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Quantification of biogas emitted from the Mubone landfill, in Bujumbura-Burundi

Ndikumana T. * 1, Manirakiza N.1,2, Girukwishaka S.1, Mboninyibuka D.1, Irakoze P.1, Bigumandondera P.3 and Jung C. G. 4**

[1] *Center for Research in Natural and Environment Sciences, University of Burundi, P.B. 2700 Bujumbura, Burundi,*
[2] *Department of Natural Sciences, Burundi Higher Institute of Education, P.B. 6983 Bujumbura, Burundi,*
[3] *Institut de Pédagogie Appliquée, Université du Burundi, Centre Universitaire de Recherche et de Pédagogie Appliquées aux Sciences (CURPAS), P. B. 2523 Bujumbura-Burundi*
[4] *Université Libre de Bruxelles, École Polytechnique, EP-4MAT, 1050 Bruxelles, Belgium*
** Ndikumana Théophile, Email address: theo.ndikumana@gmail.com*
*** Manirakiza Norbert, Email address: manorbert84@gmail.com*

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Abstract: It is well known that inadequate management of municipal solid waste poses health risks to mankind and exposes the environment to overall adverse effects. Therefore, reducing emissions of short-lived climate pollutants may be the only way to slow global warming in the short term. Cities in developing countries are characterized by a proliferation of open dumps whose fermentable fraction generates carbon and methane particles, both of which are potent greenhouse gases. Energy recovery from biogas from waste is one of the initiatives to fight these pollutants and at the same time have a positive impact in developing countries. Quantifying the gases produced by landfills is the main objective of our research, which focused on the Mubone landfill located in northern part of Bujumbura city. Landfill gas collection pilots were placed at selected locations in the landfill and at a depth of 1.5 m; a MultiTec 545 gas analyzer was used to quantify the gases. Mubone being a young landfill, it shows a significant fermentative activity, releasing methane (CH4) in the range of 33.21 to 60.03%, CO2 in the proportion of 29.28-37.5 and H2S at a rate of 6.48-12.86 ppm with peaks at 20 and even 44 ppm. This quantity of biogas is important and deserves to be captured, treated and valorized. Hydrogen sulphide is so important that it poses a health risk by inhalation to the surrounding population, especially children who often use the landfill as a playground. The three gases' emission were significantly and positively correlated between them ($p<0.05$); indeed they were negatively correlated ($p<0.05$) with the age factor of the measurement sites.

1. Introduction

Poor solid waste management leads to public health risks, negative environmental impacts and other socio-economic problems (Qdais, 2007; Sahar, 2019; Weldeyohanis *et al.*, 2020). This is evident in many developing countries. Currently, several countries realized that the management of their solid waste does not meet the objectives of sustainable development (Qdais, 2007). Indeed, landfilling of solid waste generates biogas due to the decomposition process of organic matter present in a solid waste (Menegheti *et al.*, 2022; Mousania *et al.*, 2024). The characteristics of these gases depend on several factors such as the quantity, density and composition of the waste, the localization and the thickness of the landfill, the moisture content of the waste, the temperature and the amount of oxygen present (Atemni *et al.*, 2022; Gollapalli & Kota, 2018; Haro *et al.*, 2019). Three processes are at the origin of landfill gas: bacterial decomposition, volatilization and chemical reactions. Among the typical composition of landfill gas, methane forms the predominant fraction of the gases emitted from a landfill, followed by carbon dioxide, with average of 30-70% (El-Fadel *et al.*, 1997). In most developing countries such as Burundi, Municipal Solid Waste (MSW) are dumped in uncontrolled landfills and contribute as potential GHG having global warming potential (GWP) 30–34 times greater than that of CO_2 (Li et al. 2017; Singh et al. 2016). It becomes so important to quantify these gases emitted from municipal landfills of Bujumbura, especially since, to our knowledge, this work has never been undertaken in this city.

MSW is the source of short-lived climate pollutants, as it emits chemicals that remain in the atmosphere for a few days to a few decades at most. These include black carbon from waste incineration and methane (Ek, 2012). In addition to being potent greenhouse gases, these two substances are dangerous air pollutants that have various harmful effects on human health, agriculture and ecosystems (West *et al.*, 2006, 2013; Ek, 2012; bouknana *et al.*, 2014; Abubakar *et al.*, 2022). However, the risk of these chemicals is largely unknown by the general public. Therefore, reducing emissions of short-lived climate pollutants may be a way of slowing down the global and regional warming in the short term (10-30 years), while producing immediate benefits for air quality (Ek, 2012). The use of biogas from waste to produce energy is one of the initiatives being undertaken to reduce these pollutants with a positive impact in developing countries.

In Burundi, MSW produced is increasing significantly and is frequently dumped in open air not far from houses. The complex degradation (aerobic and anaerobic) results in the formation of methane (CH_4) and carbon dioxide (CO_2), which are continuously released in the atmosphere. If these gases are not recovered, treated and recycled, they constitute potential environmental pollution: destructive impact on the ozone layer and global warming; impact on the local environment through odors and stress on vegetation; exposure of humans to landfill gas (LFG) and combustion products, etc (Purmessur & Surroop (2019).

According to WHO, children growing up in Developing Countries are surrounded by invisible threats from the outside world including landfill gas (WHO, 2018). These invisible threats can hinder their cognitive development, impair lung function, cause asthma and set the stage for problems that will be triggered in later life. These health problems include cardiovascular disease, stroke, chronic respiratory disease or cancer. Children and the elderly are generally most at risk from this invisible hazard (WHO, 2018).

The objective of the present study is to assess CH_4, CO_2 and H_2S emissions from an open dump near popular residential areas in the north of Bujumbura, the economic capital city of Burundi. The aim is (a) to verify the potential contribution of the biogas from this site to global warming on one hand, and on the other hand, (b) to evaluate the possibility of energy recovery of the biogas that could be used by the local population.

2. Material and methods

2.1 Study's area and description of the site

The study was conducted on the open dump located in Mubone, an area in the northwest of Bujumbura, the economic capital of Burundi (**Figure 1**). The Mubone landfill is subdivided into 4 parts according to their start-up period and age: from south to north, we have Mubone 1 with a surface area of 0.33 ha, a site that has been receiving all-purpose waste for about 9 years. Next is Mubone 2, with 4.54 ha, which is the oldest site opened after the closure of the Buterere site in 2009 (Mizero et al, 2015).

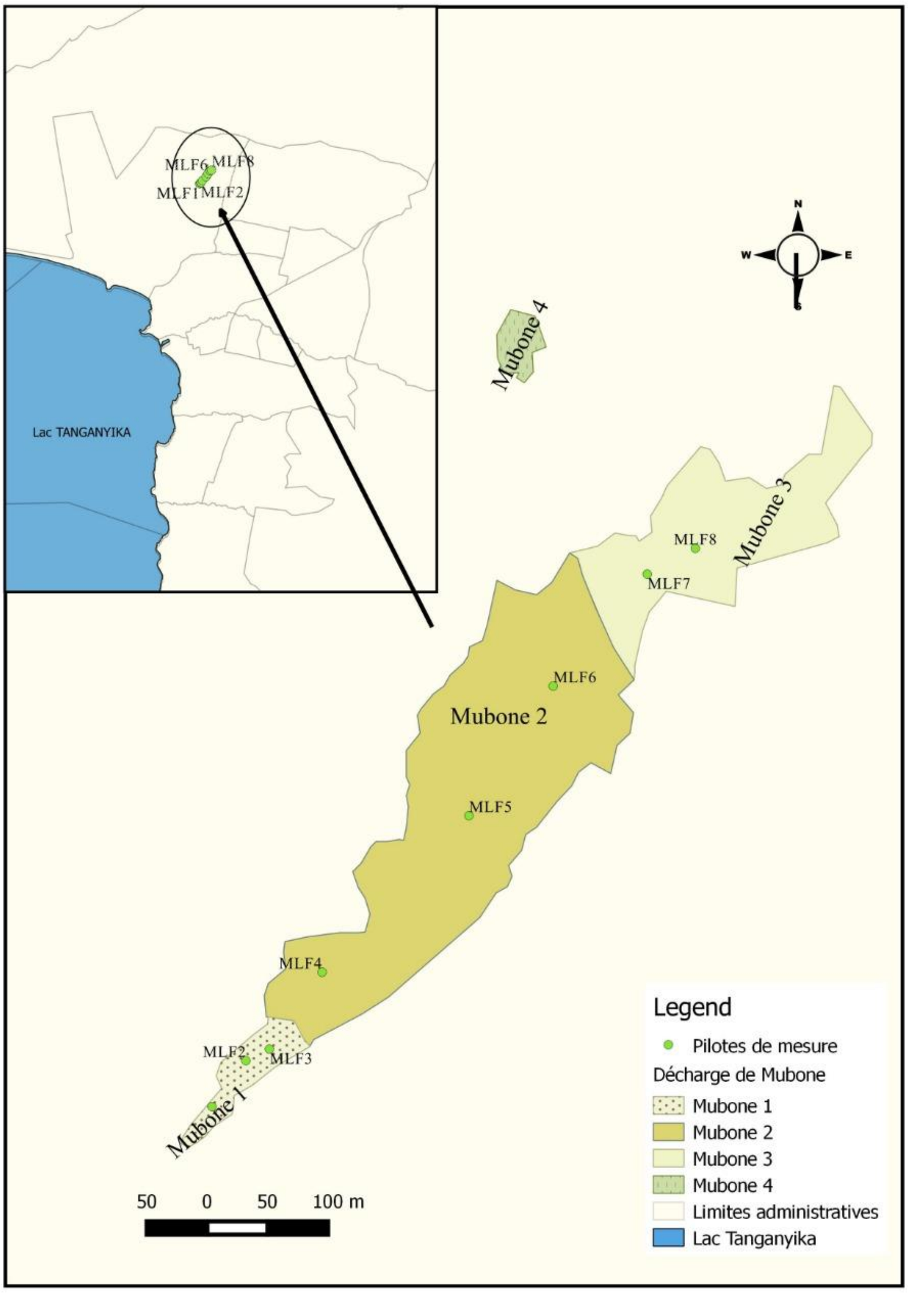

Figure 1: Mubone landfill (MLF_i indicates the measuring pilot number i)

The waste deposited there has been scattered, mixed with soil and compacted. Various crops, mainly vegetables, are grown on the site. Mubone 3, of 1.95 ha, is about 2 years old and therefore received relatively fresh waste. Finally, Mubone 4 of 1.61 ha. It should be noted that the site of Mubone 4 area was not investigated as it was just starting to receive fresh waste. For the measurement of landfill gas, we installed 8 pilots, 3 in Mubone 1 (code names MLF1, 2 and 3), two in Mubone 2 (MLF4 and 6; MLF5 was swallowed up by groundwater and not investigated) and two in Mubone 3 (MLF7 and MLF8).

2.2 *Experimental methodology*

To quantify the methane (CH_4), carbon dioxide (CO_2) and hydrogen sulphide (H_2S) gases emitted at the Mubone site, chamber pilots were set up according to the methodology recently used (Haro et al., 2019; Poulleau, 2002, Srivastava & Chakma, 2020; Manirakiza, 2021) as shown in **Figure 2**. Measurements were carried out from 6 February to 10 April 2021 by placing seven pilots, numbered MLF1 to MLF8 (Mubone LandFill), consisting of a PVC Φ110 pipe pierced with lateral slots on 1.5 meters, and placed at 2 meters' depth. Rounded river stones were placed at the base of the hole and surround the pipe to the slightly higher level of the slots, to prevent waste from clogging the slots made to collect landfill gas. After the river stones, the excavated waste was placed back down to 50 cm below the top level of the waste. This space was then filled with soil followed by a layer of concrete, and the pipe was closed with a PVC plug with a small hole to measure the emitted gases. Estimation of the landfill gases was carried out with a Multitec 545 gas analyzer equipped with IR detectors for CH_4 and CO_2, while O_2 and H_2S are assessed with electronic detectors. This instrument gives the percentage by volume of each gas present, except the H_2S which is quantified in ppm.

The measuring device has a gas intake point to which a 30 cm long tygon tube is attached and a gas ejection point into the atmosphere. A filter is placed at the gas inlet to the MT 545 to remove moisture. The instrument evaluates the proportion (%v/v) of each gas and displays the result. The measurements are repeated at approximately 5 minutes' intervals and averaged. During the evaluation period, these measurements were carried out daily between 8 am and noon.

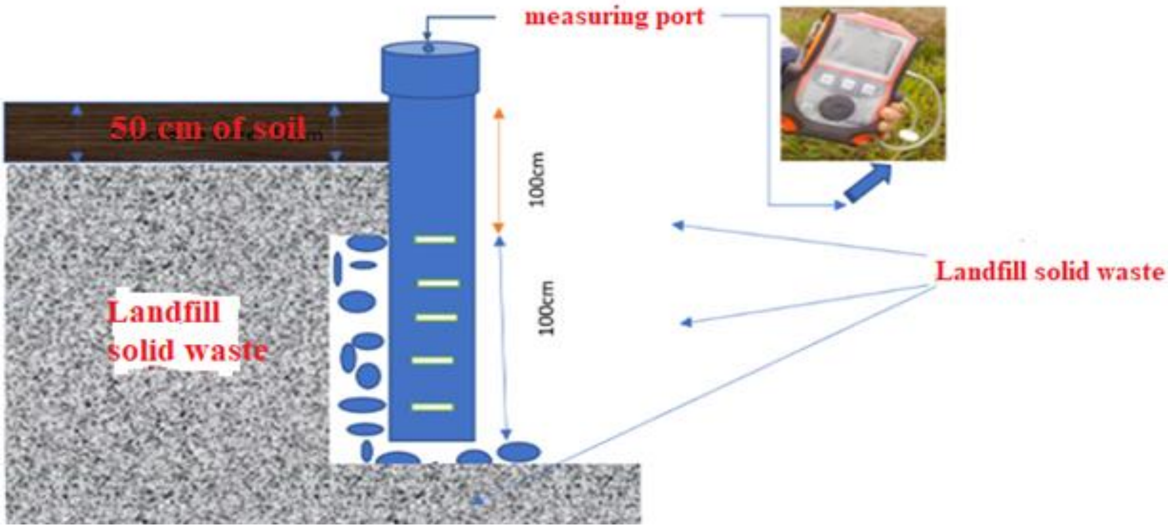

Figure 2: Experimental pilot for landfill gases quantification

2.3 *Data processing*

Data analysis was performed using SPSS version 22 software. Pearson's correlation test was determined to evaluate the possible interdependence of landfill gas levels at different study sites. Figures have been realized by OriginPro 8 software.

3. Results and Discussion

Mubone landfill, had been divided into four zones named Mubone 1, Mubone 2, Mubone 3 and Mubone 4 as shown in **Figure 1**. Results of this study showed a significant activity on the area, except for Mubone 2. This is shown in the following sections, which give respectively the values measured for methane, carbon dioxide, and hydrogen sulfide over the period covered, as well as the mean values.

3.1 Methane and carbon dioxide emissions

Landfill gases include mainly carbon dioxide, methane, and to a lesser extent hydrogen sulphide and oxygen. Both carbon dioxide and methane contribute to global climate warming (Fortuniak et al., 2017). However, we note that, according to the Intergovernmental Panel on Climate Change, methane is 28 times more potent than carbon dioxide in terms of global warming potential (Stocker et al., 2013). The results of the characterization of gaseous emissions at the Mubone landfill site show that the site emits a huge quantity of greenhouse gases, including hydrogen sulfide, a gas recognized as a toxic substance. Methane and carbon dioxide emissions are shown in **Table 1** and illustrated in **Figure 3.**

Table 2: Methane and carbon dioxide quantification at Mubone landfill

	Parameter	**CH_4 (%V/V)**			**CO_2 (%V/V)**		
Area	Pilot code	Min	Mean ±SD	Max	Min	Mean ±SD	Max
Mubone 1	MLF1	31,1	33±2	38,4	27	29 ±2	34
	MLF2	21,2	38±9	49,05	24	35 ±5	42
	MLF3	16,8	25±7	40,5	19	22 ±5,2	32
Mubone 2	MLF4	0,4	0,9±0,7	2,7	11	15 ±2,4	18
	MLF6	0,5	0,8±0,3	1,3	0	4 ±2,5	8
Mubone 3	MLF7	37,6	53±10	62,1	23	34 ±7	40
	MLF8	45	60±8	65,5	29	38 ±4	41

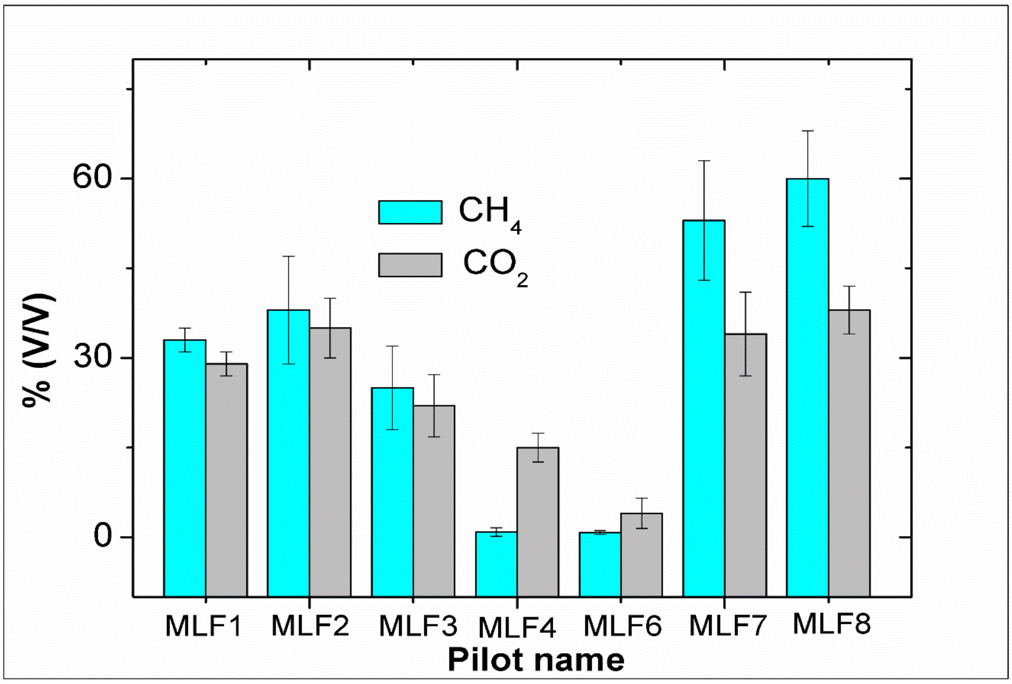

Figure 3: Average values of methane and dioxide carbon emissions on Mubone landfill

Inspection of Figure 3 clearly reveals three areas of different ages. Mubone 1 is about 4 years old and shows medium activity (see pilot numbers MLF 1, MLF2 and MLF3), with respective emission mean values of 33±2%, 38±9% and 25±7% for methane; 29 ±2%, 35 ±5% and 22 ±5.2% for carbon dioxide respectively. Mubone 2 is the oldest dumping area which has received waste since 2009, after the closing of the old Buterere dumping site (Manirakiza *et al.*, 2020 b). Then it was spread mechanically, mixed with soil and compacted so that there is no more off-gassing, with respective average emissions of 0.9±0.7% and 0.8±0.3% for methane, 15 ±2.4% and 4 ±2.5% for carbon dioxide. If we look at the maximum values of the gases emitted from Mubone 2 (MLF 4 and MLF6), we can see that there is 7 times more carbon dioxide than methane, indicating that fermentation is complete. In fact, the biodegradation time has been estimated at around 7 years, after which almost 60% of the organic carbon is converted into landfill gas (Oonk & Boom, 1995).

Finally, Mubone 3 is a recent two-year-old landfill that shows significant methanogenic activity. Figure 3 also shows that the younger the landfill it is, the more gas it emits (see MLF7 & MLF8); with respective emissions average of 53±10% and 60±8% for methane and 34±7% and 38±4% for carbon dioxide. Based on the results found at the three sites in this study area, we can see that the older the waste storage area, the less landfill gas it emits.

In the recent Mubone 3 deposits (MF7 and MF8), stable CH_4 and CO_2 ratios (**Table 2**) were obtained, with a CH_4/CO_2 ratio greater than or equal to 1.5, indicating the landfill's high methane production capacity (CH_4 volume > 1.5 CO_2 volume). These results therefore prove that the Mubone landfill, in its locality 3, has a high capacity to produce biogas.

Over the entire site, methane emission ranged from 0.5% to 65%, with a higher average of 60±8%, located in Mubone 3, precisely at site MLF8. CO_2 emission over the study area ranged from 0 to 42%, and a high release was also identified in MLF8, where deposits were recent, with an average of 38±4%. These gases are greenhouse gases, continuously released into the atmosphere and contributing to global warming. This constitutes an environmental challenge, contributing to the climatic hazards that are often frequent in this African sub-region as well as drought, torrential rains, extreme temperatures, etc.

It should be noted that the methane levels measured vary within the same margin as that released at Montaña (Villanueva-Estrada *et al.*, 2019). Our results are also of the same order of magnitude as those reported by Poulleau (2002) and Record (2009), which vary from 45 to 61% of CH_4 contained in the biogas. Finally, Table 2 shows that Mubone 3 site biogas production is comparable to the results of Nsavyimana (2014) who obtained 64% CH_4 and 36% CO_2 for the anaerobic digestion of MSW mixed with septic tank emptying material in the proportion 3:1 after 12 days of fermentation. Therefore, it is clear that if the biogas measured at Mubone dump is not harvested, it generates significant atmospheric pollution because CH_4 is a powerful greenhouse gas. The prospect of capturing the biogas from this site through pipelines and using it as cooking gas in the vicinity of this site characterized by a shortage of firewood can be proposed (Park & Shin, 2001). If implemented, this would be an environmentally friendly alternative for developing countries.

It is also important to mention that most uncontrolled municipal solid waste landfills in developing countries receive waste with a high biodegradable content of 57% (Mizero *et al.*, 2015). By sorting the waste at source, this fraction can be recovered instead of being sent to landfill (Manirakiza *et al.*, 2020b). Several routes are possible, including composting, biomethanization and the manufacture of fuel briquettes (Reddy, 2014; Diaz *et al.*, 2020; Manirakiza *et al.*, 2020c). Several such trials have already been carried out in developing countries and the current results are significant (Tun *et al.*, 2018; Manirakiza *et al.* 2020c). Even on a day-to-day basis, individual bio-methanisation plants give a usable biogas yield for cooking (Müller, 2007). This would contribute to stopping deforestation which only results in climate change responsible for drought, land warming, irregular and torrential rains, etc. (Tun *et al.*, 2018).

3.2 Sulfide emission

The results of emission measurements of landfill gas at Mubone show that the H2S threshold varies from 0 to 44 ppm, with a higher average of 15.3±15 ppm recorded in the Mubone 3 area (**Table 3**).

Table 3: Production of hydrogen sulfide at Mubone landfill

	H_2S in ppm		
Area	Min	Mean ±SD	Max
Mubone 1	0	7±5	19
	0	11±8	25
	0	2±1	3
Mubone 2	0	0.6±0.5	1
	0	1.1±8	4
Mubone 3	2	9.5±8	24
	2	15.3±15	44

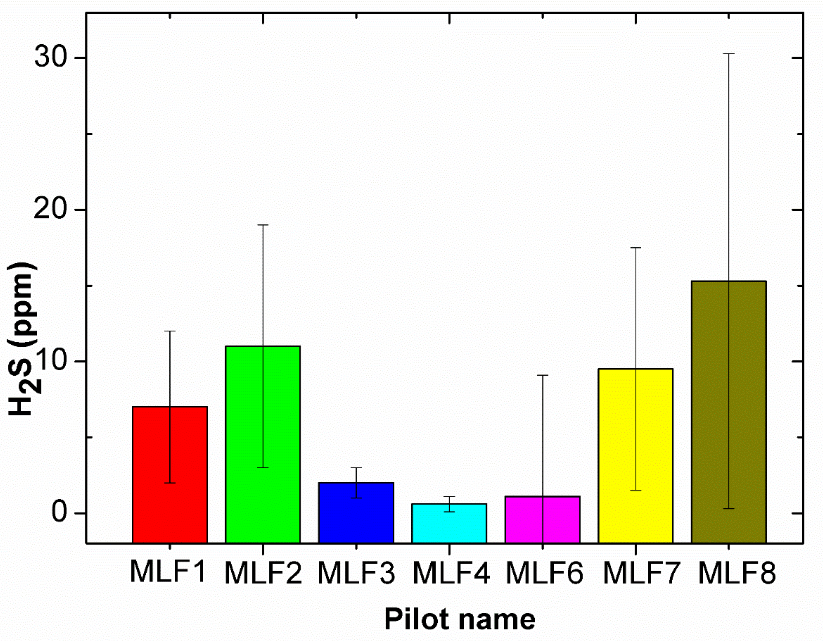

Figure 4: Average values of sulfide emissions on Mubone landfill

The Mubone 1 and 3 sectors have the highest H2S emission values compared with those detected in the Mubone 2 sector (**Figure 4**). The low level of H_2S emissions in the Mubone 2 zone can be justified by the fact that the solid waste has been stored there for a long time, compared with the Mubone 1 and Mubone 3 sites where the waste has only recently been deposited (Ko *et al.*, 2015). Generally, H_2S concentrations in landfill gas samples often range from under detection limits to thousands part per million (Ko *et al.*, 2015). Taking into the levels of H2S detected at Buterere, which range from 0 to 44ppm, this site may cause adverse health effects, such as the release of a detectable rotten egg odour, sense of smell to gas lost (20 ppm) and it is concentrations tolerated for some hours without harm, eye irritation (20-50ppm) (Ko et al., 2015). The Buterere landfill is therefore a source of H_2S, a substance that is toxic to human health. Given that this site is currently close to residential homes, and is not even isolated, and is also accessible to the surrounding population, it constitutes a site of exposure to this gaseous contaminant.

3.3. Correlation between landfill gases emission at Mubone

In addition, we find that CH_4 and CO_2 emissions are significantly and negatively correlated ($p<0.05$) with the age factor of the measurement site (**Table 4**).

Table 4 : Pearson matrix correlation between landfill gases emission

	CO_2	H_2S	CH_4	Age
CO_2	1			
H_2S	0,894*	1		
CH_4	0,933*	0,903*	1	
Age	-0,902*	-0,749	-0,905*	1

* The correlation is significant at the 0.01 level

The greater the age, the lower the emission of these two greenhouse gases. In general, the CH_4 gas generation starts a while after the disposal and it reaches its peak value 5-7 years after the waste is buried (Gollapalli & Kota, 2018). The Pearson matrix correlation ofreveals that the three main gases show a strong positive correlation ($p<0.05$) at these three sites of the Mubone landfill. In addition, it should be noted that MSW is often burnt at this site in order to reduce the volume (**Figure 5**). It is also the source of various toxic substances (including heavy metals) that end up contaminating the different environmental compartments and can even cause harm to human health (Essien et al., 2019; Manirakiza et al., 2020a).

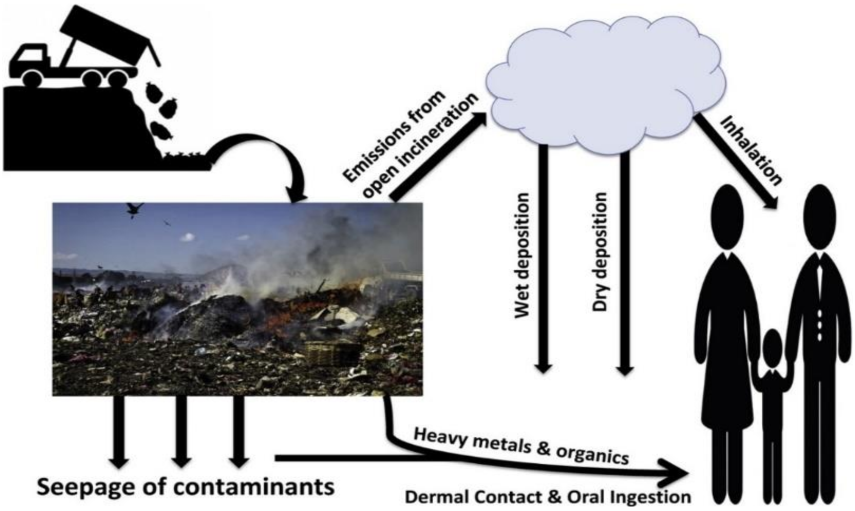

Figure 5: Ecotoxicological risk from solid waste (Essien et al., 2019)

In this same context, Poulleau (2002) also reports heavy metal contents of the order of a few micrograms in the biogas emitted by a municipal solid waste landfill where he found trace metal elements as: arsenic (16.2 µg/m3), antimony (3.5 µg/m3), chromium (41.3 µg/m3), lead (<4.4 µg/m3) and nickel (<2.9 µg/m3). In addition, and depending on the quality of the substrate, there are trace elements in varying quantities as hydrogen, hydrogen sulphide (H_2S), mercaptans (R-SH) and volatile organic compounds (alkanes, aromatic hydrocarbons, organohalogen compounds, etc.). In this context, Table 3 shows that Mubone 1 and 3 produce significant quantities of hydrogen sulphide, which together with other gases, constitute a significant health risk for local residents, especially children and the elderly (Zamoum, 2019).

Conclusion

The Mubone site emits biogas with a high methane content that can reach up to 65.5%. Public or private companies can invest in its extraction and use it in engines for energy production. Furthermore, having the technical and financial means, the sorted biodegradable municipal solid waste can be treated by solid phase biomethanization to produce biogas that can be used as substitution fuel. However, the continuous flow of methane to the atmosphere from Mubone landfill, as well as other dump sites accros Bujumbura city constitutes a pollution of the air. In the current situation, gaseous emissions from the landfill, loaded with CH_4 and CO_2, are significant greenhouse gases that we must try to avoid at all costs.The amounts of hydrogen sulphide measured at Mubone (0.6 to 15.3 ppm) are such that actions are urgently needed to avoid pollution of the surrounding and its population, especially children who use the landfill as a playground.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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