Journal of Sustainable Development

www.ccsenet.org/journal.html

Vol. 2, No. 2

July 2009

Estimation of Methane Emission from a North-Indian Subtropical Wetland

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Abstract

Methane emission from wetlands and its upscaling is a frontier area of research in global biogeochemical cycling including global warming. Though process based models are needed to account for variability in various types of wetland ecosystems, due to lack of required field data, it is till in infancy especially in the tropical countries. An attempt has been made through this study to estimate the quantitative and temporal variation of CH_4 emission from a subtropical wetland of North India dominated by *Scirpus littoralis.* A wide variation in rate of CH_4 emission was observed in an annual cycle with maximum rate reaching up to 129.82 ± 19.08 $mg\ m^{-2}\ h^{-1}$ during March to April and negative emission rates were observed in hot and dry summer months between May to July. This finding suggests that tropical wetlands act both as source and sink of CH_4 emission depending upon the specific ecological and environmental conditions. Therefore, extrapolation of single value of rate of emission for the entire year is not correct in estimating total annual CH_4 flux.

Keywords: Sub-Tropical wetlands, Methane emission, *Scirpus littoralis*, Carbon fixation

1. Introduction

Wetlands are the areas on the landscape where land and water meet and usually lie in depressions or along rivers, lakes, and coastal waters where they are subjected to periodic flooding. Wetlands in India are distributed in various ecological regions ranging from the cold and arid zone of Laddakh through the wet Imphal and Manipur, and the warm and arid zone of Rajasthan-Gujarat to the tropical central India, and the wet humid zone of the southern peninsula. Prediction of future climatic changes and global productivity estimation depends largely on realistic assessment of green house gases from terrestrial and aquatic ecosystems with reasonable accuracy understanding the relationship between the physical environment, anthropogenic and biological activities. Wetlands, both man-made and natural are considered as one of the major contributors to atmospheric methane (CH_4), and there exists complexity of processes which regulate net CH_4 flux between wetland soils and the atmosphere (Keppler & Rockmann, 2007; Chen & Prinn, 2006; Keppler, *et al.,* 2006). There have been relatively few studies in the annual fluxes of CH_4 in lakes of subtropical regions. Recent efforts in atmospheric modelling and attempts to constrain CH_4 source strengths have indicated the need to delineate the processes responsible for the large variations in emission rates found within and across wetland types. To understand and assess the possibility and implications of temporal variations in atmospheric CH_4, improved quantitative knowledge of CH_4 sources and sinks as well as improved estimation technique is required. Natural wetlands are responsible for approximately 76% of global methane emissions from natural sources, accounting for about 145 *Tg* of methane per year, while the global total CH_4 emission is estimated at ~611 *Tg*, giving an atmospheric lifetime for CH_4 ~8.5 yr (EPA, 2006). Next to the water vapour and carbon dioxide, CH_4 is most abundant greenhouse gas in the troposphere with an average concentration of 1.8 *ppm* (Keppler, *et al.,* 2006). Its atmospheric concentration has tripled since pre-industrial times (Houghton, *et al.,* 1996; Lelieveld, *et al.,* 1988). Although its tropospheric concentration is rather low compared to CO_2 (~ 378 ppm) (IPCC, 2001), it is of particular importance as it is a major greenhouse gas that contributes approximately ~20% of the current total global annual emission of ~600 Tg (10^{12} g). One molecule of CH_4 traps about 23-30 times more heat than CO_2 over a 100-year time scale, thus, contributing about 20% to global warming (Keppler & Rockmann, 2007; Watson, *et al.,* 1990; Thompson & Cicerone, 1986; Ramanathan, *et al.,* 1985).

Wetlands could be a source or sink of greenhouse gas based upon the net balance of three inter-related processes of the carbon cycle within wetland ecosystems i.e. carbon fixation, respiration and CH_4 emission. However, the role of wetlands in the net global greenhouse gas emission is conflicting. According to some reports, wetlands act as a source (Liikanen, *et al.,* 2006), while some indicate that it acts as sink for greenhouse gases (Turunen, 1999; Alm, 1997). In a waterlogged condition, swamp soils are a net source of CH_4 to the atmosphere, while during dry conditions swamp soils consume atmospheric CH_4 (Harriss, *et al.,* 1982).

The annual rate of fixation of CO_2 in tropical wetlands is highest compared to the other ecosystems. Estimates of average peak aboveground biomass in freshwater tidal wetlands range from 432 g/m^2 in *Sagittaria latifolia* to 2311 g/m^2 in *Spartina cynosuroides* with *Scirpus* sp. being 606 g/m (Chen & Prinn, 2006; Whigham, *et al.,* 1978). The global annual productivity of wetlands amounts to 4 to 9×10^{15} g of dry matter (Aselmann & Crutzen, 1989). This amounts to about 3 to 9% of the entire continental net primary productivity calculated at a rate of about 1000 $g\ m^{-2}\ yr^{-1}$ in comparison to the global mean of all vegetation types which is less and ranges between 770 – 900 $g\ m^{-1}\ yr^{-1}$ (Fung, *et al.,* 1983). Reality is lost between fluxes of CO_2 and CH_4 of the same carbon cycle within wetlands. On an annual basis up to 15% of the net carbon fixed by the wetlands may be released to the atmosphere as CH_4. Besides there are recent reports of CH_4 being emitted from terrestrial living plants to the tune of 62-236 $Tg\ yr^{-1}$ and 1 – 7 $Tg\ yr^{-1}$ from plant litter (Keppler, *et al.,* 2006).

Nevertheless, wetlands remain the single largest natural source for CH_4 emission, a share of 225 million metric tons (MMT) out of a total ~600 MMT (Keppler & Rockmann, 2007). Methane emission is influenced by seasonal, spatial and geographic differences and high variation exists between wetlands of different climes. Freshwater wetlands differ from coastal and other saline wetlands, in terms of CH_4 emission as the ecosystem is devoid of salinity; hence, rate of methanogenesis in freshwater wetlands is higher than the saline conditions (Verma, *et al.,* 2002; Purvaja & Ramesh, 2001).

There are major uncertainties about seasonal CH_4 production periods as well as differences in the relative importance of the role of climatically and ecologically distinct wetland ecosystems, particularly tropical/subtropical wetlands (Matthews, 2000). Also, the time periods of carbon fixation and CH_4 emission vary seasonally and diurnally (Brix, *et al.,* 2001). Numerous biogeochemical factors are known to affect the activity of methanogenic bacteria (Freeman, *et al.,* 1997; Conrad, *et al.,* 1989; Rudd & Taylor, 1980) and although there has been some success in relating water level (Harriss, *et al.,* 1982; Cui, *et al.,* 2005; Roulet, *et al.,* 2005; Moore, *et al.,* 1990) and temperature, (Schutz, *et al.,* 1989; Crill, *et al.,* 1988) to CH_4 emissions within particular systems, these variables are insufficient for predicting emissions across a variety of wetlands (Aselmann & Crutzen, 1989; Whalen & Reeburgh, 1992).

The tropical wetlands behave much differently than temperate wetlands because of difference in type of soil (organic or mineral), composition of vegetation, temperature, hydroperiod and nutrient availability (ombotrophic or minerotorphic) (Alm, 1997). Tropical wetlands are mineral soil wetlands and store little organic matter as they are subjected to alternate wet and dry periods (Armentano & Verhoeven, 1990).

Methane flux measurements in Asian wetlands, particularly Indian subcontinent, are still scanty from the published literature (Matthews, 2000). Most of the work on CH_4 flux in India has been reported from saline wetlands such as mangroves (Mukhopadhay, *et al.,* 2002; Purvaja & Ramesh, 2000), lagoons (Verma, *et al.,* 2002) and coastal estuaries (Shalini, *et al.,* 2006) with very few studies on freshwater tropical wetlands. An attempt has been done recently to quantify CH_4 emission from India using coarse resolution thermal data during months of May 2005 and October 2005 (Agarwal & Garg, 2006). Results indicated that CH_4 emission in the month of May 2005 was 10,515 kg from 29,419 sq. km. of area whereas in the month of October 2005 total emitted methane was 38,069 kg from 93,995 sq. km. However, their study is representative of only two month viz. May and October using coarse resolution thermal data of land surface; therefore, uncertainties abound on total methane emission.

An attempt has been made through this study to estimate the quantitative and temporal variation of CH_4 emission from a subtropical wetland of North India. Further, comparison has been made with similar studies from the Indian subcontinent. As potential complexities of processes regulate net flux of CH_4 between wetland soils and the atmosphere, it is difficult to extrapolate net flux for the entire area. This study demonstrates that the CH_4 emission from tropical wetlands dominated by *S. littorals*, is only for a short duration in a annual cycle and extrapolation of single value of rate of emission for the entire year is not correct in estimating total annual methane emission from tropical wetlands.

2. Materials and methods

2.1 Sampling Location

The study was carried in the littoral area of Lake Bhalsawa located in the floodplain of river Yamuna, which is a natural freshwater wetland located on the northern outskirts of Delhi (28˚ 44' N, 77˚ 10' E) (Figure 1). The lake is formed in a depression and the source of water is primarily rain (approximately 612 mm/year). It is estimated to be about 32,000 sq.

meters in area and average depth of 1.5 meter (Mehra, 1986). It has narrow littoral zone, roughly 80 mts, width along the western shore dominated by macrophytes such *Scirpus littoralis*, *Cyperus* sp., *Bacopa* sp. and few patches of *Typha* sp. The study was carried out in a small area of 4800 sq. meters, at the northern end of the lake. The area is a relatively undisturbed and dominated by *Scirpus littoralis.*

The climate of Delhi is semi-arid with distinct seasonality and high variation between summer and winter temperatures. The average temperature ranges from 25°C to 46°C during summer and 2°C to 5°C during winter.

2.2 Gas sampling method

CH_4 flux was determined using a closed chamber technique (Parashar, 1996) over areas both with *Scirpus littoralis* and without macrophytes from August 2001 till July 2002. The rate of methane emission for two consecutive hours were estimated and averaged out. Closed chambers were fabricated with transparent perspex sheet of 4 mm thickness. The gas samples were analyzed on a Nucon gas chromatograph series 5765 (Nucon engineers Pvt. Ltd. India) and partly on Perkin Elmer ASXL (USA) gas chromatographs. Both the instruments were fitted with Flame Ionization Detector (FID) and Porapak Q column (1.5m long with a mesh size of 80/100). FID was fired by hydrogen and compressed air. Nitrogen was used as carrier at a flow rate of 30 ml/min. The oven temperature was maintained at 45^{o}C, injector at 80^{o}C and detector temperature at 150^{o}C. Standard curve was prepared from standard CH_4 (180 ppmv) obtained from EDT Research, London supplied by Nucon Eng. Ltd (Delhi).

2.3 Estimation of methane emission

Rate of CH_4 emission were estimated by using the following equation:

$$CH_4 flux(mgm^{-2}h^{-1}) = \frac{(BV_{stp} \times C_{CH4} \times 16 \times 1000 \times 60)}{(106 \times 22400 \times A \times t)}$$

$BV_{stp} = \frac{(BV \times BP \times 273)}{[(273+T) \times 760]}$, where BV_{stp} Box air volume in cc at STP

$BV = H \times L \times W$ – *(volume of biomass inside the chamber)*

H = Height of the chamber

L = Length of the Chamber

W = width of the Chamber (cm)

C_{CH4} = difference in CH_4 concentration in (ppm) between t_0 and t_x sampling

A = area covered by the chamber in m^2

Total volume of the biomass inside the enclosure was deducted from the internal volume of the chamber during calculation. The volume of the biomass was calculated by considering *Scirpus* leaves as cone. Height and the base diameter of *Scirpus* leaves inside every enclosure were recorded to calculate the volume of total biomass. All the measurements were carried between 10:45 am to 3:45 pm.

2.4 Biomass estimation

Biomass was estimated by harvest method at monthly interval. Aboveground (AG) and belowground (BG) biomass from an area of 50 × 50 cm were harvested form the wetland in triplicates, brought to the laboratory and washed under running tap water to remove the soil and silt. The biomass was further segregated into species and AG, BG, inflorescence, litter etc. Further the biomass were enclosed in brown paper and dried in oven at 80^{o}C till constant weight. The weight of the dried biomass was recorded on a scale balance.

3. Results

Higher rate of emission was observed during February to April from both areas dominated with and without macrophytes. Methane emission showed a wide variation over *S. littoralis* dominated region and it ranged between –0.36 ± 0.27 to -0.664 ± 0.27 *mg m^{-2} h^{-1}* from September to January, 129.82 ± 19.08 *mg m^{-2} h^{-1}* to 2.986 ± 0.14 *mg m^{-2} h^{-1}* during February to April, -2.074 ± 1.34 *mg m^{-2} h^{-1}* to 0.075 ± 0.007 *mg m^{-2} h^{-1}* between May to July. (Fig 2) Whereas, over the areas devoid of any vegetation it ranged between 0.56 ± 0.29 *mg m^{-2} h^{-1}* and 0.0014 *mg m^{-2} h^{-1}* during September to January, 32.42 ± 13.94 *mg m^{-2} h^{-1}* and 2.75 ± 1.71 *mg m^{-2} h^{-1}* between February to April and -0.16 *mg m^{-2} h^{-1}* to 0.29 during May to July. A net total annual flux of 201.23 *mg m^{-2} h^{-1}* over *S. littolaris* dominated areas and 41.74 *mg m^{-2} h^{-1}* over areas without macrophytes is obtained.

Aboveground biomass of *S. littoralis* (Table 1) ranged between 123 ± 16.21 g/m^2 in April to 362.56 ± 81.97 g/m^2 in October, whereas, belowground ranged between 71.14 ± 0.48 g/m^2 in July to 1816.53 ± 395.98 g/m^2. The total biomass ranged between 553.90 g/m^2 in May and 2669.89 g/m^2 in January. The average rate of carbon fixation ranged between 3.4 g m^{-2} day^{-1} in November to a maximum of 55.2 g m^{-2} day^{-1} in January.

4. Discussion

In the present study, areas dominated by *S. littoralis* were found to emit CH_4 at higher rates than from the areas devoid of macrophytes. The rate of CH_4 emission was high in summer and low in winter. The higher rate of emission during March to April from areas dominated by *S. littoralis,* could be due to the several favourable conditions taking place simultaneously. Factors such as temperature (41- 29 ^oC) water level (16.5 to 3.25 cm) and decaying macrophytes were favorable for methanogenesis. Primary production providing fresh organic material for degradation is known to be one of the most important variables controlling CH_4 emissions from wetlands (Whiting & Chanton, 1992). It is also reported that up to half of the annual CH_4 emissions from eutrophied boreal lakes can be emitted during a short period in spring (Huttunen, et al., 2003). It was followed by a dry summer when most of the aboveground vegetation disintegrated. In absence of water, anaerobic condition could not prevail, hence negative or no emission of CH_4 was observed. The water table changes had a remarkable effect on CH_4 fluxes and this decrease in the water table decreases methane flux (Cui, *et al.,* 2005). Exposed soil surface of wetlands can become a net source of atmospheric CO_2 as photosynthesis is decreased and respiration loss is enhanced. This spatial and temporal variation in rate of emission is in conformity with other studies (Verma, *et al.,* 2002). Negative emission rates were observed during the months of April and May from Sundarban mangrove near Bay of Bengal (−10 to −42 $\mu g\ m^{-2}\ s^{-1}$ approx.) (Mukhopadhay, *et al.,* 2002). An earlier study also confirmed that swamp soils can act both as a source and sink for atmospheric methane (Harriss, *et al.,* 1982). In a waterlogged condition, swamp soils are a net source of methane to the atmosphere whereas during drought conditions, swamp soils consume atmospheric methane.

Post monsoon (September and October), water level rose to 44.6 cm, with little organic matter in its substrate, the rate of CH_4 emission was low (0.03±0.02 to 0.17±0.15 $mg\ m^{-2}\ h^{-1}$). Although significant amount of standing biomass was observed (Table1) and temperature ranged between 29.3 to 33.6 ^oC, lack of organic matter in the substratum could be the reason for low rate of emission. The accumulation of organic matter is generally high in wetlands soil during the summer and pre-monsoon seasons. High rate of decomposition of organic matter creates oxygen stress, eventually resulting in the formation of CH_4 in the subsurface (Purvaja & Ramesh, 2000).

No CH_4 emission was observed during winter months (December to January), that was inferred from negative emission rates of emission. During the wet season, immediately following the monsoon, the height of the water restricts the transfer of CH_4 from the subsurface to the atmosphere, resulting in a decrease in CH_4 flux rates (Purvaja & Ramesh, 2000). Besides, decrease in daily temperature (27.3 to 19.3 ^oC) inhibited methanogenesis, as the optimum range of temperature for methanogenesis has been found to be 25 to 30 ^oC (Dunfield, et al., 1993) and 30 to 32 ^oC (Parashar, *et al.,* 1994). Methane flux rates is generally high during summer and pre-monsoons, indicating that soil temperature has a major influence over methanogenesis.

Highest rates of emission were recorded during spring season (March) over *S. littoralis* dominated areas and over areas devoid of macrophytes. The possible reasons for higher emissions during this time of year may be explained by several favorable physical and chemical processes taking place simultaneously. Factors such as shallow water level (15.3 cm) maintains required redox potential for methanogenesis (>-250 mV), gradual death of standing biomass adds to substrate organic matter; and, the temperature range is optimum for methanogenesis (35 ^oC). *In vitro* incubation of wetland sediment under anaerobic conditions indicated a progressive decrease in benthic methanogenesis with sediment desiccation and exposure to air (Boon, *et al.,* 1997). Ephemerally inundated floodplain wetlands may be sites of significant CH_4 emission, especially over the summer months. Months following the spring are hot and dry, exposing the wetland substrate, thereby shifting the anaerobic condition of sediment to aerobic condition. Negative CH_4 emission rates observed during this period (April till July) exhibited a distinct seasonal pattern. The negative emission rates could be also due to consumption of CH_4 by methanotropic bacteria present in the surface of soil at the interface of aerobic and anaerobic environments (Neue & Roger, 1993).

The standing biomass observed during this study is in conformity with studies done earlier (Sah, 1993). The peak biomass observed during January, could be due to abundant standing water and favorable temperature. The aboveground biomass of *S. littoralis* showed a decline during the hot and dry periods, explaining the aquatic characteristic of the plant.

However, these values alone cannot be considered to estimate annual CH_4 emission from tropical wetlands as there are wide spatial and temporal variations within the wetlands of tropical regions. Studies with small sample sizes (premonsoon, monsoon and post-monsoon) are insufficient to calculate the yearly CH_4 emission. Methanogenesis is influenced by a range of factors, such as anaerobic conditions, organic matter, pathway of its release to the atmosphere, soil temperature, soil pH etc. As these factors vary from site to site, extrapolation for larger wetlands areas is not accurate. In light of this inherent problem, it is important to have more representative values from more specific bio-geographical locations to enable meaningful estimation.

5. Conclusion

The rate CH_4 emission and carbon fixation in a subtropical wetland have shown high seasonality and spatial variation. The study has observed that there is a distinct pattern of CH_4 emission, which follows a seasonal trend directly coinciding with the temperature, decomposing biomass, declining water level and growth of the dominant macrophyte. In general, the areas dominated by *S. littoralis* were found to emit more CH_4 than the areas devoid of the macrophytes. In an annual cycle, wetlands exhibit both as a source and sink for CH_4 emission, and positive flux rate could be obtained only during certain months, in our study this being evidenced during January to April. Therefore, extrapolation of single value of rate of emission for the entire year is not correct in estimating total annual CH_4 emission from tropical wetlands. The rate of carbon fixation also followed distinct seasonality with average rate of carbon fixation highest during January and lowest in November.

Acknowledgements

Authors are thankful to Prof. Brij Gopal, School of Environmental Sciences, Jawaharlal Nehru University, New Delhi for his academic input and evaluation.

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Table 1. Biomass of *Scirpus littoralis* and other plants sampled at monthly interval

Months	***S. littoralis* (AG)**	***S. littoralis* (BG)**	***Cyperus* sp. (AG)**	***Cyperus* sp. (BG)**	**Grasses (AG)**	**Grasses (BG)**	**Litter & BP**	***Suaeda* sp.**	***Echinochloa* sp.**	***Bacoppa* sp.**	**Inflorescence**	**Dry Standing Biomass**	**Total g/m^2**
September	14.00	107.35			323.04	35.28	88.64						568.31
October	446.51	234.77					106.39		277.60	224.00	10.99	17.00	1317.25
November	183.56	248.68			74.04	19.28	83.82		207.12		3.86	25.00	845.36
December	188.36	328.07	60.96	21.64	102.63	28.17	107.51			113.34	7.36		958.03
January	299.60	1816.53			277.56	11.48	264.72						2669.89
February	125.53	318.48			61.60	80.48	169.73	76.64					832.47
March	144.90	616.22	13.68	10.56			227.36			163.80		52.04	1228.56
April	123.22	414.22	35.36	29.60	152.36		132.90		251.30		4.92		1143.88
May	0.00	215.24					119.06		219.60				553.90
June	0.00	240.08	207.60	26.32			214.77						688.77
July	0.00	659.43			290.80		232.55					61.48	1244.25

Figure 2. Area and extent of Bhalsawa lake in Delhi showing the sampling location

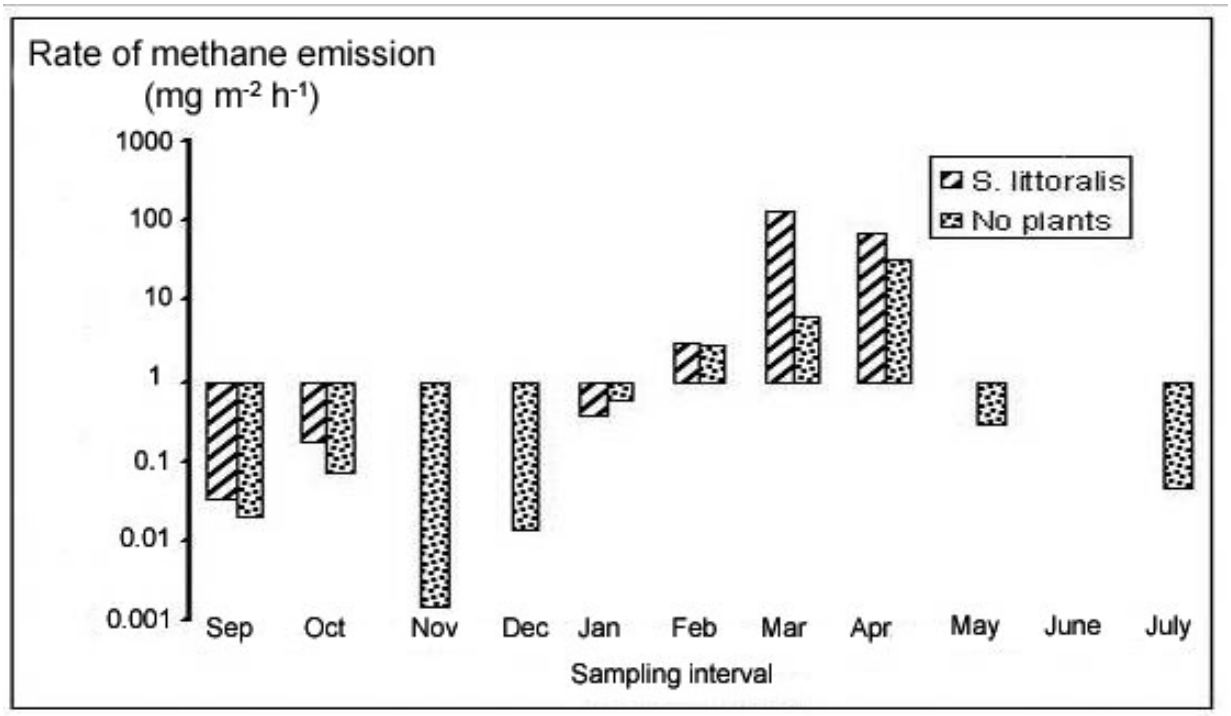

Figure 3. Average rate of Methane emission from *S. littoralis* dominated wetland