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Household Solid Waste and Climate Change in Bamako: Between Mitigation and Resilience

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Abstract: Household solid waste is an inherent part of our lives, and its management is essential for our well-being and development. Unfortunately, we observe that its mismanagement in Bamako is detrimental to our health and environment. Waste management is currently a major challenge for all stakeholders, given the proliferation of unauthorized transit sites and the lack of a properly functioning final landfill. Consequently, the numerous transit sites that are supposed to be evacuated are becoming permanent. These stabilized transit sites then become tinderboxes, sometimes permanently burning, resulting from the open burning of waste of all types. This complete or incomplete combustion releases greenhouse gases (GHG) that directly contribute to global warming. In addition to the GHG emissions from open burning, uncontrolled methanization occurs from the fermentation of organic waste from transit sites that have been stabilized for over ten years. It goes unnoticed, but it produces CO_2, nitrous gas, and methane, which is twenty-five to thirty times more harmful than CO_2. This climate change indirectly contributes to natural disasters such as flooding in a city where homes and piles of solid waste are sometimes located in low-lying areas and obstructing rainwater drainage channels. At this rate, poor management of household solid waste jeopardizes the achievement of Sustainable Development Goal (SDG11: sustainable cities and communities) and SDG 13 (climate action). Based primarily on a qualitative study, the objective of this work is to elucidate whether household solid waste has an impact on climate change and flooding in Bamako in order to propose resilience and mitigation solutions.

Keywords: *Bamako, Climate Change, Household Solid Waste, Mitigation, Resilience*.

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I. INTRODUCTION

Notwithstanding numerous studies and research on household waste management in the Bamako District, the problem remains persistent. According to Depoues V & Bordier C (2015), life is impossible without waste. It is established that waste constitutes the third largest source of anthropogenic global warming worldwide, after deforestation (due to agriculture and urbanization) and industrialization (CCAC, 2021). Regarding climate change in developing countries caused by solid household waste, it results from open-air incineration and the stabilization of unauthorized dumps. While waste incineration produces more carbon dioxide and nitrous oxide, the stabilization of dumps is more responsible for the uncontrolled emission of methane (Gex E & Steiner R, 2019). Thus, reducing methane is one of the most promising ways to limit climate change. Reducing methane emissions would help lower the rate of warming in the short term, and if emission reductions are maintained, this could also help limit the warming peak. The problem is very complex in Bamako, where these sources of air pollution particularly affect areas of high population density. The objective of our work is to analyze whether household solid waste has an impact on climate change in Bamako, and ultimately to propose resilience and mitigation solutions within the context of Mali's economic, security, and climate fragility. Our work is more qualitative than quantitative.

II. LITERATURE REVIEW

➢ *Household Solid Waste and Climate Change*

The most visible and commonly recognized harmful effect of waste management on the atmosphere is the emission of carbon oxide (carbon monoxide and carbon dioxide) from open-air incineration, while it is clearly established that the various methods of treating household solid waste produce other greenhouse gases (GHG), which include: on the one hand, methane from the anaerobic fermentation of organic waste, and on the other hand, black carbon and nitrous oxide (N_2O) released directly from incineration at landfills by uncontrolled open-air burning (Depoues V & Bordier C, 2015; Green Partners, 2019). Open incineration (open burning), a common and widespread waste management practice in developing countries, is one of the most prevalent methods, with a direct impact on human and animal health, and especially on the environment, due to

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the persistent release of climate pollutants (Tsydenova N & Patil P, 2021; Guendehou G.H. S & al, 2006). However, some African countries fail to act, underestimating the consequences of these open incinerations of solid household waste, likely by not being concerned about or ignoring the greenhouse gases they release (Mebratu D & Mbandi A, 2022). This method is primarily used by communities that lack access to waste management services in urban centers. Methane and black carbon are short-lived climate pollutants that contribute to climate change (Wiedinmyer C & al., 2014). Although short-lived, black carbon is a component of particulate substance, formed by the incomplete combustion of heterogeneous waste (e.g., wood) at low temperatures. It has a climate change potential up to 5,000 times greater than carbon dioxide (CO_2) and is also linked to adverse health impacts (Reyna-Bensusan N & al., 2019; Guendehou G.H. S & al., 2006; Green Partners, 2019).

In waste, it is primarily woody (biomass) and fossil fuels that release black carbon through incomplete combustion, a process that also releases CO_2, carbon monoxide, methane, dioxins, persistent organic pollutants, and organic carbon (Le Bonheur J., 2021). This complex mixture of gases and particles resulting from this process is often called soot. Under solar irradiation, nitrogen dioxide, one of the pollutants responsible for the photochemical production of ozone, reacts with soot to efficiently produce nitrous acid (HNO_2) over relatively long periods (Cartier C & al., 2010). In addition to the pollutants mentioned, open-air waste incineration can also produce emissions of various heavy metals such as cadmium, chromium, manganese, antimony, arsenic, lead, and mercury, depending on the volume of electronic waste in the waste composition (Cartier C & al., 2010).

As for methane emissions, they depend on the age of the landfill. Stabilized landfills (those over 10 to 15 years old) create favorable conditions for natural methanization. However, under controlled conditions such as production in a digester, the biomethane produced drastically reduces CO_2 emissions compared to fossil natural gas in a life cycle analysis. In contrast, methane released into open landfills is 30 times more harmful than carbon dioxide (Amant S et al., 2021).

The management of urban household solid waste requires greater attention in urbanizing regions and developing countries, as it represents the third largest source of anthropogenic methane emissions globally (CCAC, 2021; Powell J T et al., 2016). This ranking is the third largest emitter places urban solid waste behind agriculture and the oil and gas industry. It is responsible for approximately 20% of human-caused methane emissions worldwide (UNEP, 2008). Affected mainly by temperature and the length of time waste remains in landfills, CH_4 emissions come from incineration and incomplete combustion of waste in the open air (Guendehou G.H. S & al, 2006).

- *Household Solid Waste, Land use, and Flooding:*

Land use in flood-prone areas, linked to rapid and, in most cases, uncontrolled urbanization, increases the risk and frequency of flooding (Diallo B A & al., 2022; Descroix L et al., 2015; Carreau J & al., 2022). This is the case in Bamako, as it is in most large African cities, where spatial expansion does not receive as much attention as population growth. Fueled by a housing crisis and insatiable land speculation, this expansion, which appears to be occurring outside the framework of the Master Plan for Development and Urban Planning, is generating difficulties in planning, infrastructure, and housing, with flooding caused by the uncontrolled occupation of riverbeds and easements and the failure to clean drainage systems, which are subject to haphazard dumping of household solid waste, even though the consequences of flooding are not limited to floodplains (Lhomme S et al., 2010). This poor waste management plays a crucial role in exacerbating and intensifying floods because it clogs stormwater drainage systems (Oumessaoud N., 2023). Moreover, these floods will continue to worsen due to the enormous rainfall resulting from climate change caused by urban human activities, including poor waste management (Singha H & al., 2023). It has been observed that in Commune IV of the Bamako district, over 82% of the plots flooded during recurring floods are located within the easements and watercourses, and approximately 18% of the flooded plots are spontaneous settlements or unplanned settlements where household solid waste is used as fill in the streets. This high land consumption, which has led to urban sprawl with consequences such as the proliferation of informal settlements, insufficient or nonexistent infrastructure and sanitation systems, has occurred in floodplains, steep slopes, marshes, etc. (Diallo B A & al, 2022). These informal settlements are generally not served by waste collection services.

III. METHODOLOGY

- *Description of the Study Area*

Bamako district, capital of Mali, extends 22 km from west to east and 12 km from north to south, covering an area of approximately 267 km² (Maiga Y, 2022), pending the full implementation of the new administrative reorganization measures. Located between 12°29’57’’ and 12°42’17’’ north latitude and 7°54’22’’ and 8°04’06’’ west longitude, the city of Bamako developed in the Niger River valley, which divides it into two parts (Diallo B. A & al., 2022): the left coast and the right edge.

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Fig 1 New Administrative Map of Bamako (IGM, 2024)

Bamako district experiences a humid tropical climate with high temperatures (average annual temperature ranging between 26°C and 30°C) and annual rainfall varying from approximately 700 mm to 1100 mm. Others place Bamako in the pure tropical climate zone (North Sudanese climate), which, unlike the transitional tropical climate, records average annual summer temperatures that remain higher than winter temperatures, with a temperature range of 4°C. However, maximum temperatures during the rainy months are lower than the peaks experienced in January and December (in Bamako, 33.4°C in January compared to 30.3°C in August). This climate is characterized by a distinct dry season and rainy season.

The prevailing winds in the Bamako district are mainly the harmattan (hot and dry, blowing during the months of March and April and is oriented East and Northeast towards the West) and the wet season which blows during the rainy period with the orientation Southwest towards Northeast.

➢ *Methodology*

The methodology consists to:

- Analyzing meteorological data (temperature and rainfall) from the last thirty years.
- Cross-referencing information from previous scientific publications on climate change and related natural disasters.
- Observing practices at landfills that could exacerbate climate change.
- Visiting recycling facilities to determine whether the observed recycling methods could have an impact on climate change.

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IV. RESULTS AND DISCUSSIONS

➢ *Unauthorized Dumping Sites: Open-Pit Methane Mines*

In Bamako, there is a proliferation of illegal household waste dumps. These sites have been the focus of our studies and research. We identified sixty-six (76) transitory dumping sites, of which only ten (10), or 13.16%, are authorized and established by local authorities, while the remaining sixty-six (66), or 86.84%, are established haphazardly (Fig. 2).

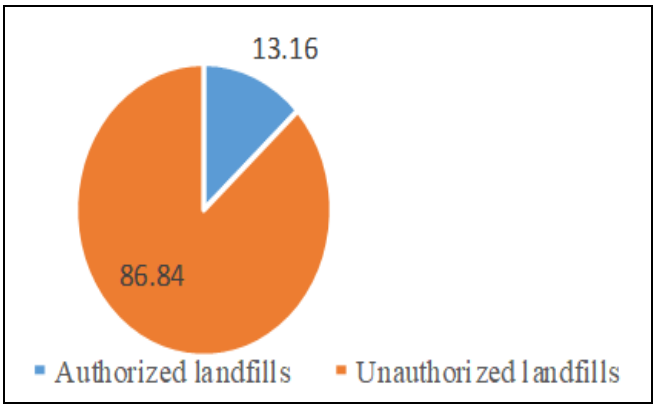

Fig 2 Distribution of Transit Solid Waste Landfills in Bamako

Unfortunately, only authorized transit landfills are evacuated towards the final landfill, and all the 66 unauthorized transit landfills are more than ten years old, an indicative duration for the start of uncontrolled methanization. The long-term storage of waste and its open-air incineration generate greenhouse gas emissions that contribute significantly to global warming. Certainly, we do not have a facility to recover the methane released by our illegal transit dumps and to quantify the CO_2 level, but it is still indisputable that these dumps produce not only uncontrolled methane but also CO_2 through open-air incineration.

➢ *Open Burning of Waste*

Household waste production continues to increase while, at the same time, there has been a decline in subscriptions to waste management services. This leads many households burning their waste in makeshift piles nearby.

While it is illegal to burn solid household waste outdoors within any urban area (Article 14 of Law N°. 2021-032/CNT), this practice remains one of the most common methods of household solid waste management (Fig. 3). This operation, which generates direct greenhouse gas (GHG) emissions, typically takes place at night or very early in the morning. Recycling is not yet an activity capable of drastically reducing the volume of household waste sent to transfer stations. Thus, open burning becomes a suitable alternative, even though it is one of the most harmful methods due to GHG emissions (Miquel G & Poignant S, 1999).

Fig 3 Burning of Waste on the Outskirts of Bamako

➢ *Waste Recycling: A Double-Edged Sword for the Climate*

While recycling is a driving force of the circular economy, the recycling methods used in developing countries can significantly contribute to climate change. All studies show that recycling reduces the volume of waste to be processed, significantly conserves resources, and creates many jobs. Unfortunately, in Bamako the techniques used (especially for recycling metals and plastics) are often artisanal or semi-industrial, relying heavily on wood or charcoal as an energy source. Moreover, this wood is burned in open fires, releasing carbon monoxide (CO) and carbon dioxide (CO_2). We observed this environmental non-compliance among various artisans and even industrial units, which can further exacerbate climate change. Whether processing plastics or metals, the commonly used procedure is artisanal casting, even if modern equipment is used to manufacture the finished product. The worst aspect is that these methods contribute directly to greenhouse gas emissions and indirectly lead to deforestation for the necessary supply of wood or charcoal.

➢ *Rainfall, Floodplain Occupation, and DSM Dynamics*

The parameter that urgently needs to be considered is the integration of land use (settlements with housing developments) into the overall master plan for the development of new neighborhoods. Otherwise, there is a risk of people continuing to settle in floodplains, as observed by Dembélé O & Ouattara I (2019). The observation of the spatial expansion of Bamako city is typical of what emerges from the results from Jha A K et al. (2012), which states that urban expansion to accommodate more inhabitants leads to the uncontrolled occupation of floodplains, characteristic of densely populated, uncontrolled settlements in developing countries. In Bamako, July, August and September are usually the rainiest months, but with the disruption of the rhythm and quantities of rain, it sometimes rains more in June than in July in Bamako and the rain can continue until November or stop abruptly, defying all forecasts.

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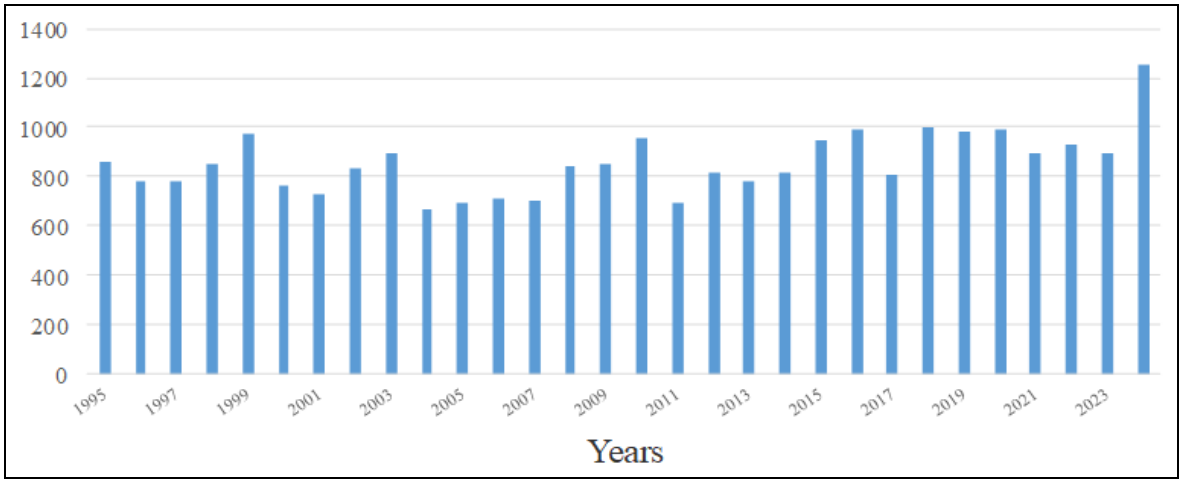

Fig 4 Annual Rainfall Amounts in Bamako from 1995 to 2024

Paradoxically, 2024, which had a shorter rainy season, recorded more rainfall than previous years (Fig. 3). During the rainy months, the ground becomes saturated with rainwater, creating a "soaked rag" effect. In this state, the soil is no longer receptive to infiltration. Therefore, rainwater must flow towards the river through natural streams, gutters, and drains to prevent flooding. Unfortunately, residents, including those involved in informal household waste collection, dump waste by filling in streams and clogging drains and gutters. In Bamako, these occupied floodplains also contain uncontrolled solid waste transit sites that obstruct the normal flow of rainwater, sometimes torrential, thus causing floods, as also concluded by Gex E & Steiner R (2019) in their synthesis on municipal solid waste management. This phenomenon is more noticeable in neighborhoods near the river or crossed by natural drainage channels. This makes them more vulnerable to flooding, especially since uncontrolled settlements in urban areas of developing countries could also influence the risk of floods due to human activities in general, and particularly the presence of uncontrolled household waste dumps in these floodplains (Jha A K & al, 2012; Descroix L & al, 2015). Particularly in Bamako, Diallo B A & al. (2022) concluded that the risk of flooding in Niamakoro and Missabougou basins is significantly exacerbated by buildings and/or garbage dumps obstructing riverbeds and stormwater drainage ditches. Diallo B A & al. (2022) also observed human encroachment on floodplains and the resulting waste. Dembélé O & Ouattara I (2019) concluded that the recurrence of flooding in certain Bamako neighborhoods, such as Banconi, Missabougou, and Djicoroni-Para, is due, on the one hand, to their expansion into marshy lowlands and, on the other hand, to the occupation of riverbeds, which thus become garbage dumps.

- *Probable Influence of Uncontrolled Methanization on Temperature Evolution*

According to AQI (Worldwide Real-Time Weather and Air Quality Data), climate change has worsened in Bamako by 47.7% over the last 15 years, with a temperature increase of approximately +0.5%, or 0.2 to 0.8°C, since late 1970. This average temperature increase is noticeable in Fig 4, where the overall trend is upward from 2010 onwards.

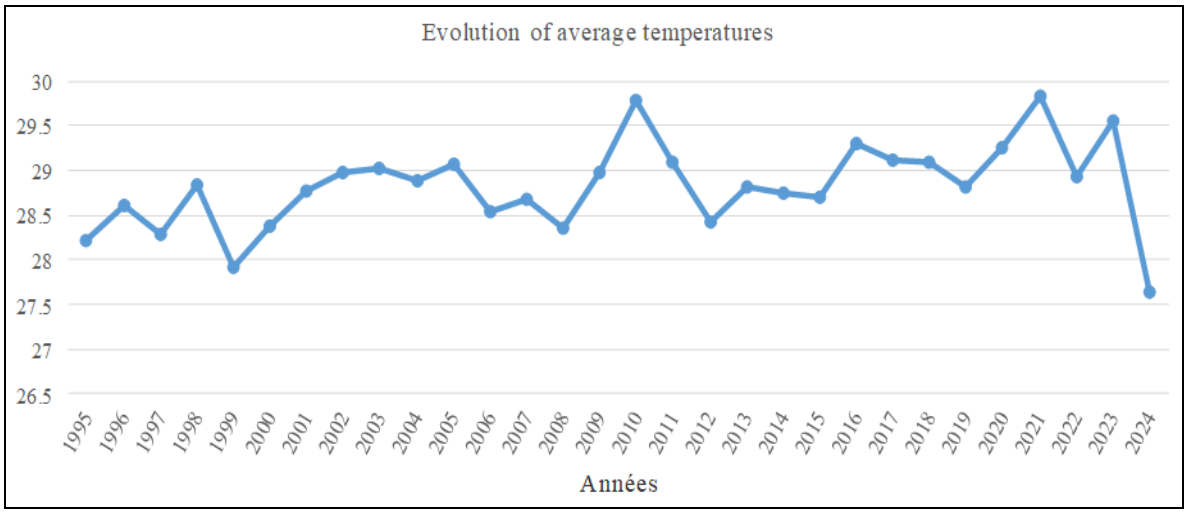

Fig 5 Changes in Average Temperatures in Bamako from 1995 to 2024

Long-term waste storage (as seen in Bamako) and open-air incineration generate greenhouse gas emissions that contribute significantly to global warming. While we lack facilities for capturing the methane released by our

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unauthorized dumpsites and quantifying the CO_2 levels, it is nonetheless undeniable that these landfills produce not only uncontrolled biomethane, given their duration and the nature of the waste dumped, but also CO_2 through open-air incineration. Since this methanization takes place under uncontrolled conditions, we cannot rely on the benefits as in Morocco, where Afilal M E & al (2013) worked on the production of improved biomethane and a biodigestate that fertilizes soils while reducing greenhouse gases. Furthermore, Pharr K & al (2023) confirmed that recent studies and data demonstrate that greenhouse gas emissions (particularly methane) are considerably underestimated. In Bamako, it is the warming, a factor influencing the temperature increase, that should draw our attention, even if we have not quantified it. While this increase in heat in Bamako is not exclusively attributable to waste, it is still partly responsible. Moreover, in Bamako, perceived temperatures are always higher than measured temperatures.

- *Advantages of Biomethane Recovery*

This waste capitalization could not only significantly reduce the amount of household solid waste sent to landfills but also produce biodigestate, an organic fertilizer that could prevent the spreading of all kinds of waste (containing more plastics) on urban and peri-urban farms.

Moreover, most of the population in Bamako uses wood energies (wood and charcoal) as a cooking energy source. Population growth can only exacerbate deforestation to meet these energy needs. Furthermore, Gex E & Steiner R (2019) highlighted that organic waste represents a significant portion of household waste in developing countries, and its inadequate management will continue to increase greenhouse gas emissions, particularly methane, which is the largest source of greenhouse gas emissions in developing countries. The cost of butane gas (a fossil energy imported) makes it inaccessible to many households. Biomethane extraction could be a large-scale solution.

- *Urban Phytomass: A Possible Solution for Mitigating the Impact of Solid Waste on Climate Change*

It is established that deforestation is the second leading cause of climate change. Once felled, trees that regulated the climate by absorbing carbon dioxide (CO_2) instead released it, contributing to atmospheric degradation by increasing greenhouse gas emissions. Thus, there is no longer a mechanism for absorbing CO_2 released directly or indirectly by waste.

Urbanization has contributed to the destruction of the savannah and gallery forests that once dotted the Manding plateau, formerly the green lungs of Bamako. According to the urbanization plan, all occupants of allocated lands should have undertaken reforestation in front of and within their plots. This was not the case, as massive reforestation would have created wooded areas, even if only within existing green spaces. Jha A K & al. (2012) concluded that urban greening would reduce the heat effect in wooded areas and consequently CO_2 emissions, thus contributing to a healthier urban environment. The national park, located on the slopes of Koulouba and Point G hills, is a perfect example. This micro-forest, free of waste dumping, offers a microclimate that attracts people for pleasant days. Dabonneville C (2015) stated that vegetation directly and positively mitigates the effects of climate change. Duchemin B, (2020); Roux A & al (2020) concluded that, for the time being, reforestation is undoubtedly the most effective means of capturing and therefore sequestering CO_2. Thus, photosynthesis of urban biomass is an effective response to offset greenhouse gas emissions. Wigneron J-P & Ciais P (2021) even established a link between tree growth and their capacity to mitigate impacts.

V. CONCLUSION

While recycling in the Bamako district is boosting a circular economy that is not yet formalized, it is evolving in a way that runs counter to its primary objective, which is to reduce the volume of waste transported to transfer stations and landfills, and consequently limit greenhouse gas emissions in an already accelerating climate change process. Unfortunately, recycling activities, which are more artisanal, rely heavily on wood energies, further contributing to deforestation in an area already threatened by desertification. Without proper management, waste will continue not only to exacerbate flooding, especially in at-risk areas where populations settle in low-lying areas, leading to the construction of makeshift transfer stations without any environmental standards, but also to stabilize, with the risk of uncontrolled methanization contributing to climate change. At this rate, poor management of household solid waste jeopardizes the achievement of targets 11.5 (disaster reduction), 11.6 (urban environmental impact), and 11.a (sustainable urbanization and resilience) of SDG 11 (sustainable cities and communities), and target 13.1 (resilience and adaptation) of SDG 13 (climate action). To reduce greenhouse gas emissions, the most effective solution is to prevent the stabilization of transitory waste deposits by removing them and avoiding open burning. This will significantly contribute to mitigating climate change and its associated negative consequences. Metal and plastic recycling methods must be controlled to limit, if not progressively eliminate, the use of wood-based energy sources. This also has the advantage of preserving the few existing trees that help capture carbon emissions to decrease the temperatures.

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