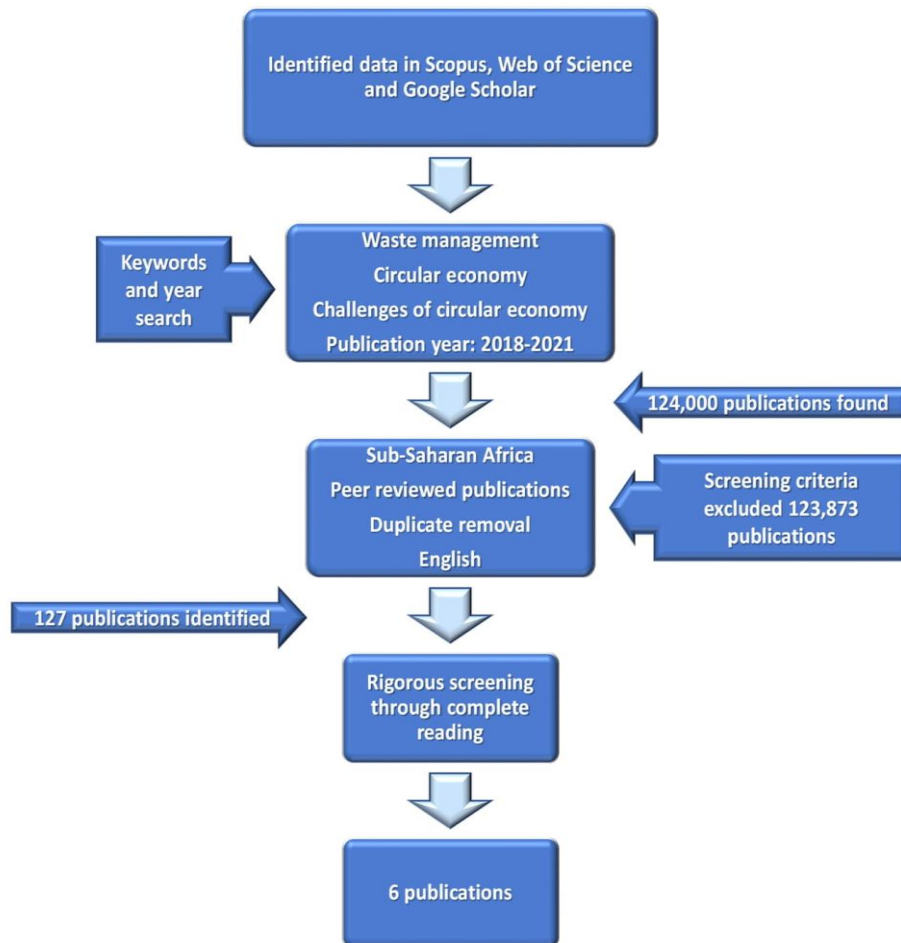


Figure 5. Scheme for the review indicating database and screened retrieved manuscripts, adapted from Panigrahi and Dubey [58] and Yu et al. [59].

3. Results and Discussion

3.1. Obstacles Hindering the Movement of Managing Waste from a Linear Economy to Circular Economy

The studies by Ayeleru et al. [12] and Diaz [65] indicate several factors that represent limitations for countries in SSA to fully implement the WM model of CE. These range from inadequate or absence of policies and regulations respecting WM, insufficient funding, lack of commitment and political will to implement CE, low capacity of the personnel actively involved in the WM, and lack of investment in the sector by the governments and entrepreneurs.

3.2. Lack of National Policies and Regulations

The literature shows that there are inadequate policies and regulations among the SSA countries such as Guinea, Sudan, Southern Sudan, Sierra Leone and Somalia [64]. The lack of regulations has made it difficult to change from the traditional linear way of managing

waste to a CE model. It should be noted that the absence of relevant national policies and regulations to guide and provide control measures for WM activities in SSA countries make it difficult for counties and metropolitan, municipal, and district assemblies to regulate and supervise the most appropriate options of waste streams to deal with [32,66,67], particularly when most policies are designed to follow the overall national goals. There may be specific cases where policies, laws, and regulations are available. However, the policies are not up to the times, so applying them, combined with a weak enforcement system, makes it very difficult to see any meaningful changes in the WM services within the SSA context. This situation makes it quite strenuous for society to be involved and participate at the domestic level, for the segregation of waste. Additionally, in SSA countries, government failure to enforce environmental legislation has resulted in a culture of lassitude, reducing the effectiveness of WM in general [32,68].

The SSA countries, including Rwanda, South Africa, Ivory Coast, Ghana and Nigeria, have initiated an ACEA to facilitate seminars, training and workshops to enhance the CE practice among member countries [57]. That alliance also intended to encourage sustainability partnerships, create coalitions for the implementation of existing projects on the CE and pilot ones, and facilitate the development of a group of African leaders who will lead the CE implementation. The scope of this organization covers, but is not limited to, the proper understanding of food waste, setting up effective systems of collection, strategically planning and installing sorting, pre-processing and recycling plants for operations, give incentives such as finance at national level and support for product design for reuse and recycling of related waste products. African countries such as Ghana, Nigeria, Rwanda, Ethiopia, South Africa, Senegal and Kenya have accepted the conditions of being part of the alliance. However, the main objective of this alliance is yet to be spelt out to all SSA countries. It will also contribute to curbing the practice where state institutions in SSA aim to use current policies and regulations in developed countries without fully considering the cost involved in implementing them [69] in the SSA region. This results in a situation where WM projects begin with the notion to include a CE model, but are abandoned without completion. This does not improve WM activities. Therefore, governments within the SSA countries must be encouraged to promulgate clear and comprehensive policies as well as related regulations on the CE, as has already been achieved by the European Union [35,70] and in other parts of the world [71], to enhance and promote more efficient use of resources, through CE. Additionally, there is the need to build strong WM and related services, strengthen policies and regulations, harmonize, monitor and regularly assess these policies for active enforcement to achieve CE results in the SSA context.

3.3. SSA Circular Economy Lacking Political Commitment and Investment

Overcoming the challenges associated with moving WM from the linear economy to CE will require practical measures such as building WM infrastructure by the relevant stakeholders [72]. These stakeholders, which include governments, private WM companies, researchers, environmental groups, NGO's and entrepreneurs in the SSA countries, need to invest in the CE projects. Even though some investments, including the support to phase out the use of plastic bags to promote sustainable consumption and production patterns in Rwanda by the African Development Bank, are being made in the WM sector to transition towards CE, much is expected to achieve the desired results. The opportunities to accelerate CE principles in SSA are increasing steadily. Kenya, for instance, is taking advantage of the emerging technologies towards better WM approaches by actively managing waste collection services, sorting, composting and plastic recycling and purchasing waste from waste materials pickers [73,74]. Ethiopia, on the other hand, has a new waste-to-energy plant in the year 2017 that is set to transform and revolutionize the entire city's approach to dealing with waste [75]. The plant is estimated to incinerate 1400 tons daily, about 80% of the city's waste. This supplies Addis Ababa with 30 % of its household electricity needs and assists in meeting international air quality emissions standards [76]. Additionally, in Rwanda, the government, in conjunction with Enviroserve [77], has built the first e-waste

recycling and refurbishing facility to process over 10,000 metric tons of waste per year [78]. The CE projects in Ghana, Kenya, Rwanda, Nigeria and Ethiopia, among others, have many benefits, which include social transformation and economic innovation as indicated by Barbaritano et al. [79] and Dung [80], with a summary of sustainability benefits, i.e., environmental, social and economic, presented in Table 1.

Table 1. Environmental, social and economic benefits derived from CE.

Benefits	CE	Reference
Environmental	CE encourages waste reduction, control of emission of greenhouse gases, recycling, and protection of the environment by taking care of end-of-life products through modification. In addition, the CE further ensures a reduction in the importation of resources since some of the raw materials used in production could be obtained from the materials in transition locally.	AUDA-UNEP [75] Dung [80] Schroeder et al. [81] Guarnieri et al. [82] Marino and Pariso [83]
Social	CE provides opportunities for job creation. As a result, the youth earn a living through employment opportunities, leading to poverty reduction, social transformation, and mitigating social impacts, such as climate change.	Debrah et al. [24] AUDA-UNEP [75]
Economic	On the aspects of economics, CE enhances technological and business transformation, market innovation and economic growth and trigger competition among the local and international organizations.	Smol et al. [84] Awan et al. [85] Bressanelli et al. [86]

The lack of political will is considered one of the main constraints affecting the desire to provide solutions for sustainable WM [86]. According to Wilson and Velis [87], the lack of political commitment culminates into insufficient funding for WM activities, and hence achieving CE will require extra efforts at this level.

For SSA to attain CE requires an estimated amount of USD 6 to 42 billion to build large-scale recycling and recovering technology-based plants [20]. However, due to the cost involved in acquiring the WM technologies, entrepreneurs show little interest and are not willing to commit funds to the CE projects. They rather prefer to invest in the linear flow model economy, which requires less capital injection into the businesses but early recouping of the profit on their investments [60]. Therefore, a better understanding of the challenges associated with the transition from the linear WM model to a CE will encourage the political leaders in SSA to commit more resources to ensure waste is adequately managed. This is very important because there is an insufficient commitment by the decision makers, such as political leaders, encouraging the preferences for cheaper disposal alternatives, such as the use of unstructured disposal sites and open dumps instead of engineered landfills [88,89]. It also has a long tie effect on the environment, health, and wellbeing of the society and increases the cost to GDP of the SSA countries. A study conducted by World Bank—WSP [13] indicates that 18 SSA countries, including Ghana, Congo, Uganda, Kenya, Rwanda, Zambia, Nigeria, Benin and Chad, lose lots of money to WM. Additionally, Mauritania, Niger, Madagascar, Mozambique and Burkina Faso lose USD 5.5 billion yearly to poor sanitation, which is between 1 and 2.5% of GDP.

It is recognized that the major stakeholders prefer to commit financial resources to visible projects such as road networks, school buildings and related infrastructure, resulting

in high support from society rather than funding sustainable WM projects [90,91]. Even though several benefits could be derived from sustainable environmental management, including improved health and general wellbeing, it will require an additional financial commitment. Moreover, only a few political leaders may be willing to invest in 'politically unpopular projects', irrespective of how urgent the construction of a sanitary engineered landfill or a modern composting plant is required to protect the environment [92].

3.4. Waste Management and Human Capacity

Studies have shown that the personnel capacity, mainly from the government sector and private industry players who are actively involved in the planning, management and, sometimes, execution of the processes, is lacking [93,94]. The technically trained professionals in CE are absent in some SSA countries such as Angola, Burundi, Central African Republic and Liberia, among others. This is because most of these professionals prefer working in other sectors of the economy, for instance, in banking, the Environmental Protection Agency (EPA) [95], insurance and NGO's, which are attractive, lucrative and more fulfilling [96] compared to the WM sector. Even though the sector requires several professionals, including but not limited to sociologists, teachers, architects, planners, environmentalists, lawyers, engineers, and financial analysts [97], to name but a few, they are not readily available and willing to serve in the field. The staff available are not technically trained to deal with the task at hand. There is, therefore, the need for professionally trained personnel to be engaged and encouraged to participate in the field of WM, assigned specific tasks based on knowledge, expertise and experience to achieve desired results.

The contributions from the CE field experts will accelerate and guarantee the attainment of some of the SDGs, such as 3, 6, 11 and 12 [98] while successfully addressing the barriers and challenges associated with WM in SSA countries.

3.5. Absence of Educational Programmes and Public Awareness of Waste Management

Analyzing the information collected indicates that some of the SSA countries, such as Togo, Benin, Angola, Burundi, Somalia, Zimbabwe, Sudan, Guinea, Sierra Leone, Chad, Congo and Eritrea, significantly and commonly lack educational programs such as community-based training on CE, waste storage and segregation of electronic, plastic, food and agricultural waste directed towards WM and related activities [4]. The primary issue is the seemingly unavailability of policies on WM educational programs, which are supposed to be geared towards the value chain of the CE at various stages of human endeavour to address the linear economy. According to Franke and Remmele [99] and Debrah et al. [4], incorporating CE into the curriculum of colleges and higher education institutions will be a source of transformation for positive change for subsequent generations [100]. It is a fact that environmental education for young people, both in the home and at school, should be prioritized because it is an effective strategy to reduce waste [99]. This is expected to change students' approach and skills to solve problems to preserve future generations' environmental resources. However, CE is yet to be completely included in the educational curricula in most developing countries, including the SSA region [101–104] and Asia [105], which will help in teaching, research programs and student activities [106]. This will aid the students in acquiring knowledge, skills and interest in the area of WM and CE in particular. In addition, specialized and customized training programs must be designed for the staff directly involved in WM in the public sector and private companies. This will offer the technical know-how to support the implementation and effective legislation and enforcement of laws to ensure sustainable WM. Furthermore, at the political and governmental levels, the training will build and impart the proper understanding and appreciation of the importance of WM to help sound decision-making on WM issues [20]. In achieving this, the full complement of professionals of all levels is required to implement the CE to save the environment [106]. Furthermore, education will incorporate WM practices into the daily lifestyles of the society [107,108] and create the needed awareness for a sustainable environmental management towards CE. Because of the lack of comprehensive educational

programs for CE within some SSA countries, the citizens have not had the opportunity to fully take part in WM activities. As a result, society is not aware of how to participate and contribute to sustainable WM solutions, particularly to CE. For SSA countries to move away from a linear economy, citizens must be educated and encouraged to participate in all activities towards CE at all stages of daily life [109,110], including behavior change.

4. SSA Future Prospects in Circular Economy

The CE is anticipated to assist in reducing resource waste and guarantee environmental sustainability [56,109]. The full implementation of CE in SSA countries is critical to achieving the SDGs. However, the transition from the current linear economic model of MW to CE, where the production and consumption patterns [111,112] need to be focused on a sustainable environment, requires practically formulated policies and commitment from major stakeholders, including WM companies, academia, entrepreneurs and governments [113]. Therefore, SSA countries leadership must be encouraged to embrace the CE model and fully implement it to protect the environment by building WM infrastructure and committing more financial resources. SSA countries need to endorse and enforce environmental sanitation-related regulations and policies and develop the capacity of the personnel involved in WM services. This will help to improve both economic and environmental development [114]. Furthermore, SSA leaders must strictly follow the CE model to boost products and service design, which will assist in preserving resources from depletion, environmental deprivation, and generating less waste. Since the CE provides a framework encouraging development, SSA countries must adopt it and develop it to ensure environmental sustainability and contribute to achieve the SDGs.

5. Conclusions

WM is a significant setback in most SSA regions. Still, Ghana, South Africa, Rwanda, Nigeria and Kenya, to mention a few countries, have partially invested in the infrastructure, logistics and equipment, such as trucks for hauling waste, but less has been accomplished in terms of approaching the CE model. Moving from the traditional WM method, i.e., take–make–dispose, to the repair, reuse, recycle method, transforming waste into new products, aiming to achieve environmental, social and economic benefits for society has not been fully realized within the SSA context.

In determining the factors hindering the practice of CE in SSA countries, this study used an integrative research analysis to perform an expert-driven literature review, collecting information from peer-reviewed scientific journals publications as well as data from government agencies and releases from well-known international organizations such as ACEA.

The results show that SSA countries have no adequate national policies to guide WM towards a CE model. The results also reveal that there is no political will or enough funds in SSA due to a lack of commitment for fully implementing the CE model. Additionally, in SSA, the personnel needed to be actively involved in WM activities to move towards CE are at a low-capacity level of knowledge. Therefore, advancing CE implementation in SSA countries requires leadership commitment. In order to achieve the SDGs good health and well-being (SDG3), clean water and sanitation (SDG6), sustainable cities and communities (SDG11) and responsible consumption and production (SDG12), thus supporting global sustainable development, there must be financial commitment to WM in SSA and human resources need to be made available to allow a smooth transition from the traditional linear waste economy to CE. Within the SSA region, the CE is imperative for creating the enabling environment for sustainable WM. SSA countries are thus encouraged to promulgate, enhance and harmonize the WM-related policies while enforcing environmental sanitation legislation to protect both the environment and human health. Finally, SSA entrepreneurs need to invest in modern WM technologies to accommodate the CE for sustainable development achievement in this region. It is recommended that CE principles, related policies and regulations be adopted

and strictly enforced by SSA countries to aid in the transition towards sustainable WM practices, contributing to overall sustainable development.

6. Limitations

This research has some limitations. Though the findings are substantially representative, the data collected did not cover every SSA country. In addition, the CE is a new concept in WM within SSA. As such, it is not fully operational in certain parts of SSA, making it difficult to collect information on this topic in the region. Hence, future studies on this subject are recommended to focus on emerging economies in SSA not practicing CE to raise awareness on these cross-cutting issues. The insights will assist in guiding policymakers and research to formulate sustainable pathways to overcome the barriers to effective WM, enhancing CE projects in SSA countries.

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INNOVATIVE USE OF PLASTIC FOR A CLEAN AND SUSTAINABLE ENVIRONMENTAL MANAGEMENT: LEARNING CASES FROM GHANA, AFRICA⁸

This article showcases how plastic waste generated within some communities in Ghana is locally used for innovative products such as blocks and artifacts for a sustainable environment. This innovation has helped improve SDGs 1 to 17.

The first author participated in this publication conceptualization, methodology development, validation, formal analysis, investigation, data curation, and the writing and editing of the manuscript. The complete citation of the publication is presented below:

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Article

Innovative Use of Plastic for a Clean and Sustainable Environmental Management: Learning Cases from Ghana, Africa

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Abstract: Addressing the plastic problem requires rigorous attention and practical education for sustainability. Due to the common effective waste management practices in some parts of the world, the plastics' menace is generally well recognized and controlled worldwide. However, some developing countries do not have acceptable waste management practices, resulting in significant environmental, social, and health cross-cutting issues. Plastic is a significant threat to the environment in Ghana, specifically the urban environment and oceans. The new paradigm shift of virtually using non-biodegradable plastics in all daily products sold increases plastic waste in the environment, which creates problems, such as choked drainage system and breeding places for insects. The scale of these issues requires innovative and practical ideas to help solve this problem. The paper shows how plastic waste is innovatively and creatively converted to artifacts and pavement blocks in Ghana. These innovative ideas have contributed to reduce the volume of plastic waste and enhance environmental sustainability in Africa. The community's benefits involving friendly environmental activities are identified and represent learning cases from Ghana to the world, particularly to Africa.

Keywords: plastic waste management; innovation; environmental sustainability; learning cases (LC)



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1. Introduction

Environmental sustainability has become an essential priority in the 21st century in most developing countries' ecological agendas. In recent years, maximum attention has been given to plastic pollution resulting in severe environmental problems caused by the lack of a waste management infrastructure, mass consumption of goods, and packaging of products globally [1]. In 2020, the global plastic contamination increased due to mismanagement of personal protective equipment for the COVID-19 pandemic, with a monthly estimate use of 129 billion face masks and 65 billion gloves [2–4].

Plastics are solid materials with one or more organic monomers forming polymers with a heavy molecular weight [5]. Plastics degrade at a slower rate due to their durability and the chemical bonds that resist the natural degradable process. Hence, plastic is classified according to its chemical structure, polarity (chemical process), and applications [6]. The chemical structure and temperature behavior of plastics (formation of heat application) allow them to be classified into thermoplastics and thermosets. Heated plastics that cannot be remolded are known to be thermosetting plastics. Oppositely, thermoplastics can be reheated, remolded, and cooled without causing any chemical changes. Examples of thermoplastics include plastic bags or polyethylene (PE), polyvinyl chloride (PVC), and nylon.

Plastic waste has become a challenging environmental issue globally, particularly in developing countries that have not invested in plastic recycling and collecting discarded

plastics [7] and where the environmental issues are not still valued. According to Lebreton et al. [8] and Neilson's [9] studies, most plastics enter the oceans and lands and potentially damage the environment. In 2010, an estimated 4.8 to 12.7 million plastic waste enter globally into the sea worldwide [10]. Due to the cheap and easy production of plastics and the difficulty for plastics to break down through natural process [3,4], selective sorting of plastic waste has become a significant priority among government agencies, communities, non-governmental organizations (NGOs), and society due to the negative impact of the plastic contribution to the environment [10–15]. From 1950 to 2018, plastic waste production globally has increased to 6.3 billion metric tons, resulting in 12% incinerated, 9% recycled, and 79% untreated plastic [11,16].

In 2016, worldwide nations produced 335 million metric tons of plastic [17]. The world plastic production went to 348 million tons in 2017 and 359 million metric tons in 2018, with China producing 29.4% of it compared with entire Europe (18.5%) and that of Africa's (7.1%) in 2017 [18,19]. Most of the plastics are made up of PE, polypropylene (PP), polystyrene (PS), and PVC, which can be used because of their chemical properties and density in different forms, such as bottles, sachets [17,20], and thus commonly found in the rivers and marine environment [21,22]. Due to population increase and socioeconomic factors of current lifestyles, plastics are part of people's daily lives [23–25]. The rise in plastic waste disposal on roads, farms, water bodies results from people's perception, behavior, and attitude towards waste [26–28]. In countries where plastics are collected and recycled or incinerated, proper waste management or training is implemented [29,30]. Still, most developing countries lack municipal solid waste management facilities to manage the plastics. In those countries, plastics are or may be collected informally by different waste collectors moving from one point to another. Some studies support such a paradigm, i.e., a survey conducted in 2010 by Oteng-Ababio [31] and metropolitan waste management departments of Takoradi in Ghana indicated that 30% of 268 tons of waste generated in the Secondi-Takoradi metropolis is comprised of plastics [31,32]. The study further reported that Accra metropolis generated 2000 tons of waste, and Kumasi metropolis generated 1200 tons of waste, but only 60% and 65% of the corresponding wastes generated were collected in Accra Metropolitan Authority and Kumasi Metropolitan Authority [32]. In 2015, a study by Miezah [33] also indicated that 14% of plastic waste is collected from the households in Ghana. Most plastics are disposed of at landfills, incinerated, and burnt by individuals at any open space within communities [31,32,34], which is not acceptable. These plastic disposal methods used in Ghana threaten the environment by polluting the atmospheric air with carbon monoxide (CO), nitrogen oxides (NO_x), sulphur oxides (SO_x), releasing dioxins, and other hazardous chemical pollutants, thus causing severe health problems [20,33–35] as well as releasing carbon dioxide (CO₂), which is known to be a significant contributor to the global warming [16]. Until more educational awareness and innovative recycling ideas are introduced in various communities for the sustainable plastic waste environment, plastic will continue to destroy Ghana's ecological environment, and the same will happen in most developing countries in Africa.

An important contribution to solve this issue, with particular emphasis on developing countries, is the Circular Economy (CE), which intends to shift the paradigm towards a more sustainable society in all dimensions: Social, economic and environmental. The main principle of CE is to add value to the products for a long period of time to minimize waste, namely, attributing a new function to a product that has lost the previous one [29,35]. According to the European Commission action plan [36], CE ensures a transition for the production of products more durable or easier to repair and to make transparent the production process to the consumers to allow them to make an informed decision. This means that CE is restorative and regenerative because materials and products enter in a cycle, rather than being discarded. CE is explored in the contextualized learning examples in the Ghana context, presented in this article.

In Ghana's case, plastic waste generated varies from one municipality to another or one district to another. The exponential growth of population and migration of people to

urban centers because of industrialization leads to high consumption of plastics. These plastics are indiscriminately discarded after use. A study conducted by Ampofo in 2013 [20] for the Center for Scientific and Industrial Research (CSRI) indicates that Ghana can release an average of GHC 1.2 million (EUR 206,896) monthly if the plastic waste generated is recycled systematically [20]. In 2016, Ghana imported over 10,000 metric tons of plastics, while the local companies in Accra manufactured or recycled an average of 38,927.57 metric tons of sorted plastics annually [37]. There has been an increase in plastics production companies and high annual importation of the plastics into Ghana due to the higher demand for packaging of products sold into the market and fewer recycling companies exist to add value to the used or unwanted plastics. According to Pwamang [38], Executive Director of the Environmental Protection Agency, about 2.58 million metric tons of raw plastics are imported into Ghana annually, and 73% effectively ends up as waste [38]. It is estimated that about 270 tons of plastics are produced in Ghana [39], and 320 tons of plastic waste are also recycled in Ghana per day [40]. The remaining plastic waste is disposed of in the streets, oceans, and other parts of the environment, negatively affecting the environment and causing respiratory illnesses when burnt and floods when it rains.

Plastic waste can be managed and reduced through less plastic consumption, infrastructure provision for plastic waste management, and environmental awareness. Less plastic consumption prevents unnecessary plastic packaging if choosing eco-friendlier or degradable material for packaging. Through formal and informal education and increasing awareness, long-term positive plastic environmental behavior change can be created, leading to reduced waste disposal through moral responsibility [41–44]. Education and awareness must aim to enforce reducing plastic consumption, reducing waste disposal, and improving behavioral change, thus minimizing plastic waste's negative environmental consequences.

Part of the plastic waste problems include releasing harmful chemicals from chlorinated plastics into the soil, which end up in the plants and water, and choking drains can be solved through innovative ideas. According to Lee et al. [45], innovative ideas are the primary key to managing plastics and creating an excellent sustainable business environment, in the entire world. These innovative ideas, which aim to serve as environmental goals, can boost managing plastic waste and improve environmental sustainability in developing countries. Sustainable innovation can be classified into weak and strong sustainability [46–48], depending on the environmental impact level [49]. The environmental impact level improves and minimizes ecological damage and promotes business [45]. For sustainable management practice, plastics waste must be in good condition and equally fit for innovative business models or ideas [50]. In plastic waste innovation, the innovators add value to plastic waste generated to recover the plastics and reduce plastic waste disposal.

To help solve the problems associated with plastics globally, many private companies have now responded well to minimize excessive plastics disposed to the environment through business and innovative minds [51] in Africa. This study aims to present learning cases (LC) in Ghana, Africa, seeking to convert plastic into other useful products pursuing environmental sustainability within the communities where the *Trashy Bags* and *Nelplast Ghana Limited* companies are located.

2. The Importance of Learning Cases Approach

The LC approach is a problem-solving process that involves participatory discussion through a critical thinking mind or skills and learning process [52]. This approach is recognized as extremely useful to reflect on problems and to innovate through learning [53]. LC methodology helps individuals generate innovative ideas that allow others to learn for knowledge impartation [54]. Alongside, LC help to improve the implementation of the UN 2030 Agenda [55] at a local level and to involve local communities and stakeholders in the transformative process towards a better society [56,57]. The LC approach is essential in knowledge transfer. It improves analyzing skills to use one's senses and the doctrine of

decision-making to solve problems. LC approach helps in implementing innovative ideas and knowledge for critical thinking skills.

The two LC described below will demonstrate how to best use plastic material and, at the same time, disseminate such ideas creatively and sustainably. They will act as a platform to share their stories and knowledge.

3. Trashy Bags Learning Case Presentation

Trashy Bags [39] is a Ghana company that converts used plastics to handbags, dresses, pencil cases, caps, among others. *Trashy Bags* Company has 60 workers who use plastic sachets collected from the local environment for innovative products. About 180,000 plastic sachets (i.e., 275.143 kg or 6000 bags) on the streets are reused per month.

3.1. Pre-Process for Production in Trashy Bags

In the innovative idea built up by *Trashy Bags*, the collected plastic sachets are sorted within the environment and then cut open. They are manually washed thoroughly, dried in the sun, and straightened for production (Figure 1).



Figure 1. Collected cut water sachets, manually washed and dried. Source: *Trashy Bags* [39].

3.2. Trashy Bags Production Process

The opened, washed, and dried plastic sachets are sewn into sheets. The sheets are made in particular sizes depending on the final product. The sheets are then converted into over 30 bags and other different designed products. These designed products, which come with specifications and other accessories, contribute to minimizing the environmental problem caused by plastics in Ghana (Figure 2).



Figure 2. Bags created from plastics collected from the environment. Source: *Trashy Bags* [39].

3.3. Trashy Bags Innovation Benefits

The innovative plastic waste idea from *Trashy Bags* has helped reduce the plastics that contaminate the streets and flood in the Ablekuman community in Accra, Ghana,

Africa, by about 257.143 kg (6000 packs) per month, aiming to contribute to environmental sustainability. Plastic waste decreases when more orders are placed on *Trashy Bags*, such as school bags, hats, car mats, etc. The process of high demand for *Trashy Bags* products leads to purchasing more plastic waste from other surrounding communities in Accra, Ghana. In the *Trashy Bags* process, the plastics within the company's localities are collected, making the environment clean, free from plastic, and healthy. *Trashy Bags* uses its environmental sustainability program to sensitize the community and people about the environmental damage associated with indiscriminate plastic waste disposal. This is done by using company volunteers to undertake community engagement programs to sensitize people about environmental problems with plastic waste and how to keep the environment clean. The outreach education, collectors of sachets, sewers, or stitches of the sachets into bags also create employment for the people within the localities, resulting in important economic benefits, crucial in developing countries in Africa.

4. Nelplast Ghana Limited Learning Case Presentation

Nelplast Ghana Limited [58] company in Ghana has 74 direct employers and about 230 indirect workers. The company uses its creative ideas to convert plastic waste into pavement blocks. In the production of pavement blocks using plastic waste, only PVC plastics are excluded. About 19,200 kg of plastic waste is required for monthly production.

4.1. Pavement Blocks Production Process

The collected plastic waste from the environment is shredded down to fine threads by locally fabricated equipment. The plastic pavement blocks are made when 70% of the shredded plastic waste is mixed with 30% of ordinary sand. The plastic pavement blocks are more robust and resilient than cement blocks due to the plastic origins' binding agent of physical elasticity.

A study conducted by Tulashie et al. [59] indicates that plastic pavement blocks' strength depends on sand mixture types. The study further showed that the plastic-pit sand pavement block (PPPB) had a fibrous surface, smaller pore volume, and grain size than the plastic-sea sand pavement block (PSPB). The same study further explains that a high quantity of plastics lower water absorptivity of plastic blocks and enhance compressive force, thus in the production of pavement blocks using plastic waste, PVC plastics are excluded (Figure 3).



Figure 3. Shredded plastic waste mixed with sand to form pavement blocks. (a) Arranging plastic pavement blocks to lay, (b) plastic pavement blocks being laid, (c) completed laid plastic pavement block, (d) house constructed from plastics. Source: *Nelplast Ghana Limited* [58].

4.2. Economic Benefits of Plastic Waste Pavement Block

Nelplast Ghana Limited uses about 19,200 kg of plastic waste to produce about 4800 pieces of pavement blocks per month. Thus, 200 plastic blocks are constructed from 800 kg of plastic waste in a day. *Nelplast Ghana Limited's* innovative idea reduces plastic waste in Ghana, thus contributing to the minimization of plastic environmental problems and public health issues. The plastic pavement blocks obtained from the plastic waste and the sand mixture are of remarkable resilience for paving roads, hospital parks, towns, and villages at cheaper costs than those acquired with traditional asphalt. A study conducted by [60] indicates that plastic pavement blocks could support a load of 53% higher than concrete pavers before they rupture, with a maximum load of 36.77 kN, whereas hydraulic concrete pavers have a full load of 19.64 kN. The study further indicated the compression test of hydraulic concrete pavements load is 340 kN, while plastic waste pavement block load 460 kN [60]. Concerning pavement blocks' durability, plastic paver blocks may perform better in flood-prone areas and saline content due to their lower water absorption power [61]. The entire production chain of *Nelplast Ghana Limited* creates jobs for the people within the community and contributes to plastic environmental sustainability.

A summary of the environmental, economic, and social benefits of these two LC and correspondent contributions to the UN 2030 Agenda are presented in Table 1.

Table 1. Environmental, economic, and social benefits of the two LC presented and correspondent contributions to the UN 2030 Agenda.

Benefits	Trashy Bags	Nelplast Ghana Limited	UN 2030 Agenda
Environmental	180,000 plastic sachets on the streets are collected per month. Reduce the plastics that contaminate the streets and cause floods.	19,200 kg of plastic waste is collected to produce about 4800 pieces of pavement blocks per month.	SDG 3, 6, 11, 13, 14 and 15
Economic	Create employment for the people within the localities. Contribute to the local economy.	Create employment for the people within the localities. Plastic paver blocks perform better in flood-prone areas and saline content due to their lower water absorption power	SDG 1, 2, 8,9, 10 and 11
Social	Sensitize the community and people about the environmental damage associated with indiscriminate plastic waste disposal. Promote social cohesion and empowerment.	Enhance local communities' sustainability awareness.	SDG 11, 12 and 17
Contribution to the local circular economy			

5. Discussion

There is an enormous threat caused by plastics to the environment within Ghana and African communities in general. It is known that plastics that are scattered and found on drainages and nearby surroundings serve as a source of breeding stocks of mosquitoes and other insects [62], a critical source of health concern in African countries due to existing high temperatures. Rampant disposal of plastics in trenches could choke and block free floor water during the rainy season and originate flooding [63]. Plastics can also suffocate ruminant animals when they graze or eat the grass that contains plastics [64]. The plastic

that is eaten prevents the ruminant animals from regurgitating their food, choking them to death in most cases.

Due to the non-degradable or slower nature of plastic degrading, plastics disposal has become a major complication within African countries' environmental sustainability. This makes the management of plastic quite difficult. Plastic waste is often burnt in the open air in some African countries where environmental awareness is not present. This process emits many toxic gases into the atmosphere, thereby polluting the air, destroying the ozone layer, and compromising its protective properties [65,66], with important negative consequences to global warming and climate change topics. Some of these gaseous substances include NO_x , CO , methane (CH_4), and SO_x . The process increases the risk of health hazards, including cancer [67,68]. The essence of the innovative business ideas, such as the *Trashy Bags* and *Nelplast Ghana Limited*, contributes to minimizing and solving some of the problems associated with plastic waste in Ghana, a developing country in Africa.

The two innovative business LC models, presented within the scope of plastic waste sustainability, offer jobs and improve people's livelihood, also enhancing the community's local economies, as suggested by the literature [69,70], namely in developing countries [71], as in the case of Ghana in Africa. These innovative business models reduce the total plastic waste generated and scattered in entire surroundings of greater Accra region communities to more than 19,457.143 kg (54.35%) in a month, contributing to the implementation of 13 of the 17 SDGs at a local level. The two LC activities use creative ideas to reduce some of the people's dependency condition in the *Trashy Bags* and *Nelplast Ghana Limited* local communities by permanently employing over 134 regular factory workers, contributing to local economic sustainability, so important in Ghana and in most African developing countries. This excludes security personnel and food vendors working in the companies' premises and over 500 plastic waste collectors paid per 1 kg of the collected plastic.

The 2020 market survey in Ghana indicates that more than GHC 6.7 million (EUR 1.15 million) are paid to the plastic waste collectors per month [40], including the LC collectors. The two LC operations have reduced the companies' pollutant emissions since most plastic waste collected is sent for recycling but not incinerated and thus avoid emitting hazardous chemical compounds to the atmosphere. There is a reduction of plastic waste to the landfills in the LC communities because plastics sorted by various households are sent to the companies for sale. Continued education by volunteers and the price tag attached to collect plastic waste has encouraged more people to sort plastics. Education creates environmental awareness, understanding, and improving of environmental behavior [72]. These innovative ideas have reduced the imports of resources such as cement and plastic artifact gifts, generally contributing to Ghana's local environmental sustainability.

The products obtained from the innovative ideas presented in this text are now serving as an alternative for other similar materials in the Ghana market at an affordable price, including carrier bags, refuse bags, buckets, dustbins, shoe soles, doormats, and car mats, and pavement blocks. Lastly, these LC innovative ideas present a clear example of CE. Both apply a holistic approach to the problem of plastic pollution by being aware of how their products impact the wider system of collection and recycling in Ghana. Moreover, they promote collaborative partnerships to innovate, contributing to the local economy and community empowerment in a developing country in Africa.

6. Conclusions

The innovative business model for sustainable plastic waste management represented by the two companies presented in this text, *Trashy Bags* and *Nelplast Ghana Limited* in Ghana, Africa, will help minimize the plastic material discarded to the environment, depicting a severe threat to Ghana's ecological environment. *Trashy Bags* and *Nelplast Ghana Limited* companies reduced the total plastic waste in the greater Accra region communities, Ghana, by over 257.143 kg (0.7%) and 19,200 kg (62.34%) of plastics a month. The plastics that end up on streets, oceans, and causing flooding are collected by some people, serving as an essential employment and income source in Ghana.

Trashy Bags and *Nelplast Ghana Limited* companies have contributed to the Ghana's local communities' development by promoting health and safety awareness and plastic waste recycling management practices. They also reduce the damage caused to animals, humans, and plants through plastic waste toxic pollutants.

This innovative way for sustainable plastic management practices in Ghana, Africa, must be further supported by the government and prioritized to achieve sustainable development in communities. It will serve as capacity building for individuals and strengthen the reliable waste management infrastructures at Ghana district levels in the future. There should be a clear policy in using and promoting products obtained through innovative ideas within environmental sustainability, valued and supported by citizens and the local management structure. Citizens and students, in particular, may use the plastics from *Trashy Bags* in school. At the same time, contractors could construct school buildings and walkways with the plastic and pavement blocks by *Nelplast Ghana Limited*.

Regarding the importance of adopted strategies for the implementation of CE, local governments must be aware of the significant role that they can play in the transition towards sustainable and circular societies. This local power can request reuse and recycling, to design local plans and set up environmental requirements to integrate the CE model within the city sustainable development. Beyond the benefits to the local communities and economic and environmental dimensions, the actions developed by local power can result in a greater attractiveness of the area by being recognized as a source of innovation, reshaping local organization and governance in the context of Africa's developing countries.

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