METHANE AND CARBON DIOXIDE EMISSIONS IN HYDROELECTRIC DAMS OF ECUADOR

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Article History: Received: 04.03.2023 **Revised:** 18.04.2023 **Accepted:** 02.06.2023

Abstract

The objective of this research was to evaluate the degradation and transformation processes of plant material in the hydroelectric reservoirs of Agoyán and Pisayambo that generate greenhouse gases like methane (CH_4) and car- bon dioxide (CO_2). Field sampling and laboratory analysis were carried out to establish the geographical, and biochemical aspects of the reservoirs, with the aim of establishing the gas flows of interest (methane and carbon dioxide) and determining the correct methodology by applying mathematical models. Reservoir diffusive emissions were measured in situ during field campaigns using a floating chamber, and calculated from gas concentration measurements using the application of an IPCC mathematical model, also the organic matter obtained from the sediment of the reservoirs as a variable, in the same way through a simple modeling by direct estimation using the biochemical oxygen demand (BOD) as a variable was using. The results found in this study indicate that the methane emissions generated in the Agoyán and Pisayambo reservoirs report a maximum value of 3,083.17 tons/year and 7,138.43 tons / year respectively, while CO_2 emissions into the atmosphere report values of 136.02 and 239.88 tons / year, indicating that in the Pisayambo reservoir there is more pollution than in the Agoyán reservoir due to emissions of CH_4 and CO_2.

Keywords: greenhouse gas (GHG), methane, static floating chamber, carbon dioxide, hydroelectric dam.

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DOI: 10.31838/ecb/2023.12.si6.223

1. INTRODUCTION

This project focuses on the study of methane emissions produced in hydroelectric reservoirs in order to estimate methane emissions and analyze their automaticity under the influence of meteorological parameters, according to different generated concentration scenarios (Flores et al., 2019). These hydroelectric dams are often considered carbon-neutral sources of energy, but recent research indicates that when used as reservoirs they are potentially significant sources of greenhouse gases such as methane, carbon dioxide, and nitrous oxides. that need to be treated and managed to comply with environmental laws (Varol, 2019).

Currently, increasingly decisive scientific evidence affirms that anthropogenic emissions of greenhouse gases into the atmosphere are causing specific changes in climate variables such as temperature, precipitation, and the frequency and intensity of extreme weather events (Dos Santos et al., 2017). Hydroelectric reservoirs are an important source of CO_2 and CH_4 as a result of the process of destruction of organic matter within the body's water reservoir and in the lower layer with the presence of sediments, which are influenced by pH, chlorophyll levels, of organic carbon, age of the deposit, wind speed and precipitation are important factors to analyze for the reduction of the emission of these biogases into the atmosphere (Saidi & Koschorreck, 2017).

Methane (CH_4) is the second most transcendental GHG in substantial warming among greenhouse gases, behind CO_2 (Cadillac, Torres, Calles, Vanacker, & Calderón, 2017). Therefore, the effective reduction of methane (CH_4) and carbon dioxide (CO_2) emissions is necessary in the short or long term to prevent the increase of their concentration in the environment, so that a greater problem can be avoided due to the increase in the contribution of this gas to the greenhouse effect (Pérez & Ponce, 2013).

Because in Ecuador there are no regulations to regulate emissions from hydroelectric dams, it is necessary to carry out studies on this subject; on the other hand, the National Energy Strategic Plan projects an increase in the Energy Matrix of 93% from hydraulic generation, which makes it mandatory to try to control methane and carbon dioxide emissions (Samaniego, 2014). This work aimed to study the processes of degradation and transformation of plant material in reservoirs Agoyán and Pisayambo hydroelectric plants that generate methane (CH_4) and carbon dioxide carbon (CO_2)" aims to analyze the environmental impact caused by reservoirs of the main hydroelectric plants in Ecuador (Agoyán and Pisayambo), in order to assess the results and be able to contribute to stopping the growth of greenhouse gases in the atmosphere (Santillán & Ramírez, 2018).

2. METHODOLOGY

2.1. Sample origin

wo hydroelectric reservoirs were selected according to their nature, land use pattern in the areas near the reservoir, type and chemical quality of the body of water that feeds the reservoir, among other factors... The Agoyán hydroelectric reservoir is located in the province of Tungurahua, 5 km east of the city of Baños and 180 km southeast of Quito, in the Agoyán sector of the Ulba parish, Los Pinos Camp. At an altitude of 1826 m at the following coordinates: 1°23'52.049''S, 78°23'0.196''W. The Pisayambo reservoir is located within the National Park Llanganates, located in the Eastern Cordillera of the Andes, approximately 40 km from the Píllaro city Province of Tungurahua. Altitude of 3380 m in the following coordinates: 1°5'10.448''S, 78°23'17.482''W. In the Figure 1 shows the location and points where samples were taken from the Pisayambo reservoir.

Figure 1. Location and sampling points of the Pisayambo reservoir

In the Figure 2 shows the location and points where samples were taken from the Agoyan reservoir.

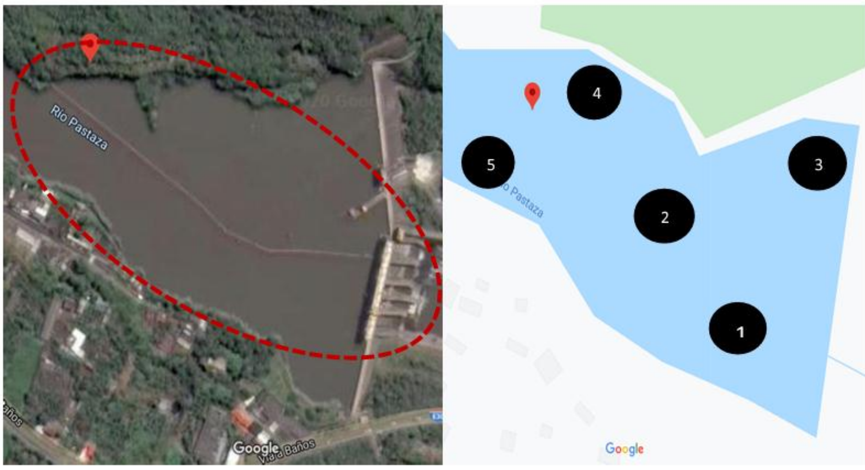

Figure 2. Location and sampling points of the Pisayambo reservoir

2.2. Experimental design and sampling

The collection of the samples in the Agoyán and Pisayambo reservoirs was carried out by in situ method for the determination of methane and carbon dioxide, in addition determined the percentage of total organic carbon, biochemical oxygen demand and- finally, the environmental parameters were established due to their great importance that presented to determine the degree of contamination of a reservoir and its fundamental contribution in the determination of methane and carbon dioxide by model mathematicians, where the geographical location, pressure, height, speed of wind, temperature, pH, depth, chlorophyll A and sediments (Vizuete & Jaramillo, 2013).

The experimental design carried out was nested, known as a double division replicated design. This alternative allowed the project to anticipate and reduce errors in the stages of either sampling or previous treatments. It consisted of taking a sample according to the protocol exposed by the National Technical Standard for each sampling point (five samples). Each sample was homogenized separately and divided into two subsamples (ten samples), which received a prior conditioning treatment (Martínez & Rodriguez, 2016)

Samples were treated according to international sampling standards and transport of materials according to NTE INEN-ISO 10381-1, taking into account that these procedures were performed to 5 samples taken at different points of the reservoirs for the evaluation of the heterogeneity of the sampling, in addition, these subsamples were carried out by duplicate to determine physicochemical parameters, obtaining two replicates for each analysis parameter and each sampling point (Balaguer, 2015).

2.3. Determination of physicochemical parameters

The collection of sampling conditions, including meteorological ones, are factors that will help further interpretations of data and for determining of methane and carbon dioxide. Firstly, as mentioned, the 5 were chosen representative points for taking samples and with the help of the boat we headed to each sampling point, then the boat was anchored at the first point and the proceeded to take the samples. Temperature was measured using a thermometer. mercury brand (H-B Instruments), the atmospheric pressure was determined with a pressure meter PCE -APM 30, the pH was measured in situ using an Apera Instruments brand digital pH meter, then the direction and speed with a Merck brand digital anemometer. Subsequently carried out the collection of sediments for which a Ponar dredger was used, this type of dredger because they are deep waters and the current of the lagoons present relatively high speeds, due to the weight of the dredger a cable was required to support from a boat (Bodger, 2003). In addition, the turbidity of the water was analyzed to which the Secchi disk was used. Finally with the help of the GPS marks GARMIN – Etrex 10 the exact geographic coordinates of each point were determined sampling in the reservoirs of Agoyán and Pisayambo (Lecca, 2014)

The measurement of the methane fluxes was carried out directly using a monitor of personal gas PID (RKI-GX-6000), where the static chamber technique was used float- ing. The chamber was built using as main material chloride of polyvinyl with a height of 30 cm and a width of 40 cm. The camera function was to ensure an adequate mixture of air inside the chamber, the same that presented two holes, one at the top and one at the bottom, the hole at the bottom allowed small amounts of water to enter and build up necessary amount of air inside the chamber, while the upper hole allowed the input of a valve that was connected directly to the infrared sensor of the RKI-GX-6000 equipment. Subsequently, the equipment was turned on and the time was necessary until it will stabilize, the results of methane emissions will be taken after about an hour and a half had elapsed, during which time there was no change in the values of methane emissions , this process was carried out at each representative point selected ab (Lallana, 2003) .

2.4. Evaluation of the process for the analysis of the number of emissions of methane in the Agoyan and Pisayambo reservoirs.

The measurement of methane flows was performed directly using a PID personal gas monitor (RKI-GX-6000), where the floating static chamber technique was used. The chamber was built using polyvinyl chloride as the main material with a height of 30 cm and a width of 40 cm. The function of the chamber was to ensure an adequate mixture of air inside the chamber, which had two holes, one at the top and one at the bottom, the hole at the bottom allowed the entry of small amounts of water. and the necessary amount of air was accumulated inside the chamber, while the upper hole allowed the entry of a valve that was directly connected to the infrared sensor of the RKI-GX-6000 equipment. Subsequently, the equipment was turned on and the time was necessary until will stabilize, methane emissions results will be taken after approximately one and a half hours have elapsed, during which time there was no change in methane emissions values null (Bernal & Rozo, 2017).

3. RESULTS

This chapter explains the results achieved in the experimental work carried out, for the study of the processes of degradation and transformation of the material plant in the hydroelectric reservoirs of Agoyán and Pisayambo that generate methane and carbon dioxide.

3.1. Analysis of the amount of methane emissions in the Agoyán reservoirs and Pisayambo by in-situ determination, using a gas monitor

The values of the methane flows, measured at each sampling point carried out in the two hydroelectric reservoirs of Agoyán and Pisayambo, are shown in Table 1 and Table 2 respectively.

Table 1. Results of methane emissions in the reservoirs of Agoyán and Pisayambo in units of %LEL and ppm, corresponding to Sampling Campaign 1 taken at the study points.

Physicochemical Parameters	Sampling Points					Location
	Point 1	Point 2	Point 3	Point 4	Point 5	Hydroelectric dam
mg CH4/m2 × day	2732,93	4 052,57	2 725,55	1 363,27	1 349,04	Pisayambo
	1 698,42	1 704,64	1 695,15	1 660,47	1 688,37	Agoyán

According to the results indicated in Table 1, it is observed that in Pisayambo there is a greater emission of methane at point 2, reaching a value of 4,052.57 mg CH4/m2 per day, while in the Agoyán reservoir the point with the greatest amount of methane flows is point 2, reaching a flow of 1,704.64 mg CH4/m2 per day as shown, this occurs at temperatures of 13 °C for point 2 in Pisayambo and 19 °C for point 2 in Agoyán as mentioned, which indicates that high temperatures favor the increase in methane flows (Ojeda, Taboada, & Margarito, 2012), in addition to point 2 for each reservoir constitutes the center of the reservoirs that in the aquatic system represent the greater depth of the same reaching a depth of 17 meters in Pisayambo and 12 meters in Agoyán as shown in Table, for which it is also concluded that the depth has a direct relationship with the increase in flow of methane (Li, Zhang, Bush, & Sullivan, 2015). Depth is directly related to methane emissions due to the formation of an anoxic layer. Presence low amount of oxygen which causes the organic load to melt, releasing methane more easily to sediments and surrounding water (Alonso & Palau, 2010).

Subsequently, the average methane flow in each reservoir was established, obtaining as a result that in the Pisayambo reservoir flows of methane of around 2,444.67 mg CH4 in each square meter per day, while that in the Agoyán reservoir the flows of methane generated occur to a lesser quantity, obtaining a value of around 1,689.41 mg CH4 in each meter square per day. Herrera Rodríguez and Rojas (2013) indicate average values of methane flows that they range between 4,282 and 733 mg CH4 m^{-2} d^{-1} for the Brazil and Neustrom Amo reservoirs respectively. When comparing the results obtained with the values of flows of emissions reported for the Brazil and Neustrom Amo reservoirs, it can be seen that the results are in the same order of magnitude, contrasting the results obtained in this research.

In the Figure 3 and Figure 4 show in a more precise way how the level of contamination occurs between the sampling points for the Pisayambo and Agoyán reservoirs respectively, indicating, as already mentioned, that the most contaminated point between the reservoirs is the point 2 in the relationship between Agoyán and Pisayambo, this is because it represents the deepest place in the reservoir, while the point with the least contamination in the Pisayambo reservoir is point 5, reaching methane emissions of 1,349.04 mg CH4/m2 per day, while in the Agoyán reservoir the point with the lowest gas emission is likewise point 4, reaching emissions of 1,660.47 mg CH4/m^2 per day.

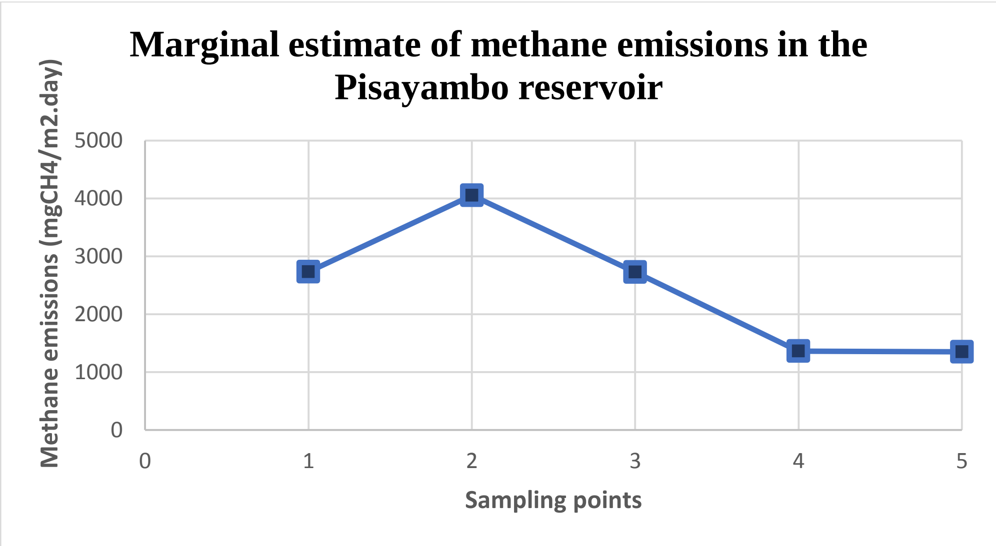

Figure 3. Mean level of contamination between the sampling points of the Pisayambo reservoir.

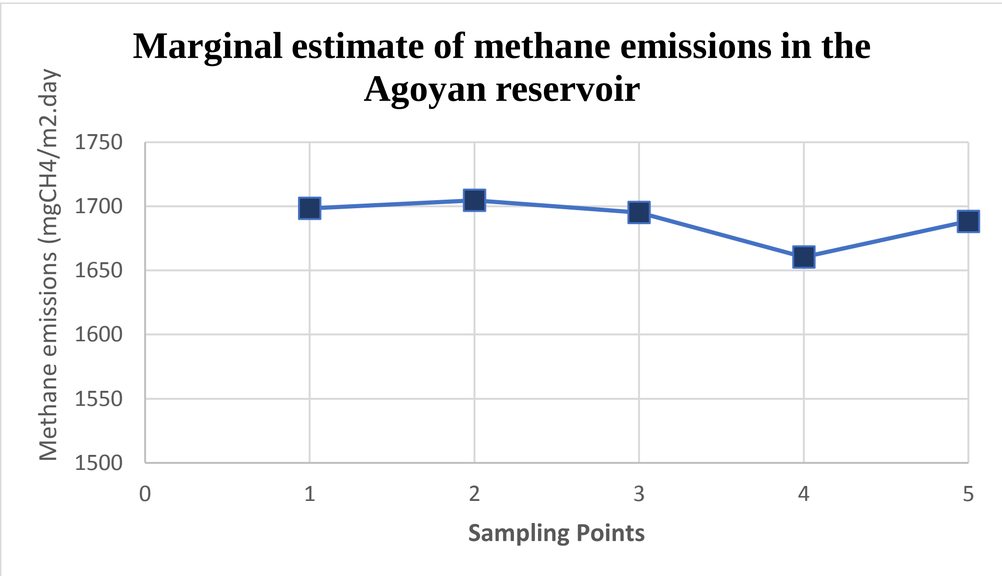

Figure 4. Mean level of contamination between the sampling points of the Agoyan reservoir.

Table 2. Average results of the Physicochemical Parameters, corresponding to Pisayambo Hydroelectric dam from two replicates taken at the study points.

Physicochemical Parameters	Sampling Points					Location
	Point 1	Point 2	Point 3	Point 4	Point 5	Hydroelectric dam
pH	7,83 ± 0,071	7,83 ± 0,142	7,83 ± 0,216	7,83 ± 0,122	7,83 ± 0,141	Pisayambo
Temperature	9,90 ± 0,057	13,3 ± 0,163	10,20 ± 0,141	9,80 ± 0,082	10,30 ± 0,058	
Sampling depth (m)	7,00 ± 0,005	16,65 ± 0,008	9,45 ± 0, 022	8,05 ± 0, 008	3,6 ± 0,082	
Atmospheric pressure (HPa)	669,60	669,10	668,40	667,70	668,20	
	Point 1	Point 2	Point 3	Point 4	Point 5	Hydroelectric dam
pH	8,38 ± 0,071	8,45 ± 0,142	8,15 ± 0,216	8,01 ± 0,122	8,12 ± 0,141	Agoyan
Temperature	12,20 ± 0,077	11,3 ± 0,163	13,20 ± 0,141	11,70 ± 0,082	14,30 ± 0,058	
Sampling depth (m)	5,00	12,65	8,45	10,05	6,60	
Atmospheric pressure (HPa)	838,90	841,50	839,70	839,20	668,20	

When analyzing the pH in the Pisayambo reservoir, it is observed that its maximum value reached is 8.8 and the minimum value is 7.5, while in the Agoyán reservoir the highest value is 8.45 and the lowest value is 8.01, so it can be stated that the two reservoirs present basic values, this may be due to the high decomposition present on the surface of the water (Losada & Martínez, 2020), in addition (Paucar & Amacha, 2015) state that the pH must be in a range of 5 to 9 for the conservation of flora and fauna in fresh water, so according to the results observed, it can be indicated that some points of the two reservoirs are in the maximum allowable (Barros, 2018).

Regarding temperature, the maximum temperature reached in the Pisayambo reservoir is 13 °C while in the Agoyán reservoir it is 19 °C, being within the permissible limit not greater than 32 °C, taking into consideration that a greater Temperature increases the solubility of oxygen, accelerating the metabolism of microorganisms and favoring the production of methane emissions (Pacheco, 2011). In this case, the temperature, being below the permissible limit, has a similar effect on the flows of methane produced in the Agoyán reservoirs and Pisayambo.

According to the depth, it is observed that the Pisayambo reservoir has a greater depth than the Agoyán reservoir reaching its maximum values of 17 meters and 12 meters respectively. Analyzing these values shows that a greater depth considerably favors the production of methane emissions because at greater depths the presence of oxygen is less, which facilitates the anaerobic oxidation and consecutively obtaining methane (M. Hernández, 2009).

4. CONCLUSIONS

The total emissions of methane into the atmosphere in the reservoirs of Agoyán and Pisayambo indicate a maximum value of 3,083.17 and 7,138.43 tons of methane/year respectively, concluding that the Pisayambo reservoir presented greater contamination due to methane emissions than the Agoyan reservoir. These results were achieved using a personal PID gas monitor (RKI-GX-6000). When comparing the results obtained in this research for the Pisayambo reservoir with those carried out by Paucar and Amacha (2015) in their research project "Estimation of emissions of methane produced by hydro-electric plants in Ecuador", where obtained as a result 11,133 tons of methane per year, it is concluded that are reproducible data because they are in the same order of magnitude and corroborates the veracity of the investigation.

The possible factors that influenced and were analyzed to estimate the reason for the highest rate of pollution from methane emissions from the Pisayambo reservoir with respect to the Agoyán reservoir are the depth, organic load biochemical oxygen demand and reservoir area. Analyzing the depth, a maximum depth of 17 m was observed in the Pisayambo reservoir and 12 m in the Agoyán reservoir, the depth is directly related to methane emissions because the higher the depth, the formation of anoxic layers is greater, which means less presence of quantities of oxygen which causes the organic load to melt releasing methane more easily into sediments and surrounding water as mentioned (Alonso, Corregidor, & Palau, 2010) and (Samaniego, 2014 in their studies. When studying the percentage of total organic matter in the Pisayambo reservoir it was observed that its average is much higher with respect to the Agoyán reservoir, reaching an average of 2.44% at each point while in the Agoyán reservoir the average of each point was 1.19%, this is another reason for the greater presence of methane emissions in Pisayambo with respect to Agoyán, considering that carbon is a direct source of methane and as there is a higher percentage of organic matter, it promotes increased methanogenesis as indicated in studies conducted by (Sanchez et al, 2013). When analyzing the reservoir area, it was established that the total area of the Pisayambo reservoir is greater than the area of the Agoyán reservoir reaching values of 8 and 5 km2 respectively therefore there is much greater presence of organic matter in Pisayambo and for this reason greater possibility of methane emissions into the atmosphere.

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