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Preliminary study of greenhouse gas emissions fluxes at Akouédo landfill

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Abstract
Landfills are recognized as one of the significant sources of air pollution because of gases emissions. This study presents the first direct measurements of greenhouse gases fluxes emissions from Akouédo landfill in Abidjan, Côte d'Ivoire. The main objective is to investigate greenhouse gases surface fluxes emissions as well as their spatial variability at Akouédo landfill. For achieving this purpose, methane, carbon dioxide and nitrous oxide fluxes were determined in different areas of Akouédo landfill during the wet (July 2016) and dry (January 2017) seasons using the static chamber technique. The results show that greenhouse gases fluxes were heterogeneous over the surveyed surfaces and vary with the seasons. Fluxes emissions are generally high in dry season than wet season for carbon dioxide and nitrous oxide, except for methane. Also, methane emissions fluxes ranged from -0.087 to 3.533 g/m^2/day and -0.735 to 0.289 g/m^2/day, respectively in wet and dry seasons. Moreover, carbon dioxide emissions fluxes ranged from 0.342 to 37.277 g/m^2/day and 5.608 to 128.049 g/m^2/day, while nitrous oxide emissions fluxes are from 1.02.10^{-3} to 0.073 g/m^2/day and 1.43.10^{-3} to 0.096 g/m^2/day, respectively in wet and dry seasons. These findings may provide to policy-makers crucial information for better solid waste management due to its impact on climate.

1. Introduction
Landfilling is expected to continue to be the conclusive management option within a typically adopted and regulated waste management hierarchy in the coming decades, throughout the world [1]. However, the anaerobic decomposition of landfilled waste is known to produce biogas composed of a high proportion of methane and carbon dioxide. For example, previous studies [2-4], revealed that the average composition of landfill gas is about 50% of methane and 45% of carbon dioxide, 5% of nitrogen gas, less than 1% of hydrogen sulphide and 2700 ppmv of Non-Methane Organic Compounds (NMOCs) such as trichloroethylene, benzene, and vinyl chloride. Also, according to [5], who investigated on the characterization of the biogas of Akouédo landfill (Abidjan, Côte d'Ivoire), methane and carbon dioxide can represent up to 94.5% of the total emission over old deposits, while about 73% was found for recent deposits. Pressure, concentration and temperature gradients that develop within the landfill result in gas emissions to the atmosphere and in lateral migration through the surrounding soils [6-8]. The uncontrolled disposal and open burning of solid waste are causing major environmental and health problems, and landfill gas (LFG) may potentially lead to negative effects in the surrounding such as

explosion hazards, health risks, damage to vegetation, odor nuisances, groundwater contamination and global climate effects [9, 8]. In recent years, due to the global discussion about human-made climate change and relevance of greenhouse gases, methane emissions from landfill have attracted a particular interest from both scientific community and decision makers. For example, in the implementation of emission reduction policies, information about processes involve in methane formation, production and oxidation need to be understood for better quantification and prediction of methane fluxes. However, often methane emissions from landfills are estimated based on prediction models using as input parameters, waste generation and efficiency of methane captured methods and therefore associated with high uncertainties [6]. There is no available landfill greenhouse emissions fluxes measurement in Akouédo landfill. However, [5] studied the characterization of Akouédo landfill biogas and found that biogas production is independent of the seasons. For better understanding of landfill methane emission, dynamic and magnitude, robust and suitable measurements methods are needed [10]. Among the existing methods such as mass balance techniques, which rely on wind-based dispersion of gases are suited to measurement of flux from small, well-defined sources (landfills and animal paddocks) and micrometeorological approaches such as eddy covariance are based on real-time direct measurement of vertical gas flux, and can provide direct measurements over large areas [11]. These methods are used to estimate landfill gas (LFG) emissions. The flux chamber method which has the advantage to be a relatively low cost, easy to apply has been widely used [12]. The sparse literature on actual field measurements of landfill methane emissions indicates wide range spanning roughly eight order magnitude (0.0014 – 50,000 $g.m^{-2}.day^{-1}$) [13]; the observed N_2O fluxes for municipal solid waste (MSW) landfills have been 1 to 2 orders of magnitude higher than those for agriculture and forest soils [1, 14]. This study used the static chamber method to measure CH_4; CO_2 and N_2O emissions fluxes. The objective of this study is to investigate the seasonal characteristics of Akouédo landfill methane, carbon dioxide and nitrous oxide fluxes emissions. Firstly, surface fluxes emissions were observed. Secondly, emissions were compared to others studies. Finally, the differences between different types of soils were studied. To achieve these objectives, the research survey was conducted in Akouédo landfill of Abidjan, Côte d'Ivoire in July 2016 and January 2017

2. Materials and Methods

2.1 Description of Akouédo landfill

Akouédo landfill (5°21'07"N, 3°56'30"W) is located in a sub-urban area about ten kilometers from the center of the municipality of Cocody, to the East of the Abidjan district (Fig. 1). The climate of the city of Abidjan is tropical wet type with two rainy seasons, one big and one small, interspersed with two dry seasons [15-17]. According to [18], the district of Abidjan is subject to a transitional equatorial climate which is divided into four (4) seasons in the annual cycle:

- the great dry season from December to April;

- the great rainy season from May to July;

- the small dry season from July to September;

- the small rainy season from October to November.

The average annual rainfall is between 1300 and 1600 mm. According to the National Aviation and Maritime Agency (ANAM), the average annual temperature is 26.5°C with a maximum of 28.7°C and a minimum of 24.6°C. The relative humidity is between 78.2 and 88.3% [15]. Open to disposal since 1965, Akouédo landfill covers an area of approximately 153 ha in a north-south thalweg, with natural drainage towards the nearby Ebrié Lagoon. This landfill was intended to bury waste from the ten (10) municipalities of Abidjan (Abobo, Adjamé, Attécoubé, Cocody, Koumassi, Marcory, plateau, Port-Bouët, Treichville, Yopougon), as well as localities around Abidjan city such as Songon, Anyama and Bingerville. Initially, the Akouédo landfill has been installed on the outskirts of the city of Abidjan. Through the urban sprawl, some concessions have become very close to landfill, which increases the riparian population vulnerability and induced health risks [19]. In 2014, more than 1 million tons of waste was received in the Akouédo landfill. This tonnage equals to 86,000 ton per month or 2,800 ton per day [20]. The landfill receives household waste but also from a variety of activities such as slaughterhouses, industrial waste, green waste, rubble, without any respect for the strict rules recommended for such conventional landfills. The pile of rubbish rises 4 to 8 m in places above road level [21].

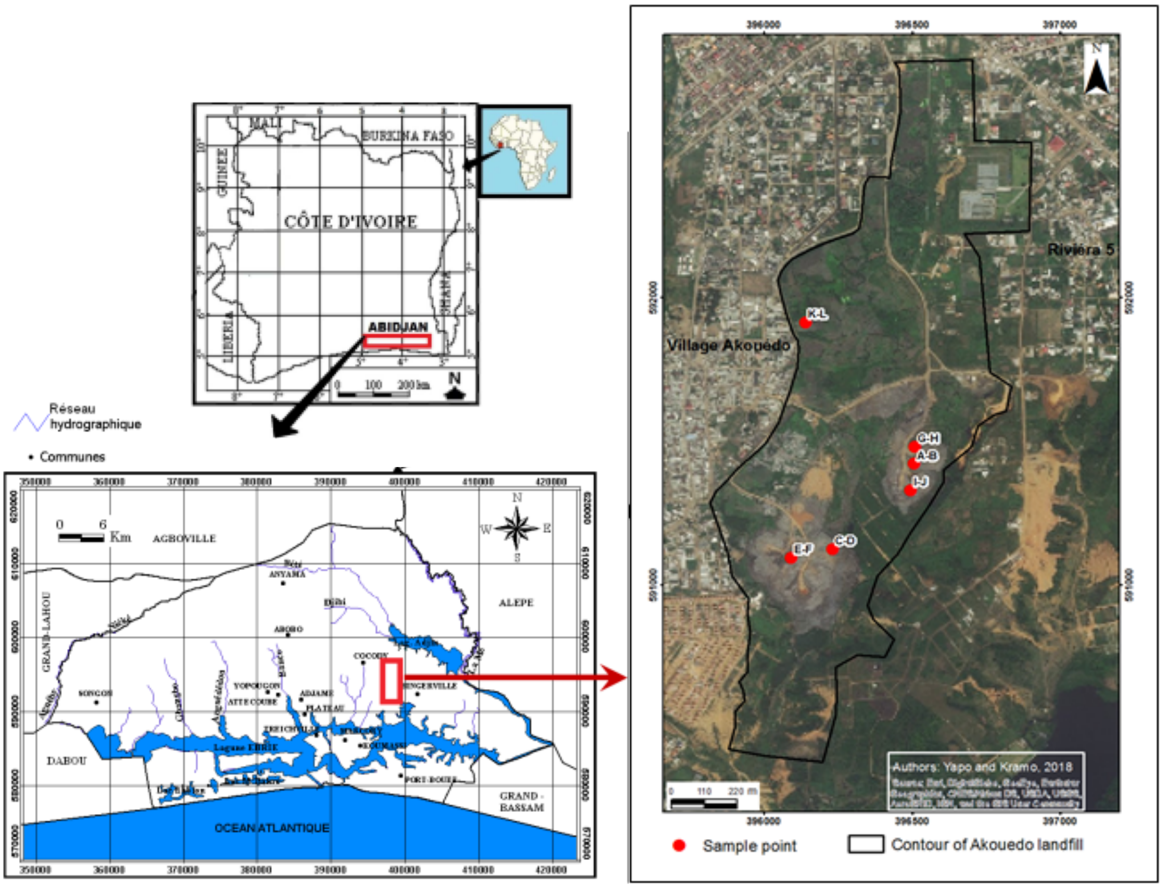

Figure 1: Location of Akouédo landfill and the points of measurement

2.2 Flux chamber technique

The method used for quantification of methane, carbon dioxide and nitrous oxide fluxes emissions in this study is the flux chamber technique, which is a simple method of measuring greenhouse gas fluxes. The static chamber is the most commonly used method to measure non-reactive greenhouse gas (GHG) fluxes, especially methane (CH_4) and nitrous oxide (N_2O), from soils [22]. The flux chamber was made of stainless steel and equipped with a sampling port (septum). The gas samples were collected with a syringe in well-sealed vials through the septum and analyzed for CH_4, CO_2 and N_2O by gas chromatography.

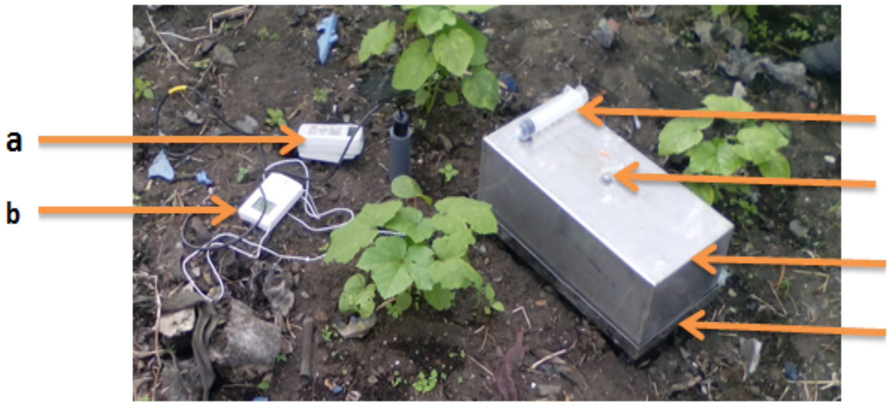

Fig. 2: Equipment used in the flux chamber measurements. **a:** soil moisture probe; **b**: air and soil temperature probe; **c**: syringe; **d**: septum (sampling port); **e**: chamber (length=40 cm * width=20 cm * height=18 cm); **f**: chamber frame inserted into the soil.

Here, the enclosed area of the flux chamber used in the present study was 0.08 m^2 and a volume to area ratio (V/A) equals to 0.18 m^3/m^2 (see figure 2). Typical flux chambers have a V/A ratio greater than 0.15 m^3/m^2 and areas range from 0.0175 m^2 to 1 m^2, while an area of 0.05–0.09 m^2 is the most common [23]. The area should be small enough to ensure uniform distribution of the environmental controls over the enclosed surface area and large enough to avoid restricting the spatial variability of the emission rate [12].

2.3 Sampling procedures

Air samples were collected by the chamber technique at the surface of Akouédo landfill during two campaigns. The first campaign was conducted in July 2016, during the wet period and the second campaign in January 2017, during the dry period. The air samples were stored in vials and analyzed by gas chromatography.

Sampling points were chosen on the basis of the accessibility of areas and their nature (cultivated areas, shallows and down talus) in order to cover the whole surface of the landfill. At each sampling point, four sequential gas samples were extracted from the chamber headspace into a 60 mL gas-tight syringe at predetermined intervals (5 min)[12]. CH_4, CO_2 and N_2O surface fluxes measurements were carried out at six (6) accessible sites of different characteristics. Ambient air temperature, soil moisture and temperature were recorded at each site during the measurement with probes fitted with detectors inserted in the soil (see Fig. 2). These are: shallows; compacted soils; cultivated soils and tableland (see table 1). At each site, measurements were duplicated in order to highlight the spatial variability of fluxes. Each duplicated measurement point was labelled from A to L (see Fig. 1).

Table 1: correspondence sample points - nature of the surface

Type of soils	Compacted	Maize fields	Shallow	Down talus	Tableland	Okra fields
Sample points	A-B	C-D	E-F	G-H	I-J	K-L

2.4 Samples analyzing

The samples were taken to the laboratory of Aerology (LA) in Toulouse, France for analysis. The concentration of oxygen, nitrogen, methane, carbon dioxide and hydrogen in the samples were analyzed using gas chromatography (GC). Methane, carbon dioxide and nitrous oxide fluxes were determined from concentration data (Concentration in mg/m^3) plotted versus elapsed time (time in minutes) [24]. The data generally fit a linear relationship, in which case, dC/dt is the slope of the fitted line. The fluxes of methane, carbon dioxide and nitrous oxide were calculated using linear regression based on the concentration change as a function of time (equation 1).

$$\phi = \left(\frac{V}{A}\right)\left(\frac{dC}{dt}\right) \quad (1)$$

where

ϕ: gas emission fluxes ($mg/m^2/day$)

V: the enclosed chamber volume (m^3)

A: the enclosed area of the chamber (m^2);

dC/dt: the rate of increase in gas concentration in the chamber with time ($mg/m^3/day$).

Only fluxes values, which square correlation coefficient $R^2 > 0.5$ for the dC/dt term of the equation (1), were considered [25].

3. Results and Discussion

3.1 Overview of CO_2, N_2O and CH_4 fluxes measurements data

The table 2 describes in details CH_4; CO_2 and N_2O fluxes values during campaign 1 (July 2016), the wet period and campaign 2 (January 2017) during the dry period. GPS coordinates, meteorological parameters (humidity and temperature) of soils are recorded. Higher soil temperatures are observed for campaign 2, during the dry period (January 2017); and higher soil humidity was observed for campaign 1, during the wet period (July 2016). CO_2 fluxes emissions are higher than CH_4 and N_2O fluxes emissions during the two campaigns. This is consistent with [26] that, CO_2 emissions were generally higher than CH_4 emissions at Robinson Deep and Marie Louise landfills. Negatives fluxes rates are observed for CH_4 emissions, this can be explained by the oxidation of CH_4 in the cover soil. Thus, these areas are considered methane sink.

3.2 Fluxes of CO_2, N_2O and CH_4 by zone and by campaign of measurement

CO_2 fluxes

The figure 3 shows the fluxes of CO_2 by zone and by campaign. It can be observed that CO_2 fluxes during the dry season (January 2017) were higher than those recorded during wet season (July 2016), with exception for the Tableland and Shallows measurement sites. The higher CO_2 fluxes are found on the down talus site during the dry season. This can be explained by the fact that, the down talus is characterized by old deposit waste in decaying, therefore produce more biogas composed mainly of CO_2 and CH_4. Lowest CO_2 fluxes are observed on cultivated soils (Okra fields and Maize fields). This can be explained by the fact that cultivated soils are poor in waste. Several factors influenced CO_2 emissions from the different land-use systems. These include the inherent properties of the soils such as texture, temperature, and moisture content, which influenced CO_2 production through their effect on soil microbial activity and root respiration [27].

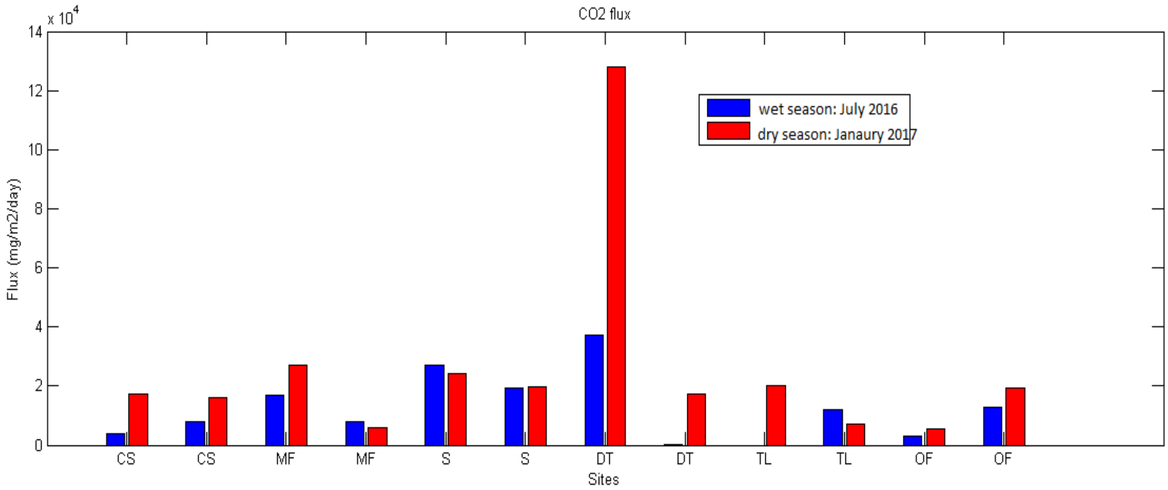

Figure 3: *Fluxes of CO_2 by site of measurement during wet season (July 2016) and dry season (January 2017). CS: compacted soil; MF: maize fields; S: shallow; DT: down talus; TL: tableland; OF: okra fields.*

N_2O fluxes

Figure 4 highlights the fluxes of N_2O at Akouédo landfill surface. It can be noticed that similarly to the case of CO_2, the fluxes of the dry season (January 2017) are higher than the fluxes of the wet season (July 2016), except one site of Down Talus and Okra Fields. This difference may be explained by the occurrence of agricultural activities on these areas during the wet season. Higher N_2O fluxes are observed on Shallows and Down Talus (old section) sites. This result is in agreement with previous work of [28] who found that more N_2O is produced inside waste and specially in the old section than fresh waste. In addition to the high flux emissions observed in shallow and down talus, we observe high fluxes of N_2O on agricultural soils (maize fields; okra fields). This result is due to the fact that Nitrous oxide (N_2O) is a greenhouse gas that mainly originates from soils and agricultural activities [29].

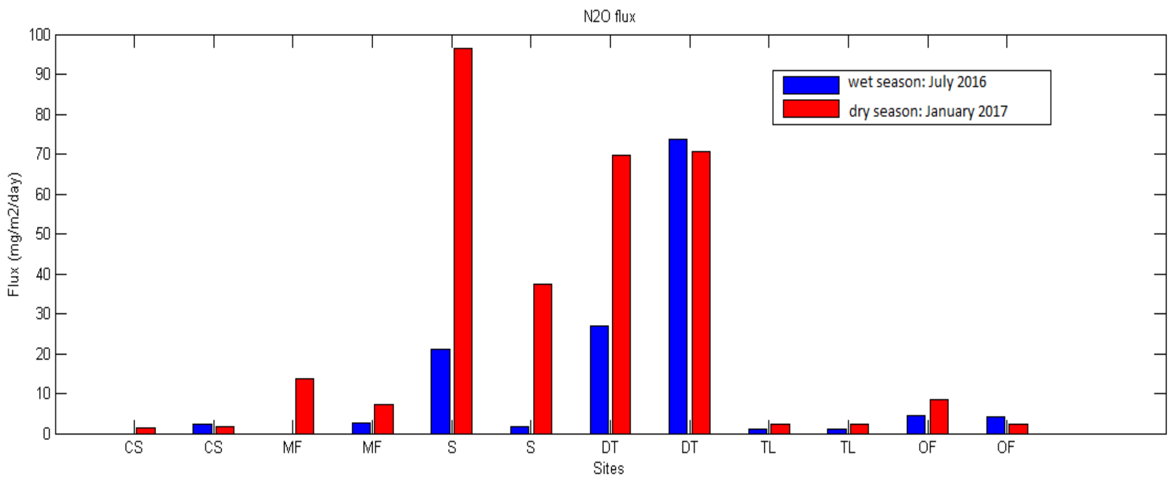

Figure 4: *Fluxes of N_2O by site of measurement during campaign 1 (July 2016) and campaign 2 (January 2017). CS: compacted soil; MF: maize fields; S: shallow; DT: down talus; TL: tableland; OF: okra fields.*

CH_4 fluxes

CH_4 fluxes spatial variation is shown on the figure 5. These fluxes are highly variable from one site to another. Also, low fluxes about 1.02 mg/m^2/day are observed on site Tableland as well as negative fluxes about -11.73 mg/m^2/day were recorded. Higher and negatives CH_4 fluxes values are also observed on Tableland, Shallows and Down Talus sites; this highlights the spatial variability of methane emissions on Akouédo landfill. Lower CH_4 fluxes values are obtained on sites without waste cover. Indeed, the low CH_4 and CO_2 surface fluxes could be attributed to the slow degradation of waste at the surface of the active cell [26]. Methane flux from soils is the result of methane production by methanogenic bacteria and methane oxidation by methane oxidizing bacteria, also called methanotrophs [30]. We noticed relatively important CH_4 fluxes on cultivated soils, this is consistent with [31] that vegetation plays an important role in CH_4 transport and oxidation in landfill cover soil.

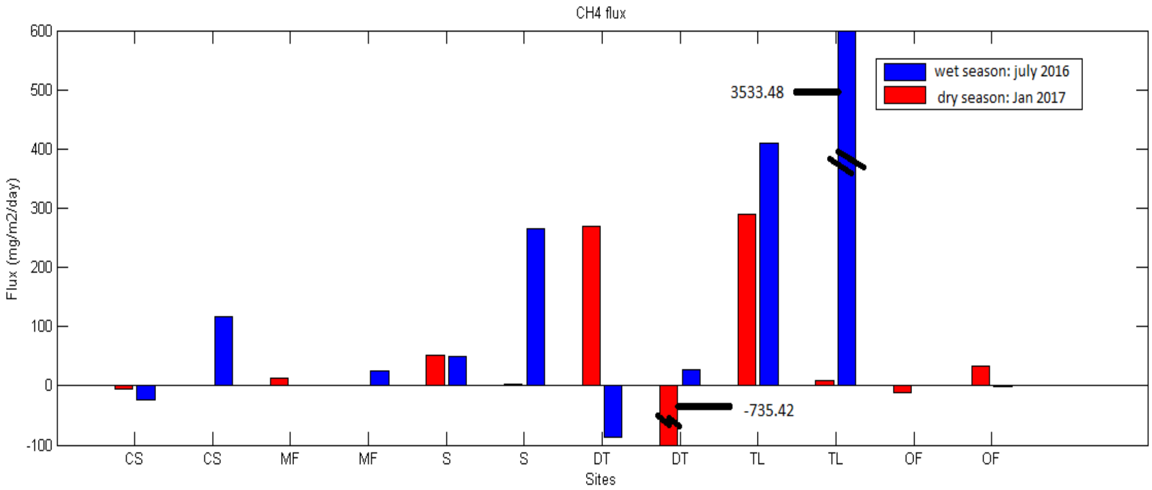

Figure 5: *Fluxes of CH_4 by site of measurement during the wet season (July 2016) and the dry season (January 2017). CS: compacted soil; MF: maize fields; S: shallow; DT: down talus; TL: tableland; OF: okra fields.*

3.3 Variations of CH_4, CO_2 and N_2O fluxes emssions at Akouédo landfill

The emissions fluxes during the dry season (January 2017) are generally higher than the fluxes of wet season (July 2016) for CO_2 and N_2O. CH_4; CO_2 and N_2O emission fluxes revealed a spatial and seasonal variability depending on the nature (clay or sandy) or the land-use (shallow, compacted soil, cultivated soils etc.) of the area. [27] reported that different land-use systems influence the emissions of greenhouse gas. Other causes of fluxes variations can be attributed to changes of humidity; the degree of compaction and the age of Municipal Solid Waste deposited [32]. Our samples sites have heterogeneous characteristics, such as compacted soils; cultivated soils (without waste); shallows (with sludge); down talus and tableland (old waste deposited). This is consistent with the finding of [33]. Thus, [33] reported that, CH_4 emissions are not uniform across the entire surface of the landfill, but occur at well-localized locations. This can explain the heterogeneity of the fluxes on the different measurement sites. The spatial variation of the fluxes is influenced by several environmental variables such as the biological process of methane oxidation in the soil (the temperature) or the physical process of transport of gas (humidity and atmospheric pressure) [33] and the inherent properties of the soils such as texture, temperature, and moisture content [27].

The relatively higher emissions fluxes during the dry season than the wet season corroborates to results found by [4] on methane emissions at three landfills in Delhi, (India). Their results showed that methane emissions in winter are lower than in summer. Also, [34] argued that emissions rates during the dry period (January-June) are significantly higher than during the wet period (July-October) due to the presence of cracks and fissures on the surface of the landfill. The negative CH_4 fluxes values can be explained by the fact that these areas are methane oxidation zones. These results also indicate that those areas act as a methane sink. According to the values of the fluxes of CH_4, fluxes measurement data can be classified into three categories: *methane emitting site*; *zero or negligible CH_4 flux*; and *Negative CH_4 flux* [35].

Table 2: Overview of data for wet season (July 2016) and dry season (January 2017)

	GPS Coordinates		Flux ($mg/m^2/day$) for wet season (July 2016) and meteorological parameters					Flux ($mg/m^2/day$) for dry season (January 2017) and meteorological parameters				
Sites	Lat.	Long.	CH_4	CO_2	N_2O	T°C	H (%)	CH_4	CO_2	N_2O	T°C	H (%)
Compacted soil	5° 20' 49.91" N	3° 56' 11.55" W	-22.78	3812.3	-	31.1	41.96	-5.42	17140	1.43	40.5	6.4
Compacted soil	5° 20' 49.91" N	3° 56' 11.55" W	115.8	7923.6	2.42	32.2	43.26	-	16013.4	1.84	43.3	7.9
Maize fields	5° 20' 48.98" N	3° 56' 16.07" W	-	16879.8	-	29	40.4	12.42	26985	13.59	39	8.63
Maize fields	5° 20' 48.98" N	3° 56' 16.07" W	25.85	7923.6	2.48	28.8	24.9	-	6015	7.17	43.1	24.63
Shallows	5° 20' 58.37" N	3° 54' 58.24" W	49.39	26980.7	21.2	27.6	31.26	51.91	24267.6	96.32	32.7	31.93
Shallows	5° 20' 58.37" N	3° 54' 58.24" W	265.8	19393	1.58	27.1	29.33	3.73	19600	37.26	33.6	27.3
Down talus	5° 21' 1.52" N	3° 55' 58.4" W	-86.92	37277.7	27.04	35.8	24.7	270.19	128049.2	69.84	39.1	22.7
Down talus	5° 21' 1.52" N	3° 55' 58.4" W	27.35	342.14	73.56	35.4	33.76	-735.42	17179.4	70.69	41.3	38.6
Tableland	5° 20' 56.65" N	3° 56' 2.99" W	409.89	-	1.23	31.2	39.26	289.68	20047.3	2.16	36.6	12.93
Tableland	5° 20' 56.65" N	3° 56' 2.99" W	3533.48	11894.3	1.02	32.7	37.1	8.04	7299.7	2.44	34.6	10.6
Okra fields	5° 21' 15.66" N	3° 56' 14.56" W	1.02	3193.3	4.33	31.7	20.43	-11.73	5608	8.47	33.4	10.5
Okra fields	5° 21' 15.66" N	3° 56' 14.56" W	-1.18	12703.6	4.23	30.6	21.4	33.07	19193.8	2.3	32.9	27.5

According to the approach of [36], the third case is identified by negative values of methane fluxes with coefficients of determination of the term dC/dt (equation 1) higher than 0.7 ($R^2 > 0.7$). The higher CO_2 emissions relative to CH_4 emissions could be attributed to CH_4 oxidation in cover soils

3.4 Comparison to others studies

Statistics of the CH_4, CO_2 and N_2O flux measurement during both campaigns are listed in Table 3. However, table 4 presents a summary of some literature values of surface emissions measured at landfills, agricultural soils and flooded soils in comparison to the present study.

Table 3. Descriptive statistics of CH_4; CO_2 and N_2O fluxes (mg/m^2/day)

Season	Wet season (July 2016)	Dry season (January 2017)
Methane (CH_4) flux		
Minimum	-86.92	-735.42
Maximum	3533.48	289.68
Mean	392.52	-8.35
Median	27.35	10.23
Standard deviation	1051.41	279.13
Carbon dioxide (CO_2) flux		
Minimum	342.14	5608
Maximum	37277.7	128049.2
Mean	13484.00	25616.53
Median	11894.3	18186.6
Standard deviation	11098.96	32973.73
Nitrous oxide (N_2O) flux		
Minimum	1.02	1.43
Maximum	73.56	96.32
Mean	13.91	26.12
Median	3.35	7.82
Standard deviation	22.87	33.95

The maximum and minimum of CH_4 and CO_2 fluxes during the wet (July) and dry (January) seasons are much lower compared to the results found by [12]. Their results showed that CH_4 and CO_2 fluxes were ranging from 0 to 1,602 g/m^2/day and from 5 to 2,753 g/m^2/day during wet and dry seasons, respectively [12]. The maximum CH_4 and CO_2 fluxes are higher compared to the results found by [26] on Robinson Deep and Marie Louise landfills in South Africa. The maximum fluxes from these landfills were 0.17; 0.44 for CH_4 and 13.27; 2.37 for CO_2 respectively at Robinson Deep and Marie Louise landfills. This difference can be explained by the fact that these landfills have landfill gas recovery systems. The range of methane fluxes emissions in wet period (July 2016) is lower compared to the results found by [37] in Japan. They found a range from -0.312 to 384 g/m^2/day and from -1.536 to 180 g/m^2/day, respectively in summer and in autumn. However, CH_4 fluxes in dry period (January 2017) are in the range of results found by [37] in winter. These results can be explained by the different landfills management. Maximum CH_4 fluxes in July, during the wet period and in January, during the dry period are closed to those found by [4] in summer and winter. They found a range from 1.98 to 7.03 g/m^2/day and from 0.31 to 1.40 g/m^2/day, respectively in summer and in winter. The maximum and minimum of N_2O emissions during the wet and dry seasons were approximately in the range of N_2O fluxes measurement reported by [32] on Chennai and Kodungaiyur landfill sites (India).

		Greenhouse gases fluxes range ($g/m^2/day$)			
Sites	Seasons (period)	**CH_4**	**CO_2**	**N_2O**	Referen
Akouédo landfill, Abidjan (Ivory Coast)	July 2016 (wet season) January 2017 (dry season)	**-0.087 to 3.533** **-0.735 to 0.289**	**0.342 to 37.277** **5.608 to 128.049**	**$1.02.10^{-3}$ to 0.073** **$1.43.10^{-3}$ to 0.096**	This stu
Malaysia	wet season dry season	0 to 1,602 5 to 2,753	0 to 1,602 5 to 2,753	- -	[2]
Thailand	Wet season Dry season	0 to 825.79 0 to 686.93	- -	- -	[8]
Sri Lanka	- -	0.041 to 1,850.273* or 0.004-1800 $mL/m^2/min$	13.851 to 5,088.251* or 4.9-1800 $mL/m^2/min$	$2.695.10^{-4}$ to 0.943* or 0.0001-0.35 $mL/m^2/min$	[13]
Perungudi landfill, Chennai (India)	-	0.0216 to 10.392* or 0.9 to 433 $mg/m^2/h$	0.295 to 23.145* or 123 to 964.4 $mg/m^2/h$	$6.48.10^{-5}$ to 0.028* or 2.7 to 1200 $mg/m^2/h$	[32]
Kodungaiyur landfill,Chennai (India)	-	0.024 to 0.564* or 1.0 to 23.5 $mg/m^2/h$	0.936 to 21.744* or 39 to 906 $mg/m^2/h$	$1.44.10^{-4}$ to $1.104.10^{-2}$* or 6 to 460 $\mu g/m^2/h$	
Gazipur, Bhalswa and Okhla landfill in Dehli, (India)	Summer Winter	1.98 to 7.03* or 82.69 to 293 $mg/m^2/h$ 0.31 to 1.401 or 12.94 to 58.41 $mg/m^2/h$	-	-	[4]
Japan	Summer Autumn Winter	-0.312 to 384* or $-1.3.10^{-2}$ to 16 $g/m^2/h$; -1.536 to 180* or $-6.4.10^{-2}$ to 7.5 $g/m^2/h$; -0.0384 to 0.36* or $-1.6.10^{-3}$ to $1.5.10^{-2}$ $g/m^2/h$	-	-	[37]
A-Su-Wei MSW Landfill, Beijing (China)	Spring, summer, *Cell A* *Cell B* Winter *Cell A* *Cell B*	 $-1.35.10^{-3}$ to 0.89* or -0.9 to 593.3 $mmol/m^2/h$ $-0.21.10^{-2}$ to 5.41* or -1.4 to 3608.1 $mmol/m^2/h$ $0.6.10^{-3}$ to 0.92* or 0.4 to 616.7 $mmol/m^2/h$ $-0.3.10^{-3}$ to 3.16* or -0.2 to 2109.5 $mmol/m^2/h$	 $2.69.10^{-3}$ to 3.65* or 4.8 to 669.6 $mmol/m^2/h$ $1.14.10^{-3}$ to 0.64* or 2.1 to 1185 $mmol/m^2/h$ $1.41.10^{-3}$ to 0.24* or 2.6 to 444.4 $mmol/m^2/h$ $0.98.10^{-3}$ to 0.83* or 1.8 to 1534 $mmol/m^2/h$		[42]
Polesgo's landfill, Ouagadougou (Burkina Faso)	2017 2018	15.76* or 657 $mg/m^2/h$ 29.06* or 1211 $mg/m^2/h$	79.80* or 3325 $mg/m^2/h$ 134.80* or 5617 $mg/m^2/h$		[43]

Mussaka dumpsite (Cameroon)		139.39* 96.80 $mg/m^2/min$	323.68* 224.78 $mg/m^2/min$	0.28* 0.2 $mg/m^2/min$	[39]
Mbellewa dumpsite (Cameroon)		307.35 213.44 $mg/m^2/min$	1589.50 1103.82 $mg/m^2/min$	0.216* 0.15 $mg/m^2/min$	
Robinson Deep landfill (SA)	-	$-2.4.10^{-3}$ to 0.17	-2.87 to 13.27	-	[26]
Marie Louise landfill, (SA)	-	5.10^{-4} to 0.44	0.6 to 2.37	-	
Legoli landfill (Tuscany, Italy)	-	<0.8 to 3,936* or <0.05 to 246 $mol/m^2/day$	0.88 to 12,100* or 0.02 to 275 $mol/m^2/day$	-	[41]
France	Campaign 2010-2011	-	-	$2.57.10^{-4}$* or 0.94 kg/ha/year	[38]
	Campaign 2011-2012	-	-	$5.31.10^{-4}$* or 1.94 kg/ha/year	

N_2O emissions fluxes are much higher than those measured by [38] in French field crop systems. Indeed, [38] measured annual average fluxes of 0.94 kg/ha/year for the campaign 2010-2011 against 1.94 kg/ha/year in 2011-2012, which is equivalent to $2.57.10^{-4}$ g/m^2/day and $5.31.10^{-4}$ g/m^2/day respectively. This result can be explained by the fact that many agricultural activities occur in Akouédo landfill. It is can be noticed that the results of CH_4, CO_2 and N_2O emissions fluxes in this study (Akouédo landfill) are closed to the results found on Indian landfills sites [4, 32] and less than the results found by [13] in Sri Lanka as shown in table 4. This may be explained by the fact that the waste buried at Akouédo landfill has the same characteristics as that of the landfills in India and is subject to almost the same weather conditions but not the case in Sri Lanka. However, mean surface emissions of CH_4, CO_2 and N_2O measured by [39] on Mussaka and Mbellewa dumpsites (Cameroon) are higher than those of our study (see Table 4). CH_4 and CO_2 fluxes measured by [43] on Polesgo's landfill in Ouagadougou (Burkina Faso) are higher than fluxes measured in Akouedo landfill. However, CH_4 fluxes are in the range of that measured by [42] in A-Su-Wei landfill in Beijing (China). On the other hand, CO_2 fluxes are higher in Akouedo landfill than A-Su-Wei landfill. Maximum CH_4 emission fluxes (in this study) is higher than results found by [40] on flooded soils in Congo River basin site in Central Africa. The highest CH_4 emission fluxes found in these areas is $4.59.10^{12}$ molecules/cm^2/s or 0.105 g/m^2/day.

Conclusion

This study contributed to quantify the emission fluxes of CH_4, CO_2 and N_2O emitted at Akouédo landfill. Quantification of fluxes was done using the flux chamber technique. This study reveals that there is a considerable (flux more than 8 g/m^2/day) carbon dioxide emission and a weak (flux less than 8 g/m^2/day) nitrous oxide emission on the surface of Akouédo landfill. The study also reveals the occurrence of methane uptake in compacted soils and on down talus area. However, greenhouse gases emissions are not uniform on the surface of Akouédo landfill. The study indicated relatively higher CO_2 and N_2O emissions during the dry season than the wet season. This might be attributed to the presence of cracks during the dry season, which facilitated gases migration to the atmosphere. CO_2 emissions were generally higher than CH_4 and N_2O emissions on sites of measurements. The highest CO_2 emissions relative to CH_4 emissions could be attributed to CH_4 oxidation in cover soils (negative flux values). CH_4, CO_2 and N_2O emissions fluxes are closed to India landfills greenhouse gases emissions studies. Geostatistical methods and more sample points are needed to determine greenhouse gas emissions from fluxes calculated over the entire landfill.

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