

GREEN HOUSE GAS EMISSIONS FROM HYDROPOWER RESERVOIRS AND ITS CATCHMENTS

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AMIT KUMAR



**ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE - 247667 (INDIA)
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ABSTRACT

The identification and accurate quantification of sources or sinks of Greenhouse Gas (GHG) have become a key task for scientists and policymakers working on climate change or global warming. The creation of a hydropower reservoir, while damming a river for power generation converts the terrestrial ecosystems into aquatic ecosystem and subsequently decomposition of flooded terrestrial soil organic matter by aerobically and anaerobically resulting emission of a significant amount of GHG to the atmosphere. Tropical or subtropical hydropower reservoirs are more significant sources of GHG compared to boreal or temperate one. The number of hydropower reservoirs continues to increase at fast pace especially in the tropical or sub-tropical regions, which still hold a significant amount of hydropower resources to be exploited.

Literature reveals that little work is available on GHG emissions from reservoir catchment related to; a) carbon sequestration of forest species and, b) carbon as Labile Organic Carbon (LOC) and its degradation rate in forest and agriculture soils. This study has performed first time to mitigate the long-term effect of GHG emissions from hydropower reservoirs on climate change or global warming. Accordingly, constructed (Koteshwar and Tehri) and under-constructed (Kotli Bhel-1A) hydropower plant, located in sub-tropical reservoir catchment, on the tributary of Ganga River, located in the Uttarakhand State of India has been studied. The key objectives of the thesis are; i) to select hydropower reservoir catchment, ii) to estimate the carbon 'C' and nutrients stock in constructed and under-constructed reservoir catchments based on plants studies and underlying soils, iii) to estimate the GHG production rates and factors affecting their rates based on analysis of forest and agriculture soil samples, iv) to carry out assessment risks of GHG emission from Koteshwar hydropower reservoir using modeling (SWAT-GRAT) approach, v) to evaluate long-term temporal changes in water quality parameters using seasonal MK-Test and, vi) to compare the emission factor ($\text{gCO}_2 \text{ eq./kWh}$) and net GHG emission of Koteshwar hydropower reservoir with global estimates of reservoirs located in similar eco-regions.

The Total Carbon Density (TCD) of different forest species in the catchments was experimentally estimated based on tree height and dbh. The results indicate that *Abies pindrow* contributes maximum TCD as 107.49 ± 71.95 , followed by Quercus species (*Q. leucotrichophora*,

Q. floribunda & *Q. semecarpifolia*) as $90.25 \pm 45.26 \text{ t ha}^{-1}$, while minimum in *Pinus* species (*P. roxburghii* & *P. wallichina*) as $45.50 \pm 35.50 \text{ t ha}^{-1}$ and other available species found in the catchment of the reservoir. Results obtained reveal that the average TCD of constructed reservoir catchment (Tehri and Koteshwar) is found as $54.92 \pm 18.07 \text{ t ha}^{-1}$, while the TCD of under-constructed reservoir (Kotli Bhel-1A) catchment is found as $57.38 \pm 41.11 \text{ t ha}^{-1}$. Further, underlying soil samples (n=185) were collected from catchment of the same reservoir and analyzed its physico-chemical characteristics. The average Soil Organic Carbon (SOC) and CO_2eq (CO_2eq = total effect of all GHG standardized to CO_2) of all the reservoir catchments are estimated as 91.29 and 334.11 t ha^{-1} . The flooded organic carbon (TCD + SOC: 144.50 t ha^{-1}) in the Koteshwar hydropower reservoir at the time of filling is calculated as 3.61 Mt (out of which 3-14% is LOC). Of 3.61 Mt, only 22 % (0.79 Mt) of carbon will be converted into GHG ('C' losses to atmosphere) within 10 years of dam operation.

The results of estimating the GHG production rates from soil samples find that the cumulative GHG production rates in studied reservoir catchment as 1.52 ± 0.26 for CO_2 , 0.13 ± 0.02 for CH_4 , and $0.0004 \pm 0.0001 \mu\text{g.gsoil}^{-1}\text{d}^{-1}$ for N_2O , which is less than global reservoirs located in the same eco-region. The CO_2 production rates are found significantly correlated with LOC (R^2 : 0.92) as confirmed by CO_2 production in the reservoir bottom when it reaches through runoffs, whereas CH_4 & N_2O gives insignificant results. The soil parameters like pH (corrected with N_2O with R^2 : 0.82), bulk density, N/P (corrected with N_2O with R^2 : 0.97), C/N (corrected with CH_4 with R^2 : 0.69) ratio are found to significantly affect the GHG production rate. Moreover, long/short term study is required to improve the knowledge about production rates and parameters affecting it.

The Water Quality (WQ) trend was analyzed based on monthly data (June 2003 to Dec 2013) collected from Central Water Commission (CWC), Lucknow. The result reveal that parameters like pH, T, TH, Ca^{+2} , Mg^{+2} , Cl^- , are showing decreasing trend, EC, K^+ , F^- , SO_4^{-2} , Na^+ , NO_3^- shows increasing trend, while Q, TA, HCO_3^- , BOD_3^{27} , o-PO_4^{-3} does not show any trend at Uttarkashi station from where the water is taken to Tehri station (upstream of Koteshwar reservoir) in which the water quality parameters like pH, TA, Ca^{+2} , Cl^- , F^- , HCO_3^- , Mg^{+2} , Na^+ , o-PO_4^{-3} , DO, and TH exhibit decreasing trend, nitrogen as $\text{NO}_2^- + \text{NO}_3^-$, T, Q, K^+ , SO_4^{-2} shows increasing trend, while EC, BOD_3^{27} does not show any trend. The trend of these parameters indicate that pH, DO, T, o-PO_4^{-3} , HCO_3^- and $\text{NO}_2^- + \text{NO}_3^-$ are found to affect GHG emissions

and considered to be in priority basis while measuring WQ for the prediction of GHG in any hydropower reservoir so that emission could be minimized by adopting catchments area treatments plan.

A coupled (SWAT-GRAT) model has been used to assess the risk of GHG from the Koteshwar hydropower project. The input parameters required to run the model are runoffs (important input of SWAT model), mean temperature & precipitation and age of the reservoir since impoundment. Initial, SWAT model was run to estimate the runoffs for the Koteshwar reservoir, and performance of the model was check by calculating R^2 , NSE, RSR, and p-value during calibration and validation, exhibiting a satisfactory model performance on monthly time step. Subsequently, GRAT model was run, and result show that after post-impoundment (the year 2010), the gross CO_2 and CH_4 emissions of Koteshwar reservoir are found to be $1396.76 \text{ mg.m}^{-2}.\text{d}^{-1}$ ($\text{CO}_2 > 645 \text{ mg.m}^{-2}.\text{d}^{-1}$) and $36.07 \text{ mg.m}^{-2}.\text{d}^{-1}$ ($\text{CH}_4 < 45 \text{ mg.m}^{-2}.\text{d}^{-1}$), respectively, indicating that the reservoir is under the medium risk in terms of CH_4 and high risk in terms of CO_2 . With the passage of time, the emissions will be rapidly reducing up to 2023 after which these will be decreasing very slowly over a period of 100 years of impoundment. Finally, it is concluded that CO_2 assessment is needed up to 2023 and after that, no assessment shall be required due to the reduction of emission to medium/low emission ranges. These findings are found in good agreement with the average values (660 for CO_2 and $224 \text{ mg.m}^{-2}.\text{d}^{-1}$ for CH_4 respectively) recommended by UNESCO/IHA for sub-tropical eco-region. From the results, it is concluded that emission factor ($\text{gCO}_2 \text{ eq./kWh}$) from Koteshwar hydropower reservoir are found as $13.63 \text{ gCO}_2 \text{ eq./kWh}$, which is less than Tehri and other reservoirs located in the world (0.20 - $152 \text{ gCO}_2 \text{ eq./kWh}$). Moreover, net GHG emission of the same reservoir is found as $167.69 \text{ Gg CO}_2 \text{ C yr}^{-1}$ which is less compared to Tehri and other global reservoirs located in the same eco-region.

The finding concludes that at present, the gross and net GHG emission of the Koteshwar hydropower reservoir is found as 2.89 and $167.69 \text{ Gg yr}^{-1}$ respectively, which is more than natural production rates (0.023 Gg yr^{-1}) computed in the present study by incubating forest and agriculture soil samples. From the above results, it is clear that naturally regenerated forest soils contributes less global warming compared to when it reaches the reservoir bottom through runoffs and undergoes the same process of degradation resulting emissions of GHG to the atmosphere.

In view of the higher rates of GHG production, the mitigation potential for all the forest types has been evaluated as per different land uses and it is observed that *Pinus roxburghii* contains minimum mitigation potential (i.e. quantity of 'C' sequestered by forest species compared to baseline 1.0) while moist alpine forests (*Abies pindrow*) has maximum (1.84) potential. This shows that soils under moist alpine forests can hold double the amount of SOC than tropical forests (Chir) and can be considered as potential carbon contributor. These reservoirs are found in medium or high risk of GHG, due to its higher production rates. Accordingly, the corrective/mitigation measures like afforestation with tree species like Oak, Deodar, Chir and Fir is recommended for adoption to lower this contribution of carbon into the soils. This will help to reduce the runoffs from the catchment reaching into the reservoir. The reduction of degradation resulting of available carbon at the bottom of reservoirs and hence lower GHG emissions.