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Impact of water quality on GHG emissions from Hydropower Reservoir

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Abstract

Under the climate change, the emission of Green house gases (GHG) like CO_2 and CH_4 from artificial reservoirs, especially, in tropics are resulting in the global warming. The CO_2 and CH_4 in hydropower reservoirs is produced due to decomposition of organic matter at the bottom. To find out relationship between CO_2/CH_4 emissions and water quality, 10 water quality parameters viz. temp, DO, COD, TDS, pH, TP, nitrite, phosphate, total alkalinity, conductivity measured in site I & site II of Oyun reservoir of Nigeria were collected from the literature. The analysis indicated that CO_2 emissions from the reservoir were, mainly, affected by pH, alkalinity and DO. CH_4 emissions are not found due to shallow nature of reservoir. It is also found that if the number of water quality parameter decreases, the value of R^2 also decreases. A deeper analysis of the relationship between the different parameters and GHG emissions using mini tab software and the multiple regression revealed that the R^2 >0.9 for site 1 and R^2 >0.8 for site II indicates that these correlations could be tentatively used to predict the emissions from Oyun reservoir in the future.

Key words: Green house gas, emission, water quality, hydropower reservoir

1. Introduction

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the major greenhouse gases (GHG) emitted from both natural as well as anthropogenic sources. Hydropower, an efficient way of producing electricity, yields emission factor between one and two orders of magnitude lower than the thermal power generation. Several factors contribute to the GHG emissions from reservoirs, such as water quality, presence of nutrients, physico-chemical factors of water, availability of phytoplankton, hydrological characteristics and reservoir ageing. The CH_4 from reservoirs represents 12% of global CH_4 emissions and 90% of this is contributed by reservoirs located in the tropics [1]. The total surface area of hydroelectric reservoirs in the world is estimated at about 350,000 km^2 [2]. Recent studies indicate that reservoirs responsible for the net emissions of methane (CH_4) are contributing to anthropogenic global warming potential [1, 3 &4]. The area occupied by global reservoirs varies from 0.26 to 1.5 million km^2 [5], and reliable area of reservoirs is around 0.5M km^2 on the basis of high resolution mapping of Global Reservoir and Dam database [6].Warmer periods and regions usually have enhanced CH_4 emissions as the bacterial methanogenesis is affected with temperature [7]. CO_2 emissions also increase with water and air temperature due to the increase in methanotrophy and transfer velocities in the mixed layer [8 & 9]. In the Everglades, CH_4 emissions during day time were found lower due to the increase in dissolved oxygen (DO) owing to O_2 evolution and enhanced methanotrophy from photosynthesis [10 &11]. Djukic et al. [12] have used the physico-chemical properties of water to assess the water quality of a reservoir [12 &13]. GHG emissions from tropical reservoirs are large compared to boreal and temperate reservoirs [14-15]. The magnitude of the GHG emissions of a reservoir in the future cannot be predicted accurately, but it is becoming a major environmental issue under the Clean Development Mechanism (CDM) of a project. Since GHG emissions from reservoirs are significantly related to water quality, the models predicting the water quality could be used to predict the extent of anoxicity of waters with good confidence. This is reported by the finding that higher anoxic conditions in tropical reservoirs favour and sustain the methanogenesis over longer period of time [16]. Recent studies have found that specific reservoir characteristics play a main role in the higher GHG emission [17 & 18].

The present paper reports the results of developing the correlations for the Oyun reservoir located in Nigeria based on water quality parameters and reservoir characteristics. These correlations can be used to accurately predict the GHG emissions in the future from this reservoir but cannot be applied to other reservoirs due to the complex variable aquatic environment and reservoir characteristics.

2. Details of reservoir site

The Oyun reservoir located in 8º30'N and 8º15'E in Offa, Kwara state of Nigeria is a shallow tropical man made reservoir was created by damming the perennial Oyun river in 1964 to supply potable water to the people of Offa and for industrial and municipal uses. The reservoir is eutropic [19] with diverse species of littoral plants. Its salient features are given in Table 1 and location map in Figure. 1.

Table 1: Salient features of Oyun Reservoir [19]

S. No	Features	Data
1.	Location	Offa, Kwara State, Nigeria
2.	Elevation	15 m
3.	Maximum length	128 m
4.	Maximum width	50 m
5.	Maximum depth	8.0 m
6.	Mean depth	2.6 m
7.	Surface area	6.9×10^5 m^2
8.	Water volume	3.50×10^6 m^3
9.	Net storage area	2.9×10^6 m^3
10.	Hydraulic residence time	12 days

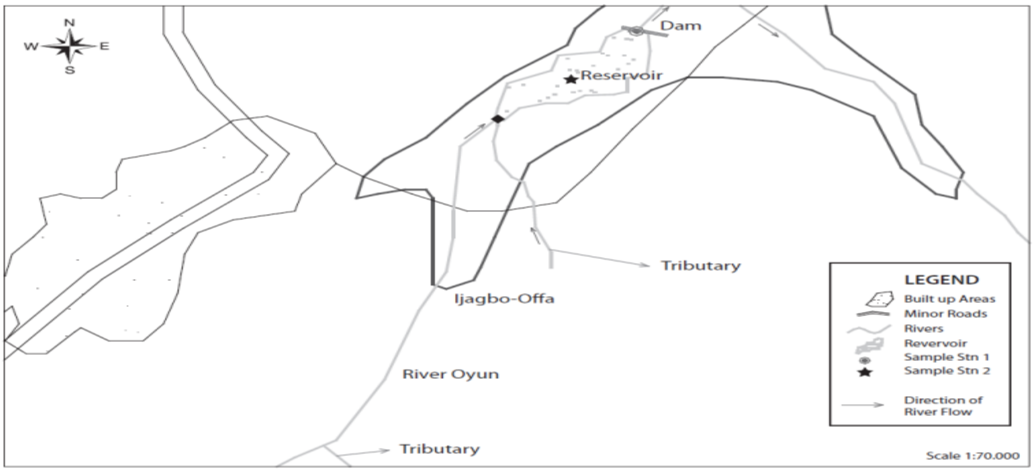

Figure 1. Map of site I (Dam site) and site II (mid section of reservoir) of Oyun reservoir [19]

3. Data collection and analysis

Since the GHG emissions data availability is very much scarce, the CO_2 concentration data was extracted from hydroelectric reservoirs from the literature [19] and converted in to CO_2 flux as shown step by step in Equation (Eq. (1)). The data like water quality, reservoir characteristic and GHG gases from reservoir site 1 (dam site) and site II (mid section of reservoir) was extracted for the period Jan 2002 to Dec 2003 from the literature [19]. The GHG emission data from Oyun hydropower reservoir was analysed with respect to water quality parameters like DO, chemical oxygen demand (COD), total dissolved solid (TDS), pH, conductivity, total alkalinity, total phosphate (TP), nitrates, temperature in order to develop relationships using Mini Tab software. The coefficient of R^2 for CO_2 emission with respect to various water quality parameters is given in Table 2 which shows that relatively good relation of CO_2 emissions with DO (R^2= 0.68), total alkalinity (0.83), temp (0.53) & TP (0.69) of site 1 and with DO (R^2= 0.53), TP (0.46) & pH (R^2= 0.51) for site II of Oyun shallow tropical reservoir is obtained. The CH_4 was not reported due to the shallow nature of reservoir. Dissolved CH_4 oxidation is dependent on the water column depth. The amount of dissolved CO_2 was higher in Tucurui Reservoir (eastern Amazon) than in Samuel Reservoir (western Amazon) because the methanotrophy is favored in deep reservoirs [20]. Further, the multiple regression equations are developed between CO_2 emissions and all the 10 parameters as given in Table 3 which yields coefficients of R^2 as 0.91 for site 1 and 0.81 for site II of the reservoir. The impact of water quality parameters on GHG emissions from lakes/reservoirs was predicted by [20 & 21] showing that the correlation cannot be universally applied to different reservoirs other than the reservoir under study. These results show that both the empirical equation can be used to predict the CO_2 emissions for both sites with more accurate emission from site1 than site II. The decrease in pH and increase in alkalinity indicated an increase in dissolved CO_2 derived from the enhancement of methanotrophy. These results show that CO_2 emissions from the reservoirs are mainly affected by pH, alkalinity and DO. The CO_2 concentration data (mg/l) have been converted to CO_2 fluxes (mg m^{-2} d^{-1}) by the equation (1):

$$mgm^{-2}d^{-1} = (\text{concentration (mg/l)}*\text{ mean depth (m)})/\ (\text{Days } *10^{-3}\ (m^3)) \qquad (1)$$

Where: Mean depth (m) of the reservoir is constant for all values (i.e.2.6m) in all these cases, Conversion of month (from Jan to Dec) into days according to no. of day in a month (31/30/28/29) and 1liter: $10^{-3}m^3$.

Table 2: Linear relation of CO_2 fluxes with water quality parameters

S. No	**Linear Relationship**	**Site I (dam axis)**		**Site II (mid section of reservoir)**	
		Equation	R²	Equation	R²
1.	CO_2 Flux vs. Temp	y = 9.2467x - 56.128	**0.53**	y = 5.0562x + 32.658	0.17
2.	CO_2 Flux vs. DO	y = -31.156x +367.33	**0.68**	y = -36.801x +437.67	**0.53**
3.	CO_2 Flux vs. COD	y = 79.355x + 21.621	0.34	y = 38.997x + 104.2	0.07
4.	CO_2 Flux vs. Total Alkalinity	y = 3.7036x + 55.887	**0.83**	y = 2.4873x + 76.104	0.41
5.	CO_2 Flux vs. Nitrate	y = -28.676x +238.59	0.07	y = -38.484x +263.12	0.33
6.	CO_2 Flux vs. TP	y = -232.21x +338.36	**0.69**	y = -489.09x +343.56	**0.46**
7.	CO_2 Flux vs. pH	y = -116.23x +1010.8	0.39	y = -43.41x + 502.88	**0.51**
8.	CO_2 Flux vs. TDS	y = -4.5519x +456.82	0.20	y = -0.5044x + 201.6	0.05
9.	CO_2 Flux vs. Conductivity	y = -2.8038x +436.83	0.27	y = -0.3653x +203.13	0.06

**The bold value indicates good regression coefficient (R²)*

Where: CO_2 Flux (mg CO_2 m^{-2} d^{-1}), Temp (^OC), DO (mg/l), COD (mg/l), Total Alkalinity (mg/l), Nitrite (mg/l), TP (mg/l), pH (unit less), TDS (mg/l), Conductivity(µs/cm).

The results of Table 2 are graphically given in Figure.2 & Figure.3 which shows the impact of individual water quality parameter on CO_2 emission for sites I & II respectively. The value of R^2 in all the cases is insignificant and so these cannot be used to assess the impact of individual parameters on CO_2 emissions. An empirical equation involving all the parameters of CO_2 emissions is shown in Table 3.

Table 3: Correlations of GHG with all the different water quality parameters (Cumulative impact of water quality on GHG emission)

Tropical reservoir		
Reservoir site	**Multiple regression equation**	**R^2 value**
Site 1	A = - 225 + 1.26 B + 15.9 C - 27.9 D + 4.40 E - 26.5 F + 122 G - 500 H + 27.9 I + 4.56 J - 1.68 K	0.91
Site II	A = 718 - 3.68 B - 34.0 C - 64.6 D + 1.09 E - 4.7 F - 112 G - 2.8 I - 1.18 J + 0.986 K	0.81

Where: A= CO_2 Flux, B= Temp, C= DO, D= COD, E= Total Alkalinity, F= Nitrite, G= Phosphate, H= TP, I= pH, J= TDS, K= Conductivity.

When relations between CO_2 emissions and all the 10 parameters are developed for site 1 as well as for site II, it is found maximum R^2 of 0.91 is found for site 1 & 0.81 is found for site II but as the number of parameters is reduced, the R^2 also decreases (Table 4 & 5) [21]. It means that empirical equation based on large number of parameters can be best used to explain the role of aquatic environment for the GHG emissions and suitable prediction can be made for the reservoir in question.

When these equations are used to predict the CO_2 emission based on all water quality parameters determined experimentally for the site, the variation between predicted and experimental CO_2 emissions for site I & II as shown in figure 4 & 5 respectively indicates that there is ± 10 % deviation from the standard curve.

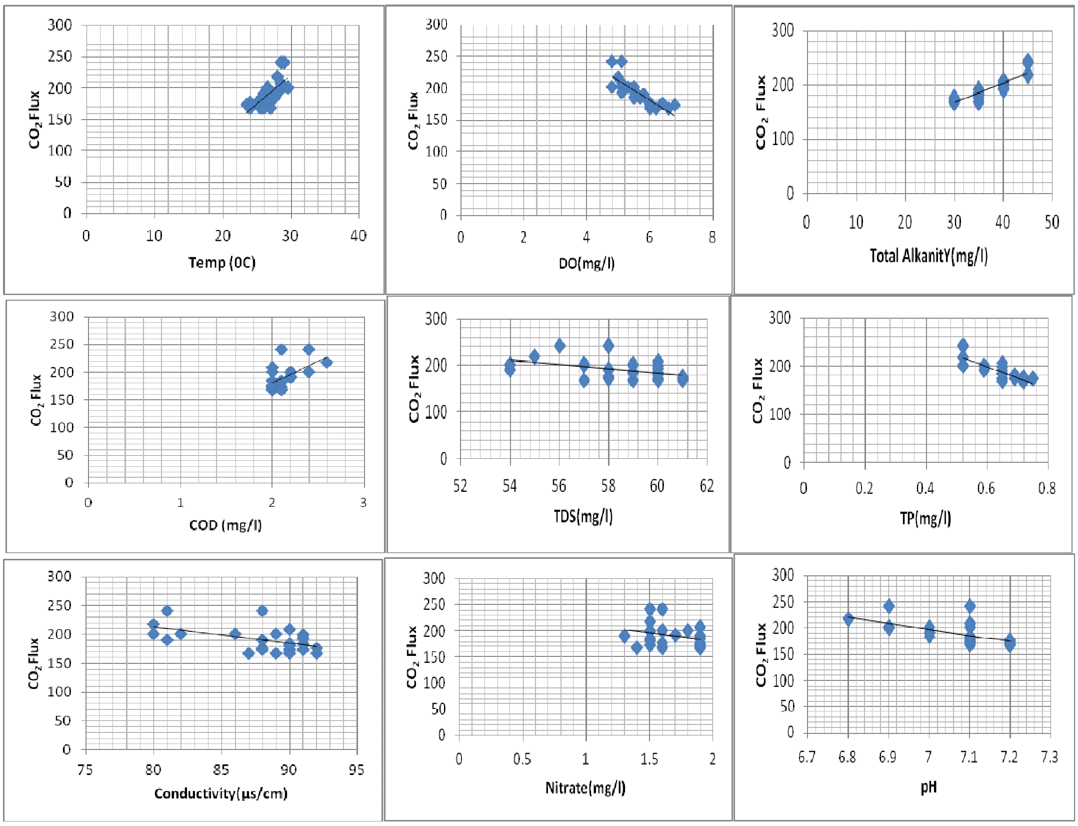

Figure 2. Relationship between CO_2 fluxes vs water quality parameters of site I

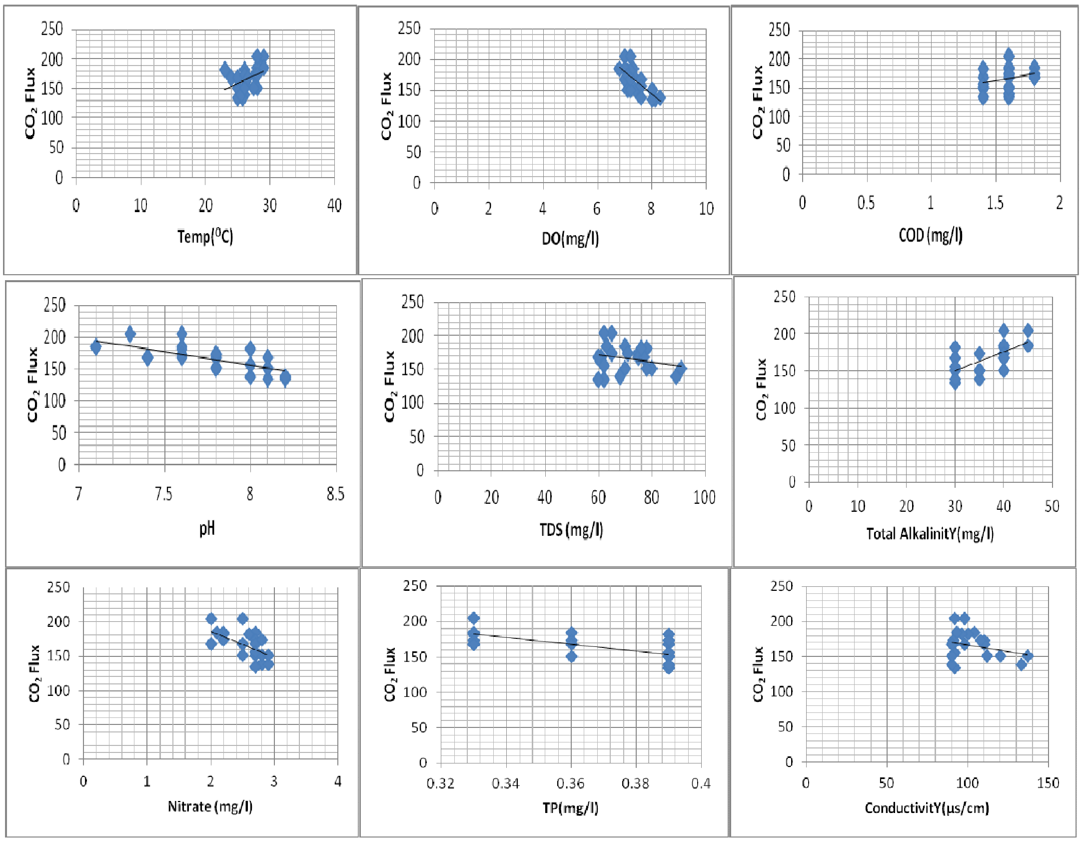

Figure 3. Relationship between CO_2 fluxes vs water quality parameters of site II

Table 4: Regression coefficient with different water quality parameters of site 1

Tropical reservoir (Site I)		
No of parameters	**Parameters**	**Value of R^2 CO_2 Flux(A_1) vs. Parameters**
10	B,C,D,E,F,G,H,I,J,K	**0.91**
9	B,C,D,E,F,G,H,I,J	0.90
8	B,C,D,E,F,G,H,I	0.89
7	B,C,D,E,F,G,H	0.88
6	B,C,D,E,F,G	0.88
5	B,C,D,E,F	0.86
4	B,C,D,E	0.83
3	B,C,D	0.76
2	B,C	0.71
1	B	0.53

Table 5: Regression coefficient with different water quality parameters of site II

Tropical reservoir (Site II)		
No of parameters	**Parameters**	**Value of R^2 CO_2 Flux(A_1) vs. Parameters**
10	B,C,D,E,F,G,H,I,J,K	**0.81**
9	B,C,D,E,F,G,H,I,J	0.78
8	B,C,D,E,F,G,H,I	0.77
7	B,C,D,E,F,G,H	0.77
6	B,C,D,E,F,G	0.77
5	B,C,D,E,F	0.75
4	B,C,D,E	0.71
3	B,C,D	0.55
2	B,C	0.55
1	B	**0.17**

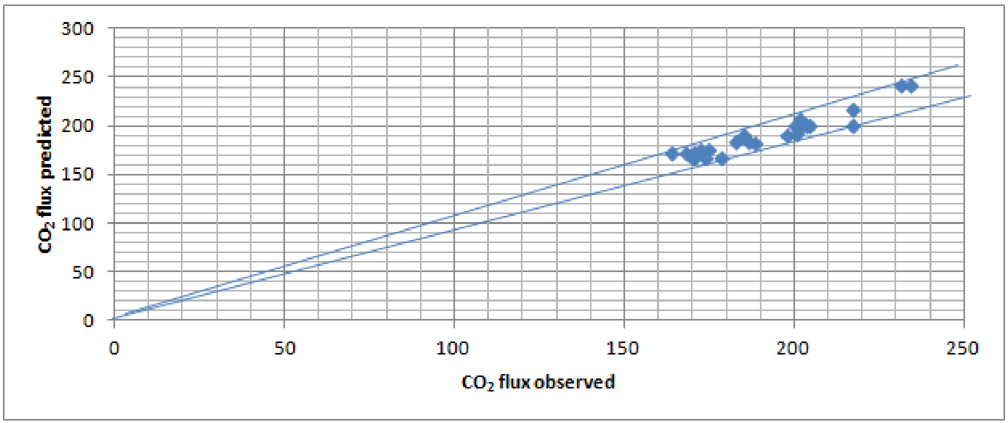

Figure 4. Monthly variation of predicted and experimental CO_2 flux of site I

A comparision of predicted and observed CO_2 fluxes(figure 4 &5) for site I &II respectivelly have indicated only ± 10 % error which shows that these equation can be suitably used for the prediction of GHG emission in Oyun reservoir in future.

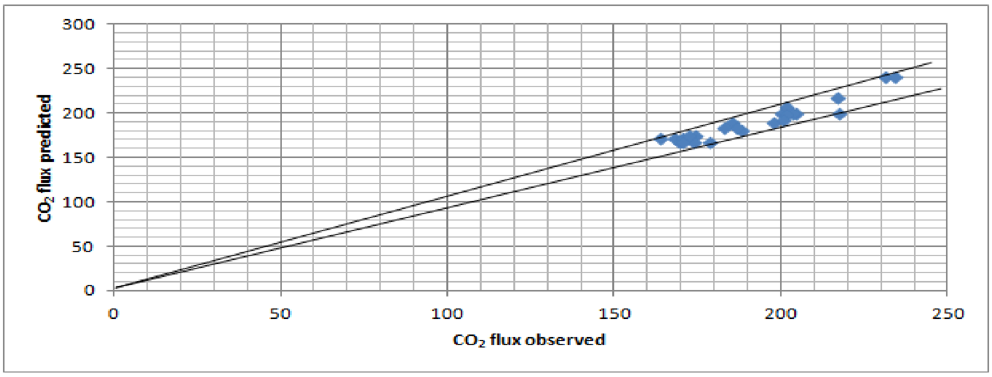

Figure 5. Monthly variation of predicted and experimental CO_2 flux of site II

Conclusions

The results indicate that CO_2 emissions from the reservoir were mainly affected by pH, Total phosphorus, DO and Alkalinity. CH_4 emissions are not found due to shallow reservoir. The results show that if the number of water quality parameter decreases, the coefficient of R^2 also decreases. A deeper analysis of the relationship between the different parameters and GHG emissions by Minitab software and the multiple regression yielded $R^2 > 0.90$ for site 1 and $R^2 > 0.80$ for site II. The GHG emissions are largely found to be affected significantly by the DO, pH and alkalinity. The CO_2 fluxes from surface of the reservoir may be different from one region to another and depends on labile organic carbon [22]. These correlations can be suitably used to predict the emissions from Oyun reservoir only in the future and cannot be applied to other reservoirs.

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