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Whether conversion of mangrove forest to rice cropland is environmentally and economically viable?

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ABSTRACT

The diverse habitat of the mangrove ecosystems all over the globe are under continuous threat of conversion for immediate and/or short-term economic benefits. Nonetheless, the emission of climatically relevant greenhouse gases increases with the disturbance of the mangrove sediment – this might undermine the credible reservoir of carbon within the sediment. This article attempts to estimate the environmental (carbon emission) and economic consequences of converting mangrove to cropland (especially rice paddy) based on field-scale study at three different sites (Khola, Gupti and Damra) within the Bhitarkanika mangrove for two consecutive years. The study suggests that the cumulative methane (CH_4) emission was significantly higher from the rice paddy (211.3 kg ha^{-1}) compared to the mangrove sediment (50.8 kg ha^{-1}), while the average nitrous oxide (N_2O) emission was significantly higher from the later (2.1 kg ha^{-1}). Multivariate statistical analysis suggests that the land use was the prime controlling factor for variation in CH_4 and N_2O emission. Total carbon equivalent emission (CEE_{TOT}) from the rice paddy was significantly higher than mangrove during the study period. The study suggests that the economic value of the mangrove ecosystem was several folds higher than that of the rice paddy. The CEE_{TOT} of the Bhitarkanika mangrove has increased approximately 212 Gg over last few decades due to the conversion of the mangrove area to the rice paddy. Such studies are imperative in developing effective regional climate change adaptation strategies. The study advocates urgent need to educate and aware people about the benefits of the mangrove compared to the cropland.

1. Introduction

Mangroves are one of the most biologically productive natural coastal ecosystems of the tropical region (Alongi, 2002). They play important role in climate regulation through the storage of significant amount of atmospheric CO_2 as the biomass and sediment carbon (Donato et al., 2011; Siikamaki et al., 2012; Pendleton et al., 2012). However, these ecosystems are also most threatened around the globe and continuously degrading due to severe anthropogenic pressures for infrastructure (port/road) development, expansion of agriculture (mainly rice), aquaculture and industry. Land conversion from mangrove to any other activities have severe implications to the ecosystem services with reduction of freshwater, excessive sediment load, habitat destruction, alteration of species composition and overall decline in biodiversity. It is suggested that worldwide mangrove deforestation generates emission of 0.02–0.12 Pg C yr^{-1}, which is close to 10% of the total emission associated with forest conversion (Donato et al., 2011). Conversion of mangrove forest area could increase the release large amounts of carbon stored in the sediment to the atmosphere in the form of methane (CH_4). Carbon loss from the system reduces the C/N ratio which increases the nitrous oxide (N_2O) emission through denitrification under anaerobic condition (Kishida et al., 2004). Over 100-year time frame, the global warming potentials (GWP) of CH_4 and N_2O are 34 and 298 times higher than that of CO_2 (Myhre et al., 2013) which is considered as a major atmospheric trace gas responsible for the global warming by the policy makers (IPCC, 2007).

In India, mangrove ecosystems cover approx. 4628 sq km of coast area (FSI, 2013). The Bhitarkanika, is one of the important mangrove area in eastern India with approximately 222 sq km of mangrove forest area extended along 35 km of coastline (Mishra et al., 2005) in the Kendrapada district, Odishalocated within the Bhitarkanika wildlife sanctuary and National Park (672 sq km) (UNESCO, 2009). The man-

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grove area was declared as Ramsar site of International Importance during 2002 (Ramsar, 2014). The Bhitarkanika mangrove ecosystem possesses largest nesting ground of the Olive Ridley turtles in the world, protected under Gahirmatha Marine Wildlife Sanctuary. Around 55 different mangrove species out of 58 total mangrove species of India are present in the Bhitarkanika mangrove (DoF, 2010). The dominant mangrove species of the Bhitarkanika mangrove are *Avicennia alba*, *A. officinalis*, *Rhizophora mucronata*, *Excoecaria agallocha*, *Acanthus illicifolius, Sonneratia apetala*, *Heritiera minor* etc. The mangrove ecosystem also harbors one of the largest populations of saltwater crocodile in India along with 216 species of avifauna. People from around 336 villages are dependent on Bhitarkanika mangrove ecosystem for fuel, fodder and other non-timber forest produce (fishery/aquaculture) (Badola et al., 2012). On the other side, rice cultivation is the most dominant and prime source of livelihood for the resource poor people in the coastal areas of Odisha. The fringe mangrove is facing continuous threat of conversion to agricultural field. Apart from this, the mangrove ecosystem of Bhitarkanika is also prone to natural calamities like cyclones annually due to its geographical location.

Agricultural land covers more than 50% of the Bhitarkanika wildlife sanctuary and accounts for more than 25% to the total income to the people of the Bhitarkanika mangrove area (Badola and Hussain, 2003). Earlier studies suggested that the agricultural activity increases the carbon loss (Lal, 2000), nitrogen leaching to the water bodies (EPA, 2010; McKague et al., 2005) and greenhouse gas (CH_4 and N_2O) emission from the soil (Robertson et al., 2000; Datta et al., 2012). Agriculture activities all over the world accounts for more than 50% (3.3×10^3 Tg CO_2 eq yr^{-1}) and 60% (2.8×10^3 Tg CO_2 eq yr^{-1}) of annual anthropogenic CH_4 and N_2O emissions respectively (Smith et al., 2007). Total amount of the mangrove forest area converted to agricultural field in four decades is significantly higher in the Bhitarkanika mangrove compared to other mangrove areas in India (Reddy et al., 2007).

An attempt was made to study the environmental and economic consequences of converting natural mangrove ecosystems to rice paddy in Bhitarkanika mangrove using the field-scale data. The CH_4 and N_2O emissions from both the mangrove and rice paddy were measured to study the environmental consequences of converting the land use. While survey and review based approach was employed to study the changes in the economic value of the land when mangrove area is converted to rice paddy.

2. Materials and methods

2.1. Description of study area

The study area was located between long. 86°48′ to 87°03′E and lat. 20°60′ to 20°80′N in the Bhitarkanika wildlife Sanctuary of the deltaic region of the Brahmani and Baitarani rivers in the northeastern part of the Kendrapada district and southeastern part of Bhadrak district of Odisha. The mangrove area is spread over Rajnagar, Rajkanika blocks of Kendrapada district and Chandbali block of Bhadrak district.

Cumulative annual precipitation in the area was about 1700 mm of which ~80% was received during August to September through Southwest monsoon. Annual temperature maxima and minima of the area were 30 °C and 15 °C respectively. Relative humidity remains between 75 and 80% throughout the year.

Three sites (Fig. 1) were selected for the study within the mangrove forest area. All sites were having mangrove forest area and nearby farmer's cropland converted from the mangrove forest in last 20–25 years. Samples were collected simultaneously from the cropland (rice paddy) area and mangrove forest at each site. The sampling site Khola (KH) [20.73°N and 86.82°E] was located near the confluence of the Baitarani and the Brahmani River. This site was dominated with freshwater mangrove species *viz. Rhizophora apiculata* and *Rhizophora mucronata*. Second sampling site Damra (DA) [20.76°N and 86.95°E] was located at the Dhamra mouth near the Bay of Bengal. The area is dominant with high salt tolerant species of *Avicennia* spp. Third sampling site Gupti (GU) [20.66°N and 86.84°E] was located near the Maipura creek representing mixing zone with fringing mangroves which are flanked with densely populated villages.

The study was conducted during the wet season (*Kharif:* June to December) of two consecutive years. During the summer season (*Rabi*: dry season) rice could not be cultivated in the area due to lack of fresh water and very high soil salinity. Additionally, summer is the breeding season of the saltwater crocodile and any activity inside the mangrove area during the breeding season was not permitted.

Standard crop management practice of the local farmers was followed in all croplands throughout the study. A salt tolerant rice variety (*cv. Canning 7*) was used in the cropland of all sites to avoid varietal variation of CH_4 and N_2O emission from rice paddy. Rice seedlings (20–25 days old seedling) were transplanted to the field (spacing: 15 × 15 cm and 2 seedlings $hill^{-1}$) with the onset of monsoon during the second week of July. The field was ploughed thoroughly to 15 cm depth with mould-board plough and flooded 2–3 days before transplanting for puddling and levelling. Phosphorus as single super phosphate (SSP) and potassium (K_2O) as muriate of potash (MoP) were applied to the field at 40 kg ha^{-1} as basal at the time of field preparation. Farm Yard Manure (FYM: organic carbon = 18–22%; total N = 0.5%) was added to soil at 5 Mg ha^{-1} during the month of April-May. A combination (2:1) of urea and ammonium sulfate (@120 kg N ha^{-1}) was broadcasted to field in three equal splits during seedling, maximum tillering and grain filling stages of the rice crop growth. No pesticide and herbicides were applied to any of the field during the growing season of rice, to avoid the additional influences on CH_4 and N_2O emission. Weeds were removed from the field manually at regular interval. Matured crop was manually harvested in middle of December when the field got dried.

2.2. GHG emission from crop land and intertidal mangrove sediment

At each sampling site, three replicated sampling locations were selected in both the mangrove and converted rice paddy. All sampling locations in the mangrove forest were selected in the intertidal zone. GHG sampling was conducted at each sampling location at 5 days intervals during the rice growing period (July–December) of 140 days.

All GHG samples from the rice paddy were collected between 8A.M. to 11A.M. (Adhya et al., 1994; Datta et al., 2012) to avoid the diurnal fluctuation of CH_4 and N_2O emission. Earlier study reported significant tidal variation of GHG emission (Chauhan et al., 2015) from the intertidal mangrove sediment. To avoid this effect of tidal variation, all the samples from the intertidal sediment of the mangrove area were collected within 3 h of the beginning of the low tide.

GHG emission from the mangrove sediments and rice paddy were measured using the manual closed chamber method. A 53 × 37 cm (length × width) aluminum baseplate was inserted to the crop land soil and intertidal sediment at each sampling location (3 × 2 × 3). The base plates were placed permanently in the rice field throughout the cropping period, whereas they were placed carefully in the sediment of the mangrove forest immediately after descending of the tidal water from the intertidal sediment. The base plates were left to settle at least for 1 h in the intertidal sediment before placing the air-tight chamber on it. Six rice hills were covered inside the aluminum base plate in the crop land; whereas, in the mangrove intertidal sediment, the baseplates were carefully placed that no pneumatophores were included inside the base plate. An air-tight perspex chamber (53 × 37 × 91 cm, length × width × height) was placed carefully (without disturbing the soil) on the base plate collect the gas samples from the rice field and the intertidal sediment of the mangrove forest. The head space gas sample from the chamber was collected in a 1L Tedlar[R] PVDF air sampling bags (with poly jaco valve) at 0 min, 15 min, 30 min, 45 min and 60 min interval using a battery operated air-circulatory pump