Greenhouse Gas Emissions from Natural and Artificial Lakes in Western Macedonia, Greece

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Abstract
Formation of artificial lakes is a common practice for hydroelectric power generation. Hydroelectricity is considered to be a green and renewable energy source in terms of factory operation. However, hydroelectricity generation may have environmental impact arisen from greenhouse gas (GHG) emissions induced by biomass degradation within water reservoir. Depending on area (rocks, cultivation fields, etc) flooded, an artificial lake may emit significant amounts of GHG, especially in the first years of its formation. In this study, the GHGs emission and water quality of two artificial lakes (Polyfytos and Ilarionas formatted in 1974 and 2012 respectively) and of one natural lake (Zazari) in the area of Western Macedonia were measured and evaluated. Results show that the old Polyfytos lake is stabilized and emits low amounts of CO_2 (maximum flux 568 mg/m^2/day) and zero CH_4.The fresh Ilarionas lake and the natural lake emit higher amounts of CH_4 (maximum fluxes 19 and 2200 mg/m^2/day respectively). The CO_2 emissions depend strongly on time of year and chlorophyll concentration in water (indicator of photosynthetic activity) and even negative fluxes were found in Ilarionas and Zazari (-395 and -732 mg/m^2/day respectively). A simple model is used to correlate and predict future GHG emissions by the lakes.
Keywords: Hydroelectricity, Artificial lake, Greenhouse Gases, Water quality

1. Introduction

Hydroelectricity is generally considered to be a clean and renewable form of energy, but it has been criticized especially in terms of greenhouse gases (GHGs) emissions and microclimate affection caused by the artificial lakes and water reservoirs that are essential for the operation of hydropower stations. Although beneficial, artificial reservoirs may act as hypertrophic natural water bodies, due to biomass trapping after land impoundment and the subsequent biomass degradation. Aerobic, anoxic and photochemical reactions take place especially in the first years after reservoirs formation. Thus, artificial reservoirs may have noticeable environmental impact such as considerable GHGs emissions etc (Samiotis et al. 2018, Delmas et al. 2001).
In this study, CO_2 and CH_4 gross diffusion fluxes of one natural lake, one 45 years old and one 7 years old hydroelectric reservoir are reported. All three water bodies are located in north-west Macedonia, Greece where the climate is Mediterranean -Continental.

2. Methods

Two artificial lakes (Polyfytos and Ilarionas) and one natural lake (Zazari) were studied. Two sampling stations were used in Polyfytos lake one at Polyfytos Dam and one at Nautical Club of Kozani (NOK) located around the center of the Polyfytos lake. One sampling station was located at the dam of Ilarionas lake. One sampling station was located in Zazari lake. At these four sampling stations both GHG's emission and water quality measurements were conducted. A fifth point at Aliakmonas river (at Paliouria Bridge) was used only for water quality sampling. Aliakmonas river is the feeding water for both Ilarionas and Polyfytos lake. GHG's measurements were conducted by the static chamber method (Goldenfum 2010). Gas samples were collected in appropriate gas sampling bags and analyzed using a Gas Chromatographer (Shimadzu model 14B). Emissions were then calculated according to the literature (Goldenfum 2010, Samiotis et al.,2018). Analysis of water physicochemical parameters was conducted according to standard methods (APHA, 2012). Water quality was evaluated by the "ΥΔΩΡ" WQI as proposed in the literature (Iakovidou et al., 2017).

3. Results and Discussion

In table 1, the results for the water quality evaluation of the five sampling stations are presented. "ΥΔΩΡ" WQI values between 0-25, 26-50, 51-75, 76-100 and >100 indicate excellent, good, fair, marginal and poor water quality respectively.

Consequently, Zazari and Polyfytos 1 (Dam) water quality is characterized as good, since "ΥΔΩΡ" WQI values were between 26-50. Water quality of the other three sampling stations is characterized as excellent, with "ΥΔΩΡ" WQI values < 26. The higher WQI values for Zazari and Polyfytos (Dam) sampling stations are mainly attributed to the high concentrations of Nitrites and Total Phosphorous. Furthermore, Zazari lake presents high chlorophyll α content (>15 μg/L), while in the other water bodies the respective values were much lower (<2,5 μg/L). Chlorophyll α concentration was not taken into account by the WQI and thus its value was not influenced by the high chlorophyll content. The average annual chlorophyll content (19 mg/m^3) of Zazari lake is in the range of eutrophic lakes as well as the total phosphorous lake. Ilarionas and Polyfytos lake exhibited characteristics of oligotrophic and mesotrophic lakes (Chapman, et al., 1996).

Zazari lake is a small natural lake that was under environmental pressure (domestic waste from surrounding villages) until 4-5 years ago. The inflow of organic matter and nutrients into a natural lake resembles the conditions in a freshly formed artificial lake where biomass has been trapped in water. Thus, it is not surprising that Zazari lake exhibited the highest emission fluxes of GHG's (Figure 1). CH_4 emissions of Zazari lake were up to two orders of magnitude higher than the respective ones of the artificial lakes. In addition, considerable negative CO_2 fluxes were measured at Zazari lake, indicative of algal carbon fixation and in accordance with the high chlorophyll α content. Ilarionas lake, which is a young reservoir formed in 2012, exhibited much lower emissions than Zazari lake. Ilarion lake's emissions were of the same order of magnitude with those from Polyfytos lake (older reservoir formed in 1974), indicating its stabilization in terms of diffusive GHG's emission. This is in accordance to Delmas et al. (2001), who reported that artificial reservoirs may stabilize in approximately 5 years after their formation. Worth mentioning that the morphology of an impounded area affects the stabilization period of a reservoir, since the morphology dictates canopy cover and biomass accumulation (Samiotis et al., 2018).

The results indicate that the young, Ilarion reservoir has started to stabilize. Modelling of Ilarionas CH_4 emissions lead also to the same conclusion (Figure 1c). Ilarion reservoir was formed mainly in a rocky area and thus low amount of biomass was covered and as a consequence a fast stabilization would be expected. Finally, the water physicochemical parameters in Polyfytos, ILarionas and Aliakmonas river exhibited approximate values and again this indicates the stabilization of the young reservoir.

4. Conclusions

Water quality of two hydroelectric reservoirs and their feeding water is similar. Old and young artificial reservoirs exhibited similar GHG's emissions. On the contrary, a natural polluted lake can act as a fresh manmade reservoir and emit high values of GHG's.

Table 1. WQI values and water characterization

Sampling point	WQI	Water Characterization
ZAZARI	44,6	Good
ILARIONAS (DAM)	16,4	Excellent
POLYFYTOS 1 (DAM)	46,2	Good
POLYFYTOS 2 (NOK)	22	Excellent
PALIOYRIA BRIDGE	25,3	Excellent

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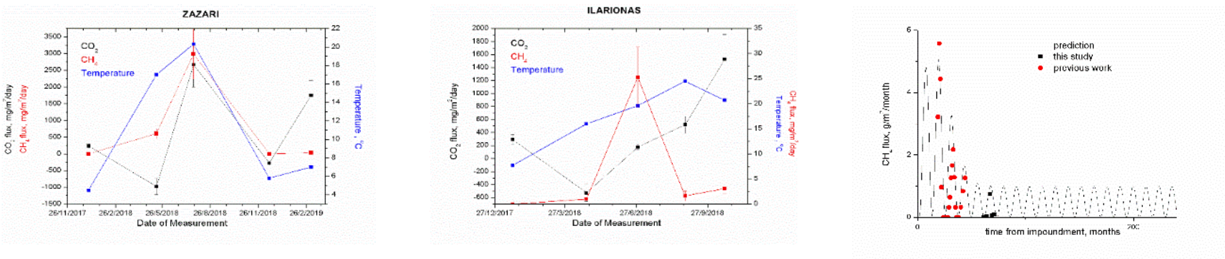

a)

b)

c)

Figure 1. CO_2 and CH_4 diffusive emissions for various measurement dates: a) Zazari, b) Ilarionas, c) Modelling of CH_4 diffusive emissions from Ilarionas lake.

References

APHA-AWWA-WEF. (2012), Standard methods for the examination of water and wastewater. 22nd Ed, American Public Health Association.

Delmas. R., Galy-Lacaux C. and Richard S. (2001), Emissions of greenhouse gases from the tropical hydroelectric reservoir of Petit Saut compared with emissions from thermal alternatives, *Global Biogeochemical Cycles*, **15**, 993-1003.

Goldenfum J.A. Editor. (2010). GHG Measurement guidelines for fresh water reservoirs. International Hydropower Association. United Kingdom, London.

Iakovidou F., Trikoilidou E., Samiotis G., Stamos A., Tsikritzis L. and Amanatidou E. (2017), Development of an updated water quality index based on legislation and expert's opinion, 10th World Congress on Water Resources and Environment "Panta Rhei". 5-7 July, Athens, Greece.

Samiotis G., Pekridis G., Kaklidis N., Trikoilidou E., Taousanidis N. and Amanatidou E. (2018), Greenhouse gas emissions from two hydroelectric reservoirs in Mediterranean region. *Environmental Monitoring and Assessment*, **190**, 363-376.

Chapman, Deborah V, WHO, Unesco & United Nations Environment Programme (1996), Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring / edited by Deborah Chapman, 2nd ed. London: E & FN