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Methane emissions from a coastal lagoon: Vembanad Lake, West Coast, India

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Importance of the work: Vembanad Lake is the largest coastal lagoon of Kerala, West Coast of India. It exhibits a wide variety of environmental conditions, which is primarily controlled by the existing salinity gradient and anthropogenic influence. Not much work has been done to understand the fluxes of methane from these tropical coastal wetlands. This data will help assess the contribution of methane from such wetlands to the global methane budget, which are largely speculative and extrapolations in the present calculations.

Abstract

An attempt has been made to estimate methane fluxes from a tropical coastal wetland the Vembanad Lake, a lagoon along the West Coast of India. It has been found that Vembanad Lake contributes significant amount of methane to the atmosphere. Average emissions varied spatially within the lake. Methane emissions were 193.2 ± 24.5 mg m^{-2} h^{-1} at Kumaragam (fresh water) as compared to 9.3 ± 9.6 mg m^{-2} h^{-1} at Pullot (brackish water) site. Seasonal variation was significant between pre- and post-monsoons. Soil temperature, time of the day, salinity sediment organic carbon, all control the rate of methane emissions from the Vembanad Lake.

Keywords: Methane emission; Variation; Coastal; Vembanad; Wetland

1. Introduction

Methane (CH_4) contributes to enhanced greenhouse effect and hence is of global concern. The total annual global CH_4 emissions are estimated to range from 420 to 620 Tg yr^{-1} (Khalil and Rasmussen, 1990) of which, 70–80% is of biogenic origin. Coastal wetlands are biologically productive regions of the ocean and appear to be responsible for about 75% of oceanic CH_4 emissions (Bange et al., 1994). Methane emissions within individual wetland regime are highly variable, both spatially and temporally, due to the heterogeneity of environmental variables.

Dissolved oxygen (DO) is a major inhibitor of CH_4 production and is toxic to methanogens causing survival of other bacterial biomass, which compete for substrates such as acetate, formate and hydrogen (Neue and Roger, 1993). Yagi and Minami (1990), Parashar et al. (1991) and Singh et al. (1998) have shown that abundant supply of organic matter and substrate are important for CH_4 production and emission from rice paddy fields. Soil temperature is critical in determining the production and emission of CH_4 from the subsurface to the atmosphere. It has been established that the optimum temperature for methane production in tropical wetlands ranges from 30 to 32 °C (Parashar et al., 1993).

Soil texture and mineralogy also has an effect on the net CH_4 emission from the waterlogged paddy soils (Neue et al., 1990; Parashar et al., 1991). Bender and Conrad (1994) showed that bulk of CH_4 oxidizing

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activity is attached with small mineral fractions (as clay, silt and fine sand). Electron acceptors other than O_2 like NO_3, NO_2, Fe^{3+}, Mn(IV) and SO_4, may also inhibit methanogenesis by stimulating the activity of other bacteria, which out compete methanogens for the reduced substrates. These substances tend disappear with depth in the sediment and thus methanogenesis occurs below the zone of depletion of other electron acceptors (Westermann, 1993; Roden and Wetzel, 1996; Ramesh et al., 1997).

Vembanad Lake is the largest lagoon on the Kerala coast with a distinct spatial freshwater-marine stratification. In this paper, measurements of CH_4 emission from the Vembanad Lake (a coastal lagoon) have been made with emphasis on the seasonal and spatial variations, the daytime fluctuations and the significance of various environmental factors influencing CH_4 emissivity.

2. Study area

Vembanad Lake occupies an area of ~256 km^2, extending from 9°30′N to 10°20′N lat and 76°13′E to 76°50′E long, with many rural and urban settlements surrounding it. The local community extensively utilizes this lake for fishing and aquaculture. In addition, fermentation of coconut husk for coir manufacture is being carried out extensively on the surface waters of the lake. Treated and untreated sewage also finds its way into the lake. The lake has two openings to the Arabian Sea, one at Gangannore and the other at Cochin. The five main rivers of Kerala (i.e.) Periyar, Muvattupuza, Meenachil, Manimala, Achankovil and Pamba discharge about 10 057 Mm^2 annually into the lake (Water Atlas of Kerala, 1995).

For the purpose of flux measurements of CH_4 spatially, the lagoon was categorized into four sectors (Fig. 1) on the basis of environmental and anthropogenic influences.

1. Pullot: The salinity of this location varies from 5‰ to 14‰ during the post- and pre-monsoon seasons respectively. Fermentation of coconut husk is carried out extensively in this location. The sediment texture is a mixture of sand and silt (silt = 22.08%, sand = 54.52%).
2. Venupady: Located near the city of Cochin (Fig. 1), this site receives treated and untreated wastes from the city. Also, because of the confluence of the lake with the Arabian Sea, the salinity of the surface waters is higher than in the other sections of the lake. Semi-diurnal tides flush the lake periodically at this site, with tidal amplitude of about 1.0 m. The sediments were sandy in nature (silt = 23.68%, sand = 68.13%).
3. Thaneermukham: This location receives considerable freshwater discharge resulting in the dilution of the surface waters. The most predominant anthropogenic influence on this location is fishing. The sediments are characterized by high sand content (silt = 26.37%, sand = 63.35%).
4. Kumaragam: Land reclamation area, with dense emergent vegetation and macrophytes such as water hyacinth, suggesting input of high organic load. Such locations account for ~5% of the lake environment. The sediment is a mixture of sand and silt (silt = 44.98%, sand = 48.26%).

3. Materials and methods

Flux measurements of CH_4 were undertaken at four sites in the Vembanad Lake (Fig. 1) during post-monsoon (December 1997) and pre-monsoon (March 1998) using the static chamber technique. An aluminum base with the dimensions 12 in. × 12 in. × 3 in. (length × width × height) was inserted into the sediment at least a few hours before sampling. A Perspex glass chamber of dimensions 12 in. × 12 in. × 18 in. (length × width × height) was placed on the groves of the aluminum base and a detailed description for CH_4 flux measurements is given in Purvaja and Ramesh (2000). The gas collected was stored and transported in a number of vials, sealed immediately after collection (Subramanian and Verma, 1998). Triplicate analysis for each sample was made and the limits of variability were within ±3%. Diel measurement of CH_4 emission was made during the pre-monsoon season for a period of 7 h during the day beginning from 9 a.m. until 4 p.m. Gas samples were collected at regular intervals of 1-h duration. We also monitored air, soil and water temperatures in situ. In addition, water level fluctuations within the chamber were continuously monitored. Gas samples were analyzed for CH_4 using a HP 5890 Gas Chromatograph, fitted with a flame ionization detector and Porapak Q Column. Nitrogen was used as a carrier and flow was maintained at 30 ml min^{-1} (Purvaja and Ramesh, 2000). Analysis of other environmental variables (Table 1) was performed using standard procedures (APHA, 1985).

4. Results and discussion

4.1. Seasonal variation in methane emission

Methane fluxes showed a wide variation among the sites and ranged from 2.54 to 175.91 mg m^{-2} h^{-1} in pre-monsoon and from 16.12 to 210.59 mg m^{-2} h^{-1} in post-monsoon (Table 2). The average CH_4 emission from the freshwater site (Location 4) was over 10 times higher than that of the brackish water site (Location 1). The

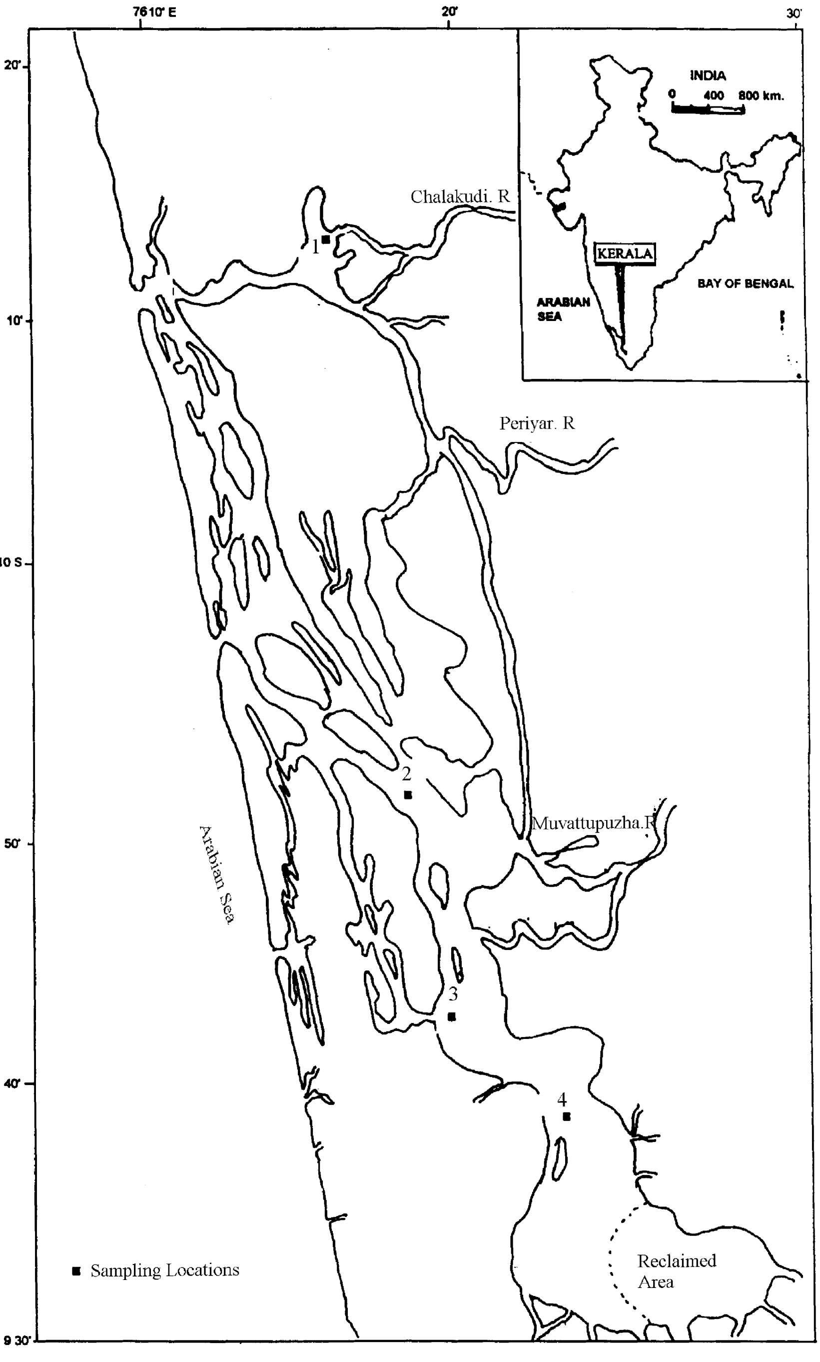

Fig. 1. Sampling locations on Vembanad Lake with inset showing the location of Kerala in India.

fluxes obtained in this study was larger in comparison to those obtained for the coastal wetlands along the east coast by Ramesh et al. (1997) and Verma et al. (1999).

Methane emission in this study shows a strong negative correlation with SO_4 ($r^2 = -0.83$) and salinity ($r^2 = -0.72$). Sulfate concentrations were high in the brackish water site in comparison to the freshwater sites (Table 2) due to the incursion of tidal waters from the Arabian Sea. At these locations however, the CH_4 fluxes were significant despite the inhibiting influence of SO_4 in the surface waters (Locations 3 and 4). Our earlier study on the Adyar estuarine system along the Bay of Bengal showed high fluxes of CH_4 as observed in this study (Ramesh et al., 1997; Verma et al., 1999; Purvaja and

Table 1
Methods of analysis of various parameters

Parameter	Method
Methane	HP gas chromatograph (GC, model: HP 5890)
TOC (sediment C)	Eltra CS-1000 C-analyzer
TN (sediment N)	Nitrogen analyzer NA-1500 from Carlo-Erba
Salinity	Mohr's titration
Nitrate, phosphate, sulfate	Colorimetric
Iron, manganese	GBC-902 AAS

Ramesh, 2000) to the presence of non-competitive substrates such as methylated amines and dimethyl sulfide (Omerland, 1988).

Methane emission shows negative correlation with electron acceptors such as dissolved iron ($r^2 = -0.77$), dissolved manganese ($r^2 = -0.98$), sediment iron ($r^2 = -0.61$) and sediment manganese ($r^2 = -0.57$). These electron acceptors out compete methanogens for the reduced substrates. It is known that neither sulfur reducers nor methanogens can dominate in anaerobic sediments, until all reducible Fe^{3+} oxide are depleted as they compete for organic substrates with methanogens (Lovely, 1991). However, in marine sediments, reduction of sulfate is more dominant as sulfate binds with iron under these conditions to form sulfides and hence making iron unavailable for microbial working. Thus, there can be a coexistence of sulfur reducers and iron reducers in the marine and coastal sediments. Such conditions can be thought to exist in the Vembanad Lake.

4.2. Spatial variations in methane emission

Pullot is a low salinity site (4.6‰ and 14.12‰) and has recorded low CH_4 efflux during the post- and pre-monsoon seasons. This may be due to the presence of high sulfate content (1949 and 2133 mg l^{-1}) in this location. Sulfate in this location is derived mainly from large-scale coconut husk fermentation. The continuous fermentation of husk creates oxygen stress leading to hypoxic and sometimes anoxia surface waters. Because of this process, hydrogen sulfide formed and is released to the overlying water column. H_2S on its migration upwards through the water column becomes oxidized to sulfate in the oxic zone. Thus, in these sediments, mineralization of organic matter is mainly through sulfate reduction and hence lower methane efflux.

Venupady has higher salinity (10.98–12.69‰) but also higher CH_4 emission (Table 2). This is due to higher amount of organic carbon (2.75–2.94%) in the sediments. It is believed that both the methanogens and the sulfate reducers co-exist under two possible conditions (i) availability of competitive substrates that allows the existence of both methanogens and sulfate reduces and (ii) presence of non-competitive substrates such as methylated amines which are utilized exclusively by the methanogens for methanogenesis (Omerland, 1988). It is possible that either of the above conditions may have been prevalent in the present study.

Thaneermukham and Kumaragam are freshwater sites with seawater intrusion in summer with low CH_4 emissions during pre-monsoon as compared to post-monsoon (Table 2). The low sulfate content (75–805 mg l^{-1} and 72–615 mg l^{-1} respectively) in these sediments enhances high production of CH_4 from these locations. In fresh-water sediments, concentration of sulfate and nitrate is low; thus methanogenesis is dominant and responsible for mineralization of organic carbon in the sediments. The presence of water hyacinth at Kumaragam, helps the plant transport CH_4 through aerenchyma from sediments to surface. This mechanism leads to bubble ebullition in this location.

Table 2
Seasonal methane efflux and other environmental variables in Vembanad Lake, West Coast of India for different locations

Parameter	Pullot		Venupady		Tanneermukham		Kumaragum	
	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon
Methane (mg m^{-2} h^{-1})	16.12	2.54	51.43	4.30	138.48	3.80	210.59	175.91
Salinity (‰)	4.6	14.24	10.98	12.69	0.04	3.52	0.02	3.19
SO_4^{-2} (mg l^{-1})	1949	2133	3112	1745	75	805	72	615
P–PO_4^{-3} (mg l^{-1})	0.064	0.064	0.159	0.491	0.219	0.188	0.064	0.197
N–NO_3^- (mg l^{-1})	4.1	37.4	2.6	5.5	2.8	25.9	1.0	18.8
Diss Mn (mg l^{-1})	0.04	0.03	0.01	0.13	0.03	0.04	0.01	0.04
Diss Fe (mg l^{-1})	0.87	1.13	0.87	2.15	1.38	1.64	1.12	0.61
Sediment C (%)	2.99	1.58	2.94	2.75	0.54	0.35	0.11	0.04
Sediment N (%)	0.171	0.103	0.263	0.265	0.02	0.014	0.013	0.006
Sediment Mn (%)	198	198	593	593	593	593	198	198
Sediment Fe (%)	3.22	3.22	0.69	0.69	4.75	4.75	0.35	0.35

4.3. Daytime variation in methane emission

Daytime variation in methane efflux was measured at all four sites during the pre-monsoon season to understand the effect of soil temperature and tidal fluctuations on CH_4 emission. There is an appreciable variation in methane efflux during the day at all the locations (Fig. 2). The average soil temperature in the study area at the time of sampling ranged from 29.0 to 33.0 °C (Fig. 2). Soil temperature significantly affects the activity of soil microorganisms and the optimum temperature for CH_4 production in this environment is between 30 and 33 °C (Ramesh et al., 1997; Verma et al., 1999).

The peak methane efflux is obtained at noon coinciding with increase in atmospheric temperature excepting at Venupady. Maximum rates in CH_4 emission has been observed at Kumaragam, due to excessive organic pollution and the domination of aquatic macrophytes (water hyacinth) in this location. The area under major coastal wetland categories of India as given by the Space Application Centre (1992) has been used for computing the probable CH_4 emissions from the coastal wetlands (Table 3). The minimum and maximum CH_4 emission observed at Vembanad Lake was used to predict the range in CH_4 emission for the coastal wetlands of India. CH_4 emissions form Kumaragam has not been

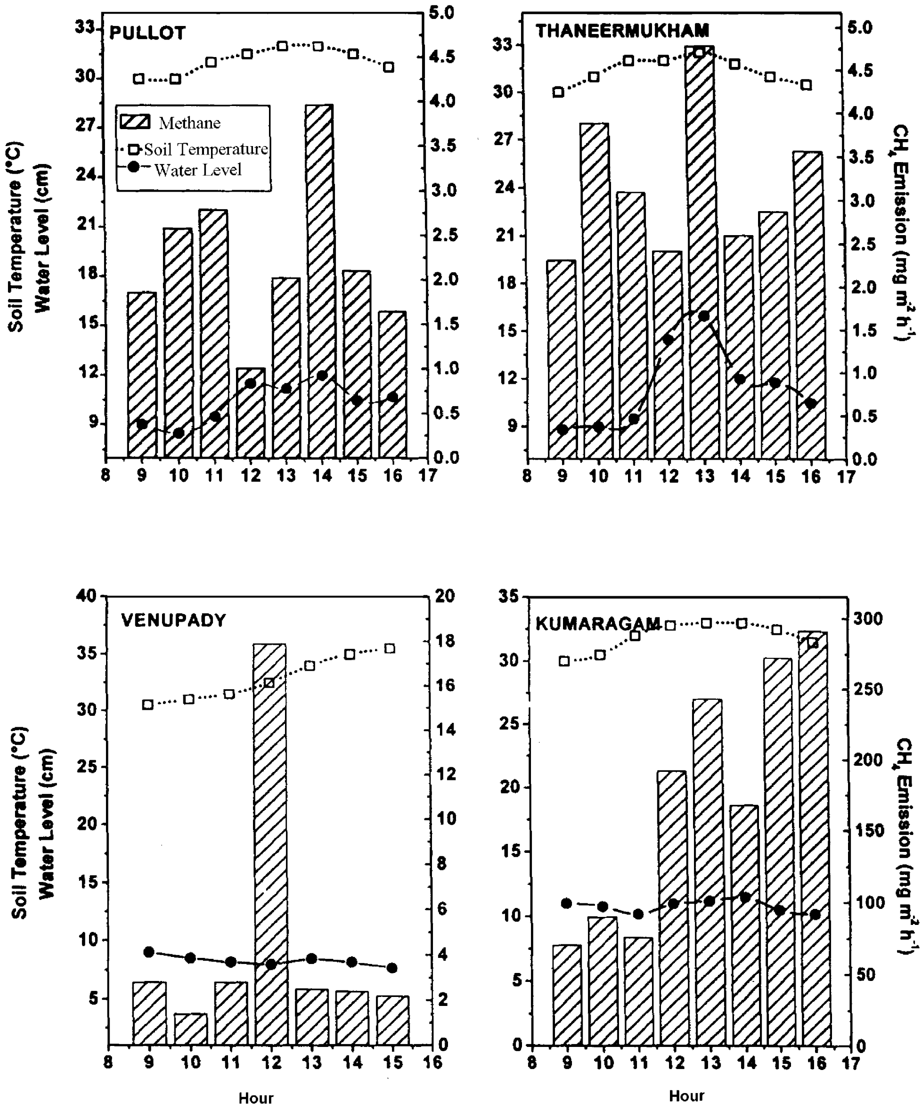

Fig. 2. Variation of methane, water level and soil temperature during the day at various locations in Vembanad Lake during pre-monsoon.

Table 3
Range in methane efflux from coastal wetland ecosystem of India

Wetland category	Area (km^2)	Range in CH_4 emission (10^{12} g yr^{-1})	
		Minimum	Maximum
Mudflat	22 961	0.424	13.81
Mangroves	3979	0.074	2.39
Marsh vegetation	370	0.007	0.22
Mudflat with vegetation	6125	0.113	3.68
Lagoon/backwater	2132	0.039	1.28
Flood-prone area	3437	0.064	2.07
Reclaimed area	1212	0.022	0.73
Total	40 216	0.743	24.19

A minimum value of 2.11 mg m^{-2} h^{-1} and maximum 68.67 mg m^{-2} h^{-1} have been used to calculate the range of CH_4 emission from the coastal ecosystems of India. CH_4 Tg yr^{-1} = CH_4 emission (g km^{-2} h^{-1}) × 24 × 365 × Areal extent of coastal wetlands (sq km).

used as it represents a small section of the lake under severe stress due to human activities. Based on this, annual CH_4 emission ranges from 0.74 to 24.19×10^{12} g yr^{-1}.

5. Conclusion

Tropical wetlands contribute to increased CH_4 to the atmosphere, due to high temperature and high rates of organic matter decomposition. The methane emission from the Vembanad Lake shows both temporal and spatial variation. The spatial variation is largely due to the salinity gradient across the lake. Higher CH_4 values are reported from the southern parts of the lake, which is mostly freshwater and due to presence of emergent vegetation. Seasonal variation in the methane emissions is due to dilution effect by the input of freshwater from the rivers. Daytime variations in CH_4 emissions suggest increases with increasing atmospheric temperature. Also, from our results, it is evident that tropical coastal wetlands contribute to CH_4 increases in the atmosphere especially when anthropogenically disturbed.

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