GREEN HOUSE GAS EMISSIONS FROM RESERVOIR

A THESIS

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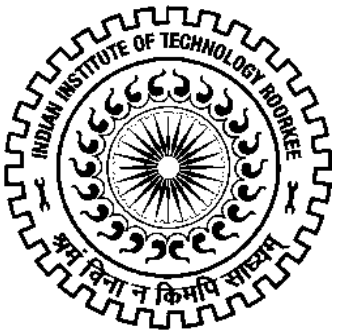

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ABSTRACT

Reservoirs considered earlier as green source of energy, in recent years, are being questioned due to greenhose gas (GHG) emissions. The major GHGs related to creation of hydropower reservoir are carbon dioxide (CO_2) and methane (CH_4). The contribution of reservoirs to the atmospheric GHGs concentrations is a rising concern and the identification and accurate quantification of sinks or sources of GHG emissions over space and time is a key challenge. As there is lack of studies in India for this subject area, present study aims to find out the detailed nature and extent of GHG emissions from a hydropower reservoir in India. Tehri hydropower reservoir is selected for this study being one of the important reservoirs in India in terms of hydropower production (1000 MW installed capacity and another 1000 MW of pump atorage is under construction) and water supply (3540 MCM gross storage) built at the confluence of river Bhagirathi (upstream name of river Ganga) and its tributary Bhilangana in Uttarakhand state. It is one of the largest reservoirs in India impounded recently in 2006 with water spread over 42 km^2 area.

An estimate of impounded carbon, the main source of GHG emission during initial years was computed using two remote sensing methods i.e. land use classification and using Normalized Difference Vegetation Index (NDVI). This impounded carbon was computed by taking difference in the pre and post impounded carbon stock. However, due to growth in forest after creation of reservoir, post impoundment data shows increament in carbon stock and the remote sensing methods failed to compute impounded carbon. Further, the same was computed by multiplying carbon density before impounded with extended river area for the creation of reservoir. Impounded area and the carbon densities at particular land use type were taken from the land use classification. The average estimate of impounded carbon was computed as 0.67 Mt.

GHG emissions, water quality and sediment characteristics were measured at different locations spread over reservoir surface and downstream in four different seasons of the year to investigate the spatial and temporal variability. Gases fluxes were measured using surface chamber, bubbling fluxes were measured using funnels whereas degassing fluxes were computed on the basis of difference in measured gases concentration upstream and downstream of dam. All the sampling sites were found saturated with CO_2 and CH_4 except

few locations where negative fluxes during the summer and pre-monsoon seasons were found due to eutrophication.

Lower concentration of CO_2 in the epilimnion compared to hypolimnion was due to the evasion that occurs at the air-water interface and photosynthetic activities in the upper water column of the reservoir. Results suggest that vertical profile depends on physical and hydrodynamic conditions in the water column. The negative correlation with DO (-0.56) and pH (R^2 = -0.55) indicate the consumption of CO_2 and production of O_2 due to photosynthetic activities in the surface water. Higher chl a and DOC concentration in the surface water than in the hypolimnion water suggest that organic matter produced during photosynthesis releases DOC in the water and primary production lowers CO_2 concentration significantly. In the bottom layers of reservoir, positive correlation coefficients between CO_2 (R^2 = 0.48) and organic carbon present in the sediments suggest a dependency of heterotrophic pelagic and benthic respiration.

CO_2 fluxes were observed maximum during the summer and pre-monsoon season due to high temperature as increasing water temperature during these seasons decreases gas solubility and low water inflows increase the photo oxidation and respiration in the water column builds up high concentration in the epilimnion. However, low temperature and continuous mixing of freash water due to high water input, shows lower fluxes in winter and post-monsoon season. The spatial variability among the sampling locations is due to the organic carbon present in the bottom and water column. A positive correlation was observed with the depth, temperature and organic carbon present in water column.

CO_2 fluxes at the reservoir surface were found in the range of −430 to 1482 mg m^{-2} d^{-1} with an average of 950 + 65 mg m^{-2} d^{-1}. In case of bubbling emission, due to high solubility of CO_2 in water, CO_2 content in the sampled bubbles was very low, ranging from 8.2 to 21.2 mg m^{-2} d^{-1} (average 8.9 + 8.8 mg m^{-2} d^{-1}). At the downstream location, CO_2 in the form of degassing was observed varying from 270 to 856 mg m^{-2} d^{-1} (average 512 + 203 .4 mg m^{-2} d^{-1}) while in the form of diffusive fluxes it varied from 120 to 554 mg m^{-2} d^{-1} (average 343.3 + 67 mg m^{-2} d^{-1}). Gross CO_2 emissions were computed as 11799 + 243 t CO_2eq yr^{-1} by adding emissions observed during three pathways i.e. diffusive fluxes, bubbling emission and degassing which contributing 75%, 21% and 4% respectively.

Similar to dissolved CO_2 concentration, CH_4 shows high concentration at the bottom due to anaerobic atmosphere and organic matter present in the sediment and lower

concentration was due to oxidation of CH_4 in the oxic water column. CH_4 concentration shows high variability due to spatial and temporal variability in hypolimnion. It shows positive correlation with water temperature (R^2 = 0.7) as temperature increases the rate of methanogenesis and decreases solubility. Hence CH_4 concentrations were maximum during summer and pre-monsoon season. During winter, concentration decreases slowly as low temperature increases solubility while it sharply decreases during post-monsoon season due to high inflow as mixing favours the penetration of O_2 from surface to bottom, hence CH_4 oxidation. Spatial variability is mainly associated with the depth of the location and DO present in the water column. A negative correlation was observed with the depth (R^2 = −0.67) and DO (R^2 = −0.87) as higher depth increases the length of water column and presence of DO oxidize more CH_4 hence less CH_4 concentration at the surface.

CH_4 fluxes at the reservoir surface were found in the range of 6 to 22.7 mg m^{-2} d^{-1} compared to global average of 16.01 + 6.1 mg m^{-2} d^{-1}. In case of bubbling emission, CH_4 bubbles were observed only at the locations where depth was < 30 m and emission ranged from 3.3 to 27.8 mg m^{-2} d^{-1} (average of 4.7 ± 7.9 mg m^{-2} d^{-1}). At the downstream locations, CH_4 emissions in the form of degassing were observed varying from 9 to 27.6 mg m^{-2} d^{-1} (average 12.2 + 5.6 mg m^{-2} d^{-1}) through water released from the turbine outlet having the deep intake (over 188 m) while diffusive fluxes varied from 6 to 45 mg m^{-2} d^{-1} (average 8 + 7.8 mg m^{-2} d^{-1}). Gross CH_4 emissions were computed as 5302 + 187 t CO_2eq yr^{-1}, in which diffusive fluxes, bubbling emission and degassing contributed 40%, 53% and 7% respectively. Gross GHG emissions from Tehri reservoir for the year 2011-2012 were thus computed as 17105 t CO_2eq yr^{-1} in which CO_2 and CH_4 emissions contributed 69 % and 31 % respectively.

Net GHG emissions were found similar to gross emissions as overall impounded land was carbon sink before impoundment. Though Tehri reservoir is emitting GHG emissions even after the 6 year of impoundment, however range of CO_2 and CH_4 emissions at different locations are less than the emission range −860 to 10400 mg CO_2 m^{-2} d^{-1} and −137 to 1140 mg CH_4 m^{-2} d^{-1} given by Varis et al., (2012) for tropical reservoirs. Global warming potential (GWP) was computed for Tehri reservoir as 3.14 gCO_2 kWh^{-1} which is much lower than of conventional energy sources.

Significant correlation was found for CO_2 emission with depth, temperature, pH, DO, TOC, DOC and chl a and for CH_4 emission showed with the depth of water, temperature, DO

TOC and DOC. Empirical equations for the reservoir emissions have been developed on the basis of these parameters for four different seasons. F test statistics indicated significant α values less than 0.05 with R^2 = 0.7 to 0.9.

Carbon balance was computed on the basis of GHG emissions and incoming carbon through inflow. Average GHG emissions of 0.004 Mt C yr^{-1} were observed which is about 4% of the incoming TOC and remaining flushed through turbine discharge (87% of total TOC) and about 9% of it is deposited at the bottom of the reservoir. Since the GHG emission (0.004 Mt C yr^{-1}) is less than the TOC available (0.011 Mt C), it may be concluded that present GHG emissions are due to incoming TOC and no impact of impounded carbon has been left after 6 year of impoundment.

Global warming potential (GWP) for 100 year life time of hydropower dam was computed on the basis of flooded carbon using Monte Carlo simulation and found the dominance of GHG emission during operation phase (around 70 - 80 g CO_2eq (kWh^{-1})) compared to the construction phase (2.5 g CO_2eq $(kWh)^{-1}$) and decommissioning phase (0.42 g CO_2eq $(kWh)^{-1}$). Hence total GWP were 76.02 + 4.06 g CO_2eq $(kWh)^{-1}$ for the life time of 100 years. For more direct comparison of GHG emission factors related to power generation, it is more relevant to use the cumulative GHG emissions throughout the lifespan of the generating facilities on the basis of actual measurements. It is difficult at this point to accurately estimate the trend of the Tehri reservoir net GHG budget over the next 100 years and this may be done in future.

Factors affecting GHG emissions from reservoir based hydropower vary from one climatic region to another. This result should only be attributed to sub-tropical or tropical reservoir, and not to temperate or boreal reservoirs. Further, GHG emission can also vary within a climatic region from one reservoir to another due to varied design.

It may be concluded that the creation of the Tehri reservoir resulted in a significant shift in the global GHG budget due to flooded carbon and will continue due to incoming carbon through inflows. The results of this work highlights the importance of process understanding as well as assessment of the GHG exchanges of the natural landscapes both pre and post impoundment while finding net emissions from Tehri hydropower reservoir in tropical region.