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Methane Emissions from Landfills Sites and Their Contribution to Global Climate Change in the Greater Lomé Area of Togo (West Africa)

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Abstract

This study was carried out in the city of Lomé in Togo. The study looked at the contribution of illegal waste landfills to climate change. The focus was on the quantities of methane released by uncontrolled landfills. In order to achieve the objectives, set by this study, the quantity of methane was recorded at twenty (20) landfills in thirteen (13) localities using microsensors over a period of thirty-two (32) days. The measurements were taken at the landfills with the measuring device stationed in the middle of the landfill at a height of 25 cm above the waste. The data collected was processed and a probability diagram was drawn up, making it possible to assess whether or not a set of data follows a given distribution such as the normal or Weibull distribution. Similarly, the contribution of each of the landfills to climate change was determined. During the measurement period, it was found that the TOGBLEKOPE 2 (6.338 g/m3 ± 4.881) with a contribution of 133.09; AMOUTIEVE (5.565 g/m3 ± 2.889) with a contribution of 116.86; ADETIKOPE GUERINKA (5.56 g/m3 ± 2.123) with a contribution of 116.76; GBOSSIME (5.323 g/m3 ± 4.442) with a contribution of 111.78; HOUNBI (4.702 g/m3 ± 3.59) with a contribution of 98.742; ADETIKOPE KPETAVE (4.363 g/m3 ± 2.841) with a contribution of 91.62 and NYEKONAKPOE 2 (4.017 g/m3 ± 3.067) with a contribution of 84.357; release more methane into the atmosphere. This shows the contribution of landfill sites in the fight against climate change.

Keywords: methane emissions, global climate change, Lomé area, Togo, West Africa

1. Introduction

Methane (CH_4) is a very common gas that occurs naturally on Earth and is widely used as a source of energy (Dufresne 2009; Dessus *et al*., 2008, Forster *et al.,* 2007; Manne and Richels, 2001; Hansen et al., 2000). It is also the second most important anthropogenic greenhouse gas after carbon dioxide (CO_2) (Tol *et al.,* 2008; Boucher and Reddy, 2008). According to van Vuuren et al (2006) and Hansen *et al* (2000), reducing emissions of greenhouse gases other than carbon dioxide is of great interest, as it can reduce the cost of climate policies by 30 to 40%.

Landfills sites are one of the anthropogenic sources of methane (Report by the French Academy of Technology 2013). When landfill is degraded by aerobic fermentation (Shaw *et al.,* 1999), it serves as a source of organic carbon for micro-organisms in the presence of oxygen and the mechanization process is triggered, producing carbon dioxide and methane (CH4). Several authors have shown that landfill sites can produce 40-80 million tonnes of methane per year (Boucher, 2010). Around 600 million tonnes of methane released per year are both natural and anthropogenic and are not the subject of any particular attention.

Unfortunately, methane (CH4) does not receive the same attention as carbon dioxide. According to several authors, methane is considered to be a gas that contributes excessively to global warming (Dessus *et al*., 2008; Boucher *et al.,* 2009; Boucher, 2010; Rapport de l'académie des technologies, 2013; Pinti *et al*., 2013; Dollé *et al*., 2015; Dessus and Laponche, 2017; Laabouri, *et al*., 2022). The importance of methane in the fight against global warming is sometimes ignored by many researchers. The landfills that are responsible for methane production are sometimes overlooked. To date, national and international information on the contribution of landfill sites to the fight against global warming remains fragmentary. At local level, between 20,000 and 30,000 tonnes of unauthorised rubbish are dumped in Togolese towns and cities every year (Koledzi *et al*., 2014). These unauthorised landfills receive all categories of waste, including household waste, bulky waste, municipal waste,

road and market waste, sewage plant sludge and green waste from public spaces. It is therefore important to carry out studies on illegal waste landfills in order to demonstrate their importance in the phenomenon of global warming, as well as the loss of income they can represent for the local economy. This involves:

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(i) Assessing the quantities of methane produced by landfill sites in the city of Lomé in Togo;

(ii) Assess their contribution to the fight against global warming.

2. Methodology

2.1 Study framework

Data were collected in thirteen (13) communes across Greater Lomé, which mainly comprises the prefecture of Golfe and the prefecture of Agoènyivé. Greater Lomé is located in the south-western tip of the coastal sedimentary basin known as Togo's maritime coastal plain, between longitudes 1°11' and 1°17' East and latitudes 6°06' and 6°12' North. It is bordered to the south by the Atlantic Ocean, to the west by Ghana, to the north by the Zio and Avé prefectures and to the east by the Lacs prefecture. According to the RGPH5 (2022), Greater Lomé has a population of 2,188,376, including 1,127,872 women and 1,060,504 men. Several activities take place in Greater Lomé, including trade, agriculture, fishing and industrial activities. Pre-collection and waste collection are organised by the municipalities, which carry them out through private companies and NGOs.

2.2 Sampling of Landfills

Landfill consist of waste brought clandestinely by individuals or companies without any municipal or prefectural authorization. This waste could be recycled, recovered or destroyed by household waste collection services.

As part of this study, twenty (20) landfills were measured for methane quantities using two approaches:

The first approach is based on interviews with the technical departments of the town halls in order to identify the most important landfills in the various municipalities considered. This approach made it possible to obtain the names and locations of the landfills identified from the local authorities. The second approach, which complemented the first, consisted of direct interviews with local people and households who directed the sampling team to the existing waste dumping sites. This was because the local councils do not have a complete map of all the landfill sites, since landfills sites are created spontaneously (in the wild) and when necessary, by local people.

The choice of landfills was based on two (2) criteria, including the minimum age of creation (≥ 1 year) and the surface area of the landfill (≥ 300 m²). Only active landfills still receiving waste were selected. Based on these criteria, 20 active landfills were selected in Greater Lomé.

2.3 Measurement of Methane Emissions

Methane was measured at the landfills using microsensors. Standardised microsensors were used to access methane concentration levels with a high degree of accuracy corresponding to the specific quality objectives (Zaher, 2012). In this study, aeroqual series 500 type sensors equipped with a removable monitor and gas sensitive semiconductor (GSS) sensors from the manufacturer aeroqual with the following characteristics were used:

- Measurement range: 0-10000 ppm
- Minimum detection limit: 10ppm
- Resolution: 1ppm
- Response time: 60s
- Temperature: 0 to 40°C
- Relative humidity: 10 to 90%.

The measurements were carried out on the landfills with the measuring device stationed in the middle of the landfill at a height of 25 cm above the waste. The data were taken during July and August, corresponding to the short dry season, at temperatures ranging from 30°C to 39°C, depending on the time of day, between 8:00 and 16:00.

For each measurement, the monitor was zeroed using the calibration sensor, and each measurement or sensor mounting session lasted between 1 minute and 3 minutes, with measurements taken at 10 repeats.

2.4 Data Processing

The data collected were entered into an Excel 2023 spreadsheet. Averages and standard deviations were calculated for each type of landfill. In order to compare the different quantities of methane released by each landfill and by locality, ANOVA analyses were carried out. The probability diagram (Chambers, 1983) was used to assess whether

or not a set of data follows a given distribution such as normal or distribution of Weibull. The data were plotted against a theoretical distribution in such a way that the points formed approximately a straight line. A probability plot shows each value in relation to the percentage of values in the sample that are less than or equal to it, along a fitted distribution line. The p-value was calculated at 5%.

The visual representation of the time series data was plotted linearly, with the measurement period on the x-axis and the quantity of methane measured on the y-axis.

The contribution of landfills (C) was calculated using the formula:

$$C = AV\_QtiesCH4 * 21$$

Where AV_QtiesCH4 is the average quantity of methane released by a landfill, and 21 is the global warming potential of methane (IPCC, 2023). All the analyses were carried out using Minitab software version 16.00 coupled with Excel 2023.

3. Results

3.1 KOHE Site

Analysis of figure 1a shows that the quantity of CH4 measured at the KOHE site is gradually increasing, although it is not stable over the period during which the measurements were taken. It becomes higher and higher from day 17 onwards. The highest values were recorded on day 25 (1,879 g/m3) and day 30 (1,865 g/m3). It was low on day 31 (0.720 g/m3), then gradually increased on day 32 (1.209 g/m3). At the 95% CI threshold, Figure 1b shows that the distribution of the CH4 values measured is not normal. This reveals that there is a significant difference between the values recorded over the 32 days that the measurements were taken (p-value < 0.005). The average of the measured values is equal to 1.107 g/m3 ± 0.4065 with AD = 1.333.

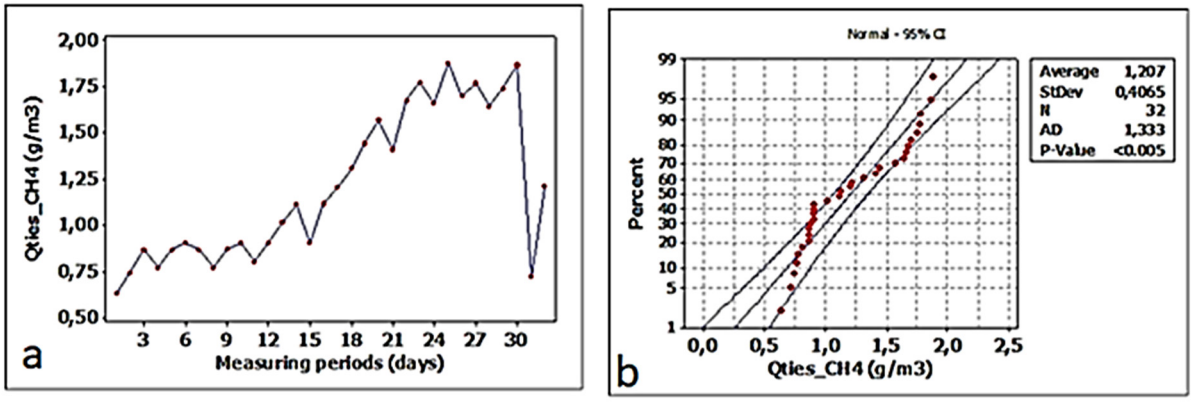

Figure 1. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.2 ANANDA Site (Agbelepodogan)

Analysis of figure 2a shows that the quantity of CH4 measured at the ANANDA site was not stable over the period during which the measurements were taken. The highest values were recorded on day 16 (0.901 g/m3), day 29 (1.021 g/m3), day 30 (0.981 g/m3) and day 31 (1.292 g/m3). The lowest value was recorded on day 1 (0.083 g/m3). At the 95% CI threshold, Figure 2b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. This reveals that there is a highly significant difference between the values recorded over the 32 days that the measurements were taken (p-value < 0.005). The average of the measured values is equal to 0.3039 g/m3 ± 0.3127 with AD = 5.403.

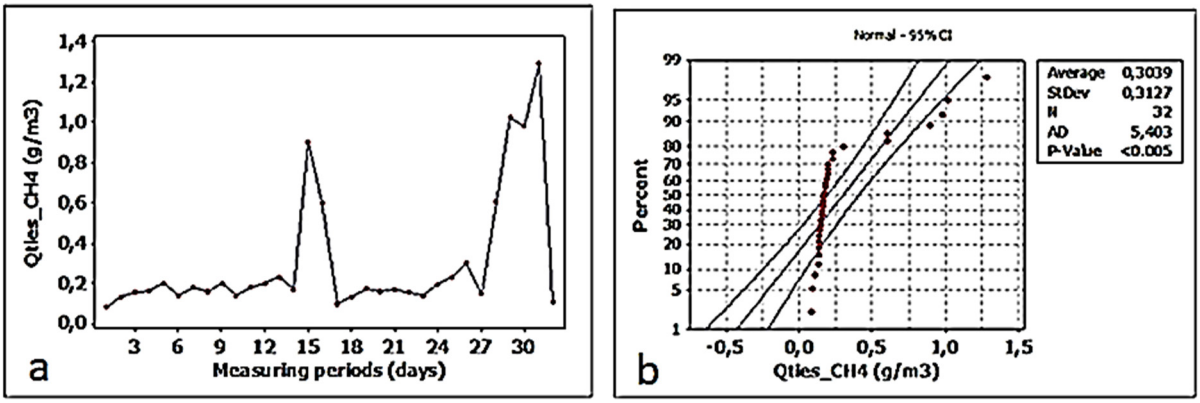

Figure 2. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.3 AMOUTIEVE Site

Analysis of figure 3a shows that the quantity of CH4 measured at the AMOUTIEVE site was not stable over the period during which the measurements were taken. The highest values were recorded on day 8 (8,458 g/m3), day 19 (9,789 g/m3), day 21 (9,894 g/m3), day 22 (9,788 g/m3), day 23 (9,223 g/m3), day 24 (10,129 g/m3) and day 25 (10,123 g/m3). The lowest values were recorded on day 3 (1,229 g/m3), day 16 (1,185 g/m3) and day 20 (1,594 g/m3). At the 95% CI threshold, Figure 3b shows that the distribution of CH4 values measured is not normal throughout the measurement period. This shows that there is no significant difference between the values recorded over the 32 days that the measurements were taken (p-value = 0.192). The average of the measured values is equal to 5.565 g/m3 ± 2.889 with AD = 0.502.

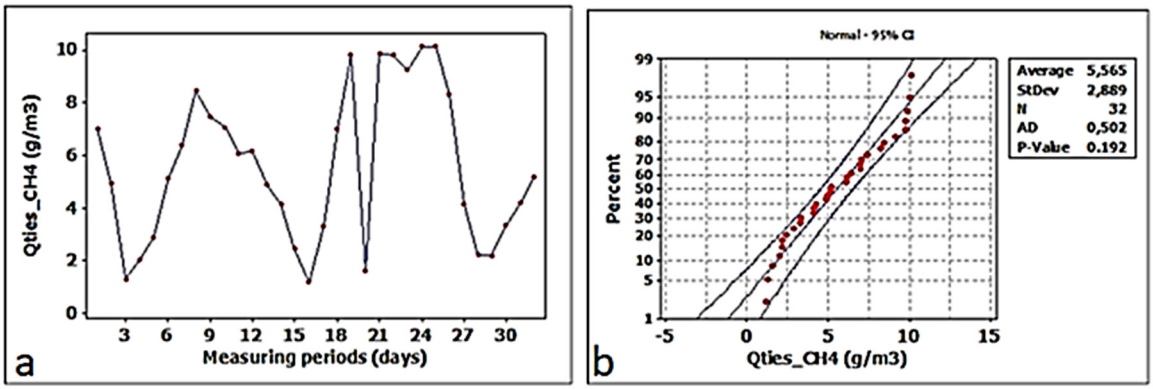

Figure 3. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.4 NYEKONAKPOE 1 Site

Analysis of figure 4a shows that the quantity of CH4 measured at the NYEKONAKPOE 1 site was not stable during the period when the measurements were taken. The highest values were recorded between day 2 and day 11 and varied between 1,213 g/m3 and 1,659 g/m3. The highest value was recorded on day 7 (1,659 g/m3). The lowest value was recorded on day 32 (0.22 g/m3). At the 95% CI threshold, Figure 4b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. This shows that there is no significant difference between the values recorded over the 32 days that the measurements were taken (p-value < 0.005). The average of the measured values is equal to 0.7892 g/m3 ± 0.4814 with AD = 1.345.

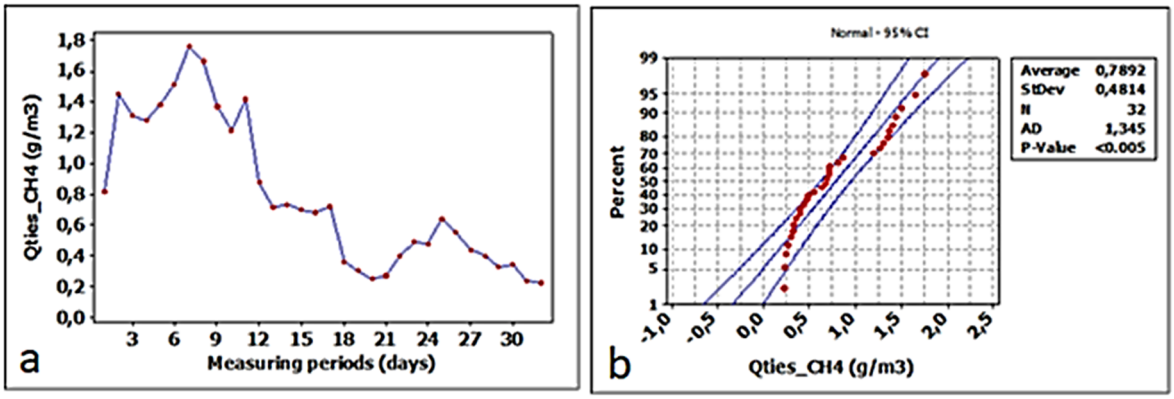

Figure 4. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.5 NYEKONAKPOE 2 Site

Analysis of figure 5a shows that the quantity of CH4 measured at the NYEKONAKPOE 2 site was not stable over the period during which the measurements were taken. The highest values were recorded on day 7 (9.98 g/m3) and day 17 (10.598 g/m3). The lowest values were obtained between day 1 and day 6 and between day 10 and day 16 and were all ≤ 2 g/m3. The distribution of the CH4 values measured was not normal throughout the measurement period (Figure 5b). The p-value ($p < 0.005$) shows that there is a significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 4.017 g/m3 ± 3.067 with AD = 2.043.

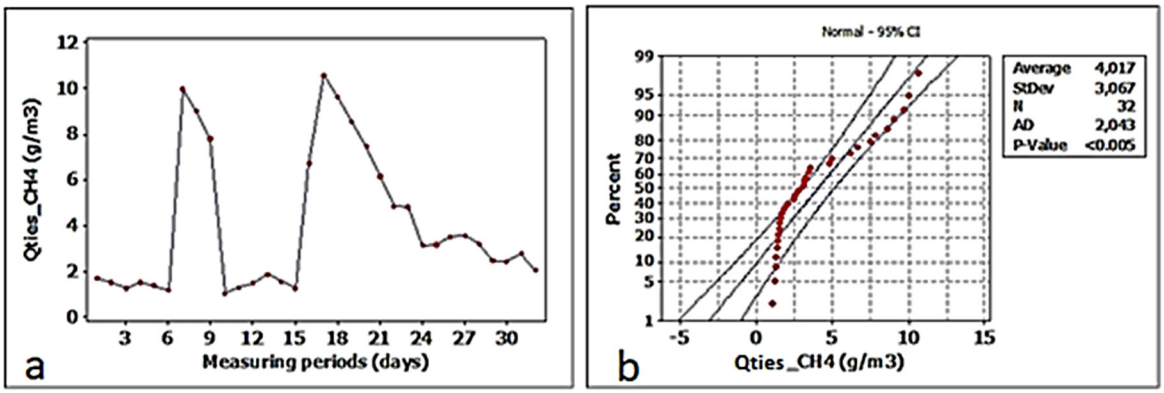

Figure 5. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.6 KEGUE KOUMAKO Site

Analysis of figure 6a shows that the quantity of CH4 measured at the KEGUE KOUMAKO site was not stable over the period during which the measurements were taken. The highest values were recorded on day 15 (3,721 g/m3) and day 16 (3,419 g/m3). The lowest values were obtained between day 1 and day 14 and between day 17 and day 32 and were all ≤ 2 g/m3. At the 95% CI threshold, Figure 6b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. The p-value ($p < 0.005$) shows that there is a significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 1.190 g/m3 ± 0.1454 with AD = 2.041.

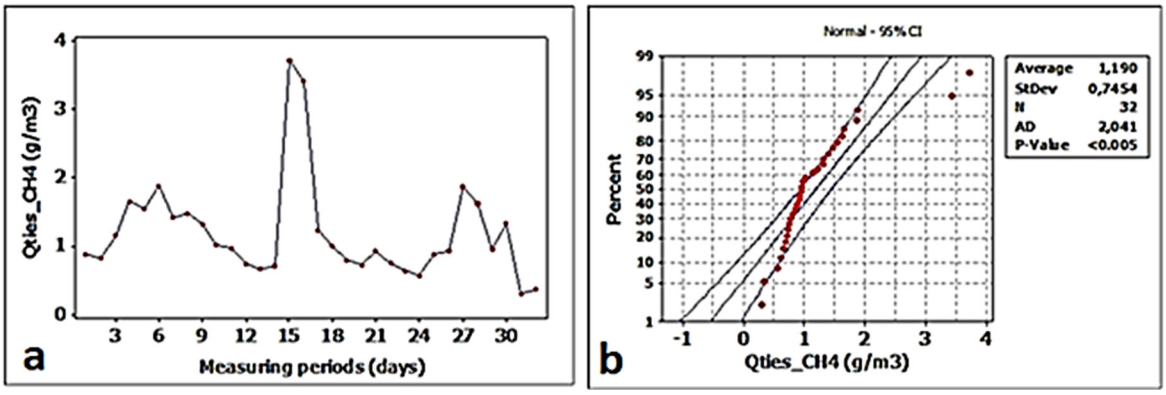

Figure 6. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.7 ZAZI Site (MASSSOUHOUN)

Analysis of figure 7a shows that the quantity of CH4 measured at the ZAZI site (MASSSOUHOUN) was not stable during the period in which the measurements were taken. The highest values were recorded on day 24 (7,641 g/m3), day 25 with the peak (8,482 g/m3) and day 26 (7,493 g/m3). There was a regression in values between day 27 and day 32. The lowest values were obtained between day 1 and day 15 and were all ≤ 2 g/m3. At the 95% CI threshold, Figure 7b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. The p-value ($p < 0.005$) shows that there is a significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 1.933 g/m3 ± 2.212 with AD = 3.301.

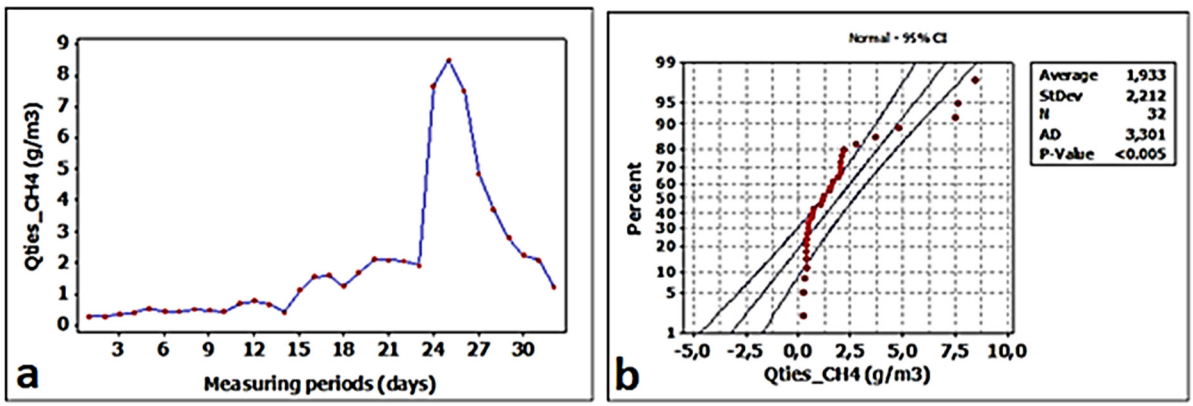

Figure 7. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.8 ATTIÉGOU YÉSUKOMÉ Site

Analysis of figure 8a shows that the quantity of CH4 measured at the ATTIÉGOU YÉSUKOMÉ site was not stable over the period during which the measurements were taken. The highest values were recorded on day 8 (3,539 g/m3), day 10 (2,497 g/m3), day 11 (2,538 g/m3), day 13 (3,043 g/m3) and day 26 (3,115 g/m3). From day 27 onwards, the values decreased until day 32, when the lowest value (0.522 g/m3) was recorded. The lowest values (Qties_CH4 ≤ 1 g/m3) were recorded between day 1 and day 7, day 18 and day 32. At the 95% CI threshold, Figure 8b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. The p-value ($p = 0.0875$) means that there is no significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 1.572 g/m3 ± 0.8265 with AD = 0.640.

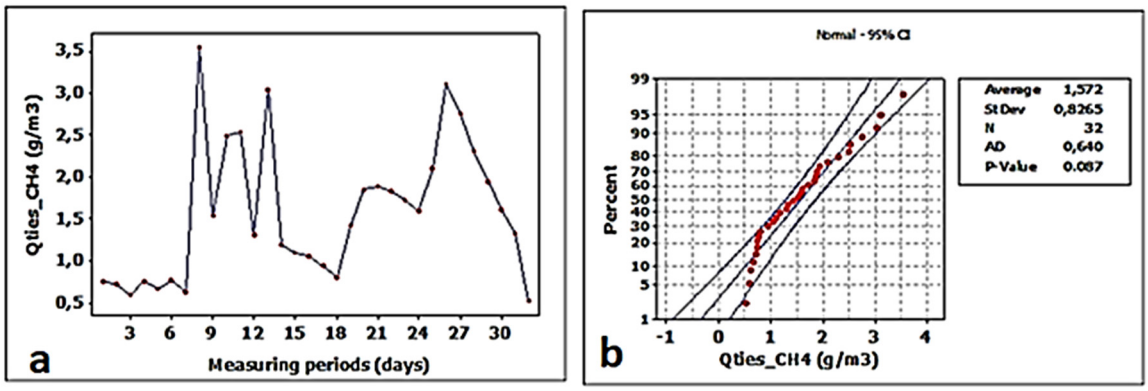

Figure 8. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.9 ATTIÉGOU SAWLOÈTO Site

Analysis of figure 9a shows that the quantity of CH4 measured at the Attiégou Sawloèto site evolved in a jagged pattern over the period during which the measurements were taken. The highest values were recorded on day 14 (5.881 g/m3), day 15 (4.882 g/m3), day 16 (4.163 g/m3), day 19 (8.68 g/m3), day 20 (6.18 g/m3), day 21 (4.381 g/m3) and day 28 (3.991 g/m3). The lowest values (Qties_CH4 ≤ 1 g/m3) were recorded between day 1 and day 8. At the 95% CI threshold, Figure 9b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. The p-value ($p < 0.005$) means that there is a significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 2.245 g/m3 ± 2.119 with AD = 1.304.

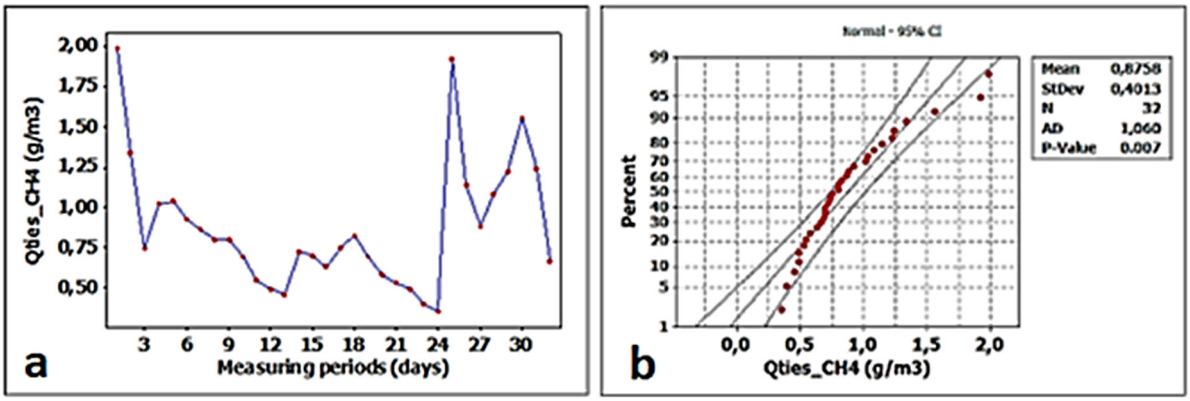

Figure 9. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.10 BAGUIDA AFANOUKOPÉ Site

Analysis of figure 10a shows that the quantity of CH4 measured at the BAGUIDA AFANOUKOPÉ site evolved in a sawtooth pattern over the period during which the measurements were taken. The highest values were recorded on day 16 (5.391g/m3), day 17 (7 g/m3), day 18 (7.423g/m3), day 19 (8.431g/m3), day 20 (9.014g/m3) and day 21 (6.61 g/m3). The lowest values (Qties_CH4 ≤ 2 g/m3) were recorded between day 1 and day 7. At the 95% CI threshold, Figure 10b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. The p-value ($p < 0.005$) means that there is a significant difference between the values recorded over the 32 days that the measurements were carried out. The average of the measured values is equal to 3.070 g/m3 ± 2.426 with AD = 1.249.

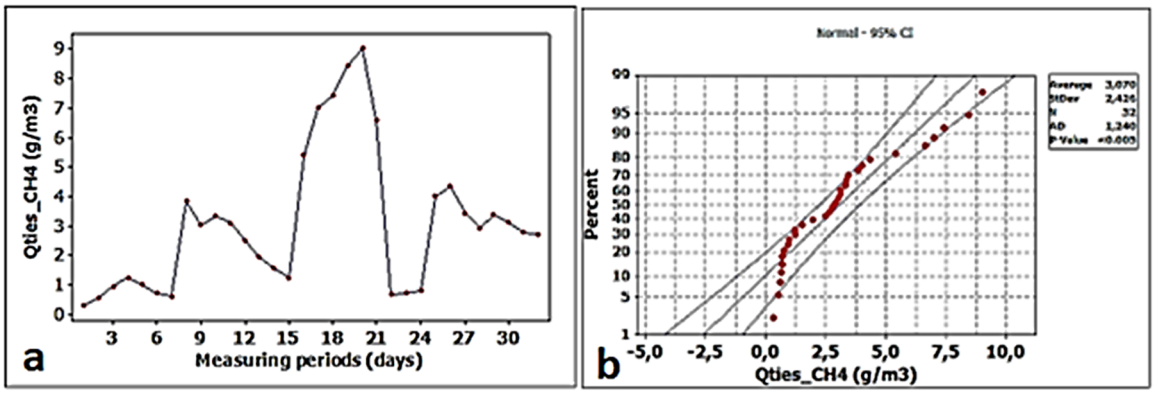

Figure 10. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.11 BAGUIDA PIÈRE CORNER Site

Analysis of figure 11a shows that the quantity of CH4 measured at the BAGUIDA PIÈRE CORNER site evolved in a sawtooth pattern over the period during which the measurements were taken. The highest values were recorded on day 1 (1.983 g/m3), day 25 (1.921 g/m3) and day 30 (1.559 g/m3). Low values (Qties_CH4 ≤ 0.5 g/m3) were recorded on days 12 and 13, 22, 23 and 24. At the 95% CI threshold, Figure 11b shows that the distribution of the CH4 values measured was not normal throughout the measurement period. The p-value (p = 0.007) means that there is no significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 0.8758 g/m3 ± 0.4013 with AD = 1.060.

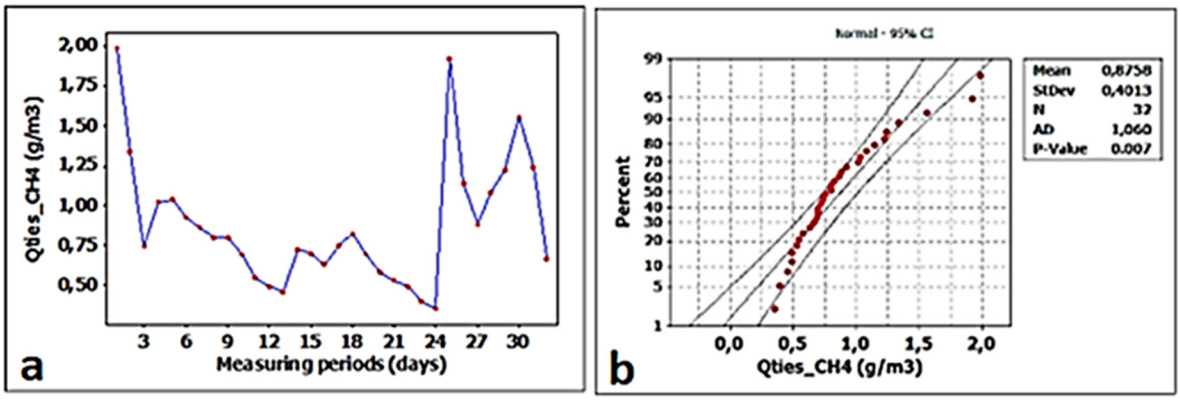

Figure 11. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.12 MAYAKOPÉ 2 Site

Analysis of figure 12a shows that there was a fluctuation in the quantity of CH4 measured at the MAYAKOPÉ 2 site during the period when the measurements were taken. The highest values were recorded on day 10 (3.047 g/m3), day 11 (3.879 g/m3), day 12 (4.208 g/m3), day 13 (5.011 g/m3), day 14 (6.031 g/m3), day 15 (3.222 g/m3), day 16 (3.323 g/m3), day 17 (3.464 g/m3), day 18 (3.875 g/m3), day 19 (2.746 g/m3). The lowest values (Qties_CH4 ≤ 0.5 g/m3) were recorded between day 1 and day 6 and between day 31 and day 32. At the 95% CI threshold, Figure 12b shows that the distribution of the CH4 values measured was not normal throughout the measurement period. The p-value (p < 0.005) means that there is a significant difference between the values recorded over the 32 days that the measurements were carried out. The average of the measured values is equal to 2.017 g/m3 ± 1.469 with AD = 1.575.

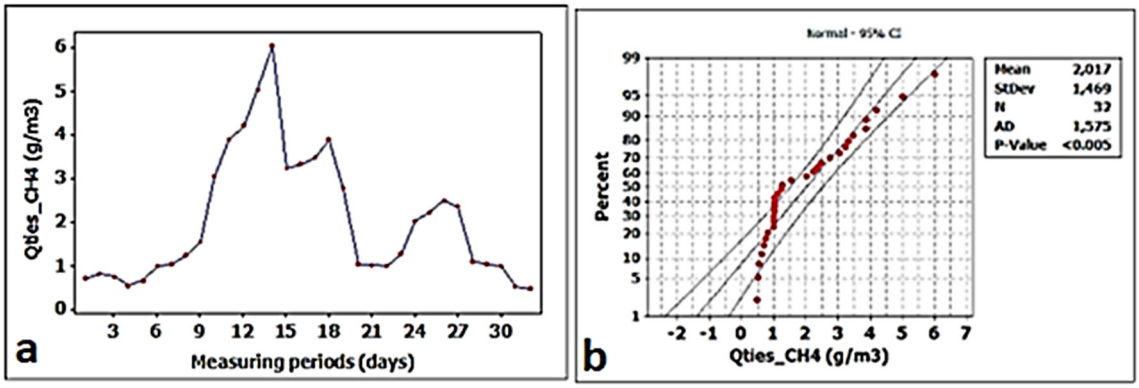

Figure 12. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.13 AZIKPÉVI Site

Analysis of figure 13a shows that there was a fluctuation in the quantity of CH4 measured at the AZIKPÉVI site during the period in which the measurements were taken. The highest values were recorded on day 9 (4.337g/m3), day 10 (4.936g/m3), day 11 (4.337g/m3), day 12 (4.936g/m3), day 13 (4.574 g/m3), day 14 (5.253 g/m3), day 15 (6.182 g/m3), day 16 (6.24 g/m3), day 17 (5.676 g/m3) and day 18 (4.434 g/m3). The lowest values (Qties_CH4 ≤ 1.5 g/m3) were recorded between day 1 and day 7. At the 95% CI threshold, Figure 13b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. The p-value (p = 0.182) means that there is no significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 3.093 g/m3 ± 1.698 with AD = 0.511.

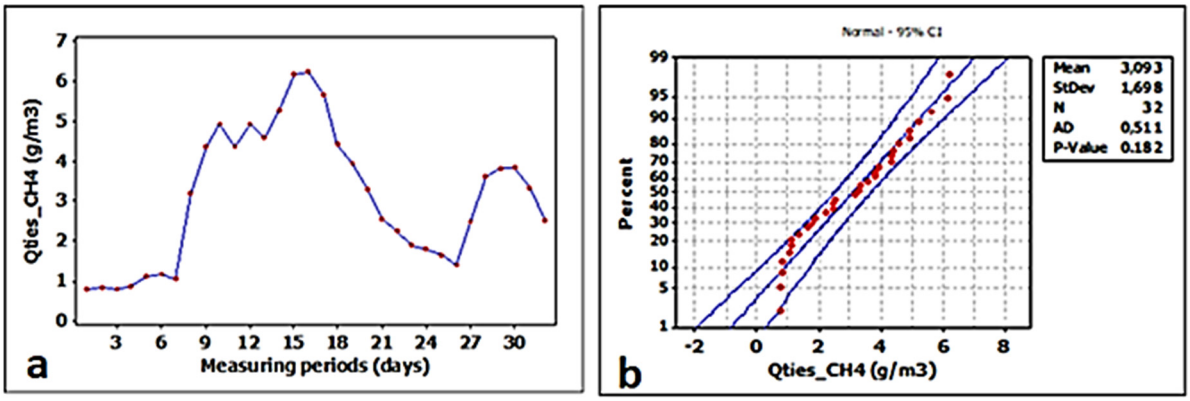

Figure 13. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.14 GBOSSIME Site

Analysis of figure 14a shows that there is a fluctuation in the quantity of CH4 measured at the GBOSSIME site during the period when the measurements were taken. The highest values were recorded on day 27 (8.993 g/m3), day 28 (16.601 g/m3), day 29 (12.23 g/m3), day 30 (12.961 g/m3), day 31 (18.88 g/m3) and day 32 (9.081 g/m3). The lowest values (Qties_CH4 ≤ 1.5 g/m3) were recorded between day 14 and day 15; between days 23, 24 and 25. At the 95% CI threshold, Figure 14b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. The p-value (p < 0.005) means that there is a significant difference between the values recorded over the 32 days that the measurements were carried out. The average of the measured values is equal to 5.323 g/m3 ± 4.442 with AD = 1.954.

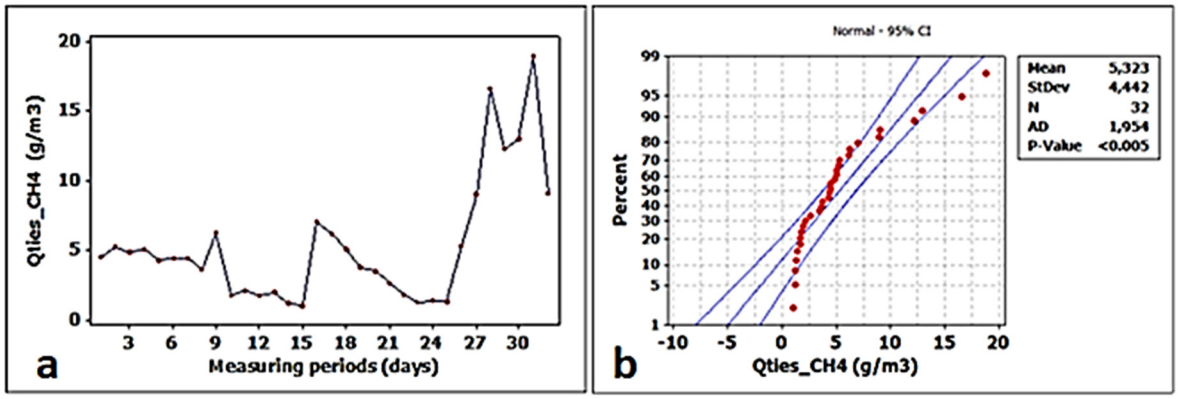

Figure 14. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.15 HOUNBI Site

Analysis of figure 15a shows that there is a fluctuation in the quantity of CH4 measured at the HOUNBI site during the period when the measurements were taken. The highest values were recorded on day 15 (11.204 g/m3), day 20 (9.685 g/m3), day 21 (9.108 g/m3), day 22 (8.649 g/m3), day 23 (9.027 g/m3), day 24 (8.993 g/m3), day 25 (9.814 g/m3), day 26 (8.322 g/m3), day 27 (8.351 g/m3) and day 28 (9.365 g/m3). The lowest values (Qties_CH4 ≤ 2 g/m3) were recorded between day 1 and day 8. At the 95% CI threshold, Figure 15b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. The p-value (p = 0.005) means that there is a significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 4.702 g/m3 ± 3.596 with AD = 1.116.

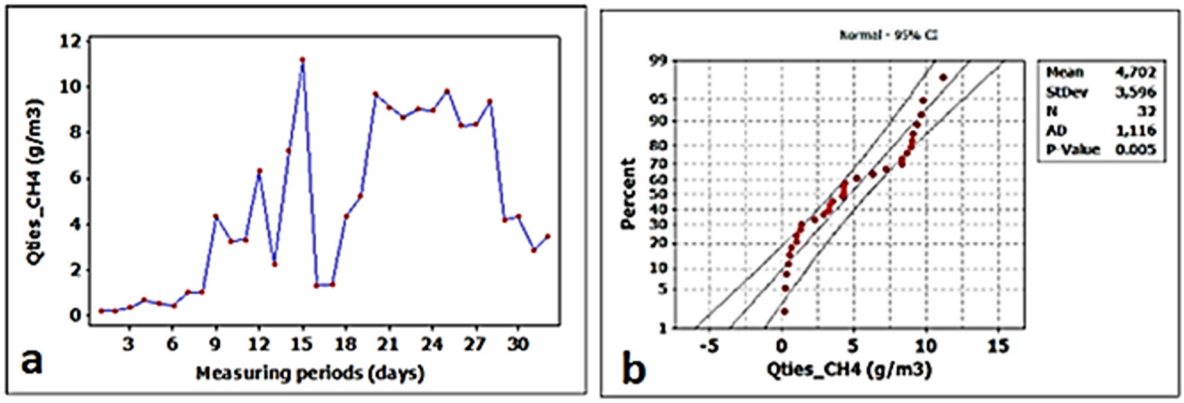

Figure 15. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.16 AVINATO Site

Analysis of figure 16a shows that there was a fluctuation in the quantity of CH4 measured at the AVINATO site during the period in which the measurements were taken. The highest values were recorded on day 9 (9.111 g/m3), day 10 (9.604 g/m3), day 11 (8.163 g/m3), day 12 (8.81 g/m3), day 13 (9.64 g/m3), day 14 (7.083 g/m3) and day 23 (7.131 g/m3). The lowest values (Qties_CH4 ≤ 2 g/m3) were recorded between day 1 and day 8. At the 95% CI threshold, Figure 16b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. The p-value (p < 0.005) means that there is a significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 3.685 g/m3 ± 3.000 with AD = 1.378.

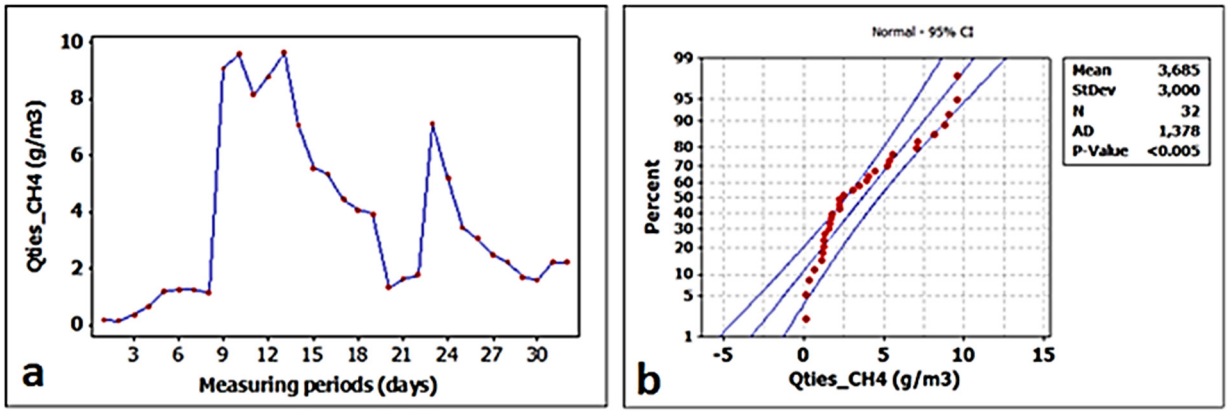

Figure 16. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.17 ADETIKOPE KPETAVE Site

Analysis of figure 17a shows that there was a fluctuation in the quantity of CH4 measured at the ADETIKOPE KPETAVE site during the period when the measurements were taken. The highest values were recorded on day 9 (6.434g/m3), day 10 (7.118g/m3), day 11 (6.936 g/m3), day 12 (6.417 g/m3), day 13 (5, 422 g/m3), day 17 (6.637 g/m3), day 18 (6.957 g/m3), day 19 (12.359 g/m3), day 20 (10.353 g/m3), day 21 (8.656 g/m3) and day 22 (7.167 g/m3). The lowest values (Qties_CH4 ≤ 2 g/m3) were recorded between day 1 and day 7. At the 95% CI threshold, Figure 17b shows that the distribution of the CH4 values measured is not normal throughout the measurement period. The p-value (p = 0.017) means that there is no significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 4.363 g/m3 ± 2.841 with AD = 0.916.

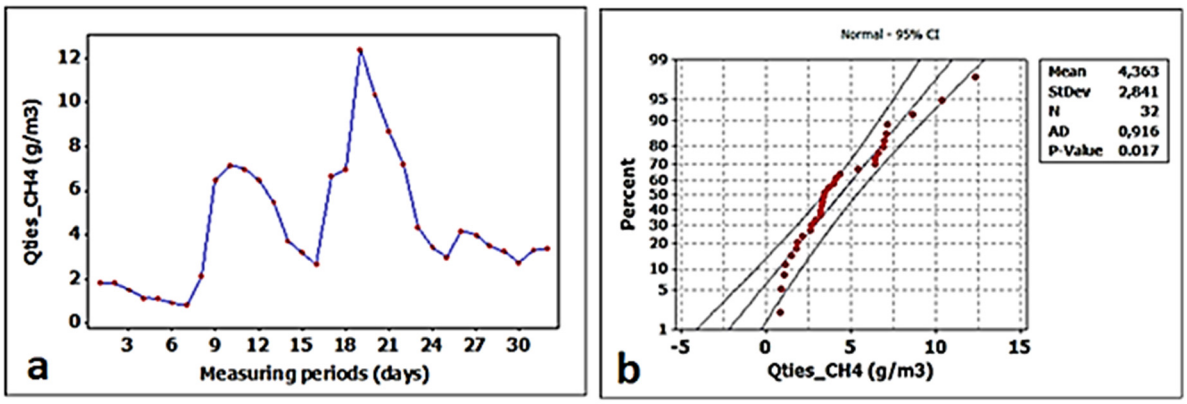

Figure 17. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.18 ADETIKOPE GUERINKIN Site

Analysis of figure 18a shows that there was a fluctuation in the quantity of CH4 measured at the ADETIKOPE GUERINKIN site during the period when the measurements were taken. The highest values were recorded on day 6 (7.507 g/m3), day 7 (11.509 g/m3), day 8 (9.535 g/m3), day 9 (8.224 g/m3), day 10 (8.123 g/m3), day 11 (7.112 g/m3), day 12 (7.321 g/m3), day 13 (6.939 g/m3) and day 14 (7.217 g/m3). However, there was a gradual increase between day 1 and day 8. From day 8 onwards, there was a gradual decrease until day 23. From day 24 onwards, a gradual increase was again observed, but the values recorded remained below 6 g/m3. At the 95% CI threshold, Figure 18b shows that the distribution of CH4 values measured is not normal throughout the measurement period. The p-value (p = 0.637) means that there is no significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 5.560 g/m3 ± 2.123 with AD = 0.275.

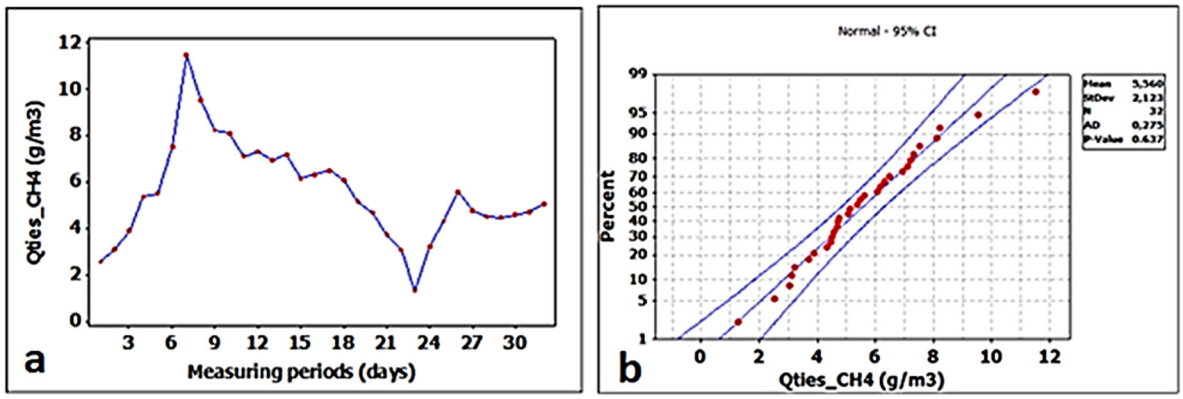

Figure 18. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.19 TOGBLEKOPE 1 Site (ATSAVE)

Analysis of figure 19a shows that there is a fluctuation in the quantity of CH4 measured at the TOGBLEKOPE 1 site during the period when the measurements were taken. Between day 1 and day 14, the values recorded are low (Qties_CH4 ≤ 1 g/m3). They increased gradually from day 15, when the peak was observed (3.711 g/m3); however, there were slight fluctuations. From day 26 onwards, we see a regression until day 32. At the 95% CI threshold, Figure 19b shows that the distribution of CH4 values measured is not normal throughout the measurement period. The p-value ($p < 0.005$) means that there is a significant difference between the values recorded over the 32 days that the measurements were taken. The average of the measured values is equal to 1.406 g/m3 ± 0.9386 with AD = 1.815.

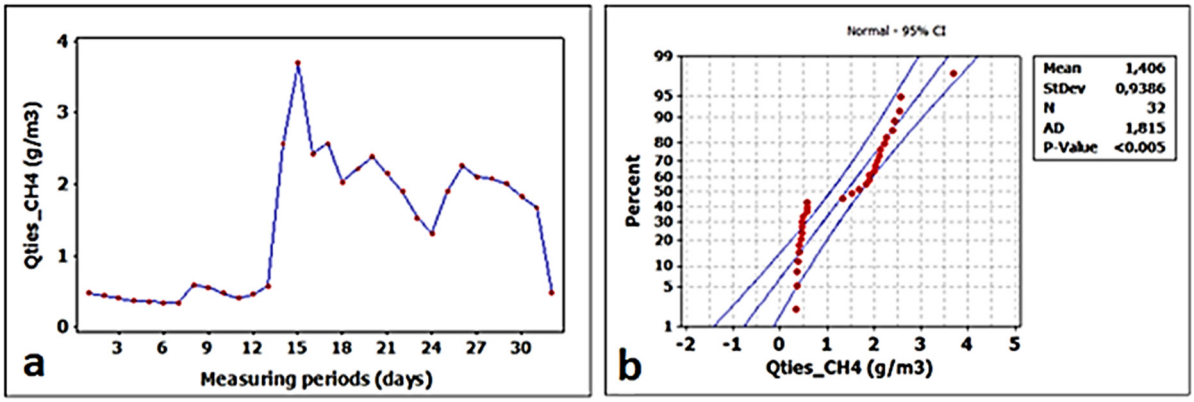

Figure 19. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.20 TOGBLEKOPE 2 Site

Analysis of figure 20a shows that there was a fluctuation in the quantity of CH4 measured at the TOGBLEKOPE 2 site during the period in which the measurements were taken. The highest values were recorded on the 1st day, with a value of 13.613 g/m3. But between the 2nd day, the 3rd day, the 4th day and the 17th day, they become very low (Qties_CH4 ≤ 1.5 g/m3). On day 5 (13.983 g/m3), day 6 (15.032 g/m3), day 7 (12.361 g/m3), day 8 (19.031 g/m3), day 9 (13.072 g/m3), day 10 (10.433 g/m3), day 11 (8.224 g/m3) and day 12 (12.618 g/m3), the quantity of CH4 increased. At the 95% CI threshold, Figure 20b shows that the distribution of CH4 values measured is not normal throughout the measurement period. The p-value ($p < 0.005$) means that there is a significant difference between the values recorded over the 32 days that the measurements were carried out. The average of the measured values is equal to 6.338 g/m3 ± 4.811 with AD = 1.586.

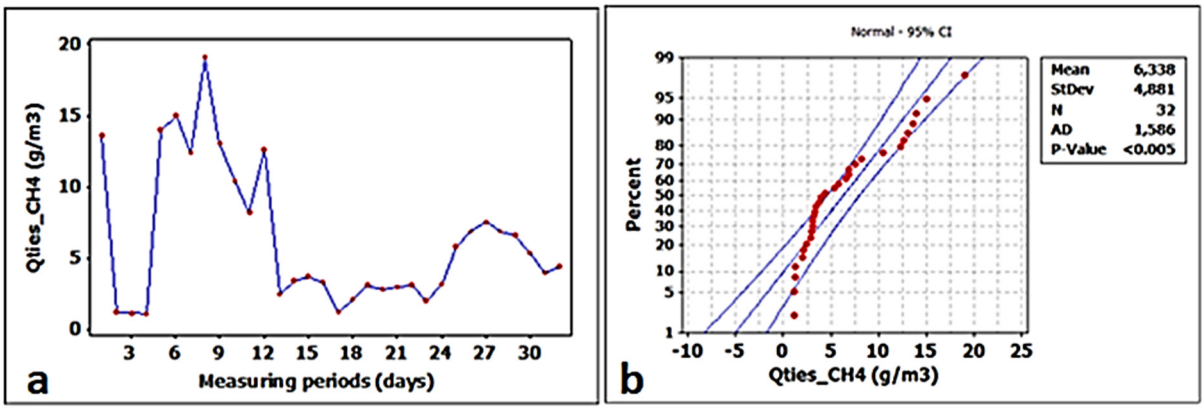

Figure 20. Quantity of CH4 according mesuring period (a); Quantity of CH4 according to the diagram of probability (b)

3.21 Total Quantity of CH4 Per Landfill during the Measurement Period

During the 32 days of measurements, the TOGBLEKOPE 2 landfill (202.811 g/m3) released the most CH4 (∑Qties_CH4 = 202.811 g/m3 with a maximum value of 19.031 g/m3 and a minimum value of 1.108 g/m3) followed by the AMOUTIÉVÉ landfill (∑Qties_CH4 = 178.089 g/m3 with a maximum value of 10, 129 g/m3 and a minimum value of 1.185 g/m3), the ADÉTIKOPÉ GUÉRINKA landfill (∑Qties_CH4 = 177.935 g/m3 with a maximum value of 11.509 g/m3 and a minimum value of 1.281 g/m3), the GBOSSIME GUÉRINKA landfill (∑Qties_CH4 = 170.341 g/m3 with a maximum value of 18, 88 g/m3 and a minimum value of 1.033 g/m3), the HOUNBI landfill (∑Qties_CH4 = 150.45 g/m3 with a maximum value of 11.204 g/m3 and a minimum value of 0.189 g/m3), the ADÉTIKOPÉ (KPÉTAVÉ) landfill (∑Qties_CH4 = 139.619 g/m3 with a maximum value of 12.359 g/m3 and a minimum value of 1, 033 g/m3), the NYÉKONAKPOÈ 2 landfill (∑Qties_CH4 = 128.534 g/m3 with a maximum value of 10.598 g/m3 and a minimum value of 1.033 g/m3), the AVINATO landfill (∑Qties_CH4 = 117.924 g/m3 with a maximum value of 9.64 g/m3 and a minimum value of 0.149 g/m3).

Table 1. Total quantity of CH4 per landfill during the measurement period

LOCATIONS	∑Qties_CH4 (g/m3)	Max_Qties_CH4 (g/m3)	Min_Qties_CH4 (g/m3)
TOGBLÉKOPÉ 2 (DAR SALAM)	202.811	19.031	1.108
AMOUTIÉVÉ	178.089	10.129	1.185
ADÉTIKOPÉ(GUÉRINKA)	177.935	11.509	1.281
GBOSSIMÉ	170.341	18.88	1.033
HOUNBI	150.45	11.204	0.189
ADÉTIKOPÉ (KPÉTAVÉ)	139.619	12.359	0.802
NYÉKONAKPOÈ 2	128.534	10.598	1.033
AVINATO	117.924	9.64	0.149
AZIKPÉVI	98.989	6.24	0.784
BAGUIDA AFANOUKOPÉ	98.255	9.014	0.301
ATTIÉGOU SAWLOÈTO	71.84	8.68	0.152
MAYAKOPÉ 2	64.534	6.031	0.481
ZAZI (MASSOUHOUN)	61.842	8.482	0.248
ATTIÉGOU YÉSUKOMÉ	50.306	3.539	0.522
TOGBLÉKOPÉ 1(ATSAVÉ)	45.005	3.711	0.343
KOHÉ	38.629	1.879	0.632
KÉGUÉ KOUMAKO	38.07	3.721	0.289
BAGUIDA PIÈRE CORNER	28.027	1.983	0.352
NYÉKONAKPOÈ 1	25.256	1.758	0.22
ANANDA(AGBALÉPÉDOGAN)	9.726	1.292	0.083

3.22 Comparison of CH4 Quantities and the Contribution of Landfill Sites in Different Localities

During the measurement period, it was noted that in certain localities, the quantities of CH4 recorded were higher. This was the case for TOGBLEKOPE 2 (6.338 g/m3 ± 4.881) with a contribution of 133.09; AMOUTIEVE (5.565 g/m3 ± 2.889) with a contribution of 116.86; ADETIKOPE GUERINKA (5.56 g/m3 ± 2.123) with a contribution of 116.76; GBOSSIME (5.323 g/m3 ± 4.442) with a contribution of 111.78; HOUNBI (4.702 g/m3 ± 3.59) with a contribution of 98.742; ADETIKOPE KPETAVE (4.363 g/m3 ± 2.841) with a contribution of 91.62 and NYEKONAKPOE 2 (4.017 g/m3 ± 3.067) with a contribution of 84.357.

Table 2. Comparison of CH4 quantities and the contribution of landfill sites in different localities

Localities	AV (g/m3) ± Deviation	landfill contribution (C)
TOGBLEKOPE 2	6.338 ± 4.881^{a}	133.09
AMOUTIEVÉ	5.565 ± 2.889^{ab}	116.86
ADÉTIKOPÉ GUERINKA	5.562 ± 2.123^{ab}	116.76
GBOSSIMÉ	5.323 ± 4.442^{abc}	111.78
HOUNBI	4.702 ± 3.596^{bcd}	98.742
ADÉTIKOPE KPETAVE	4.363 ± 2.841^{cd}	91.62
NYÉKONAKPOÈ 2	4.017 ± 3.067^{de}	84.357
AVINATO	3.685 ± 3.000^{de}	77.385
AZIKPEVI	3.093 ± 1.698^{ef}	64.953
BAGUIDA AFANOUKOPE	3.070 ± 2.426^{ef}	64.47
ATTIÉGOU SAWLOETO	2.245 ± 2.119^{fg}	47.145
MAYAKOPE 2	2.017 ± 1.469^{fgh}	42.357
ZAZI	1.933 ± 2.212^{fghi}	40.593
ATTIÉGOU YÉSOUKOMÉ	1.572 ± 0.827^{ghi}	33.012
TOGBLEKOPE 1	1.406 ± 0.939^{ghij}	29.526
KOHÉ	1.207 ± 0.407^{ghij}	25.347
KUÉGUÉ KOUMAKO	1.190 ± 0.745^{ghij}	24.99
BAGUIDA PIERRE CORNER	0.876 ± 0.401^{hij}	18.396
NYÉKONAKPOÈ 1	0.789 ± 0.481^{ij}	16.569
ANANDA	0.304 ± 0.313^{j}	6.384

Grouping of localities using Fisher's method. Means that do not share a letter are significantly different.

4. Discussion

Like most cities in sub-Saharan Africa, Lomé is regularly confronted with a variety of environmental problems. This work presents the importance of methane in the balance of the environment in Togo and particularly in the city of Lomé. This study has shown that methane not only causes imbalances in the biosphere's ecosystems, but also represents a loss of earnings in terms of energy production. To gain a better understanding of the contribution of methane to climate change, measurements were taken at twenty (20) landfill sites across the city of Lomé. The results showed that landfill sites contribute enormously to the production of methane gas. The Academic Technologies report (2013) and Kondoh *et al* (2019) point out that landfill sites are among the sources of methane gas. On the other hand, the meteorological report (2010) stresses that landfill sites are among the main producers of methane gas; they can produce around 40-80 million tonnes of CH4 per year.

According to the results, during the thirty-two (32) days of measurements, we found that the quantity of methane released varied from one landfill to another. This variation would probably be due to several parameters, in particular the size of the landfill, the age of the landfill and the conditions in which the landfill was left (relative humidity, evapotranspiration, pressure and temperature) and above all the nature of the waste deposited there (organic, biodegradable, inert waste, etc.). The older the landfill becomes, the more methane it releases, which could lead to excess methane in the atmosphere, which would have a negative impact on the environment. Behanzin et al. 2021, however, have shown that landfill sites produce biogas containing a significant proportion of methane (CH4), which is harmful to human health. In Benin, Gbinlo (2010) compared the production of three greenhouse gases, namely CO2 (1875.02 kg), CH4 (5040.74 kg) and CO (2807.02 kg). According to these studies, the presence of methane in the atmosphere is around 3 times higher than CO2 and 2 times higher than CO. This situation is mainly due to the increase in the number of vehicles on the road, which is essentially dominated by second-hand vehicles, and to the poor management of solid and liquid waste. This clearly demonstrates the contribution of methane to environmental health.

According to our results, it was found that twelve (12) landfills out of 20, release an average quantity ≥ 2 g/cm3 with an average contribution of 87,459. See table below.

Table 3. Twelve (12) landfills out of 20, release an average quantity ≥ 2 g/cm3

Localities	AV (g/m3) ± Deviation	landfill contribution (C)
TOGBLEKOPE 2	6.338 ± 4.881^{a}	133.09
AMOUTIEVÉ	5.565 ± 2.889^{ab}	116.86
ADÉTIKOPÉ GUERINKA	5.562 ± 2.123^{ab}	116.76
GBOSSIMÉ	5.323 ± 4.442^{abc}	111.78
HOUNBI	4.702 ± 3.596^{bcd}	98.742
ADÉTIKOPE KPETAVE	4.363 ± 2.841^{cd}	91.62
NYÉKONAKPOÈ 2	4.017 ± 3.067^{de}	84.357
AVINATO	3.685 ± 3.000^{de}	77.385
AZIKPEVI	3.093 ± 1.698^{ef}	64.953
BAGUIDA AFANOUKOPE	3.070 ± 2.426^{ef}	64.47
ATTIÉGOU SAWLOETO	2.245 ± 2.119^{fg}	47.145
MAYAKOPE 2	2.017 ± 1.469^{fgh}	42.357
Average contribution		87,459

The TOGBLEKOPE 2 landfill releases more methane into the atmosphere (6.338 g/m3 ± 4.881) with a contribution of 133.09. Special attention must be paid by the competent authorities to ensure that these landfills are not left in the wild for so long. Climate change is a long-term problem and, according to Boucher (2010), we must not exceed a warming of 2 or 3°C over this century and the following centuries. However, the methane produced by landfill sites can be used as a source of energy to limit its excess in nature. Several authors have reported that burning methane at 25°C releases energy of 39.77 MJ/m3 (55.53 MJ/kg), or 11.05 kWh/m3 (15.42 kWh/kg) (Geitmann, 2007; report by the French Academy of Technology, 2013).

Methane is part of the basket of six greenhouse gases covered by the Kyoto Protocol. According to van Vuuren *et al* (2006), reducing emissions of greenhouse gases other than carbon dioxide is still very attractive, as it can reduce the cost of climate policies by 30 to 40%.

5. Conclusion

This study is a contribution to our knowledge of the importance of landfill sites in the fight against global warming. According to the results, landfill sites make a remarkable contribution to climate change. The work was carried out on twenty (20) landfill sites in the city of Lomé. Methane measurements were carried out and the quantities of methane released per landfill were recorded. During the measurement period, it was noted that in certain localities the quantities of CH4 recorded were higher. This was the case in TOGBLEKOPE 2 (6.338 g/m3 ± 4.881) with a contribution of 133.09; AMOUTIEVE (5.565 g/m3 ± 2.889) with a contribution of 116.86; ADETIKOPE GUERINKA (5.56 g/m3 ± 2.123) with a contribution of 116.76; GBOSSIME (5.323 g/m3 ± 4.442) with a contribution of 111.78; HOUNBI (4.702 g/m3 ± 3.59) with a contribution of 98.742; ADETIKOPE KPETAVE (4.363 g/m3 ± 2.841) with a contribution of 91.62 and NYEKONAKPOE 2 (4.017 g/m3 ± 3.067) with a contribution of 84.357.

It is therefore important to pay particular attention to landfill sites in order to limit excess methane gas in the atmosphere, which could cause irreversible damage to human health and the environment.

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Data sharing statement

No additional data are available.