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Quantification and Mitigation of Landfill Greenhouse-Gas Emissions at the Kumasi Landfill, Ghana: An Assessment of Emission Sources, Environmental Exposure and Feasibility of Control Options

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ABSTRACT

Landfills are important sources of methane (CH_4) because biodegradable organic materials decompose under predominantly anaerobic conditions. This study assesses greenhouse-gas emissions from the Kumasi landfill in Ghana by linking landfill characteristics and waste inputs to estimated methane generation, environmental exposure, community-reported impacts, and the feasibility of mitigation measures. The study used annual waste-disposal records for 2017–2025 and applies the Intergovernmental Panel on Climate Change (IPCC) First Order Decay (FOD) approach in a Tier 1 spreadsheet framework. The analysis indicates that annual waste delivered to the landfill ranged from 241,525.64 to 401,116.95 tonnes over the study period, while the adopted waste-composition profile contained 58.3% organics. Modelled methane generation increased from 0Gg in 2017 to 2Gg in 2018 and 2019, 3Gg in 2020, and 4Gg annually from 2021 to 2025. Food waste was the dominant methane-generating fraction, with paper contributing a smaller share. The study also used questionnaires with 80 households to document environmental exposure and coping responses. Respondents reported odour, leachate, mosquitoes, houseflies, rodents and snakes, together with household health concerns. These responses constituted community-reported experiences and perceptions; they do not constitute clinical or epidemiological evidence establishing that the landfill caused specific diseases. The study found operational weaknesses in waste spreading, compaction, covering and routine vector-control practices and reported no existing landfill-gas recovery system. The recommended mitigation sequence is therefore source reduction and organic-waste diversion, improved waste placement and cover management, leachate control, landfill-gas collection, and either controlled flaring or beneficial energy recovery. Technical feasibility is strongest for operational improvements and gas collection/flaring, while electricity generation requires site-specific gas-flow, energy-yield and financial appraisal. Environmental feasibility is favourable because source control, methane capture and improved leachate management address several exposure pathways simultaneously. A key limitation is the absence of direct field measurements of ambient methane, landfill-gas flow, gas composition and meteorological conditions; accordingly, the methane results should be interpreted as modelled estimates rather than direct measurements. Also, the study assessed community-reported health concerns but did not conduct a clinical or epidemiological assessment of health impacts attributable to landfill emissions. This is a substantive methodological boundary. The health implications remain important because they indicate perceived burdens and provide a basis for preventive environmental management. However, a future health-impact study would require a separate design, including exposure measurement, clinically validated outcomes and an appropriate comparison group.

INTRODUCTION/BACKGROUND

Within today's Anthropocene epoch, our planet is changing, and climate change poses an existential threat to the human race that transcends beyond social, political, economic, and geographical boundaries (Brauch, 2025; Schoog, 2025). Appropriate mitigation efforts are necessary since the effects of climate change pose a serious danger to livelihoods, global ecosystems, and economic stability (Nega, 2025). Climate change is one of the most important worldwide issues of our day because to its extensive and significant effects (Neira et al., 2023). It explains how Earth's climate and weather patterns have gradually changed since the Industrial Revolution,

mostly due to human activity (Koch et al., 2024). The planet's natural energy equilibrium has been disturbed by human activities including burning fossil fuels excessively, clearing forests, and industrialising processes, which have caused greenhouse gas (GHG) emissions to soar (Filonchyk et al., 2024). Global warming and anthropogenic climate change have unquestionably been caused by the rapid accumulation of greenhouse gases in the atmosphere, which has been linked to the rapid combustion of fossil fuels and unexplained changes in land use (Intergovernmental Panel on Climate Change, IPCC, 2021).

The Intergovernmental Panel on Climate Change (IPCC), observed that the last few decades have been the warmest in recorded history, human activity is the primary driver of the present rate of climate change rather than natural factors (Solecki et al., 2024). The ramifications of this warming will be extensive and intricate. Sea levels have increased, glaciers have melted more quickly (Rounce et al., 2023), and the rise in global temperatures has increased the frequency of extreme weather events including cyclones, floods, and droughts (Kumar et al., 2023). Ecosystems are changing more quickly than they can adapt, endangering food security and biodiversity. Agricultural and freshwater systems are especially vulnerable, and human health is increasingly threatened by heatwaves, vector-borne diseases, and air pollution (Abbasi, 2025; de Souza & Weaver, 2024). From an economic standpoint, climate change undermines people's ability to make a living, deteriorates infrastructure, and widens the gap between affluent and developing countries (SenGupta & Atal, 2024).

Climate change is still a major problem for the country and the entire planet. A single ministry or government cannot regulate the complex effects of climate change, which need national, regional, and international engagement. The term "climate change" refers to the slow but noticeable transformation of Earth's weather patterns brought about by human activity throughout the last several decades. Earth's temperature has always been influenced by natural causes, but the current acceleration of warming is mostly the result of human activity (Stein, 2024). The buildup of atmospheric greenhouse gases, which act as heat traps and cause an increase in global surface temperatures (Al-Ismail et al., 2023), is the primary factor responsible for climate change. The buildup of greenhouse gases in the atmosphere, which act as heat traps and elevate global surface temperatures, is the primary cause of climate change (Al-Ismail et al., 2023). They are mostly discharged into the atmosphere as a result of deforestation and the burning of fossil fuels including coal, oil, and natural gas for industry (Filonchyk et al., 2024), transportation (Azhar et al., 2024), and generation of electricity (Wang & Azam, 2024).

The IPCC noticed that, fossil fuels are responsible for about 90% of CO_2 emissions and over 75% of global GHG emissions. Methane (CH_4): Emitted by cows, fields of rice, landfills, and the burning of fossil fuels. Methane is more effective at absorbing heat than CO2, although it has a shorter persistence period (Rajendran et al., 2024; Sikiru et al., 2024; Wang et al., 2024; Yu et al., 2023). Manure, agricultural fertilisers, and some industrial processes create nitrous oxide (N2O), a potent and long-lasting greenhouse gas (Grace et al., 2023; Zhu et al., 2025). Other gases and particles: The atmosphere's fluorinated gases and aerosols can influence weather patterns, with the latter having both warming and cooling effects (Grace et al., 2023; Wang et al., 2023). One way that deforestation and land degradation worsen global warming is through the loss of flora and its ability to absorb carbon dioxide (CO_2). Local temperatures, biodiversity, land reflectivity, water cycles, agricultural usage, and urban development are all impacted by forest clearing (Abera et al., 2024).

Agriculture is a major source of methane and nitrous oxide emissions into the atmosphere (Zhang et al., 2024). Livestock, fertiliser use, rice paddies, and land conversion for agriculture account for a significant number of global emissions (Gerber et al., 2021). Ocean currents, solar flares, and volcanic eruptions are examples of natural climate change variables, but they are not enough to account for the current pace of warming. The effects of global warming are intensified by human-caused feedbacks, such as the decrease in reflectivity brought on by melting ice or the release of methane from thawing permafrost (Ansor et al., 2023; McCulloch et al., 2024). A global approach to mitigate the severity of these consequences must include reduced emissions, switching to renewable energy, more sustainable land-use practices, and improved climate governance (Pivac et al., 2024). Cooperation among nations under accords like the Paris Agreement is one way to reduce global warming and promote a low-carbon future (Li et al., 2024). In Ghana, there is already indications of the direct effects of climate change, such as rising temperatures, unexpected severe rainfall events, rising sea levels, rising greenhouse gas emissions, and the loss of carbon sinks. In accordance with Handisyde et al. (2021)

studies, floods can bring predators, cause stock to flee, and damage facilities. As indicated by Asiedu et al. (2021), changes in climatic factors are having an impact on Ghanaian small-scale fish farmers' performance by increasing the frequency and severity of floods, storms, temperatures and droughts.

These jeopardise the livelihood and socioeconomic advancement of the impoverished small-scale fish farmers who operate in rural areas. Based on Moss et al. (2025) assertion, freshwater aquaculture is severely hampered by hydrological unpredictability brought on by climate change, particularly the consequences of droughts and floods that upset ecological balances and operations. Aquaculture in Ghana is mostly small-scale and concentrated on Oreochromis niloticus and Clarias gariepinus, with over 90% of farms producing less than 50 metric tonnes yearly (FAO, 2024). Per a report by the FAO, between 12,000 and 13,000 direct employments are supported by small-scale aquaculture (FAO, 2024). Despite these advantages, the agricultural sector and small-scale aquaculture both confront several difficulties. One new threat to its sustainability is climate change. The weather has a big impact on aquaculture production. Many of these farmers have moderate yields, tiny ponds, and negligible capital expenditures.

Therefore, current vulnerabilities may be made worse by changes in temperature, humidity, wind speed, rainfall patterns, and other climatic parameters (Asiedu et al., 2021). This might eventually jeopardise food production and rural livelihoods by having an impact on fish productivity and water quality (Asiedu et al., 2021). The viability and profitability of small-scale aquaculture systems are threatened by climatic variability, according to recent research conducted in Ghana (Enchill et al., 2025; Mensah et al., 2024). However, there is still a dearth of focused empirical data measuring these effects at the farm level. This impacts various facets of Ghana’s socio-economic structure, especially with its high reliance on sectors such as agriculture, forestry and energy production which are predominantly sensitive to climate change. This and more prompts the researcher to undertake this current study to examine the adaptation and mitigation of climate resilience systems in Ghana with reference to flood, food production, water safety, wastes emissions.

The danger of detrimental consequences on human systems is increasing daily by changing climatic hazards, such as more frequent and severe heatwaves or heavy precipitation events, combined with a lack of readiness to deal with these disasters (IPCC, 2022a). For instance, severe and protracted droughts endanger freshwater availability, agriculture and crop production, and food security (Brás, 2021); heavy precipitation events that impact poorly planned cities cause damage to vital infrastructure, disruption of essential services (like drinkable water), and possibly high morbidity and mortality (Peirce et al., 2022); and severe heatwaves can raise the risk of various illnesses and death among the most vulnerable populations (Romanello, 2022). Global warming and the ensuing anticipated changes in the climate system would be limited if anthropogenic GHG emissions were reduced through mitigation techniques (IPCC, 2021, 2022b). The growth of Ghana's economy is largely dependent on fisheries and aquaculture. As stated by Asiedu et al. (2021), the industry helps create jobs, reduce poverty, provide food security, and generate national revenue.

Additionally, the industry sustains the livelihoods of more than three million people through farming, fishing, and other value chains; fish in particular account for almost 60% of the nation's animal protein consumption (Ministry of Fisheries and Aquaculture Development (MoFAD), 2023). Ghana consumes about 28 kilograms of fish per person (Asiedu et al., 2023). This figure is higher than the world average of 20.5 kg and the African average of 10.5 kg (FAO, 2024). Based on the International Convention on Wetlands, the Muni-Pomadze in Ghana’s Central Region was named a Ramsar site in 1992 (Boanu et al. 2022). The majority of these wetlands are now degrading as a result of urbanisation. One of the wetlands endangered by human activity is Ghana's Muni Pomadze lagoon. Despite the many benefits they offer to the local community and beyond, lagoons and their catchment regions have been described as the most exploited and degraded lagoons in most nations (Erostate et al., 2022). In reality, the question of whether the Muni lagoon should be designated as an endangered zone has recently been debated by scholars and government organisations (Adu-Boahen et al., 2018).

However, not much research has been carried out at the Kumasi landfill site. Knowledge and awareness of climate change, and the perception that people have about it is very important because it has more forward impacts on the way individuals provide response to it (Adu-Boahen et al., 2018). The awareness and perception level of farmers may influence the adaptability of farmers and fishermen to changes in climate.

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While attention has been on the environment, biodiversity and conservation studies, little attention has been paid to climate change knowledge, awareness and risk perception concerning the people living around the Kumasi landfill site. Yet, factors that influence the awareness, risk perception level, and the adoption of climate change adaptation strategies are important to look at. Based on the modern-day lifestyles worldwide, human beings are wasteful a lot, everything we do produces some kind of solid, liquid and or gaseous output which is disregarded as ‘‘waste’’. Solid waste management remains one of the major problems in many developing countries. This research seeks to fundamentally fill an existing gap in knowledge on methane gas emission in the Kumasi landfill site and its contribution towards climate change in the Kumasi metropolis and the nation as a whole. This study narrows the analytical focus to a defensible chain of evidence. Firstly, the physical and operational characteristics of the landfill are established. Secondly, waste quantities and composition are used to estimate methane generation. Also, environmental exposure is considered through community observations of odour, leachate and biological vectors, while maintaining a clear distinction between perception and measured exposure. Fourth, mitigation options are evaluated against technical, economic and environmental feasibility. Finally, an implementation and monitoring framework is proposed so that future reductions can be measured rather than assumed. The aim of this study is to quantify and assess landfill greenhouse-gas emissions at the Kumasi landfill, identify major emission and exposure pathways, and evaluate feasible mitigation measures. Specifically, the research seeks:

a. To determine the levels of Methane gas emissions from the Kumasi Landfill in Ghana.
b. To determine biotic factors around the land fill site and impacts of the landfill.
c. To determine coping strategies of the people.

LITERATURE REVIEW

Definitions and Explanations of Key Concepts

Resilience

The term resilience was first coined by ecologist Holling (1973), and it is defined as the natural capacity of an ecological system to buffer change (i.e., absorb impacts and recover from some pre-disturbed state) (Folke, 2006). While preventing their escalation, climate resilience is the ability to effectively deal with and mitigate the effects of climate change according to the Union of Concerned Scientists (2022). A low-carbon, climate-resilient society would be prepared to deal with the challenges posed by a warming globe. In line with Mehryar (2022) study, resilience to climate change is the ability to minimise harm to the environment, the economy, and social welfare while anticipating, responding to, and recovering from the effects of adverse climate events. Legislation, services, infrastructure, education, planning, and communication are all included in this. Thus, enhancing climate resilience requires a thorough and diversified approach to bolster communities' social, psychological, ecological, physical, and financial capacities to endure and recover from the impacts of climate change.

Adaptation

Adaptation describes actions that can make the physical effects of climate change less dam-aging. It is sometimes also referred to as adjustments in natural or human systems in response to the impacts of climate change (Forsyth, 2023). The IPCC (2022a) defines adaptation as: adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Interventions Regarding Changes in Climate

The two primary categories of climate change interventions are adaptation and mitigation. Mitigation strategies are employed to address the causes of climate change. Strong policy tools are essential to any effort to reduce climate change. A historic globally framework, the Paris Agreement aims to keep global warming well below 2 degrees Celsius, preferably below 1.5 degrees (Guzović et al., 2023). "Nationally Determined Contributions"

(NDCs) are decisions taken at the national level to cut emissions (Carmona et al., 2024). Economic policies that offer financial incentives for more ecologically friendly choices include carbon pricing, cap-and-trade programs, and the removal of fossil fuel subsidies (Antimiani et al., 2023; Tat et al., 2023). Effective governance, international cooperation, and transparent reporting all contribute to increased accountability and advancement (Kavadis et al., 2024). Climate mitigation must be equitable and inclusive. The transition to a low-carbon economic model may upend those who live in fossil fuel-dependent areas (Feng et al., 2023). Workers impacted by the change should be guaranteed new job opportunities, retraining programs, and social safety nets (Carcillo & Scarpetta, 2024). To guarantee a fair global response to climate change, it is imperative that wealthier nations help developing ones financially and through the transfer of technology.

Mitigation

Actions and/or activities that prevent greenhouse gas (GHG) emissions from entering the atmosphere and/or lower their concentrations in the atmosphere are referred to as climate change mitigation (IPCC, 2023). Per IPCC (2022a), mitigation is an action taken by humans to lessen the sources of greenhouse gases or increase their sinks. Reducing GHG emissions from energy production and use, such as by using fewer fossil fuels, as well as land use and strategies to slow down global warming, like carbon sinks that remove emissions from the atmosphere through land use or other (including artificial) mechanisms, are all part of the mitigation process (IPCC, 2023). Given the time lag between the decrease of GHG emissions and the achievement of equilibrium of the concentration in the atmosphere, the advantages of mitigation are usually considered from a global, long-term perspective (IPCC, 2023). Methane and nitrous oxide emissions are also decreased by better farming techniques such crop rotation, optimised fertiliser use, and enhanced manure management. Carbon dioxide is captured and ecosystems are preserved by preserving existing forests and reforesting damaged areas. On the basis of recent research, Nature-Based Solutions (NBS) use ecosystems' innate ability to deliver ecosystem services including preservation of biodiversity in order to accomplish sustainable development objectives (Shadrack, 2024).

Climate Change Adaptations

The United Nations Framework Convention on Climate Change (UNFCCC) provides that all Parties must formulate and implement national or regional programmes containing measures to facilitate adequate adaptation to climate change (Art. 4.1b cited in FAO, 2024).

Defining Various Terms in Adapting to Changes in Climate

While understanding concepts of adapting to changes in climate, certain terms often used in adaptation literature needs to be understood as well.

Adaptive Capacity

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences of various changes, such as those induced by climate change, represents the latent potential for adaptation and thus a key component of vulnerability (IPCC, 2023). Assessing adaptive capacity means evaluating this potential by identifying strengths and weaknesses in the system's core social, eco-nomic, and institutional structures taking into account a range of factors that include economic and technological resources, information and skills, infrastructure quality, institutional effectiveness, and strength of social networks and collective organization (IPCC, 2023).

Adaptability

This is dynamisms in the extent where adjusting to the situation is possible in terms of processes, structures or practices are projected (IPCC, 2023).

Adaptation Methods

Adaptation methods are those strategies that enable the individual or the community to cope with or adjust to the impacts of the climate in the local areas. Such strategies include the adoption of efficient environmental resources management practices such as the planting of early maturing crops, adoption of hardy varieties of crops and selective keeping of livestock in areas where rainfall has declined. They also include the use of technological products that enable the individual to function in the new condition (Nyong et al., 2021). From various definitions and concepts in adaptation, Gebre and Kifle (2021) extracted the following major principles: adapting to climate change encompasses processes of learning that are continuous as they are responses to risks that are expected or real. As part of the principles, it is clear that, adapting to changes in climate results in an integration in preventing or mitigating, being spontaneous or planned, being practices or management or processes of management or even being able to reduce susceptibility of a system while increasing its resilience.

Types of Climate Change Adaptations

Autonomous adaptation is the reaction of, for example, a farmer to changing precipitation patterns, in that he changes crops or uses different harvest and planting/sowing dates (FAO, 2024). Planned adaptation measures are conscious policy options or response strategies, often multi-sectoral in nature, aimed at altering the adaptive capacity of the agricultural system or facilitating specific adaptations. For example, deliberate crop selection and distribution strategies across different agro climatic zones, substitution of new crops for old ones and resource substitution induced by scarcity (FAO, 2024). Adjustments that are of short term are regarded as autonomous such that no significant sector is required to implement and develop climate change (FAO, 2024). Key structural dynamisms in long term adaptations are to overcoming adversities like land use changes results in evolving conditions (FAO, 2024). Societies, organizations and individuals have adjusted their behaviour in response to past climatic change. Much of this adaptation is reactive, in the sense that it is triggered by past or current events, but it is also anticipatory in the sense that it is based on some assessment of conditions in the future (Adger et al., 2021).

Adaptations Strategies from the World Over

Adaptation strategies aim to reduce vulnerability and enhance the resilience of ecosystems, infrastructure, and communities to current and projected climatic stresses (IPCC, 2023). The consequences of climate change have made climate adaptation a critical issue. Additionally, individuals dealing with climate change are developing a number of adaption strategies. This calls into doubt the efficacy of adaptive techniques (Savari & Moradi, 2022). As a result, a number of writers have addressed this problem (Pisor et al., 2022; Singh et al., 2022). Examining the sustainability of adaptation is especially complicated since it can be complex to differentiate adaptation measures from development initiatives, which makes categorisation problematic (Owen, 2021). People and institutions are taking action to adapt to the effects of climate change, according to a growing body of information on the tracking of adaptation efforts at the global, regional, national, and local levels (Araos et al., 2021; Berrang-Ford et al., 2021; Garschagen et al., 2021). Current risk management systems face additional difficulties as they adjust to the unprecedented effects of climate change. A number of players at many levels of social structure, including the government, corporations, civil society, homes, and people, are known to be involved in adaptation (Petzold et al., 2023).

Therefore, addressing adaptation issues would need coordinated efforts from many societal actors, ideally with a clear division of responsibilities and duties and a shared understanding of common adaptation goals (Mees et al., 2021). In actuality, divergent perspectives on the objectives of societal adaptation or the roles and duties that players assign to themselves or other actor groups often define multi-actor constellations (Doshi & Garschagen, 2023a; Ommer et al., 2024). The specific impacts of climate change will depend on the climate variance and change it experiences as well as its geographical, social, cultural, economic and political situations. As a result, countries require a diversity of adaptation measures that reflect their unique circumstances-(UN General Assembly, 2008:1). Adaptation is made up of actions throughout society, by individuals, groups and governments (Adger et al., 2021). Every society differs from the other and so are their actions (adaptations) towards climate change. Nevertheless, some adaptation strategies from one society can be

adopted by another in facing climate change impacts. For developing countries, despite their strategies and plans to implement adaptation activities, they have limitations in capacity (especially in human capacity and financial resources) making adaptation difficult (UN General Assembly, 2008). Nevertheless, their adaptive strategies address a variety of high-risk sectors. For instance, severe climatic conditions threaten Kenya's food production and put strain on the nation's economy, livelihoods, food and nutrition security, and environment (Ogola et al., 2023). Farmers will be greatly impacted, and these incidents are likely to worsen if the solutions put out by different climate change adaptation campaigners are not implemented.

As stated by Maina and Parádi-Dolgos (2024), with greater impacts shown in nations with moderate human development indices and climate cash allocated to adaptation considerably lowers recipient countries' susceptibility to climate change in Africa. Similar results are reported by Kelly and Ndeffo (2025), who demonstrate that environmental taxes and climate financing considerably lessen environmental deterioration, especially in nations with better governance and human capital. Masud et al. (2023) in South Asia also show how climate money may lessen climate vulnerability, finding that it considerably reduces recipient nations' yearly and long-term climate risk. Scandurra et al. (2020) shown that foreign direct investment (FDI) and support for green energy generation and environmental preservation greatly lessen climate vulnerability in small island developing states. Sohail et al. (2024), who show that green finance greatly improves high-quality economic development while maintaining ecological sustainability, further support these beneficial benefits of climate-related funding on sustainable growth.

Adaptation strategies that address a variety of environmental pressures and conditions are the most successful for emerging nations. These strategies should focus on lowering poverty, increasing food security, providing access to water, guaranteeing a decline in biodiversity and ecological services, and finally strengthening adaptive capacity (UN Generally, 2008). For developed countries, a country like Canada has identified 96 different adaptation measures in their agricultural sector including change in topography of land (11 measures), use of artificial systems to improve water use/availability and protect against soil erosion (29), change in farming systems (21), change in timing of farm operations (2), use of different crop varieties (7), governmental and institutional policies and programmes (16), and research into new technologies (10). Many of these involve improved resource management – an option with benefits that extend beyond adaptation (FAO, 2024). To enable effective adaptation measures, both governments and non-government organizations, must consider integrating climate change in their planning and budgeting in all levels of decision making (UN General Assembly, 2008).

Adoption of Adaptation Strategies

Infrastructure modifications (such as flood defences), agricultural practices (such as drought-resistant crops), ecosystem-based approaches (such as mangrove restoration), and policy changes (such as land-use planning) are all examples of adaptation strategies (Dawson et al., 2021). In order to improve efficacy and equality, community-based adaptation places a strong emphasis on local knowledge, involvement, and capacity building (Reid et al., 2021). In order to minimise losses or seize advantageous possibilities, climate change adaptation methods concentrate on lowering exposure and susceptibility to climate change through processes of adjustment to present or anticipated climatic risks (IPCC, 2022a). Multisectoral and intersectoral adaptation strategies should be developed and put into action to maximise total resources and societal benefits due to the many possible consequences of climate risks on human systems (Marten, 2021; Buse, 2022).Mitigation refers to efforts to reduce greenhouse gas (GHG) emissions, enhance natural carbon sinks, and stabilise or reverse climate change (Wang et al., 2023). It includes technological innovation, new regulations, behavioural shifts, and global collaboration (Wang et al., 2023). The ultimate goal is to achieve sustainable growth while limiting global warming.

The world has to switch from fossil fuels to low-carbon and renewable energy sources in order to lower carbon emissions (Singh et al., 2023). Burning fossil fuels like coal, oil, and natural gas releases most of the carbon dioxide into the atmosphere (Murphy, 2024). Energy stability is ensured and emissions are significantly reduced by replacing them with renewable energy sources such as hydro, solar, geothermal, wind, and bioenergy (Chen et al., 2023). Decarbonising industry and electrifying transport infrastructure, including public transport and electric vehicles, are essential for achieving a sustainable energy transition (Sovacool et

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al., 2024; Liu et al., 2024). Cleaner industrial practices and energy-efficient technologies must also be used to support low-carbon development. Reducing emissions across all industries requires improving energy efficiency. By installing smart grids, improving building insulation, upgrading appliances, and streamlining industrial operations, societies can lower their overall energy consumption (Abdelaoui et al., 2023; Saleem et al., 2023; Szczotka et al., 2023). Behavioural measures like reducing excessive use and saving power are crucial in addition to technical developments. Together with each other, these efforts reduce expenses, increase energy security, and reduce emissions (Altassan, 2023; Papadakis & Katsaprakakis, 2023).

As carbon sinks, soils and forests are crucial (Liu et al., 2024). Mitigation strategies such as replanting and afforestation increase biodiversity and carbon absorption (Zhu et al., 2023). Avoiding deforestation is one of the best short-term solutions, especially in tropical areas (Heinrich et al., 2023; Nzabarinda et al., 2025). Agroforestry and other sustainable forest management techniques improve erosion control, soil fertility, and carbon sequestration (Pan et al., 2025). When preserved, wetlands and peatlands boost carbon sequestration and strengthen communities' ability to withstand natural calamities (Li et al., 2024). Two of the main causes of air pollution in agriculture are nitrous oxide from fertilisers and methane from livestock (Ogwu et al., 2024). This impact can be mitigated by switching to a more ecologically friendly agricultural style. Precision fertilisation, crop rotation, organic farming, and conservation tillage are techniques that boost productivity without compromising yield (Arshad et al., 2023). Another advantage of promoting plant-based diets and reducing food waste is lowering emissions. Sustainable agriculture not only lessens its negative effects on the environment but also enhances food security and rural residents' quality of life (Bhatia et al., 2023). New technologies such as Carbon Capture, Utilisation, and Storage (CCUS) provide hope for the direct removal of CO2 from industrial emissions or the air (Hanson et al., 2025). These technologies are essential to achieving net-zero goals, but they are costly and yet in their infancy. Deep decarbonisation also depends on developments in renewable energy storage, green manufacturing, and hydrogen fuel (Akinpelu et al., 2023; Miao et al., 2025). By expanding research and promoting global technology transfer, we can accelerate progress. 4.6. Waste Management and the Circular Economy Transitioning from a linear "takemake-dispose" paradigm to a circular economy can reduce resource extraction and waste production (Cruz, 2025; Daga et al., 2025).

The main objective of recycling, material reuse, and energy conversion techniques like methane recovery and biogas generation is to reduce emissions (Deng et al., 2025). Using clean technologies to decarbonise heavy industries is another crucial component of this plan (Tian et al., 2023). Technological solutions won't work until society changes in tandem. Promoting eco-friendly lifestyles, sustainable consumption, and raising climate knowledge are essential (Arya, 2023; Pekez et al., 2025). Emissions can be considerably reduced by a combination of behavioural adjustments, such as consuming less meat, consuming less energy, and favouring public or non-motorized transportation (Zhang et al., 2025; Lambrecht et al., 2023). The promotion of responsibility and awareness is an important function of community programs, the media, and educational institutions (Ghazy & Fathy, 2023). On Ghana’s coast, since occupations of residents on the coast is mainly dependent on fish resources, susceptibility of livelihood is associated with climate change considerations or without them. The catchment area of the Muni Pomadze wetland is inundated with human settlements, which generate a large quantity of waste daily, and these pollutants end up in the wetland without any treatment.

The concentration of metals in the region rises as a result of human activity increasing the metal inflow that enters the wetland through surface water erosion or runoff. As indicated by Okyere et al. (2023), the ongoing buildup of these heavy metals leads to a significant amount and presents major health risks to both people and animals. Since the beginning of time, wetlands have played a crucial role in many aspects of human development and progress. For example, Babuponnusami et al. (2023) believed that by protecting water bodies, lagoons lessen the negative impacts of pollution on the ecosystem. By reducing the pollutants' chemical makeup, this is accomplished. To be competitive and productive, climate change adaptation is essential. In order to counteract the ameliorating effects of unfavourable climatic conditions on land, water, and human capital—all essential inputs in food production, adapting to climate change would require a shift to new and appropriate production methods and techniques for food production activities such as farming, fishing, and livestock rearing (FAO, 2024).

Adaptation and Mitigation

Adaptation and mitigation differ in terms of the actors who are involved. Mitigation refers to efforts to reduce or prevent the emission of GHGs or enhance their sinks to limit the scale and rate of climate change (UNFCCC, 2015). It involves technological, behavioural, and policy measures aimed at stabilizing atmospheric GHG concentrations at a level that prevents dangerous anthropogenic interference with the climate system (IPCC, 2023). Adaptation involves the process of adjustment to actual or expected climate stimuli and their effects to moderate harm or exploits beneficial opportunities (Smit & Wandel, 2021). It can be anticipatory or reactive, autonomous or planned, and operates across multiple scales—from individual and community to national and global levels (IPCC, 2023). Adaptation is essential for reducing vulnerability and enhancing resilience in the face of unavoidable climate impacts (Adger et al., 2021).

Providing Funds for Interventions in Changes in Climate

Interventions of adaptations and mitigations need significant monetary resources. It was suggested by the World Bank that, mitigation costs can be more than 350 billion dollars per year spanning from 2010 to 2030 with adaptation costs being more than 75 billion dollars from 2010 to 2050. One of the major pillars of the Action Plan of the Bali is strengthening efforts of investments and finances which guides present negotiation for evolving international treaties as long as changes in climate is concerned (UNFCCC, 2008). The estimates of the World Bank are entirely the same as that of UNFCCC that was carried out in 2007. Multiplication of fund sources for climate change has moved up the ladder into more multilateral and bilateral initiatives of funding. Large-scale mitigation initiatives require substantial climate finance. Public-private partnerships, green bonds, and international climate funds can all be used to finance clean technology adoption and renewable energy projects (Alamgir & Cheng, 2023; Bei & Wang, 2023). MRV systems, which stand for monitoring, reporting, and verification, are crucial for tracking progress and maintaining transparency and integrity. Adaptation strategies that may be used with mitigation to create synergy and boost overall climate resilience include the use of drought-tolerant crops or climate-resilient infrastructure (Singh et al., 2024).

Ghana’s Changing Climate and its Impacts

Ghana is not exempt from the reality of climate change. Over 26,000 people were displaced in the Lower Volta area in November 2023 due to flooding caused by a spill from Ghana's largest hydroelectric dam, Akosombo, which was released to relieve pressure on the dam following an exceptionally heavy rainfall (Bawakyillenuo et al., 2026). Thousands of people have been displaced, property and infrastructure have been destroyed, and productivity and livelihoods have decreased as a result of Ghana's rapid loss of coastal areas due to erosion and sea level rise (World Bank Group, 2023). Working in Fuveme in the Volta Region, Dzokoto et al. (2025) describe how climate-related floods and WASH interruptions cause anxiety at the start of rainstorms, depressed tendencies after losing a livelihood, and a reliance on family support and self-comfort as coping strategies. Similarly, Hagan et al. (2025) demonstrate that, despite ongoing sea-defense initiatives, rising sea levels and frequent flooding are linked to significant psychological effects, such as anxiety, despair, learned helplessness, and in certain cases, severe mental illness, in impoverished urban coastal communities in Accra (Glefe, Gbegbeyise, and Shiabu).

In line with recent research by ACRC (2023), Accra's general structural change trend is similar to that of other African cities, but it conceals notable sub-city variations (Danquah et al., 2024). While labour productivity in Accra's commercial enterprises is usually poor, there are notable neighborhood-specific variations. Climate change poses a threat to Ghana's main cities' development and prosperity. in relation to the World Bank's country risk assessment for Ghana, the average annual temperature has risen by almost one degree Celsius over the past fifty years, and the average number of "hot" days and nights has also grown dramatically over time (World Bank, 2021). Rising sea levels and shifting hydrodynamics along the West African coast have intensified coastal erosion, and rainfall has also grown more unpredictable (World Bank, 2021). Despite natural fluctuation, the global surface temperature in the Accra metropolitan region is increasing over time, and rainfall patterns are erratic. Economic operations in cities are greatly impacted by the detrimental consequences of climate-related catastrophes including floods, rising temperatures, and frequent and unfavourable weather patterns. Labour productivity and structural change at the city level may be negatively

impacted by these effects, which can be both direct (such as the loss of properties, lives, and livelihoods) and indirect (such as increased heat and rainfall) (World Bank Group, 2022). Ghana was one of the first nations in Sub-Saharan Africa to join the Compact for the Comprehensive Africa Agriculture Development Program (CAADP) in 2009 (Amanor & Iddrisu, 2022). The Malabo Declaration, which was issued by heads of state in 2014, aimed to maintain the GDP growth rate for agriculture while increasing food production by 2025. This was an effort to alleviate hunger and lessen poverty (IPCC, 2018). Ghana's performance was deemed "off track" following four years of implementation.

Three recommendations were made after the Biennial Review in 2018 where Ghana was asked to: (1) Increase the share of agriculture land under sustainable land and water management practices from the current low level of 0.04%; (2) increase public agriculture expenditure as a share of total public expenditure to the Malabo Declaration target of 10%; and (3) put in place policies that would facilitate and promote intraregional African trade in agriculture commodities and services. The country's poverty rate decreased from 56.5% in 1991 to 24.2% in 2017 thanks to the government's efforts to encourage economic growth during the past three decades, fulfilling the Sustainable Development Goal (SDG) one aim of halving poverty (Kansanga et al. 2019). There are significant differences in the nation notwithstanding these advancements. Ghana's northern region is notable for having made the least progress in reducing poverty. As stated by Owusu et al. (2024), the region has the most impoverished households in the nation. In addition to being more prevalent, poverty is quite severe in certain areas (Northern, Upper West, Savannah, North-East, and Upper East) (Tesfahunegn et al. 2021).

The vulnerabilities encountered by smallholder farming households in Ghana's Savanna and Sudan agroecological zones are made worse by non-climatic concerns such the high cost of agricultural inputs, bad roads, insufficient irrigation systems, and capital resources (Alidu et al., 2022). For example, Fagariba et al. (2021) found that impoverished smallholder farmers in northern Ghana are unable to mitigate the issues associated with climate change due to the high cost of inputs such fertiliser, tractor services, insecticides, and weedicides, as well as a shortage of farm labour. The majority of smallholder farmers utilise unimproved groundnut seeds from the local market due to the high cost of improved seeds, according to Challinor et al. (2021). A research by Fagariba et al. (2021), poor extension services and a lack of logistics are preventing smallholder farmers, especially those in rural locations, from receiving enough climatic information. Due to a lack of infrastructure development, poor literacy, and high rates of poverty, which worsen the consequences of climate variability on their livelihoods, smallholder farmers in the area are more susceptible to both climatic and non-climatic threats (Abdulai, 2022).

The significance of proactive institutional actions in reducing flood risks in Ghana is highlighted by a research by Ibrahim et al. (2023). These actions include Economically Weaker Sections (EWS) implementation, training, awareness-raising, and spatial planning. The study found that while these strategies hold promise for reducing flood impacts, their effectiveness is undermined by several systemic challenges. Enforcement of flood management regulations is inconsistent, and governance issues, such as inadequate resources and limited coordination between institutions, hinder the long-term success of these interventions. For instance, top-down measures like forced evictions and demolitions have often failed to provide lasting solutions, as rapid re-siltation of waterways and continued littering persist, leaving vulnerable populations at risk. The case study underscores the need for a shift toward more participatory and inclusive flood management strategies. Strengthening governance frameworks is crucial to addressing enforcement gaps and ensuring that flood risk reduction measures are both effective and sustainable. This requires adequate resourcing for institutions tasked with flood management, as well as improved coordination among stakeholders to harmonize efforts. Moreover, fostering community engagement is key to achieving long-term resilience.

Climate Change Vulnerability and Resilience

Vulnerability is one of the system characteristics of adaptation in the context of climate change, and can be defined as the "degree to which a system is susceptible to injury, damage or harm" (Smit & Wandel, 2021). Garba et al. (2022) averred that, vulnerability is often described as a social concept that is intimately tied to exposure, which is the temporal and geographical distribution of people and assets. Vulnerability research may be conducted using resilience, entitlement and sustainable livelihoods, natural hazards, and integrated research

traditions (Gumel, 2022). Traditional ecological knowledge has long been important to many African groups, who have developed adaptation techniques over many generations (Asmamaw et al., 2022). One of the most pressing social issues of our day is climate change, which is causing temperatures to rise, precipitation patterns to alter, and extreme weather events to become more often and severe (IPCC, 2023). As these effects worsen, they pose existential risks to our civilisation (Simpson et al., 2023) and put people and ecosystems at risk globally (Birkmann et al., 2022). Coastal regions are especially vulnerable because of the close links between human systems and ecosystems and the convergence of vulnerabilities to climate-related change (Pérezner & Roberts, 2022). Millions of people in Africa rely on rain-fed agriculture for their livelihoods, which increases climate vulnerability (Ayodotun et al., 2022).

In accordance with estimates, populations in West Africa would be more vulnerable to compound occurrences, such as concurrent heatwaves and heavy precipitation, that jeopardise food security and public health due to rising temperatures, unpredictable rainfall, and frequent droughts (Quenum et al., 2021). Industries, communities, and societies in coastal and river flood plains, those whose economies are directly dependent on climate-sensitive resources, and those in regions vulnerable to extreme weather events—particularly those experiencing rapid urbanization—are typically the most vulnerable (UN General Assembly, 2008). The least developed countries (LDCs), developing nations, and small island developing states (SIDS) are therefore particularly vulnerable to the effects of climate change due to their reduced ability to manage disasters, which may hinder the achievement of the Millennium Development Goals (UN General Assembly, 2008; UNEP, 2024).

Conversely, resilience is the process, capacity, or result of successfully adapting to the environment in spite of hazardous or unfavourable circumstances. Resilience is an important component of wellness, and everyone will experience hardship at some time (Karam et al., 2021). The ability to endure life's challenges and preserve our physical and emotional well-being in the midst of hardship is known as resilience (Clauss-Ehlers, 2021). A fundamental concept in climate change adaptation and mitigation, resilience is extensively used in a variety of fields, including as social policy, environmental sciences, and economics (Nyangon, 2024). Although definitions of resilience differ, they all agree that it represents the ability of systems, whether ecological, economic, or infrastructural, to withstand shocks, adjust to shifting circumstances, and recover without losing their essential functions (Nisioti et al., 2023).

Interventions on Climate Change and Evaluation of Impacts

As pointed out by the IPCC (2023), climate change has already caused widespread impacts and associated damage to socio-ecological systems, leading to changes in terrestrial, freshwater, and oceanic ecosystems worldwide. Minimizing waste generation through measures such as reduced packaging, material reuse, and enhanced recycling reduces the volume of organic material entering landfills, thereby lowering methane emissions a potent, short-lived climate pollutant (Tawo, 2025). Investments in biological treatment technologies, especially anaerobic digestion, and source separation of organic waste allow for the capture and utilisation of landfill and biogas for power and heat generation or safe flaring to prevent atmospheric emission (Tripathy et al., 2025). When combined with the inclusive formalisation of the informal waste sector, these interventions can boost livelihoods, restrict local air and groundwater pollution, provide low-carbon energy, and reduce reliance on imported fuels (UNEP, 2024).

Future attempts to mitigate climate change will be centred on technological innovation (Rane et al., 2024). In contrast to conventional renewable energy and efficiency gains, cutting-edge technologies provide new paths for monitoring and lowering greenhouse gas emissions. One example is the application of artificial intelligence (AI) in climate modelling. By forecasting supply and demand patterns, AI algorithms improve the integration of renewable energy sources into power grids, cutting waste and boosting system dependability (Rane et al., 2024; Sankarananth et al., 2023). AI-driven precision farming in agriculture reduces emissions related to overuse by optimising the use of pesticides, fertilisers, and water (Padhiary, 2025). As indicated by Karthikeyan (2025), AI helps analyse big climate information to enhance forecasting and risk management, promoting more intelligent mitigation and adaptation measures. Consequently, Schulz and Feist (2021) averred that, blockchain technology provides a way to improve climate action accountability. Blockchain can track greenhouse gas (GHG) emissions throughout supply chains and validate carbon credits or offsets by

establishing safe, unchangeable ledgers. Blockchain-based systems assist decentralised renewable energy projects and enable peer-to-peer energy trade (Alam et al., 2024).

Fullerton et al. (2025) contend that distributive fairness and the moral implications of intervention beyond tipping points must be taken into consideration when discussing climate policy. In a similar vein, Williams et al., (2024) provide an ethical framework for climate technology governance that demands openness, inclusion, and respect for many values. These viewpoints draw attention to the enduring philosophical and ethical issues that underlie climate mitigation, such as whether global solutions should put local autonomy or the welfare of the planet first, and whether it is only appropriate for wealthier countries to impose mitigation pathways that might disadvantage developing economies with limited technological capacity. Local government initiatives in Ghana, such as regular dredging of the Odaw canal, destruction of buildings in waterways, and sporadic flood-control projects, supplement household efforts but also often have a transient effect (Owusu & Obour, 2021).

Local adaptation techniques are also influenced by who makes decisions and how inclusive local procedures are, in addition to the technology and practices that are now accessible. Koomson (2023) demonstrates that although rural women make substantial contributions to the planning and execution of climate adaptation, their responsibilities are limited by current gender norms, power hierarchies and project design, which limits the extent to which local policies represent their objectives. Building on this, Koomson and Koomson (2025) demonstrate that "group inclusiveness" is a crucial factor in locally acceptable, vulnerability-responsive adaptation choices, with more inclusive groups more likely to give highly exposed and marginalised households' requirements top priority. At a more general level of governance, Yeleliere et al. (2022) point out that successful adaptation in northern Ghana depends on coordinated action and alignment of interests between government agencies, traditional authorities, NGOs, and farmers, with stakeholder engagement and power disparities greatly influencing which adaptation options are put into practice. Research by Corvalan et al. (2022) and Charlson et al. (2022) examined how climate change affects people's mental health and psychosocial well-being as well as how it directly affects the frequency and severity of climate change impacts and disaster events on an annual and long-term basis.

The Concept of Climate Change (Global Changing Climate)

Climate change is a long-term, naturally occurring shift in weather patterns and temperatures that takes place across geological timeframes (Waseem et al., 2024). However, human activity has significantly accelerated these changes during the past century. The Intergovernmental Panel on Climate Change (IPCC, 2023) defines climate change as a shift in the climate's state that is detectable by variations in the average and/or variability of its characteristics and that lasts for a long time, usually decades or more. One of the most evident consequences of climate change is rising global temperatures. The previous few decades have seen the warmest years on record (Cheng et al., 2023; Esper et al., 2024), and global surface temperatures have increased by more than 1°C on average since pre-industrial times (Jenkins et al., 2023). This growth has resulted in shorter cold spells, longer warm seasons, and extreme heat waves. In many regions of the world, hotter-than-ever weather is devastating ecosystems, water supplies, and human survival (Li et al., 2023). Another important indicator is the melting of polar ice caps and glaciers. Globally, sea levels are increasing as a result of the Arctic and Antarctic ice caps melting quickly (Fang et al., 2023; Maure et al., 2023).

Melting glaciers are endangering areas that depend on glacial meltwater for their freshwater supply, such as the Himalayas (Karakoti et al., 2024). Rising seas will increase floods, erosion, and land loss, endangering coastal communities, islands, and deltas (Roy et al., 2023). Low-lying countries like Bangladesh and the Maldives face existential concerns (Cardarelli & Pomper, n.d.). There has been a discernible change in precipitation patterns throughout the world. Some areas experience protracted droughts, while others experience flooding with excessive rains (Qiu et al., 2023). This shift exacerbates water insecurity, damages infrastructure, and disturbs agricultural cycles. The frequency and intensity of extreme weather events such as hurricanes, cyclones, and unseasonal monsoons have also increased (Islam, 2025). Since the seas absorb so much of the additional heat and carbon dioxide gas from the atmosphere, they are also in a very dangerous position. Ocean warming is upsetting marine ecosystems, leading to fish species migrating to cooler seas and coral bleaching (Yin et al., 2023). Coral reefs, shell-forming organisms, and the millions of people whose livelihoods depend

on fishing are all at risk due to ocean acidification, which is brought on by rising CO2 absorption (Martins Medeiros & Souza, 2023).

Africa's Changing Climate

Despite making up just 3% of the world's greenhouse gas emissions, the African continent is among the most sensitive to climate change and is predicted to suffer some of its most severe effects (Notre Dame Global Adaptation Initiative, 2023). Africa is the continent most susceptible to the effects of climate change, according to the African Climate Change Summit (Chibundu, 2023). Africa is a continent rich in resources, with a varied climate, environment, and culture (Iyiola & ValboJørgensen, 2023). The continent is expected to see an increase in economic activity due to its estimated population of 2 billion people by 2050, the majority of whom are young (Adedini et al., 2023). Nonetheless, it is generally acknowledged that Africa is the continent most susceptible to the effects of climate change, with several environmental and climate-related issues that seriously jeopardise its social and economic advancement (Adedini et al. 2023; Bedair et al. 2023).

In addition to creating new threats that need immediate response, climate change exacerbates pre-existing issues including food insecurity, water shortages, and displacement (Busayo & Kalumba 2020). Senegal, for example, has been severely impacted by extreme weather occurrences. On September 5, 2020, nearly 90 mm of rain fell in Dakar in a single day, causing widespread flooding and forcing thousands of people to flee their homes (Diedhiou et al. 2024). Similar to this, extreme weather events have had a significant socioecological impact on Kenya's informal settlements, resulting in health crises, financial disruptions, and increased vulnerability among marginalised groups, especially women (Balakrishnan et al. 2024). Furthermore, food insecurity and undernutrition among children under five have gotten worse in Kenya's Kilifi County due to agricultural droughts and unpredictable rainfall (Cheruiyot et al. 2022). Over 65% of Nigeria has seen increased drought risks and substantial economic losses from floods and droughts in recent decades, making the country's agriculture industry very vulnerable to extreme weather events (Olayide et al. 2024).

Furthermore, agriculture and ecosystems are disrupted by warming trends in Nigeria's Sahel area, which are characterised by rising maximum temperatures and drier conditions (Yahaya et al., 2024). Ethiopia is another example of the social and economic effects of climatic extremes; its agriculture-based economy is being challenged by the Zarima subbasin's growing dry spells and decreasing rainfall patterns (Kassahun et al., 2024). Improving healthcare access, ensuring clean water and sanitation, strengthening disaster preparedness and response, boosting investment in raising public awareness, research and development, and promoting sustainable development are just a few of the many strategies needed to combat the effects of these issues (Ameer & Saba, 2023). Based on Villarreal-Rosas et al. (2023) study, researchers have recommended increasing the use of strategies for risk reduction and adaptation related to climate change that are well-thought-out, accepted, and successful. As a result, several scientific and indigenous approaches to disaster risk reduction (DRR) and climate change adaptation (CCA) have been implemented, and more are now underway at various governmental levels throughout Africa. Busayo and Kalumba (2020) added that DRR and CCA have a common goal and a lot of overlap. The former deals with all man-made hazards, such as hydro-meteorological or geophysical hazards, while the latter deals with climate variability and hazards.

However, Busayo and Kalumba (2020) argue that CCA focuses primarily on communities' long-term adaptations to changing climatic conditions, emphasising the benefits that may result from these adaptations. DRR, on the other hand, is concerned solely with extreme events that cause disaster. Aside from the high mortality rates, disasters impede local economic stability and development in the majority of middle- and low-income countries (Saeed et al. 2023). Leveraging appropriate measures, such as disaster management strategies and policies, reducing the vulnerability of property and people, improving preparedness for extreme events, minimising society's vulnerability or exposure to potential dangers and risks, and sustainable management of land and environment, can reduce man-made and natural hazards and society's susceptibility or exposure to these risks (Khurana et al., 2022; Das, 2023). In the case of hazardous systems, catastrophe risk and losses may grow if disaster management policies and procedures are not implemented or maintained (Sindall et al. 2022).

Climate Change Impacts (Global Impacts)

Agriculture, which is vital to many nations, is seriously threatened by climate change (Ritchie, 2024). Variations in temperature, erratic rainfall, and an increase in pests all contribute to lower agricultural yields and productivity (Yuan et al., 2024). Considering a research, the production of major crops including wheat, rice, and maize may decrease by 7–23% in vulnerable areas. Warmer weather accelerates crop maturity, increases plant stress, and reduces soil moisture, all of which lead to lower-quality product (Rezaei et al., 2023). Climate change has a significant influence on water and soil resources. While prolonged droughts deplete reservoirs and groundwater supplies, excessive rainfall exacerbates soil erosion, nutrient degradation, and waterlogging (Ji et al., 2024). Arable land in coastal areas becomes useless due to saltwater intrusion brought on by increasing sea levels (Tarolli et al., 2023). Melting ice in many river systems, particularly those that get their water from the Himalayas, is endangering the freshwater supply for almost two billion people.

Livestock and fisheries are under a lot of strain. Rising temperatures promote heat-related diseases in animals, which reduces the output of meat and dairy products (Chauhan et al., 2023). Ocean acidification and warming have an impact on fish migration and reproduction, which in turn impacts food availability and fishing populations' means of subsistence (Gilfoyle & Baird, 2023). Concerns about food insecurity are increasing as agricultural production declines. The impact of lower yields, rising food costs, and disrupted supply chains on people's capacity to feed and earn a livelihood is especially dangerous for developing nations (Kaur & Watson, 2024). Rural communities that depend on agriculture for a living are most affected, which leads to social instability and an economic collapse (Khatri et al., 2024). Climate change is upending natural ecosystems, changing habitats, and threatening biodiversity. While some species can eventually adapt and relocate to higher or colder climates, others cannot. As coral reefs fade and forests transform, many plant and animal species face extinction (Hald-Mortensen, 2023). Ecological imbalances promote the expansion of foreign species and new pest outbreaks, which exacerbate the situation for native plant and animal species (Zhang et al., 2024; Guégan et al., 2023).

Rising temperatures and climate change have both short-term and long-term effects on human health. As stated by Wu et al. (2025), heat stroke and cardiac issues are more prevalent in hot and humid areas, and they pose a particular risk to those who work outside or are old. In warmer climates, mosquito-borne illnesses such dengue, chikungunya, and malaria are more prevalent (Kumar et al., 2023). Water pollution, poor air quality, and wildfires all make respiratory and infectious diseases worse (Monoson et al., 2023). Climate change also contributes to migration and displacement. The resources, infrastructure, and social stability of the areas that accept the millions of people who have been forced to leave their homes owing to natural disasters like floods, rising sea levels, and failing crops are strained (Parveen, 2024). Climate change-related natural disasters have significant financial repercussions. The annual cost of repairing infrastructure, homes, and crops damaged by extreme weather events is in the billions (Ferreira, 2024; Newman & Noy, 2023). Consequently, poverty and inequality in emerging countries are getting worse. Heatwaves, floods, and energy usage are putting more and more strain on urban systems, making it difficult for vital infrastructure like transit, healthcare, and electrical grids to keep up.

Theoretical Framework

The Dynamic Capacities Theory of Management serves as the foundation for this study. The concept of dynamic capabilities was first presented by David J. Teece, Gary Pisano, and Amy Shuen in their 1997 paper, "Dynamic Capabilities and Strategic Management." An organization's ability to modify and reorganise its resources and skills in response to shifting circumstances is referred to as dynamic capabilities (Folke, 2006; Teece, 2007). Dynamic capacity theory is predicated on the premise that organisations function in contexts marked by complexity, unpredictability, and quick change. Static resources and abilities might not be sufficient in such situations to sustain a competitive advantage over time. Therefore, maintaining a competitive advantage requires a firm's ability to dynamically produce and reorganise its resources in response to shifting market conditions (Teece et al., 1997). Organisations that are more resilient to climate change are better positioned to retain their operational continuity and minimise the negative repercussions of such disruptions, which is the basis for the implications of the aforementioned theory to the subject under consideration.

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Additionally, resilient establishments are better able to preserve their long-term viability and efficiently manage climatic risks (Akpan et al., 2022).

Organisations may improve their reputation as ethical corporate citizens by demonstrating a dedication to climate change resilience through sustainable practices, emission reductions, and adaption methods. Increased stakeholder trust, brand loyalty, and a competitive edge in the market can result from this. Proactively incorporating climate issues into their operations put resilient organisations in a better position to manage changing regulatory environments and steer clear of any fines or liabilities related to non-compliance. Resilient organisations may find new chances for innovation, product creation, market growth, and cost reductions by realising the connection between environmental sustainability and commercial success. Additionally, they may form strategic partnerships with other resilient organisations from various industries to jointly tackle a shared climate concern.

METHODS

The study area is situated in Kumasi, Ghana. Kumasi is located in the transitional forest zone and is about 270km north of the national capital, Accra. It is between latitude 6.35º – 6.40º and longitude 1.30º – 1.35º, an elevation which ranges between 250 – 300 meters above sea level. The land area of the Metropolis is about 254sq/km and approximately ten (10) kilometers in radius. There are 103 communities. The Kumasi Metropolis is the most populous district in the country. It has a Population of 2,035,064 (2010 census) with an annual growth rate of 4.8% as against 3.1% of Accra Metropolitan District. There are more males (50.2) in the Metropolis than females (48.8). This translates in their sex too.

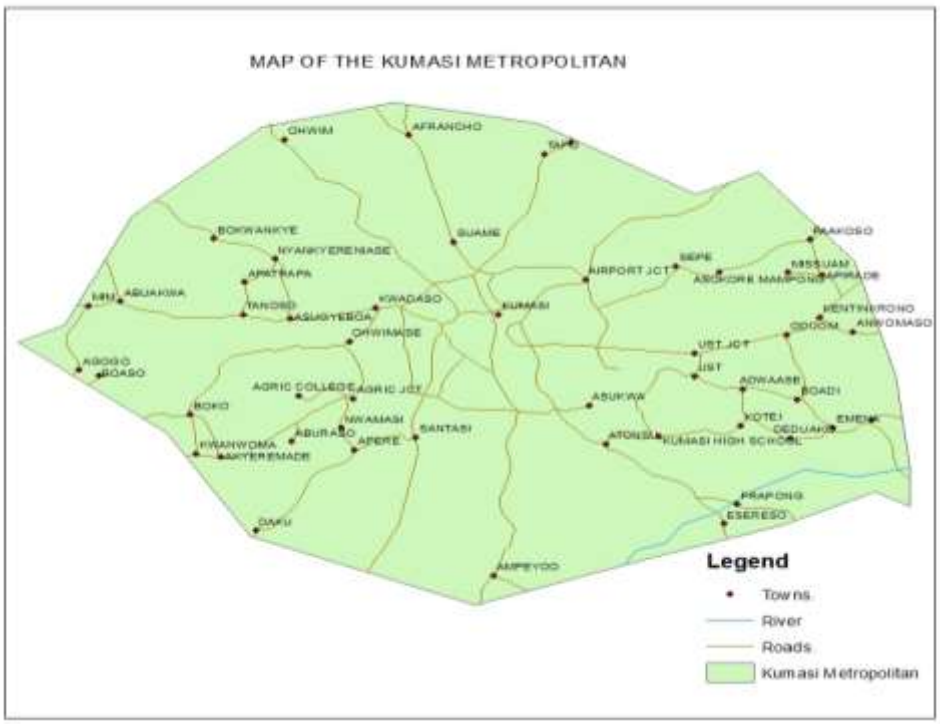


Figure 3.1: Map of Study Area

Landfill gas is generated by the decomposition of organic waste. Methane is the primary greenhouse gas assessed quantitatively in this study. Carbon dioxide is also produced during decomposition, while landfill gas can contain smaller quantities of non-methane organic compounds and other trace constituents. The study therefore uses a pollutant hierarchy: CH_4 is the principal quantified greenhouse gas; CO_2 and non-methane landfill-gas constituents are associated pollutants discussed in relation to gas management; and odour, leachate and vectors are treated as environmental exposure concerns rather than greenhouse gases. The IPCC methodology for estimating CH4 emissions from SWDS is based on the First Order Decay (FOD) method. However, laboratory and field observations on CH4 generation data suggest that the overall decomposition process can be approximated by first order kinetics (e.g., Hoeks, 1983), and this has been widely accepted.

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IPCC has therefore adopted the relatively simple FOD model as basis for the estimation of CH4 emissions from SWDS. This research therefore will make use of the simple spreadsheet model designed by IPCC to assist countries in using the FOD method to estimate. This spread sheet was developed from the following equations and assumptions;

First Order Decay Equation

$DDOCm = DDOCm \bullet e^{-kt}$

Where:

DDOCm = mass of degradable organic carbon that will decompose under anaerobic conditions in disposal site at time t

DDOCm0 = mass of DDOC in the disposal site at time 0, when the reaction starts

k = decay rate constant in y-1

t = time in years.

DDOCM remaining after 1 year of decay

At t = 1, $DDOCm = DDOCm0 \bullet e^{-k}$

Calculation of decomposable DOCm from waste disposal data

$DDOCmdT = WT \bullet DOC \bullet DOCf \bullet MCF$

Where:

DDOCmdT = DDOCm disposed in year T, Gg

WT = mass of waste disposed in year T, Gg

DOC = Degradable organic carbon in disposal year (fraction), Gg C/Gg waste

DOCf = fraction of DOC that can decompose in the anaerobic conditions in the SWDS (fraction)

MCF = CH4 correction factor for year of disposal (fraction)

CH4 generated from decomposed DDOCm

$CH4\ generated\ T = DDOCm\ decomp\ T \bullet F \bullet 16/12$

Where:

CH4 generated T = amount of CH4 generated from the DDOCm which decomposes

DDOCm decomp T = DDOCm decomposed in year T, Gg

F = fraction of CH4, by volume, in generated landfill gas

16/12 = molecular weight ratio CH4/C (ratio).

The CH4 generated by each category of waste disposed is added to get total CH4 generated in each year. Finally, emissions of CH4 are calculated by subtracting first the CH4 gas recovered from the disposal site, and then CH4 oxidized to carbon dioxide in the cover layer.

CH4 emitted from SWDS

CH4 emitted =(∑_xCH4generatedxT-RT)*(1-OXT)

(The final results from the spreadsheet)

Where:

CH4 emitted T = CH4 emitted in year T, Gg

x = waste type/material or waste category

RT = CH4 recovered in year T, Gg

OXT = Oxidation factor in year T, (fraction)

The FOD method of estimating CH4 makes use of several assumptions and parameters that are country specific. Selection of these parameters for the Kumasi landfill site will therefore fall under the default values for Ghana and Western Africa. The estimations of the Tier 1 methods which are based on the IPCC FOD method using mainly default activity data and default parameters will be used. This assumption is made since there is no historical data on the CH4 emissions from this landfill. CH4 generated at SWDS can be recovered and combusted in a flare or energy device. However, the Kumasi landfill has no such devices to recover the gas, hence the amount of CH4 which is recovered as expressed as R in the calculations will be assumed to be zero. The period between deposition of the waste and full production of CH4 is chemically complex and involves successive microbial reactions. Time estimates for the delay time are uncertain, and will probably vary with waste composition and climatic conditions. The IPCC provides a default value of six months for the time delay (IPCC, 2023). This research will therefore stick to a default delay time of six (6) months. Collected data was coded and entered into IPCC spread sheet and analyzed.

All other assumptions that are coded in the spreadsheet will be applied and the corresponding values will also be used accordingly. In this study the methodology includes: sources of data, population and sample, sampling technique, data collection method, data analysis. The individual essentials of the methodology are discussed in the succeeding subsections. Two main sources of data were used for this study. These include primary and secondary sources of data. Primary information consisted of questionnaires administered to 80 households/residents around the landfill and interviews with relevant landfill-management and public-sector stakeholders. Secondary information included landfill management records, population information and published literature. Annual waste-disposal quantities were obtained from landfill management records for 2017–2025. Interviews were also conducted for the KMA Waste Management Department, Environmental Protection Agency and Managers of the Landfill. Sample of the questionnaire are contained in the Appendix. Information from secondary data sources were particularly important in providing the views, findings and perspectives of other researchers and hence served as the foundation for the entire study. The study uses two types of data-quantitative and qualitative data. Quantitative data was collected from the management of the landfill which included Yearly Tonnage of waste. Another source of quantitative data was also collected from the Ghana statistical Services department on population of the people within the catchment area of the land fill. Qualitative data was derived from questionnaires and interviews.

The population for the survey has been done using a stratified random sampling approach which included adult male and female who lived around the Landfill site. The total number of people who were interviewed was 80. The sampling technique adopted for this study is purposive sampling technique. This approach, which is classified as non-probability sampling, depends on the deliberate and careful selection of participants or instances that satisfy particular, predetermined criteria crucial to the study's goal (Andrade, 2021; Saunders et al., 2023). Purposive sampling allows researchers to obtain richer, more contextually grounded insights and greater understanding of complex subjects by focusing on those most pertinent to the topic (Saunders et al., 2023; Aguinis, 2024).

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A set of interview questionnaire was prepared based on the objective of this research work. Structure and development of questionnaire were reviewed from various survey literatures. A total of 25 questions were prepared considering various aspects of study goal. Questionnaire discovered areas to obtain information about the demographic details of respondents, landfill impacts and coping strategies. Interview session was placed during the end of March and early May, 2026. The average time spent was 20 minutes maximum and 10 minutes minimum. As indicated by Babajide (2022), data analysis entails analysing, improving, reorganising, and structuring data in order to get significant insights that inform conclusions, support hypotheses, and strengthen evidence-based decision-making. Primary data collected through the administration of questionnaires was cleaned, edited coded and entered into Statistical Package for Social Sciences (SPSS) computer software. Analytical instruments like frequency, descriptive, regression, percentages and correlation analytic tools to identify phenomena and the relationship between the variables.

As in every study or survey of this type, this study has its limitations. This study was conducted in selected Households within the study area. The household survey addressed demographic characteristics, odour, leachate, biological vectors, reported sickness and coping strategies. Given the limited sample size and the confined coverage, the findings of the study may not represent the whole region. However, the outcome will be significantly the same in all areas. The outcome of the study therefore is more indicative than representative. Some of the respondents had the general tendency of hiding exact information due to various reasons while some others were hesitant, some claimed ignorance. The study having been conducted within a short period of time and with many other constraints might possess some errors methodologically.

RESULTS

The IPCC spreadsheet makes use of parameters that are country and region specific. Since the study area is Kumasi, the column for Country will be Ghana and that of the Region will be African Western. Hence choosing these specifics will generate the following parameters; Fraction of Methane in developed Gas, F=0.5, Conversion Factor, C to CH4 =1.33 and Oxidation Factor (OX) of 0. These parameters will be used in the subsequent steps. The IPCC guidelines for estimating Methane Gas Suggest those for a land fill with the following characteristics; Semi-aerobic managed solid waste disposal sites: These must have controlled placement of waste and will include all of the following structures for introducing air to waste layer: (i) permeable cover material; (ii) leachate drainage system; (iii) regulating pondage; and (iv) gas ventilation system, a default value of 0.5 MCF should be used. Hence this research made used of a MCF value of 0.5

Table 4.1: SWDS Classification and MCF

Type of Site	MCF
Managed-anaerobic	1
Managed Semi-Aerobic	0.5
Unmanaged Deep (>5m waste)/high water table	0.8
Unmanaged Shallow (<5m waste)	0.4
Uncategorized SWDS	0.6

Sources: IPCC (2023)

Under the activity Column of the IPC spreadsheet, parameters to feed into it included year, population and per capita waste generated. For the purpose of this study, data was limited to the period from 2017 to 2025. The Landfill started operation in 2004.

Population of Landfill Waste Dumping Catchment Area

The research through interviews conducted for KMA Waste department and Managers of the Land fill revealed that Waste going into landfill emanated from the following MMDAs as indicated in the table below. The aggregate population increased from approximately 2.03 million residents in 2017 to about 2.28 million in 2025, representing a growth of roughly 12.2 percent over the period. Kumasi Metropolitan Assembly remained

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the most populous jurisdiction, while Oforikrom, Asokore Mampong and Kwadaso continued to experience substantial demographic expansion. This sustained growth is expected to exert increasing pressure on solid waste generation, collection systems, transportation logistics and landfill management operations, underscoring the need for enhanced waste infrastructure and long-term environmental planning within the Greater Kumasi urban area. The Ghana Statistical Services department was then contacted for data on population for those MMDAs and the results are revealed in the same table below.

Table 4.2: Population of Landfill Waste Dumping Catchment Area

Year	Kwadaso	Suame	Oforikrom	KMA	Asokwa	Old Tafo	Asokore Mampong	Total
2017	251,215	161,199	303,016	728,634	140,161	146,024	304,249	2,034,498
2018	254,097	163,049	306,493	736,994	141,769	147,699	308,158	2,058,259
2019	257,669	165,341	310,801	747,354	143,762	149,776	313,695	2,088,398
2020	261,540	167,825	315,470	758,584	145,921	152,026	318,404	2,119,770
2021	265,464	170,342	320,202	769,963	148,110	154,306	323,180	2,151,567
2022	269,446	172,897	325,005	781,512	150,332	156,620	328,028	2,183,840
2023	273,488	175,490	329,880	793,235	152,587	158,970	332,948	2,216,598
2024	277,590	178,122	334,828	805,134	154,876	161,354	337,942	2,249,846
2025	281,754	180,794	339,850	817,211	157,199	163,774	343,011	2,283,593

Source: Adapted from Ghana Statistical Service population estimates and intercensal growth projections for the Kumasi Metropolitan Area and adjoining municipalities

Annual Waste Tonnage and Per capita Waste Generation

Data on annual waste collected to the landfill was obtained from the landfill management as revealed in the table below. Per capita waste generation was then calculated using the population and the annual waste values and the results are also tabulated in the subsequent table

Table 4.3: Annual Waste Disposed at the Kumasi Landfill Facility

Year	Waste Quantity (kg)	Amount of Waste (Tonnes)
2017	401,116,953	401,116.95
2018	321,982,318	321,982.32
2019	361,449,006	361,449.01
2020	385,032,317	385,032.32
2021	287,600,318	287,600.32
2022	267,822,160	267,822.16
2023	241,525,640	241,525.64
2024	290,230,000	290,230.00
2025	256,556,000	256,556.00

Source: Kumasi Landfill Management Records; Survey Work, 2026

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Table 4.4: Per Capita Waste Generation

Year	Population	Total Waste Generated (kg)	Per Capita Waste Generation (kg/capita/year)
2017	2,034,498	401,116,953	197.16
2018	2,058,259	321,982,318	156.43
2019	2,088,398	361,449,006	173.07
2020	2,149,423	385,032,317	179.13
2021	2,200,224	287,600,318	130.71
2022	2,254,783	267,822,160	118.78
2023	2,308,829	241,525,640	104.61
2024	2,364,066	290,230,000	122.77
2025	2,420,101	256,556,907	106.01

Source: Survey work, 2026

Waste Composition

The default values of waste composition for tier one countries as specified in the IPCC Guidelines for National Greenhouse Gas Inventories was adopted for this research. The results are tabulated below.

Table 4.5: Landfill Characteristics

Waste Category	Low income group (%)	Middle income group (%)	High income group (%)	Average (%)
Organics	48	56	71	58.3
Plastics	8	5	6	6.3
Paper	2	2	4	2.7
Metal	2	1	2	1.7
Glass	1	2	2	1.7
Wood	2	1	1	1.3
Textiles	3	6	2	3.7
Miscellaneous	34	27	12	24.3
Total	**100**	**100**	**100**	**100**

Source: Landfill Characteristics of Kumasi by Ketibuah et al., 2025

After feeding the above information into the spreadsheet and running, the results are generated. The results are in two categories. One is about the various compositions of the waste and the amount of Methane gas generated by each component. The second category gives the total amount of the gas generated (i.e. by summing the values of the various components of waste).

Methane Emission by Waste Components

The results generated revealed that the waste components that had generated methane gas are Food waste and Paper Waste. Further analysis showed that Food waste is the highest generated of the gas. Food waste has generated 50% (1Gg) 0f methane in 2021, 100% (2Gg) in 2022, 100% (3Gg) in 2023 and 75% from 2024 to 2025. There was no Methane generated in the first year. This is because the first will not experience much decomposition due to unfavourable anaerobic conditions hence the spreadsheet had made provision for such case. The amounts of Methane gas generated by each waste component are detailed in the under listed table and figure.

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Table 4.6: Methane Emission by Waste Composition

Year	Food Waste (Gg)	Paper (Gg)	Total (Gg)
2017	0	0	0
2018	1	1	2
2019	2	0	2
2020	3	0	3
2021	3	1	4
2022	3	1	4
2023	3	1	4
2024	3	1	4
2025	3	1	4

Source: Results from IPCC Spread Sheet, 2026

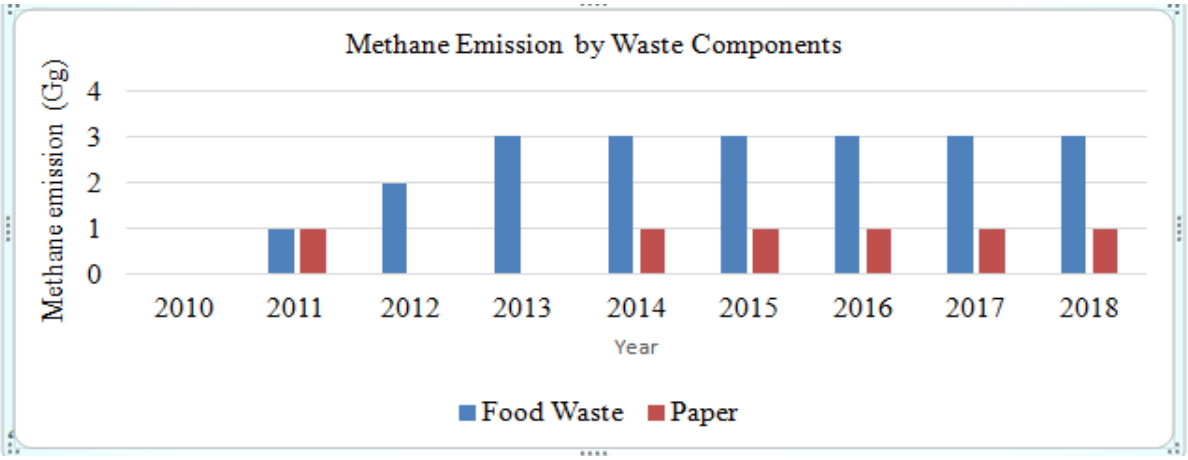


Figure 4.1: Methane Emission by Waste Components

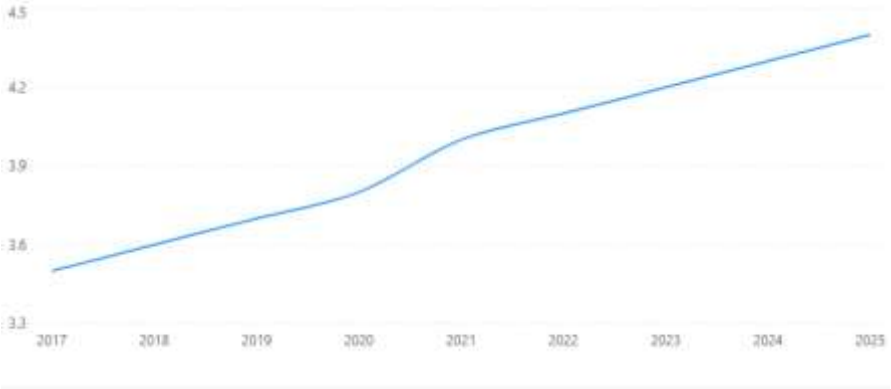
Methane Gas Generation

The results from the IPCC spreadsheet for the Methane gas generated are presented in the table below. It is evident from Fig 4.2 that the CH4 generation remained constant from the first and second years of generation at 2Gg in 2011 and 2012. It however added on 1Gg each in the subsequent two years (i.e 3Gg in 2013 and 4Gg in 2015) and remained constant at 4Gg for the rest of the preceding years. The first year of operation, 2010 did not yield any methane as explained in sub heading 4.1.3a above.

Table 4.7: Methane Estimation

Year	Methane Emission (Gg)
2017	0
2018	2
2019	2
2020	3
2021	4
2022	4
2023	4
2024	4
2025	4

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Source: Field Work Analysis, 2026

Figure 4.2: Methane Emission

Methane Emission (Gg)

The study showed that methane will continue to increase each year or remain constant from previous year (s) as depicted from Figure 4.2. This annual increment is due to population growth which is a driving factor for increase in waste at the landfill. However, the values are small and insignificant as compared to other developed countries where operation and maintenance of landfills are better. Methane production requires favourable conditions for anaerobic activities to take place. But the study revealed that the management condition at the Kumasi Landfill is not standard. This is because activities such as spreading, compacting and covering are not frequently and effectively done. However, there is an opportunity for reduction of the waste-related emissions by recovering methane through landfill gas recovery and related electricity generation if proper operational measures are put in place. Another benefit is through flaring to reduce the amount of methane escaping since this will result in reduction of GHGs and possibly resulting in winning carbon credit.

Biotic Factors and Impacts of the Landfill

This section of the analysis will focus on three main areas; a) Demographic characteristics of respondents, b) Odour levels and its impacts c) Leachate levels and its impacts d) Biotic factors and their impacts.

Table 4.8: Pollutants and Environmental Variables Assessed

Category	Variable	Status in this study
Primary GHG	Methane (CH_4)	Quantified by IPCC FOD model; not directly measured in the field.
Associated landfill gas	CO_2 and non-methane landfill-gas constituents	Discussed as associated gas constituents; not independently quantified in the study.
Odour / local air concern	Community-reported odour and breathing difficulty	Survey-based perception; no ambient concentration measurement.
Leachate	Presence, perceived trend and perceived impacts	Survey evidence; no laboratory leachate chemistry reported.
Biological vectors	Mosquitoes, houseflies, rodents, snakes	Household observations reported through questionnaire.
Health concerns	Malaria, typhoid, cholera and respiratory complaints	Self-reported household experience; no clinical attribution analysis.

Source: Field Work Analysis, 2026

Table 4.9: Waste Quantity and Composition

Year	Waste disposed (tonnes)	Per-capita waste (kg/person/year)
2017	401,116.95	197.16
2018	321,982.32	156.43
2019	361,449.01	173.07
2020	385,032.32	179.13
2021	287,600.32	130.71
2022	267,822.16	118.78
2023	241,525.64	104.61
2024	290,230.00	122.77
2025	256,556.00	106.01

Source: Field Work Analysis, 2026

The adopted waste-composition profile was 58.3% organics, 6.3% plastics, 2.7% paper, 1.7% metal, 1.7% glass, 1.3% wood, 3.7% textiles and 24.3% miscellaneous material. These composition values were adopted from the available waste-characterisation source rather than generated through a new site-specific waste-sort campaign (Ketibuah et al., 2025).

Table 4.10: Waste-Composition Profile

Waste Category	Average Share (%)
Organics	58.3
Plastics	6.3
Paper	2.7
Metal	1.7
Glass	1.7
Wood	1.3
Textiles	3.7
Miscellaneous	24.3

Source: Field Work Analysis, 2026

Methane Estimation Method

Methane generation was estimated using the IPCC First Order Decay (FOD) spreadsheet approach. The model uses the mass of waste disposed, degradable organic carbon, the fraction of degradable carbon that decomposes anaerobically, the methane correction factor, methane fraction in landfill gas and the molecular-weight ratio of methane to carbon. The model also allows methane recovery and oxidation to be considered (IPCC, 2019; IPCC, 2023). For this study, Tier 1/default parameters were adopted because historical site-specific methane-emission measurements were not available. There was a six-month default delay time and assumes zero methane recovery because no landfill-gas collection/control system was reported. These assumptions mean that the resulting values are modelled estimates rather than direct measurements of atmospheric methane. The basic FOD relationship used in the study can be represented conceptually as: DDOCm(t) = DDOCm(0)e^(-kt), where DDOCm represents degradable organic carbon remaining under anaerobic decomposition and k is the decay constant. Methane generation is then derived from the decomposed carbon and the assumed methane fraction. The important methodological point is that annual waste deposited in one year can generate methane over subsequent years; therefore, methane generation is not expected to follow annual waste tonnage one-for-one.

Temporal and Spatial Variation

Temporal variation was assessed through the 2017–2025 annual waste and methane estimates. Thus, the modelled emission period is nine years, while the facility age is approximately sixteen years by 2026. The questionnaire additionally captured residents' perceptions of changes in odour and leachate over approximately ten years. Spatial variation, however, was not directly measured through a systematic air-monitoring network in the original study. The framework therefore treats spatial exposure as a limitation and proposes four monitoring zones for future work: (1) active disposal areas, (2) older/closed waste areas, (3) the landfill boundary, and (4) nearby residential receptor locations, with each receptor classified according to upwind/downwind position.

Meteorological Factors

Meteorological conditions can influence atmospheric dispersion and the timing and intensity of odour exposure. Temperature, rainfall, wind speed, wind direction and atmospheric stability are therefore relevant covariates for a future direct-exposure programme. The meteorology is discussed as a relevant explanatory factor rather than analysed statistically in the present dataset.

Baseline and Ambient-Air Measurements

No baseline ambient-air measurement campaign for methane or other landfill-gas constituents was found. The study's odour and exposure evidence came from household questionnaires rather than instrumental ambient-air monitoring.

Table 4.11: Estimated Methane Generation

Year	Food waste CH_4 (Gg)	Paper CH_4 (Gg)	Total CH_4 (Gg)
2017	0	0	0
2018	1	1	2
2019	2	0	2
2020	3	0	3
2021	3	1	4
2022	3	1	4
2023	3	1	4
2024	3	1	4
2025	3	1	4

Source: Field Work Analysis, 2026

The model estimates zero methane generation for 2017, followed by 2 Gg in 2018 and 2019, 3 Gg in 2020, and 4 Gg annually from 2021 to 2025. Food waste is the dominant estimated methane-generating fraction. Paper contributes a smaller amount in the model output. The zero value in the first modelled year should not be interpreted as proof that the landfill emitted no methane to the atmosphere. It is a consequence of the model assumptions and the available waste/decomposition inputs.

Table 4.12: Environmental Exposure Findings

Indicator	Finding from 80 respondents
Increase in odour over approximately ten years	51 agreed; 27 strongly agreed; 2 disagreed
Perceived causes of odour	Gases: 72; poor management: 67; too much waste: 55; chemicals: 41
Reported impacts of odour	Sickness: 31 (38.75%); unpleasant environment: 25 (31.25%); breathing difficulty: 24 (30.00%)

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Perceived increase in leachate	47 agreed (reported as 60%); 5 disagreed; 27 undecided
Perceived effects of leachate	Groundwater pollution: 77 (96.25%); aquatic-life destruction: 53 (66.25%); unpleasant smell: 45 (56.25%)
Reasons for biological vectors	Breeding in waste: 43 (54%); feeding on waste: 34 (42%); undecided: 3 (4%)

Source: Field Work Analysis, 2026

Respondents also reported mosquitoes, houseflies, snakes and rodents around households. Household respondents identified malaria, typhoid, cholera and respiratory complaints among reported illnesses. These observations demonstrate perceived exposure and community concern, but they do not establish clinical causation or a dose-response relationship.

Mitigation Options, Feasibility and Expected Reduction

Mitigation Hierarchy

The preferred approach is a hierarchy rather than a single intervention. Source reduction and organic-waste diversion reduce the amount of biodegradable material entering the landfill. Better landfill operation reduces exposed waste and improves control. Leachate management protects water pathways. Gas collection addresses methane at source. Flaring provides a control route where beneficial use is not yet economically justified, while energy recovery can create an additional economic benefit when gas quantity and quality are sufficient.

Table 4.13: Mitigation Hierarchy

Mitigation Option	Main Target	Technical Feasibility	Economic Feasibility	Environmental Feasibility	Expected Reduction Indicator
Source separation and organic-waste diversion	Future CH_4 generation	Moderate; requires collection and treatment systems	Moderate; depends on markets and treatment costs	High; reduces organic loading and multiple impacts	Tonnes of organic waste diverted; reduction in modelled future CH_4
Improved spreading and compaction	Odour, exposed waste, uncontrolled pathways	High	High relative to capital-intensive options	High	Covered/compacted area; odour complaints; surface methane hotspots
Daily/intermediate cover	Odour, vectors, surface gas migration	High	Moderate to high depending on cover material	High	Area receiving compliant cover; surface CH_4 concentration
Leachate collection/treatment	Groundwater/surface-water exposure	Moderate	Moderate to high	High	Leachate volume/quality; groundwater indicators
Landfill-gas collection	Atmospheric CH_4	Moderate; requires wellfield, piping and blower system	Requires site-specific appraisal	High if properly operated	CH_4 recovered (mass/time); collection efficiency
Controlled flaring	Atmospheric CH_4	Moderate to high once gas	Potentially more feasible than energy	High; destroys collected CH_4	CH_4 sent to flare and destruction efficiency

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		collection exists	recovery at low gas volumes	but produces CO_2	
Electricity generation from LFG	CH_4 + energy demand	Moderate; requires adequate sustained gas flow and treatment	Site-specific; depends on CAPEX, O&M, tariff and gas yield	High if gas is otherwise emitted	kWh generated; CH_4 recovered/destroyed; net GHG benefit

Source; Field Work Analysis, 2026

Technical Feasibility

Operational improvements are the most immediately feasible interventions because they address practices already identified as weak in the study. Spreading, compaction and cover management can be strengthened without waiting for a full gas-to-energy project. Leachate control requires more infrastructure and engineering design. Landfill-gas recovery is technically feasible in principle, but the actual design should follow a field assessment of waste depth, landfill geometry, age distribution, gas pressure, methane concentration, moisture and gas flow. Vertical collection wells are commonly used in mature waste areas, while horizontal collectors can be useful in actively filling areas. A blower/flare system can provide controlled extraction and destruction. Energy recovery should be considered only after the recoverable gas flow and gas quality are established.

Environmental Feasibility

The proposed controls have multiple environmental benefits. Improved cover and compaction can reduce exposed waste, odour and vector access. Leachate control can reduce pollutant movement to water resources. Methane collection and destruction directly address the principal quantified greenhouse-gas emission. Beneficial energy recovery can additionally displace some conventional energy use. Environmental feasibility is therefore strongest when the interventions are implemented as an integrated system rather than as isolated actions. Authoritative landfill-gas guidance indicates that methane destruction in properly operating flares can exceed 99% of the methane routed to the flare, while overall landfill collection efficiency varies with cover condition, wellfield coverage and system operation.

Proposed Measurement, Verification and Monitoring Framework

The following monitoring framework has been recommended for the next phase of the Kumasi landfill programme.

Table 4.14: Monitoring Framework for the Next Phase of the Kumasi Landfill Programme

Component	Measurement	Frequency	Spatial design	Purpose
Landfill gas	CH_4 concentration, CO_2, O_2 and gas flow	Continuous/regular operational monitoring after installation	Each wellfield and header	Quantify recovered gas and optimise collection
Surface methane	Portable methane screening and confirmatory measurements	Routine surveys, with more intensive surveys after system changes	Systematic grid over waste surface and boundary	Locate leaks and estimate uncontrolled surface emissions
Ambient air	CH_4 and selected odour/air-quality indicators	Repeated campaigns across dry/wet and contrasting wind periods	Upwind background plus downwind residential receptors	Establish ambient exposure gradient
Meteorology	Wind speed/direction,	Continuous or high-frequency logging	At or near landfill	Interpret dispersion and

	temperature, rainfall			temporal variability
Leachate	Volume and relevant chemical indicators	Monthly/quarterly depending on parameter	Collection points and downstream receptors	Track treatment performance and water-risk pathway
Groundwater	Site-appropriate physicochemical indicators	Periodic monitoring	Upgradient and downgradient wells	Establish baseline and detect changes
Waste	Incoming tonnage and periodic composition audit	Daily tonnage; periodic composition study	Incoming waste stream and landfill cells	Improve FOD inputs and diversion planning

Source: Field Work Analysis, 2026

Table 4.15: Implementation Roadmap

Phase	Priority Action	Lead Responsibility	Performance Indicator
Phase 1: 0–6 months	Operational audit; restore spreading/compaction; establish routine cover; document waste quantities; create monitoring baseline	Landfill operator / municipal authority	Daily operational records; cover compliance; baseline dataset
Phase 2: 6–18 months	Improve leachate control; initiate surface methane and ambient-air monitoring; undertake waste-characterisation audit	Landfill operator / environmental regulator	Leachate control performance; spatial monitoring records
Phase 3: 12–24 months	Design and install pilot/priority landfill-gas collection system	Municipal authority + technical partner	CH_4 flow and concentration; collection coverage
Phase 4: 18–30 months	Select flaring or beneficial energy use based on measured gas supply and economic appraisal	Municipal authority + project developer	Verified CH_4 destruction/use; financial feasibility
Phase 5: Continuing	MRV, maintenance, community engagement and periodic performance review	Operator / regulator / community stakeholders	Annual emission-reduction report

Source: Field Work Analysis, 2026

Demographic Characteristics of Respondents

The table and figures below show the details of the demographic characteristics of the respondents.

Table 4.16: Demographic Details of Respondents

Variables	Frequency=80	Pencentage (%)
GENDER		
Male	31	38.75
Female	49	61.25
AGE BRACKET (YERARS)		
Below 30	5	6.25
31-40	13	16.25
41-50	29	36.25
51-60	20	25
≥61	13	16.25
EDUCATIONAL BACKGOUND		

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No Formal Education	2	2.5
Basic (Prim. JHS, Middle Sch.)	28	35
Secondary (SHS/Voc./Tech.)	34	42.5
Tertiary (College/Poly/University)	16	20
OCCUPATION		
Government Worker	11	13.75
Private Company	8	10
Self Employed/Entrepreneur	45	56.25
Unemployed	7	8.75
Student	9	11.25
MARITAL STATUS		
Married	51	63.75
Single	12	15
Divorced	3	3.75
Widowed	14	17.5
RELIGIOUS AFFILIATION		
Christianity	47	58.75
Islamic	28	35
Traditionalist	5	6.25

Source: Field Survey, 2026

A total number of 80 people from 80 households were interviewed during the research. These comprises of 31 males representing 39% and 49 females representing 61%.

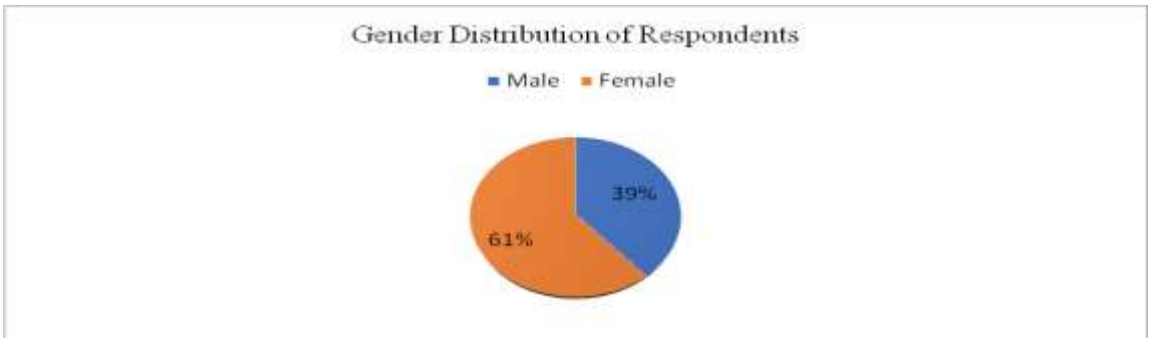


Figure 4.3: Gender of Respondents

The highest age brackets of respondents were between 41-50years representing 36% and the lowest age bracket was the ages below 30years representing 7% of the respondents.

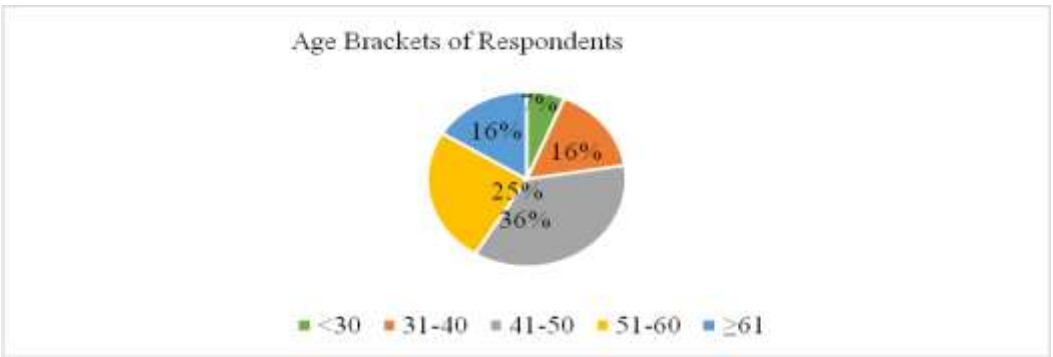


Figure 4.4: Age of Respondents

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The study also revealed that 34% of the interviewees had secondary school education whilst 2% of them had no formal education.

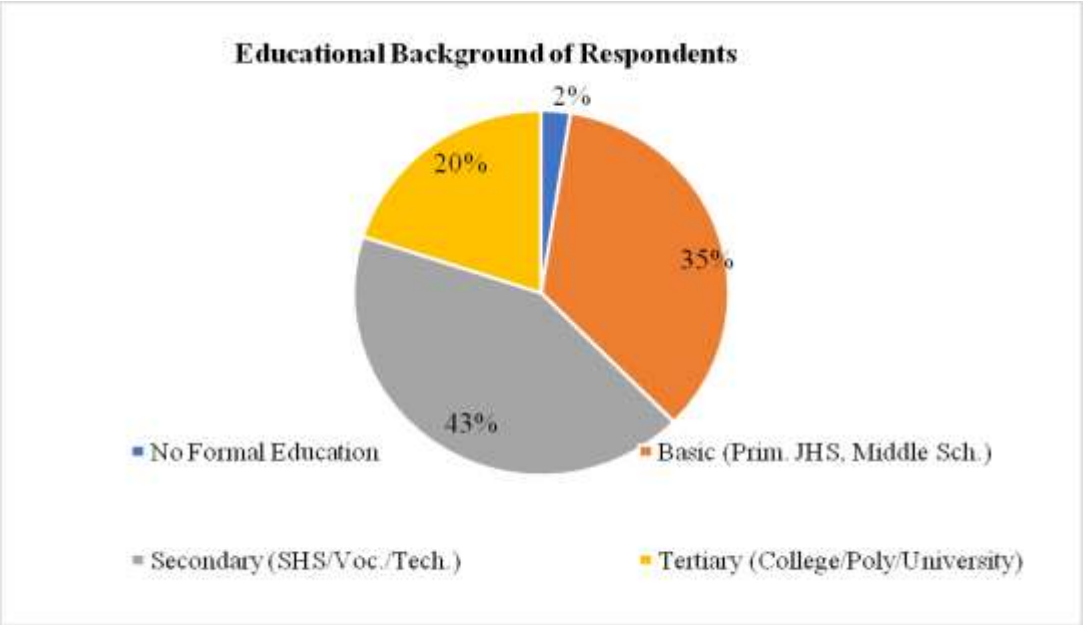


Figure 4.5: Educational Background

The research further showed that 11(14%) respondents render their services the Government, 8(10%) to Private companies and 45(56%) had their own business. Also, 9 (11%) of them were students whilst 7(9%) had no jobs.

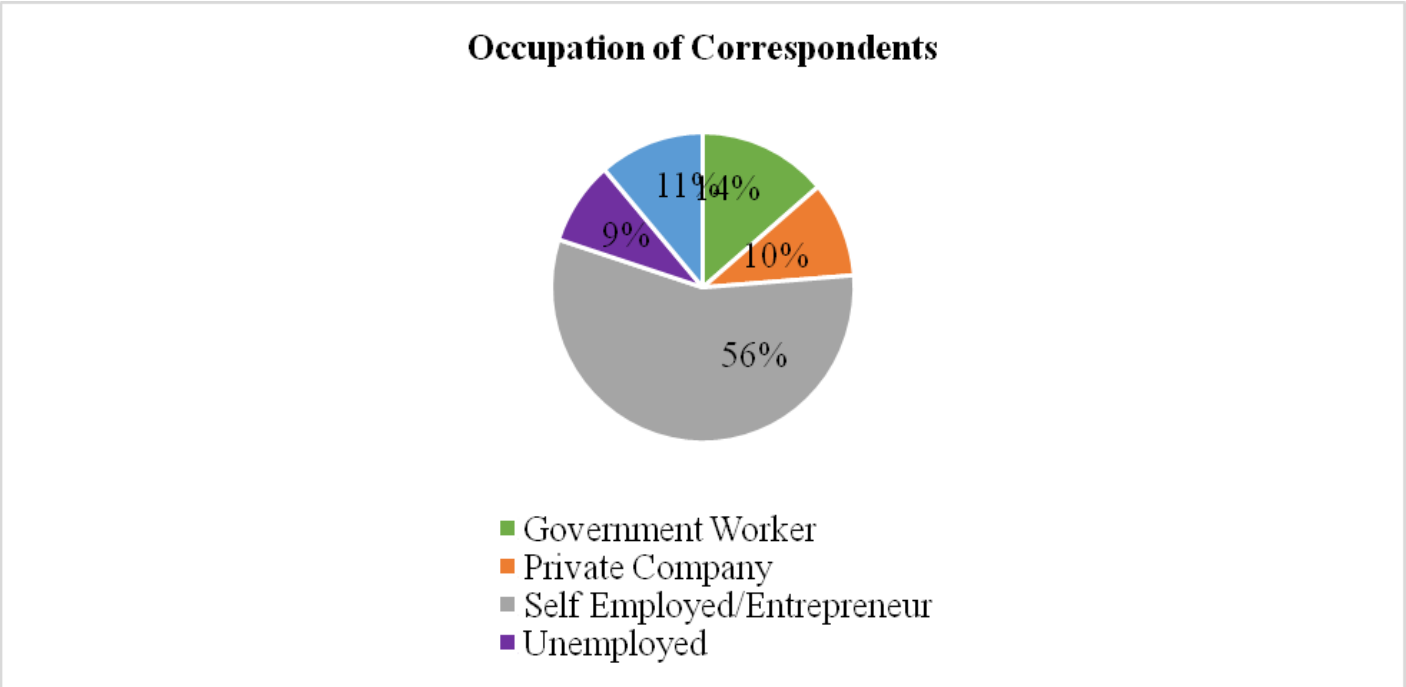


Figure 4.6: Occupation of Respondents

The diagram indicates that 64% of the respondents answered that they are married, 15% are single, 4% are divorced and the remaining 17% has lost their spouses.

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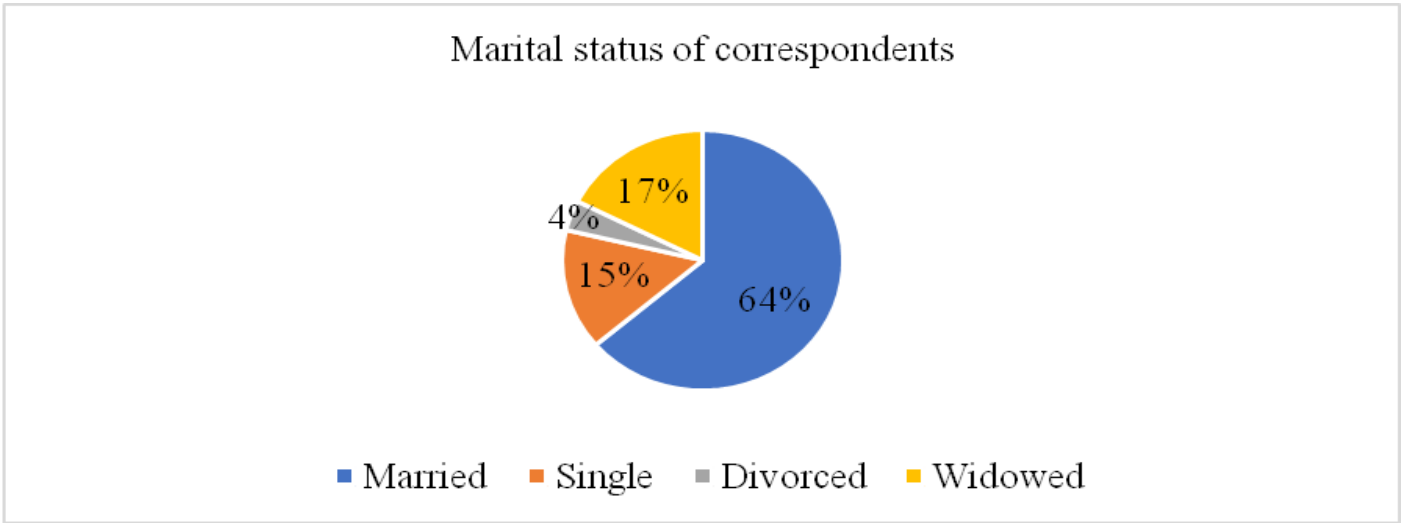


Figure 4.7: Marital Status of Respondents

The study revealed that out of the 80 people interviewed, 59% of them are Christians, 35% are Moslems and the least among them are affiliated to the Traditional Religion representing 6%.

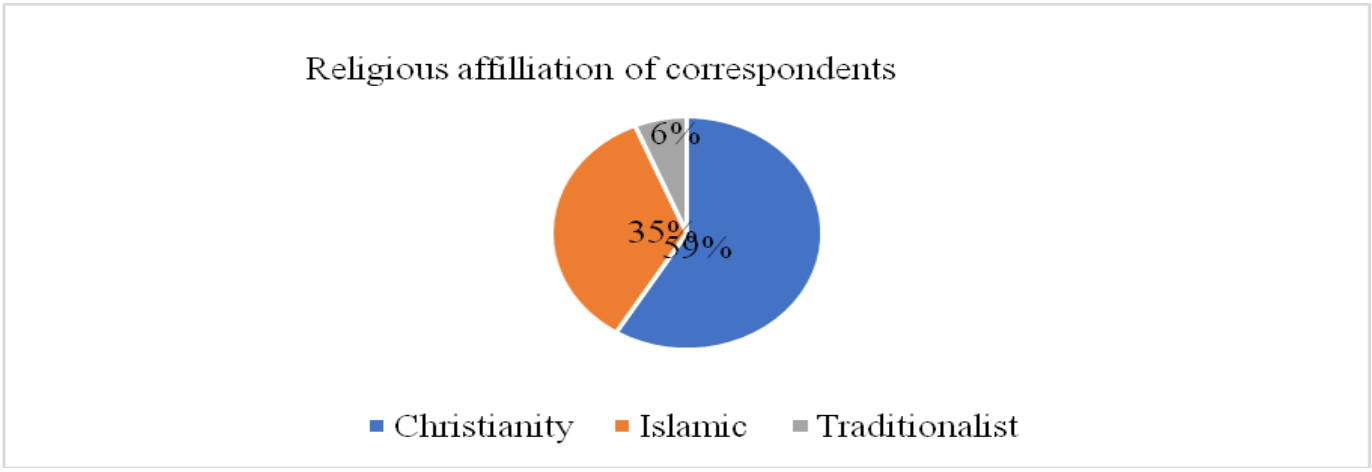


Figure 4.8: Religious Affiliation of Respondents

The research took into consideration, the existence of odour, the reasons for its existence and its impacts on residents living close to the landfill

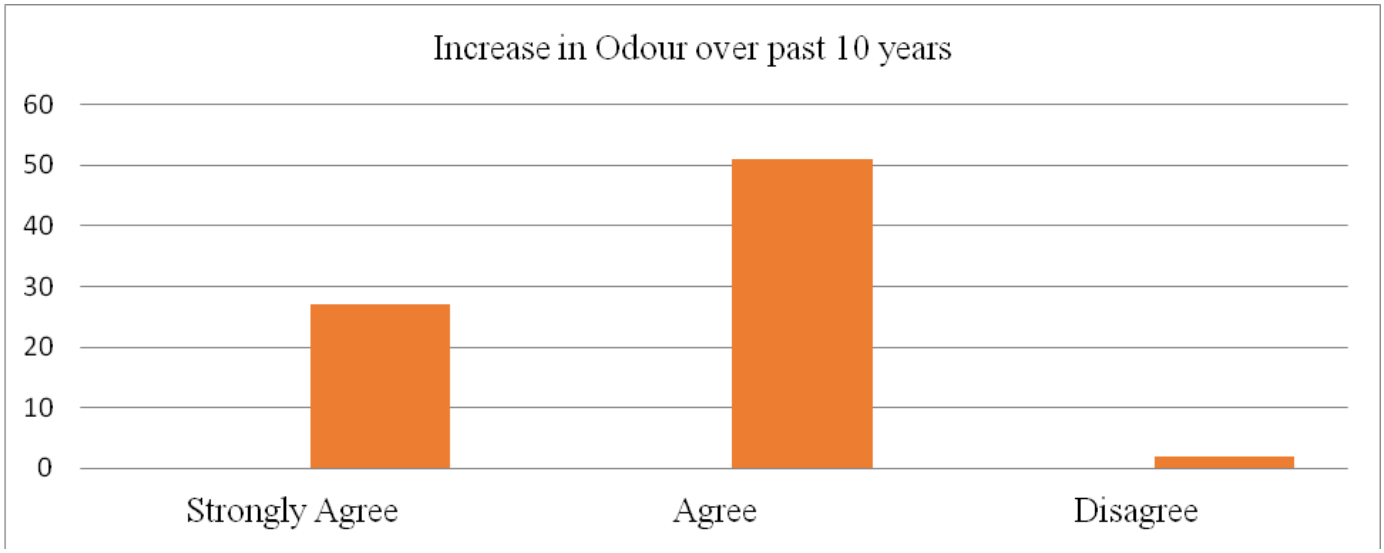


Figure 4.9: Increase in Odour Over Past Ten Years

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With reference to the figure above, agreement was made by many participants of the study such that an increment in odour has existed for about ten years now with 51 of them subscribing to this. Also 27 of them strongly agreed this whilst 2 respondents answered in the affirmative. From these analyses, it is evident that odour increases within the landfill area over the past ten (10) years. The researcher in trying to find out why there is the massive response on the increase in odour, adopted the following methodology and the responses are detailed in the subsequent table and figure.

Table 4.17: Causes of Increase in Odour

Variable	Frequency =80
Presence of Gases	72
Presence of Chemicals	41
Too much Waste	55
Poor management of waste	67

Source: Field Survey, 2026

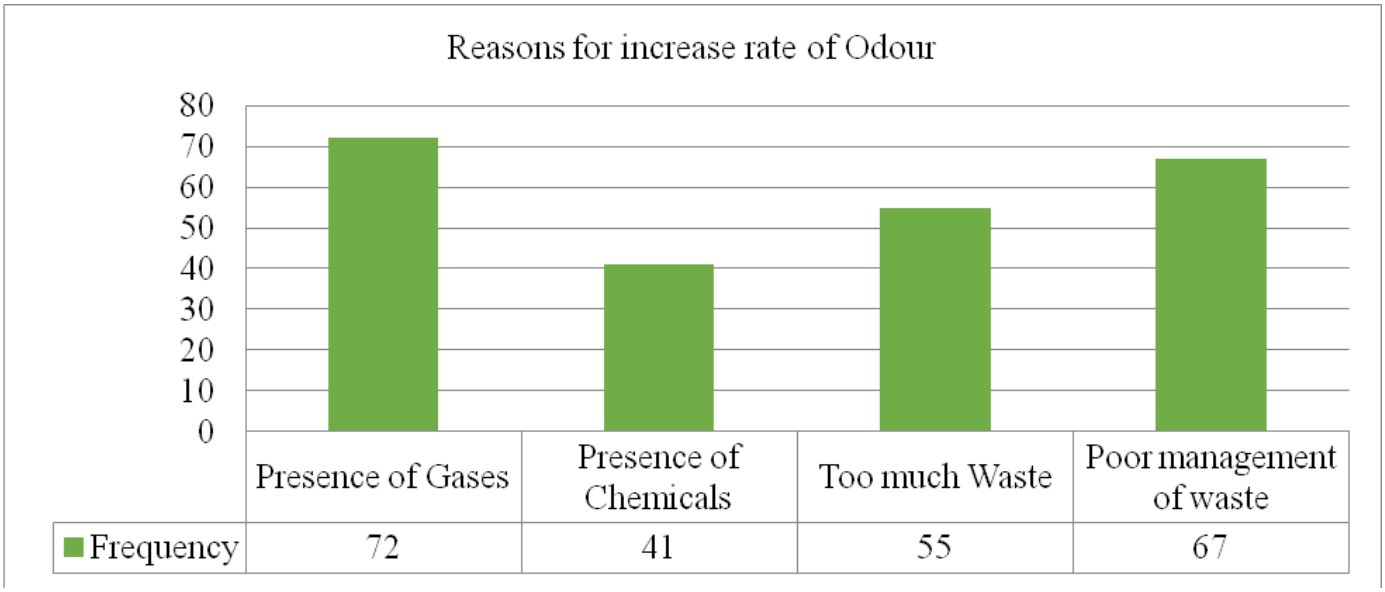


Figure 4.10: Reasons for Increase Rate of Odour

Also, from fig 4.10 below, it is clear that majority of the respondents answered that the cause of the odour is because of the presence of gases in the waste. However, a good number of the responses also revealed that poor management of the landfill and too much waste coming to the landfill could also give rise to the increase in odour. From the Figure above, majority of the respondents representing 39% revealed that the main effect of the odour is sicknesses. However, 30% also showed that the odour could give rise to difficulty in breathing whilst 25 of them representing 31% also revealed that the odour canker could result in unpleasant environmental condition.

Table 4.18: Impacts of Odour

Variable	Frequency =80	Percentage (%)
Sicknesses	31	38.75
Unpleasant environment	25	31.25
Difficulty in breathing	24	30

Source: Field Survey, 2026

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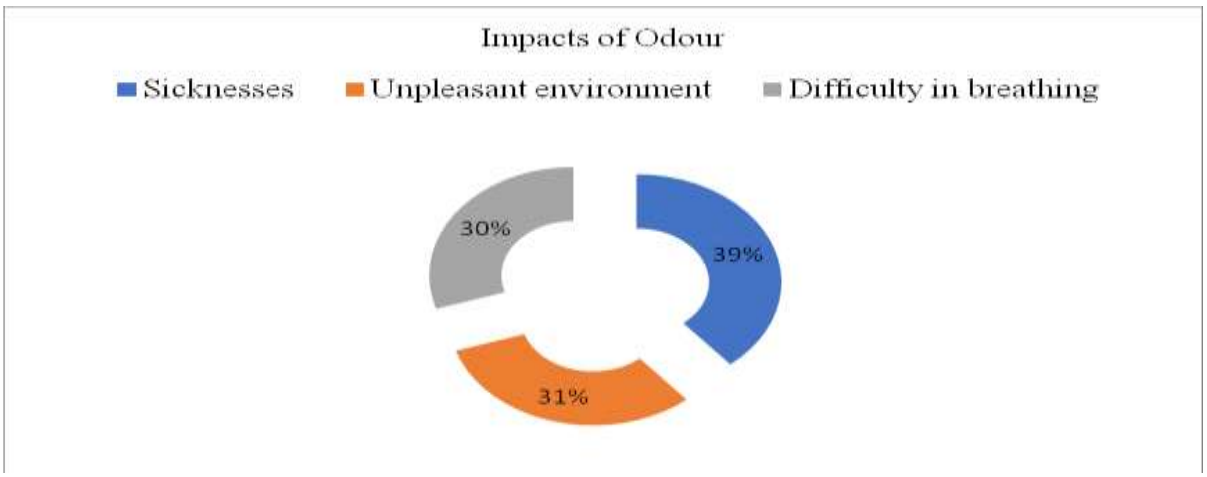


Figure 4.11: Impacts of Odour

The study from the table and figure below revealed that the presence of leachate and its rate of increase are evident. Majority of the respondents representing 60% attested to this fact, whilst 34% could not give a decision and 6% also disagreed with this fact.

Table 4.19: Why the increase in Leachate Over the past ten (10) years

Variable	Frequency =80	Percentage (%)
Agreed	47	60
Disagreed	5	6
Undecided	27	34

Source: Field Survey, 2026

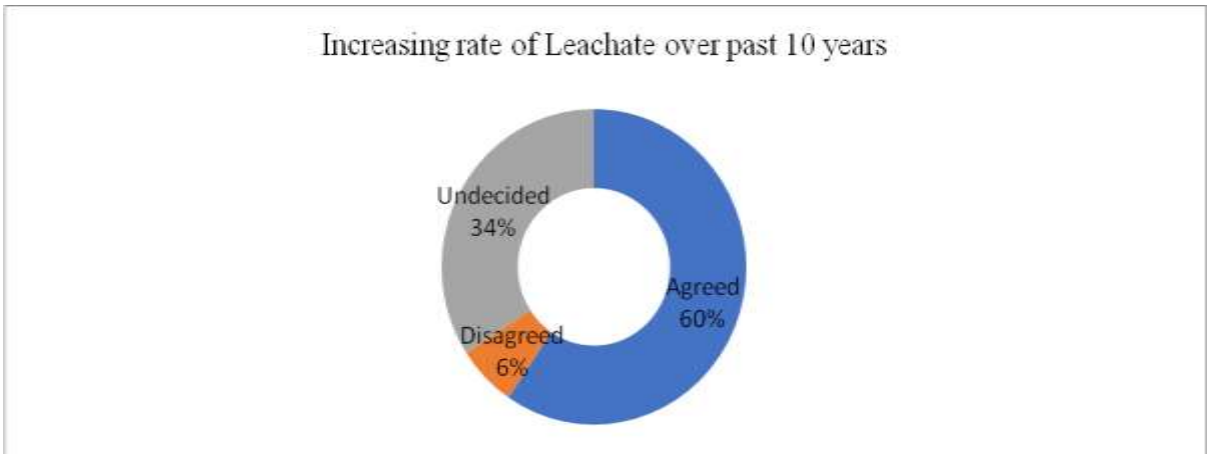


Figure 4.12: Why increasing Rate of Leachate

50% of the causes of leachate at the landfill are attributed to poor management of the project. Too much waste coming into the landfill could also result in leachate production as shown in the figure below. Yet a good number of the residents (34%) could not tell the causes of the leachate. This could probably mean that those residents are upstream so could not feel the effects of the leachate.

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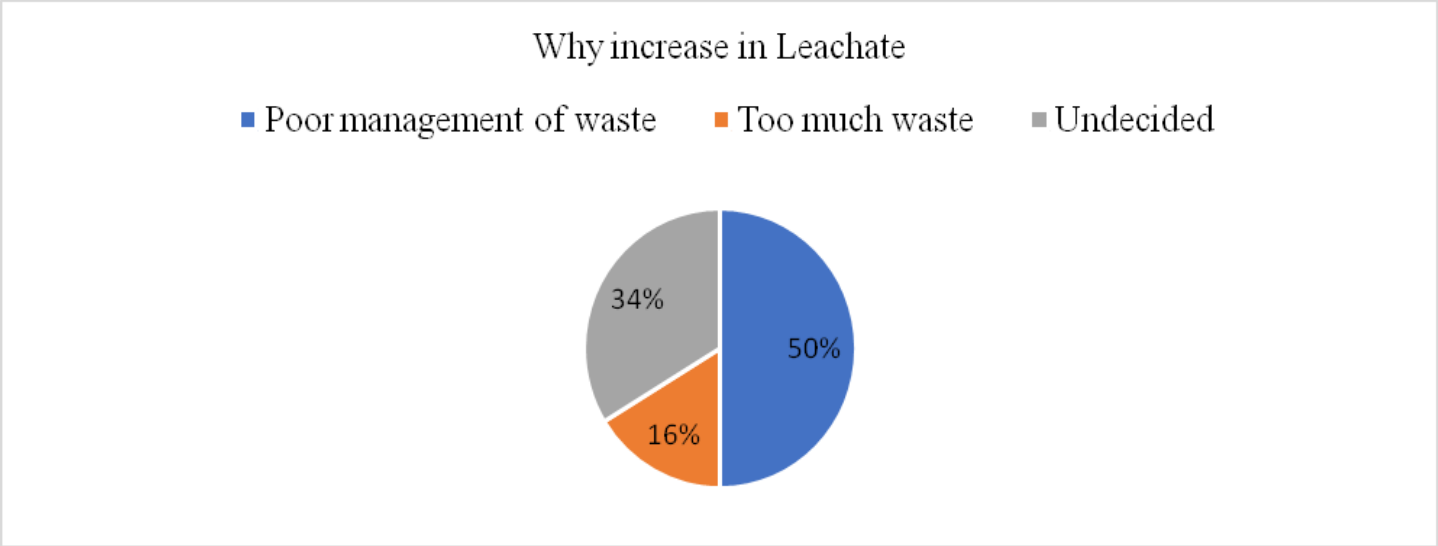


Figure 4.13: Causes of Leachate

The impacts of Leachate from the survey are Ground water pollution (96%), Aquatic life destruction (66%) and Unpleasant smell (56%). It can therefore be concluded that the effects of Leachate are enormous but the leading one is Ground water pollution as can deduced from the under listed graph.

Table 4.20: Effects of Leachate

Variable	Frequency =80	Percentage (%)
Ground water pollution	77	96.25
Aquatic life destruction	53	66.25
Unpleasant smell	45	56.25

Source: Field Survey, 2026

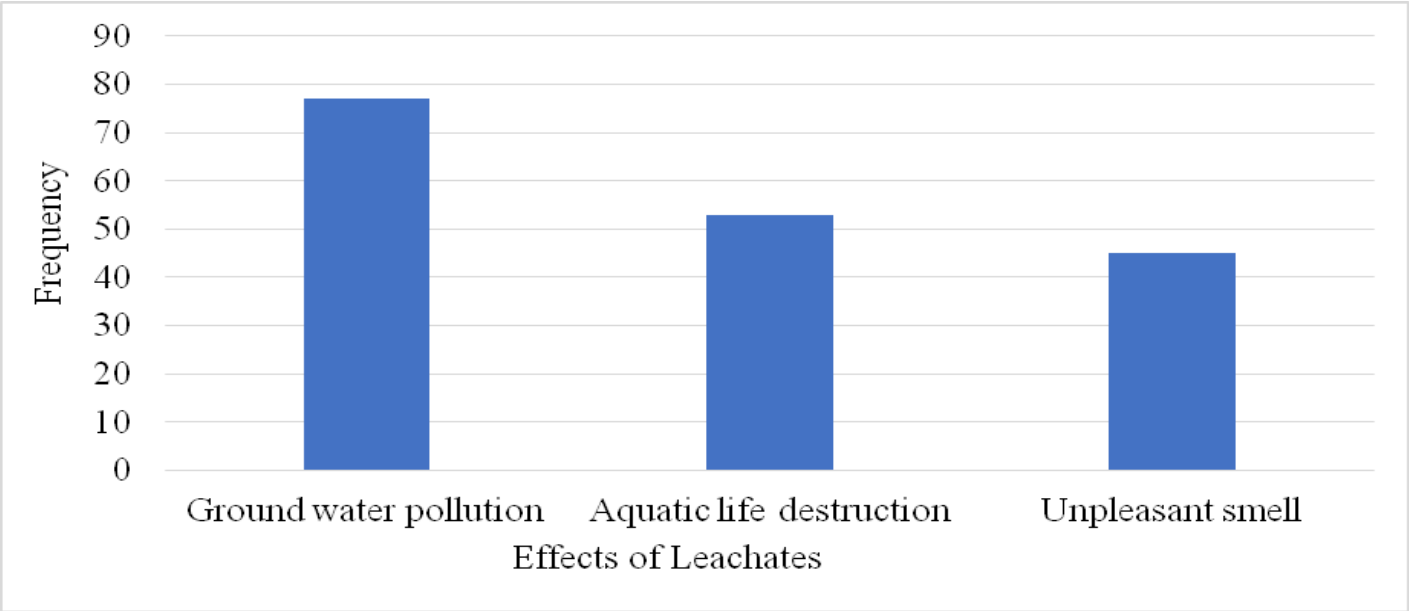


Figure 4.14: Impacts of Leachate

Landfills are required to use plastic liners to collect and treat leachate, but presence of leachate in this research work can be concluded that such plastic liners were not used. The creation of leachate, presents a major threat

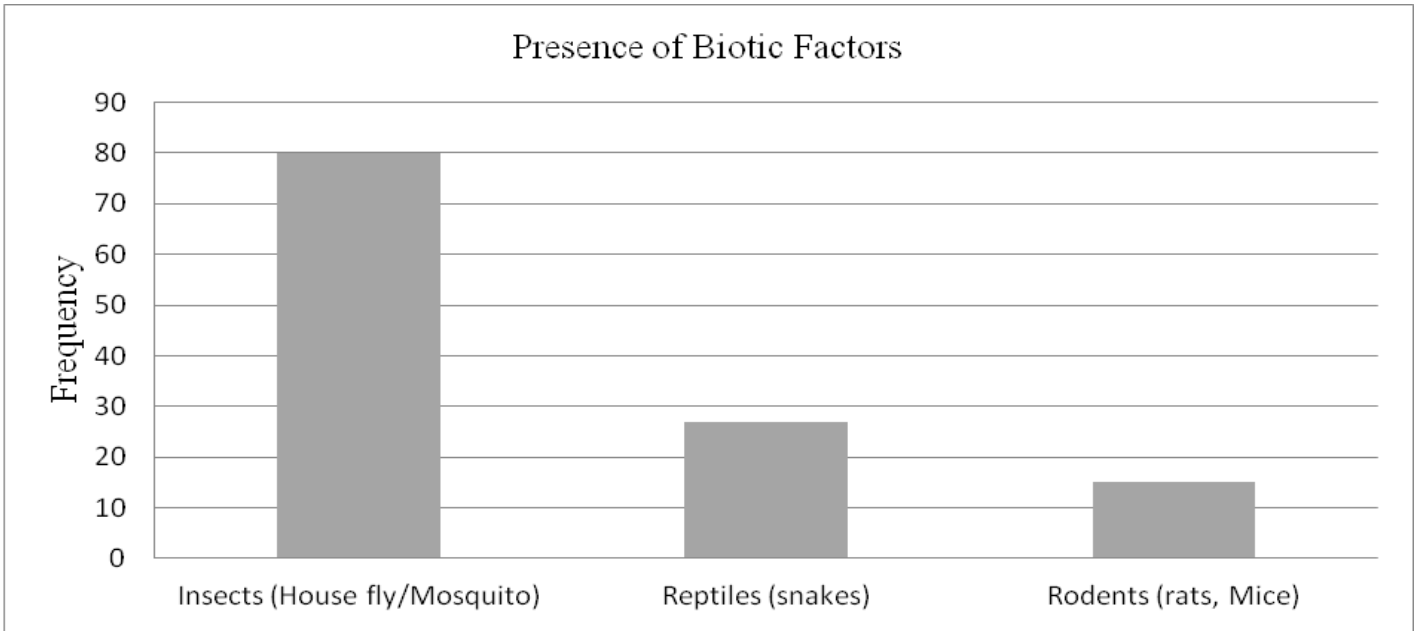
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to the current and future quality of groundwater. This was made known during the research as 77 out 80 respondents (fig 4.13) testified that leachate causes ground water contamination. Apart from groundwater contamination and odour, leachate also provides breeding grounds for disease-carrying vectors like mosquitoes, house flies, etc. Groundwater protection standards should be developed for the landfill, setting a national precedent for solid waste management that may eventually become the standard for all types of landfills Ghana.

Biotic Factors and their Impacts

The study showed that there was the presence of house flies and mosquitoes within the households. The presence of snakes is also felt to some extent. About 19% (15) of the residence also reported on the prevalence of rats and mice in their houses. The figure below illustrates the percentage of respondents in each class of Biotic Factor.

Figure 4.15: Presence of Biotic Factors



Again, the research revealed that, the reasons for the presence of biotic factors are largely due to them breeding in the landfill (54%) and feeding on the landfill (42%). However, 3 (4%) respondents could not give any reason. The figure below represents the views of the respondents.

Table 4.21: Reasons for the Presence of Biotic Factors

Variable	Frequency =80	Percentage (%)
Feed on waste	34	42
Breed in waste	43	54
Undecided	3	4

Source: Field Survey, 2026

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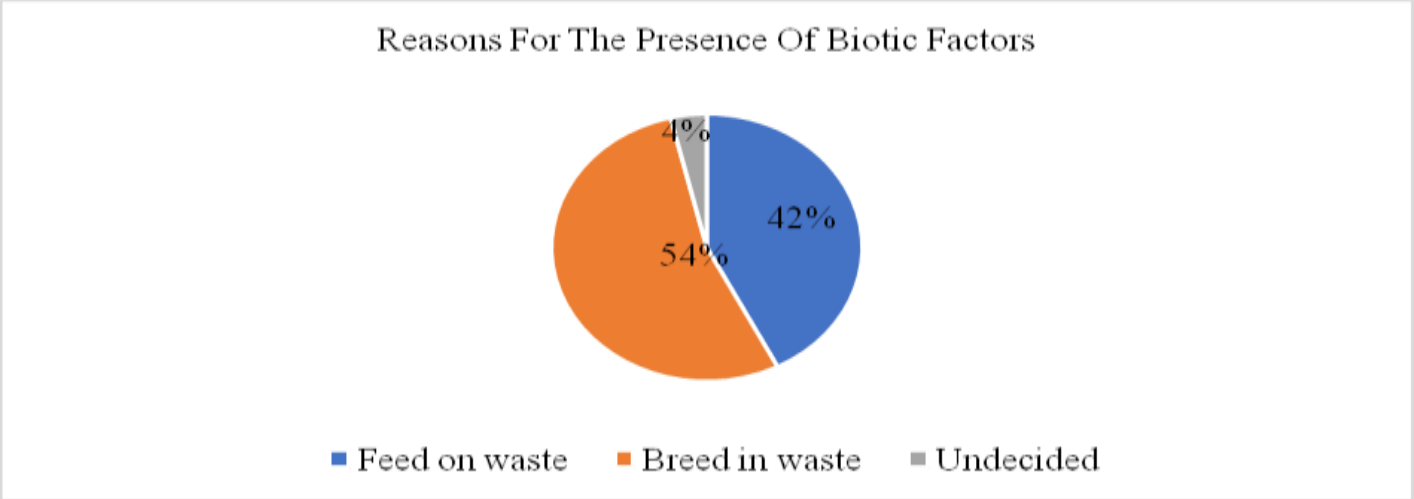


Figure 4.16: Reasons for the Presence of Biotic Factors

The figure below showed that biotic factors within the catchment area of the project are the main causes of sicknesses. This can be attributed to predominance of house flies and mosquitoes in the vicinity. One other effect of these Biotic factors is that the cause nuisance in the environment.

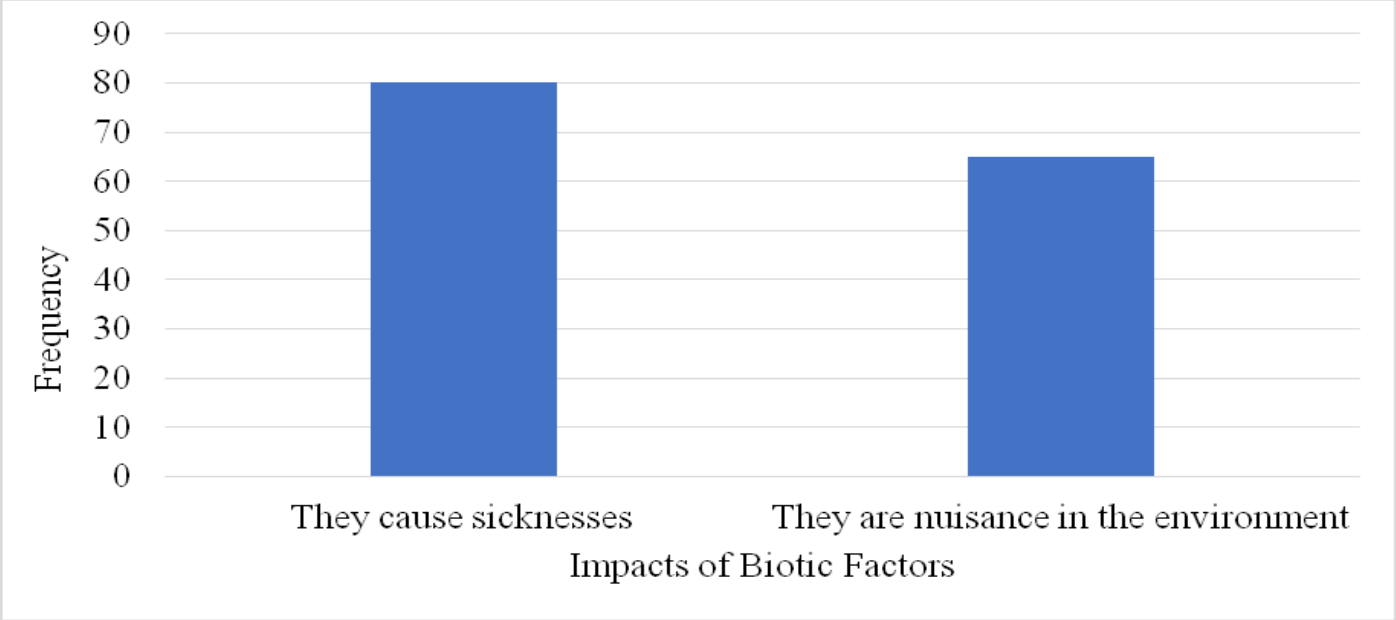


Figure 4.17: Impacts of Biotic Factors

In a similar vein, malaria is a leading disease in the Kumasi and Kuwait communities as revealed by residents in these communities. All the respondents agreed that malaria dominates in their households, followed by typhoid with 75 responses. Cholera is third household disease with 42 respondents subscribing to that effect whilst Asthma was the last with 5 responses. Malaria is a leading disease in the Kumasi and Kuwait communities as revealed by residents in these communities. All the respondents agreed that malaria dominates in their households, followed by typhoid with 75 responses. Cholera is third household disease with 42 respondents subscribing to that effect whilst Asthma was the last with 5 responses.

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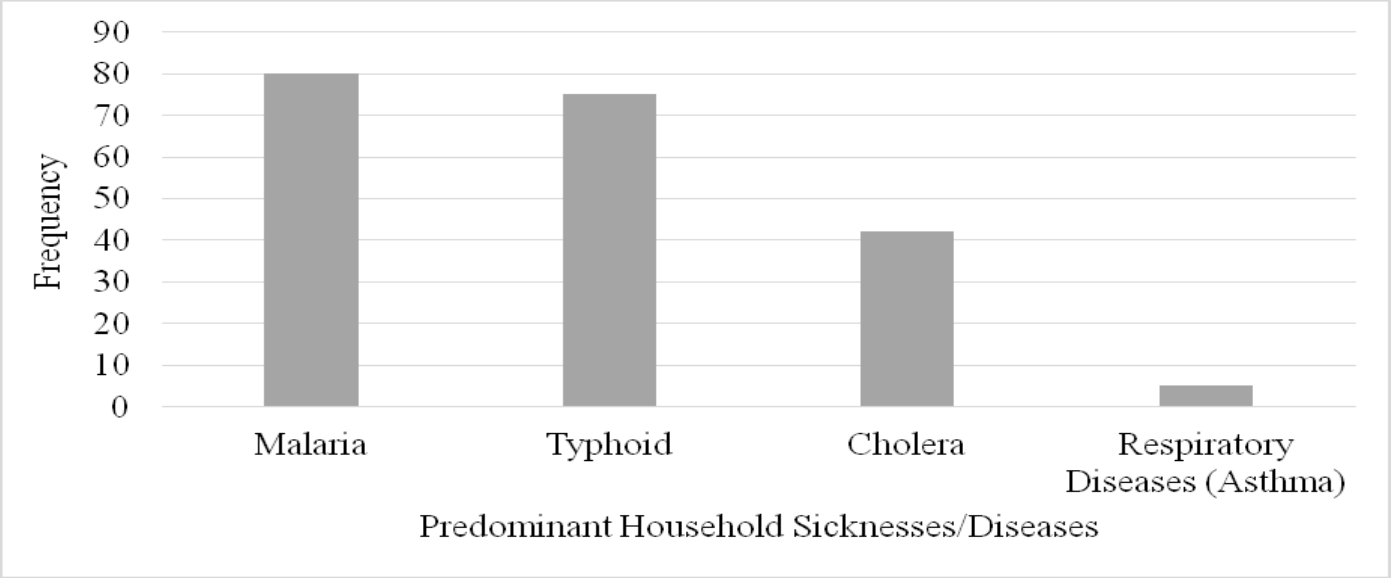


Figure 4.18: Predominance of Household Sicknesses/Diseases

Coping Strategies of the People

This section will look at strategies that residents are adopting in dealing with the impacts enumerated above. The research will further take in consideration the nature of improvements of these strategies and challenges associated with them.

Coping Strategies for Combating Odour

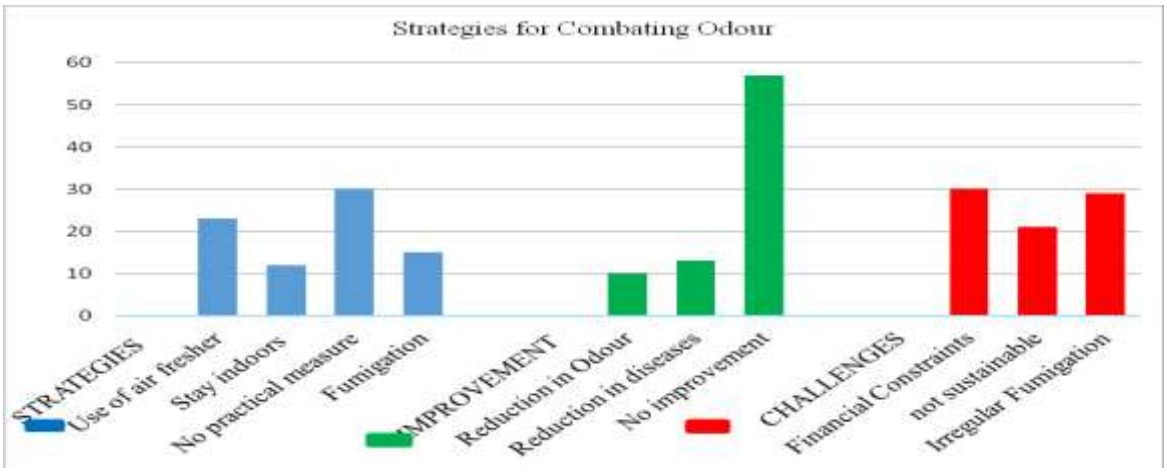


Figure 4.19: Strategies for Combating Odour

The residents revealed that the measures they adopt to control odour includes; Fumigation by KMA (19%), staying indoors and closing their doors and windows (15%), use of air fresher (29%). On the affirmative, 37% of the respondents revealed that they could virtually do nothing to the curb odour. Going further to determine whether these measures could yield any improvements in their lives also show that, the measures have no much improvement (71%), others said there is reduction in odour and sicknesses (13% and 16% respectively). The challenges of these strategies according the respondents are; financial constraints (38%), irregular fumigation by KMA (36%) and last one is that the strategies are not sustainable (26%).

Odour is mainly due to the existence of organic acids and hydrogen sulfide in solid waste. When odours get mixed with wastewater in warmer months it can become problematic. According to a research study, landfill waste odour alone yields over 700,000 results. It is clear from the research that the odour emanates from the waste due to gases and chemicals present. Also evident from the research is that odours occur due to poor management of the land fill. Spreading and compaction is not properly done so the entire waste is exposed to

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the atmosphere, lack of odour trapping devices and plants to absorb the odour also contributes to its presence. Measures to control or reduce the impacts of odour are; proper operational activities (compaction and daily covering), use of plant extracts, deploying a gas collection and control system for energy purposes.

Coping Strategies for combating Sickness/Disease

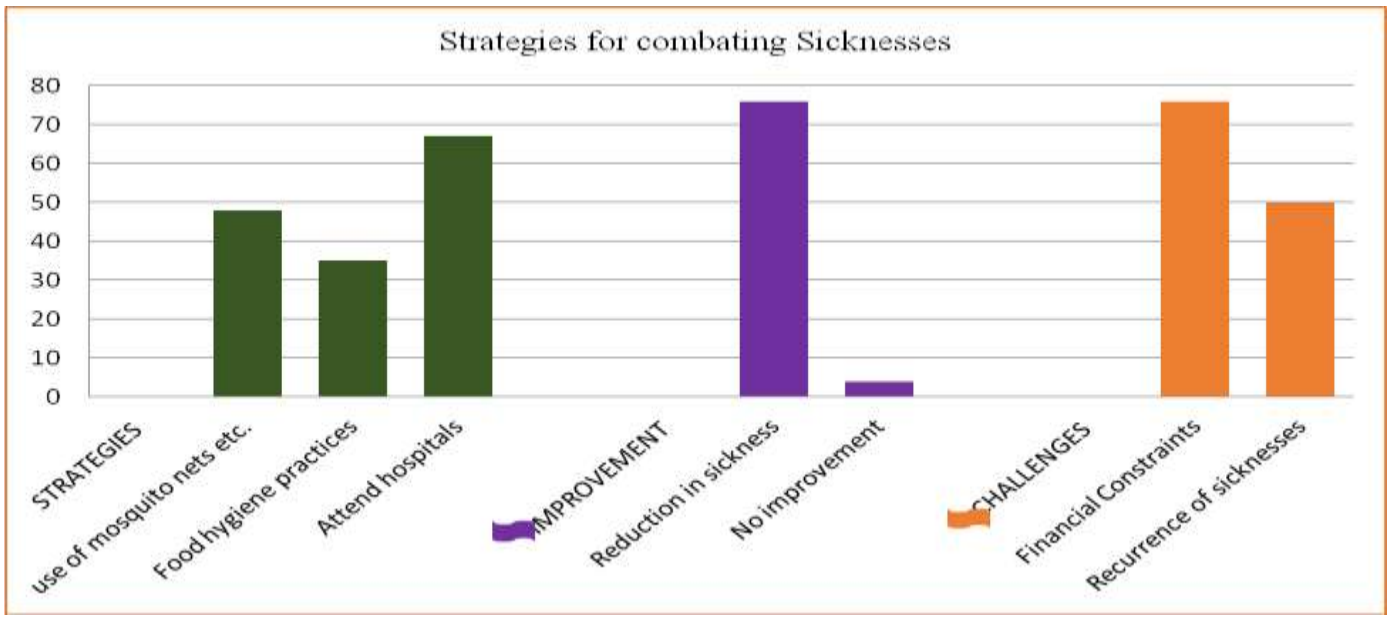


Figure 4.20: Strategies for combating Sickness/Disease

The research, as shown in the figure above revealed that resident adopts the following measures to combat sickness in their localities; Use of mosquito nets (48 responses), Food hygiene practices (35 responses) and medical care/attending Hospitals (67 responses). 95% of the respondents said these measures could reduce sicknesses while 5% said the measures have no improvements. Majority of the respondents revealed that the main challenge of these strategies is financial constraints (76 responses). 50 responses were also received on recurrence of sicknesses.

Coping Strategies for Combating Biotic Factors

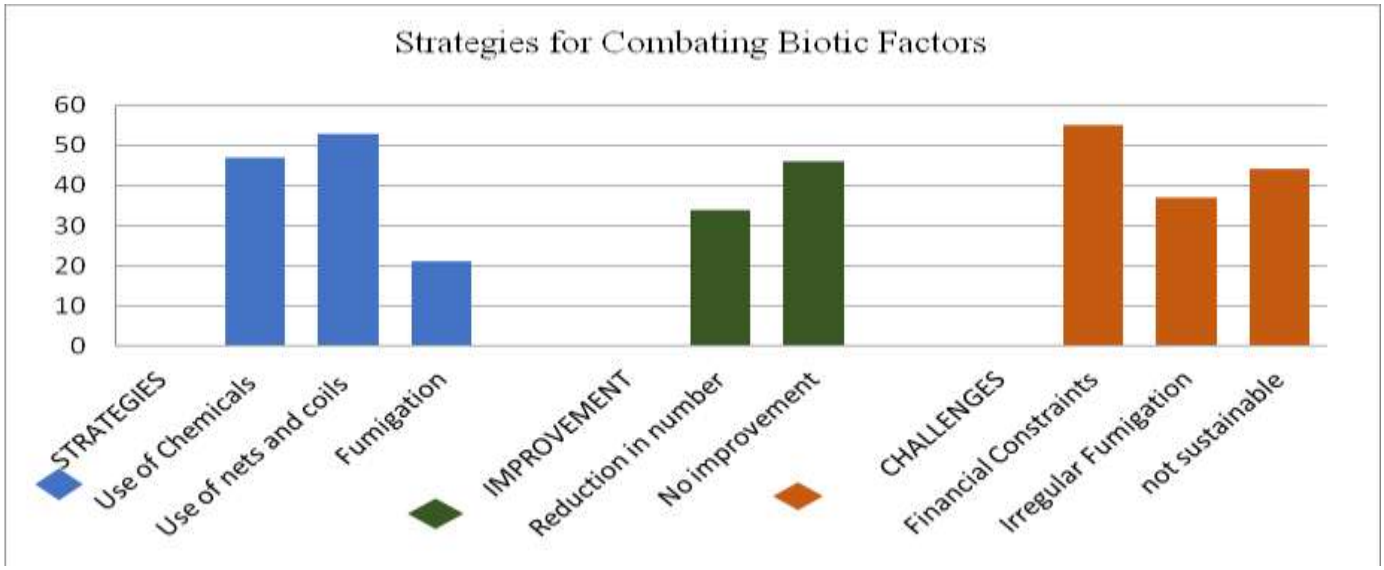


Figure 4.21: Strategies for Combating Biotic Factors

In a bid to combat biotic factors, residents resort to the use of chemicals (i.e. insecticides, anti-snakes etc), use of mosquito nets and coils, fumigation. According to some of them, these measures could result in reduction in

the number of biotic factors. However, majority of them said the measures have no much improvement. In accessing the challenges, they face in using these strategies, residence made mention of the following; Financial constraints, irregular fumigation and non-sustainability of the strategies.

During this research the biotic factors of concern were mosquitoes, houseflies, snakes and mice. Residents were able to ascertain the presence of these biotic factors and also revealed that their presence was due to the existence of the landfill which served as breeding and feeding grounds for them. They also revealed that these factors are vectors that transmit diseases like malaria, typhoid, cholera etc. Poor spreading, compaction and daily covering of waste will expose the waste to these vectors. Also, when leachate is not properly treated, it serves as breeding grounds for these factors. Proper management of the landfill will therefore reduce the number of these factors considerably.

Mitigation Measures of Impacts by Landfill Management and KMA

The research revealed that the management of the landfill is not the best, hence the increase in odour, leachate, biotic factors, sicknesses etc. Spreading and compaction is not done to achieved the desired thickness, daily covering is totally not done and this give rise to the aforementioned and even lowers the lifespan of the landfill. KMA been mandated to ensure periodic fumigation also fail to perform their roles due to financial constraints. Good compaction improves safety by providing a stable surface upon which the machinery and people work. A dense waste mass also reduces the major nuisance factors of vectors (rodents), odour, blowing paper and surface-water contamination. Proper landfill compaction maximizes the use of a landfill's capacities and thereby reduces costs and prolonging the life span of the landfill.

DISCUSSION OF RESULTS

The first objective sought to determine the level of methane (CH_4) emissions from the Kumasi landfill. The results indicate that estimated methane emissions increased from 0Gg in 2017 to 2Gg in 2018 and 2019, 3Gg in 2020, and 4 Gg annually from 2021 to 2025. The results demonstrated that food waste constituted the principal source of methane, while paper contributed comparatively smaller quantities. This pattern is consistent with the high proportion of organic materials in the waste stream, with organics accounting for an average of 58.3% of the waste composition. The initial absence of methane in 2017 can be associated with the time required for anaerobic decomposition and methane formation within newly deposited waste. The subsequent increase and eventual stabilisation at approximately 4 Gg suggest that methane generation is influenced by the accumulation and decomposition of biodegradable materials rather than simply the annual quantity of waste deposited. This interpretation agrees with the IPCC (2023), which identifies organic waste decomposition under anaerobic conditions as an important source of landfill methane.

Annual waste delivered to the landfill fluctuated considerably rather than following a monotonic upward trend. The 2025 value was 256,556.00 tonnes. The per-capita figures similarly declined overall across the period, although year-to-year variation occurred. The waste-composition profile is dominated by organic material, which represents 58.3% of the assumed waste stream. This is important because the biodegradable fraction is the principal substrate for methane generation. The operational survey, however, indicates weaknesses in spreading, compaction and covering, while routine fumigation was described as irregular (Ketibuah et al., 2025; IPCC, 2019). The findings further suggest that population growth within the landfill catchment, which increased from about 2.03 million in 2017 to 2.28 million in 2025, creates continuing pressure on waste-generation systems. Although the estimated emissions appear relatively modest, the results should not be interpreted as evidence that landfill methane is environmentally insignificant. Rather, they highlight the importance of landfill operation and methane-control practices. The reported deficiencies in waste spreading, compaction and daily covering can increase exposure of waste to the atmosphere and reduce the efficiency of landfill management. As noted by Tawo (2025) and Tripathy et al. (2025), waste reduction, source separation, biological treatment, methane recovery and biogas utilisation can substantially reduce landfill-related emissions. Thus, the results support the need for improved operational management and the possible installation of gas-recovery or flaring systems as practical mitigation measures.

The second objective examined the biotic factors surrounding the landfill and their associated impacts on neighbouring communities. The findings established that landfill-related environmental effects extend beyond methane emissions to odour, leachate, vectors and household health concerns. A substantial majority of respondents perceived an increase in odour over the previous decade, with 72 respondents associating the problem with gases, 67 with poor waste management and 55 with excessive waste accumulation. The reported consequences included sicknesses (38.75%), unpleasant environmental conditions (31.25%) and breathing difficulties (30%). Similarly, 60% of respondents perceived an increase in leachate, while 96.25% identified groundwater pollution as its major effect, followed by aquatic-life destruction (66.25%) and unpleasant smell (56.25%). These findings are particularly important because leachate provides a pathway through which pollutants can move from waste deposits into surrounding soil and water systems. They are broadly consistent with Okyere et al. (2023), who associate the accumulation of pollutants from human activities with risks to humans and ecosystems, and with the broader IPCC (2023) position that environmental change can generate interconnected impacts across socio-ecological systems. The results also show the presence of mosquitoes, houseflies, snakes and rodents around households, with 54% of respondents attributing their presence to breeding in waste and 42% to feeding on waste. The reported predominance of malaria, followed by typhoid and cholera, reinforces residents' perception of a relationship between poor environmental conditions and household health; however, these survey responses should be regarded as reported community experiences rather than clinical evidence establishing causation. Overall, the findings correspond with the literature on vulnerability and resilience, which recognises that environmental risks become more pronounced where infrastructure, institutional capacity and environmental management are inadequate (Smit & Wandel, 2021; IPCC, 2023). The results therefore suggest that inadequate landfill management can simultaneously create environmental nuisance, ecological pressures and perceived public-health risks.

The third objective assessed the coping strategies adopted by residents in response to landfill-related impacts. The findings indicated that coping is largely household-based and reactive, rather than supported by sustained structural interventions. In dealing with odour, respondents reported the use of air fresheners (29%), KMA fumigation (19%), staying indoors and closing doors and windows (15%), while 37% indicated that they could do virtually nothing. Moreover, 71% reported little improvement from existing odour-control measures, with financial constraints (38%), irregular fumigation (36%) and lack of sustainability (26%) identified as major challenges. For sickness, residents relied mainly on hospital or medical care, mosquito nets and food-hygiene practices, with 95% believing these measures could reduce illness, although financial constraints remained a major barrier. Similar challenges were identified in controlling biotic factors through insecticides, mosquito nets, coils and fumigation. These findings reflect the distinction between autonomous and planned adaptation discussed by the FAO (2024) and IPCC (2023): residents are making immediate adjustments to protect themselves, but many of these responses do not address the underlying environmental causes of exposure.

The findings also support Adger et al. (2021), who argued that adaptation may be reactive or anticipatory, while Reid et al. (2021) emphasise the importance of community participation and capacity building in sustainable adaptation. The limited effectiveness of household responses further indicates that individual coping cannot substitute for institutional action. Improved landfill compaction, regular covering of waste, effective leachate management, systematic vector control, odour-control measures and methane recovery would address risks closer to their source. This is consistent with Tripathy et al. (2025), who emphasise biological treatment and methane capture, and with Mees et al. (2021), who stress coordinated responsibilities among governmental, community and other societal actors. Consequently, the results suggest that strengthening the resilience of communities around the landfill requires a shift from predominantly household-level coping towards integrated landfill management, environmental monitoring, community participation and adequately resourced institutional interventions.

CONCLUSION AND RECOMMENDATIONS

Based on the results obtained and the discussions in chapter four, it is evident that the impacts of the landfill on the lives of the people are enormous and worrying. The findings indicate that methane emissions from the Kumasi landfill have increased over time, with IPCC First Order Decay (FOD) estimates rising from 0 Gg in 2017 to approximately 4 Gg annually between 2021 and 2025. Food waste was identified as the dominant

contributor to methane generation. However, these values are model-based estimates rather than direct atmospheric measurements, highlighting the limitations of the available emissions data.

Beyond greenhouse-gas emissions, the landfill presents environmental and community concerns associated with odour, leachate accumulation, and biological vectors. Inadequate waste handling, ineffective leachate management, and poor maintenance of the surrounding environment may contribute to these conditions. Potential contamination of nearby water bodies and the presence of disease vectors raise concerns about environmental quality and public health. Although residents reported malaria, typhoid, and cholera in surrounding communities, the findings do not establish a direct causal relationship between these illnesses and landfill operations. The study further indicates that existing community coping measures and reported institutional interventions have not adequately addressed these concerns. Poor maintenance of the vegetated buffer zone and limitations in environmental management suggest weaknesses in the consistent implementation of landfill-control measures.

Generally, the Kumasi Landfill represents both a source of methane emissions and a potential environmental-exposure setting. The findings demonstrate the importance of effective landfill operations, improved leachate and vector management, and reliable monitoring of emissions and environmental conditions. While phased mitigation measures, including improved waste compaction and cover application, landfill-gas collection, and possible flaring or energy recovery, offer potential pathways for reducing impacts, their effectiveness and feasibility require further assessment. Strengthened monitoring, institutional accountability, and evidence-based management are therefore central to reducing methane emissions and addressing the landfill's wider environmental and community-health implications. Depending on findings obtained along with the conclusions reached, the following measures are recommended for adoption by the stakeholders involved in the management of Landfill;

i. Strengthen landfill monitoring and record-keeping by maintaining annual records of waste received, composition, active-cell area, waste depth, and operational practices. Conduct site-specific waste characterisation and establish routine landfill-gas monitoring, ambient-air monitoring, and groundwater surveillance, including concurrent meteorological data collection.

ii. Improve landfill operations and environmental protection through proper waste spreading, compaction, and daily or intermediate covering. Install and maintain effective leachate collection and treatment systems, and establish an appropriate buffer zone with odour-controlling vegetation.

iii. Implement landfill-gas collection and control by assessing the technical and economic feasibility of electricity generation using measured gas flow and composition. Where energy recovery is not yet viable, adopt controlled flaring where technically feasible to destroy methane, reduce greenhouse-gas emissions, and minimise odour and related environmental risks.

iv. Strengthen health and environmental assessments by treating community-reported health concerns as preliminary observations and conducting dedicated epidemiological or clinical studies before attributing health outcomes to landfill emissions.

v. Ensure transparent emissions reporting through an annual measurement, reporting, and verification (MRV) report documenting baseline emissions, methane recovered, methane flared or utilised, surface-emission monitoring results, and verified emission reductions.

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APPENDICES

Kumasi Landfill



A Tricycle Loading Waste to Landfill Site



Questionnaires for Residence around the Landfill

RESEARCH QUESTIONNAIRE

This survey is to examine strategies for optimize reduction of the impacts of land fill Emissions from the Kumasi Landfill in Ghana. Data collected would be used solely for academic purposes and you are assured of the confidentiality of information provided. KINDLY HELP BY RESPONDING TO THE QUESTIONS PROVIDED. Please tick where necessary in the bracket with the answer.

RESEARCH FOR RESPONDENTS WITHIN KUMASI LAND FILL AREA

SECTION A: DEMOGRAPHIC DETAILS

1. GENDER: a. Male [ ] b. Female [ ]

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2. AGE: a< 30 [ ] b. 31-40 [ ] c. 40-51 [ ] d.51-60[ ] e 61 years and above [ ]

3. EDUCATIONAL BACKGROUND:

a. No formal Education [ ] b. Basic (Primary, Middle, JHS) [ ] c. Secondary (SHS, Vocational Institution) [ ] d. Tertiary Institution (Training College, Poly or University)

4. OCCUPATION:

a. Government Worker [ ] b. Private Company [ ] c. Self Employed/ Entrepreneur [ ] d. Student [ ] e. Unemployed [ ]

5. MARITAL STATUS:

a Single [ ] b. Married [ ] c. Separated [ ] d. Divorced [ ] e. Widowed [ ]

6. RELIGIOUS AFFILIATION:

a. Moslem [ ] b. Christian [ ] c. Traditionalist [ ] d. Any other (specify)……..

SECTION B: LAND FILL IMPACTS

1. Over the past five years, is the Odour within this community keeps rising due to the Kumasi landfill site.

Do you agree?

a. Strongly Agreed [ ] b. Agreed [ ] c. Disagree Strongly [ ] d. Disagree [ ] e. Undecided [ ]

2. Leachate (liquid) is increasing every year within this community due to the Kumasi landfill site. Do you agree?

a. Strongly Agreed [ ] b. Agreed [ ] c. Disagree Strongly [ ] d. Disagree [ ] e. Undecided [ ]

3. The Odour is changing within this community due to the Kumasi landfill site. Do you agree?

a. Strongly Agreed [ ] b. Agreed [ ] c. Disagree Strongly [ ] d. Disagree [ ] e. Undecided [ ]

4. What do you think is the main cause of the odour in the area?

a. Presence of gases [ ] b. Presence of chemical [ ] c. Enraged gods [ ] d. Too much waste [ ] e. Undecided [ ] f. Poor Management of Waste [ ]

5. If you have observed any changes in Odour in your area due to the Kumasi landfill site, how does this impact on your household?

a. We can't breathe b. Some time, we fall sick

6. is respiratory sicknesses prevalent in your household? a. yes [ ] b. no [ ]

7. What are other two (2) top most Sicknesses that are prevalent in your household?

……

8. Do you think that these Sicknesses are as a result of the land fill? a. yes [ ] b. no [ ]

If yes, how? .....

9. are Insects, reptiles, rodents present in your household? a. yes [ ] b. no [ ]

10. Do you think that these insects/reptiles/rodents are as a result of the land fill? a. yes [ ] b. no [ ]

If yes, how? .....

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SECTION C: COPING STRATEGIES

1. What adaptation strategies do you use in combating Odour in your area due to the Kumasi landfill site?

……
……

2. How are these strategies improving your living conditions?

……
……

3. What challenges do you face using these adaptation strategies?

……
……

4. What adaptation strategies do you use in combating Sickness in your area due to the Kumasi landfill site?

……
……

5. How are these strategies improving your living conditions?

……
……

6. What challenges do you face using these adaptation strategies?

……
……

7. What adaptation strategies do you use in combating Insects/reptiles/rodents in your area due to the Kumasi landfill site?

……
……

8. How are these strategies improving your living conditions?

……
……

9. What challenges do you face using these adaptation strategies?

……
……

Thank you for your cooperation and precious time.