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# Factors influencing spatio-temporal variation of methane and nitrous oxide emission from a tropical mangrove of eastern coast of India

Rita Chauhan [a, b], Arindam Datta [c, *], AL. Ramanathan [a], T.K. Adhya [d, e]

[a] School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India
[b] Indira Gandhi National Open University, New Delhi 110068, India
[c] Center for Environmental Studies, Earth Sciences and Climate Change Division, The Energy and Resources Institute, New Delhi, 110003, India
[d] Soil Science and Microbiology Laboratory, Crop Production Division, Central Rice Research Institute, Cuttack 753006, India
[e] School of Biotechnology, KIIT University, Bhubaneswar, 751024, India

## HIGHLIGHTS

- Seasonal and tidal variability of $CH_4$ and $N_2O$ emission from mangrove sediment.
- Significantly higher $CH_4$ and $N_2O$ emission during winter season.
- Allochthonous materials control the seasonal variation of $N_2O$ emission.
- $N_2O$ emission was significantly higher during low tide.
- Tidal variation of gaseous emissions were attributed to sediment temperature, salinity and pH.

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## ABSTRACT

We have studied the seasonal and tidal variation of methane ($CH_4$) and nitrous oxide ($N_2O$) emission from the intertidal sediment of Bhitarkanika mangrove in the east coast of India. Seasonal variability study was conducted at five sites (three replicate of each site) inside the core area of the national park during three different seasons (summer, monsoon and winter) whereas tidal variation was studied at three different sites outside the core area during monsoon and winter season. Both $CH_4$ and $N_2O$ emission from the intertidal sediment were significantly higher under the low tide condition during the winter season. During the study period $CH_4$ emission from five different sites was ranged between 0.08 and 2.30 mg $m^{-2}$ $h^{-1}$ and the $N_2O$ emission was ranged between 9.0 and 187.58 μg $m^{-2}$ $h^{-1}$. Average seasonal $N_2O$ emission (μg $m^{-2}$ $h^{-1}$) from five different sites followed the order: winter (115.60 ± 21.90) > summer (45.29 ± 7.78) > monsoon (16.98 ± 2.54). $CH_4$ and $N_2O$ emission was also recorded significantly higher during the winter season over the tidal cycle of three sampling locations. The $CH_4$ emission was negatively correlated with sediment salinity ($r = -0.91$, $P < 0.05$) and $SO_4^{-2}$ ($r = -0.89$, $P < 0.05$) concentration whereas; the $N_2O$ emission was positively correlated with sediment salinity ($r = 0.48$) and $NO_3^-{-}N$ ($r = 0.88$, $P < 0.05$) concentration during the monsoon season. Positive correlation of $N_2O$ emission with the sediment $NO_3^-{-}N$ indicates possible influence of upstream anthropogenic activities on $N_2O$ emission from the mangrove sediment. In general, methylamine utilizing methanogen and denitrifying bacterial population was significantly higher during winter season in the mangrove sediment. The study concludes that the $CH_4$ and $N_2O$ emission from the sediment at different sites during different seasons are influenced by allochthonous carbon and nitrogenous materials.



## 1. Introduction

Methane ($CH_4$) and nitrous oxide ($N_2O$) are two important greenhouse gases (GHG) with global warming potential (GWP) of 34 and 298 respectively (Myhre et al., 2013). At present, global

* Corresponding author.
*E-mail address:* arindam.datta@teri.res.in (A. Datta).

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ambient mixing ratios of $CH_4$ and $N_2O$ are 1.89 μmol mol$^{-1}$ and 326 nmol mol$^{-1}$ respectively compare to their respective pre-industrial value of 0.7 μmol mol$^{-1}$ and 296 nmol mol$^{-1}$ (NOAA, 2014). It has been estimated that natural sources account for 37% of total $CH_4$ and 64% of total $N_2O$ emission to the atmosphere (EPA, 2010). However, large spatial and temporal variations in the emission of these gases attribute to higher uncertainty in their estimation (IPCC, 2007). Climate driven fluctuation of GHG emission from the natural wetland and coastal ecosystems is the major driver of the global inter annual variability of GHG emission (Stocker et al., 2013).

Mangrove ecosystem is one of the natural coastal habitats of the tropics. It provides a diverse array of ecosystem services e.g. fishery production, coastline protection, pollution buffering, and high rates of atmospheric carbon sequestration (Alongi et al., 2002). Large amount of suspended organic/inorganic matter are brought into the mangrove by tides and rivers from the marine sources and upper catchment areas respectively. Further, periodic fluctuation of freshwater and salt water intrusion leads to short term fluctuations in sediment salinity, acidity, redox potential (Eh), organic matter and nutrients that affects the oxidation condition of the sediment. This creates suitable environment for the production of GHG (e.g. $CH_4$ and $N_2O$) through microbial activities (Alongi, 2005).

$CH_4$ is produced during the terminal stage of anaerobic decomposition of organic matter by methanogens under the anoxic environment of the sediment (Ferry et al., 1992). On the other hand, $N_2O$ is produced by nitrification process via microbial transformation of ammonium ($NH_4^+$–N) to nitrate ($NO_3^-$–N) through nitrifiers under aerobic conditions or by denitrification process that involves the microbial reduction of $NO_3^-$–N to $N_2$ under anaerobic conditions (Conrad, 1995). However, the GHG production and emission from the mangrove have been found to vary geographically, based on variations in natural factors like temperature, salinity and organic carbon content of the sediment (Dacey et al., 1994). In addition, several anthropogenic factors, like disposal of sewage and agricultural runoff into the mangrove ecosystem enhance the GHG emission. The availability of nitrogenous compounds and the oxidation state of the sediment determine the process of microbial transformation of the nitrogenous compound (Corredor et al., 1999).

Most studies of GHG emission from the coastal ecosystems are reported from the temperate and sub-tropical regions. However, published literature on GHG emission from tropical mangroves is rare (Corredor et al., 1999; Allen et al., 2007). Further, the direct measurement of $CH_4$ and $N_2O$ emission at tidal scale from mangrove ecosystem has been sparingly studied (Lu et al., 1999; Barnes et al., 2006; Allen et al., 2007). Most of the reported studies have estimated the $CH_4$ and $N_2O$ emission from mangroves through indirect flux measurement from dissolved GHG concentration gradient method (Mukhopadaya et al., 2001; Biswas et al., 2007; Divia et al., 2013; Linto et al., 2014). However, few studies have reported diurnal variation of $CH_4$ and $N_2O$ emission from mangrove measured through direct chamber method (Lu et al., 1999; Allen et al., 2007), but these studies did not cover the entire spectrum of variation of the tidal inundation of the sediment. However, it is required to investigate the GHG fluxes from the mangrove sediment over complete tidal inundation cycle and seasonal variations (Chen et al., 2010).

The GHG emission from the mangrove sediment is a microbial process. However, the microbial studies conducted over Indian mangrove ecosystem dealt mainly with structural aspect instead of their functional implications (Kathiresan and Selvam, 2006; Ramanthan et al., 2008; Thatoi et al., 2012; Torres-Alvarado et al., 2013). Again, a comprehensive study on the relationship of microbial population with $CH_4$ and $N_2O$ emission from the mangrove sediment over wide range of seasonal variation is limited.

We have estimated the GHG ($CH_4$ and $N_2O$) emission from the mangrove sediment at the Bhitarkanika mangrove located along the eastern coast of India with the objective to determine factors controlling the seasonal and tidal variability of $CH_4$ and $N_2O$ emission from the mangrove sediment. Based on the available literature, we hypothesized significant seasonal and tidal variability of GHG emission from the mangrove sediment. Initial survey of the study area indicates the possibility of large human influence in certain area of the mangrove.

This is probably the first report to establish the relationship among microbial dynamics and seasonal variations of GHG emission to understand the biogeochemical process of the mangrove sediment. Such studies are also imperative to deduce role of mangrove ecosystem towards the source/sink of GHG to global budget.

## 2. Materials and methods

### 2.1. Site description

The Bhitarkanika mangrove is located between Lat: 20°65′ to 20°80′N and Long: 86°80′ to 87°00′ E in the deltaic-estuarine region of Brahmani and Baitarani rivers in the northeastern part of Kendrapada district in Odisha state of India. It is the habitat for 55 different mangrove species out of 58 known mangrove species of India (DoF, 2010). The mangrove ecosystem harbors one of the largest population of saltwater crocodile in India along with 216 species of avifauna. Gahirmatha beach of the mangrove is the World's important nesting ground of the olive ridley turtles. It was declared Bhitarkanika wild life sanctuary with an area of 670 km$^2$ during 1972. The core area of the sanctuary (145 km$^2$) was notified as Bhitarkanika national park during 1998 and subsequently designated as a Ramsar wetland of International importance in 2002.

The study area experiences a humid tropical climate with three distinct seasons: summer (March to June), monsoon (July to October) and winter (November to February). During summer the temperature ranges from 20 °C (night) to 42 °C (day). The temperature of the area during winter varies between 15 °C and 28 °C. Average annual precipitation of the area is ~1700 mm; about 80% of that is received during monsoon through South-West monsoon. Relative humidity of the area ranges between 75 and 90% throughout year. The mangrove exhibits semidiurnal pattern of tidal cycle, that indicates the river flow is influenced twice daily by high and low tides at approximately six hourly intervals. The general elevation above mean tide level ranges from 1.5 to 2 m.

### 2.2. Sampling locations

Samples to estimate the GHG ($CH_4$ and $N_2O$) emission from the mangrove sediment and different sediment parameters (physical, chemical and biological) was collected from five sampling sites (Fig. 1: B1, B2, B3, B4, B5) in the core area of Bhitarkanika national park during three seasons (Summer, Monsoon and Winter) to study the seasonal variability. A short description of each sampling site is given in Table 1. Five replicate samples were collected from each sampling site during each season.

Three sampling sites (Dhamra: DA, Khola: KH and Gupti: GU) were selected in the intertidal zone to study the tidal variation (Fig. 1) of GHG emission during winter and monsoon season. All three sites were outside the core area of the national park. Any kind of sampling/activities are not permitted inside the core area of the national park after the dusk; hence, we had selected sites to study