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Carbon sequestration by mangrove forest: One approach for managing carbon dioxide emission from coal-based power plant

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ABSTRACT

Mangroves are known as natural carbon sinks, taking CO_2 out of the atmosphere and store it in their biomass for many years. This study aimed to investigate the capacity of world's largest mangrove, the Sundarbans (Indian part) to sequester anthropogenic CO_2 emitted from the proximate coal-based thermal power plant in Kolaghat (~100 km away from mangrove site). Study also includes Kolkata, one of the largest metropolises of India (~150 km away from mangrove site) for comparing micrometeorological parameters, biosphere-atmosphere CO_2 exchange fluxes and atmospheric pollutants between three distinct environments: mangrove-power plant-metropolis. Hourly sampling of atmospheric CO_2 in all three sites (late December 2011 and early January 2012) revealed that CO_2 concentrations and emission fluxes were maximum around the power plant (360–621 ppmv, 5.6–56.7 mg $m^{-2}s^{-1}$ respectively) followed by the metropolis (383–459 ppmv, 3.8–20.4 mg $m^{-2}s^{-1}$ respectively) and mangroves (277–408 ppmv, −8.9–11.4 mg $m^{-2}s^{-1}$, respectively). Monthly coal consumption rates (41–57, in 10^4 ton $month^{-1}$) were converted to CO_2 suggesting that 2.83 Tg C was added to the atmosphere in 2011 for the generation of 7469732 MW energy from the power plant. Indian Sundarbans (4264 km^2) sequestered total of 2.79 Tg C which was 0.64% of the annual fossil fuel emission from India in the same time period. Based on these data from 2010 to 2011, it is calculated that about 4328 km^2 mangrove forest coverage is needed to sequester all CO_2 emitted from the Kolaghat power plant.

1. Introduction

As per IPCC AR5 (2014), in the past decade of 2000–2010, anthropogenic emissions of green house gases (GHGs) increased at a rate of 2.2% per year and reached up to 49 ± 4.5 Pg CO_2-equivalent per year in 2010 (1 Pg = 10^{15} g). Same report revealed that emissions of carbon dioxide (CO_2) from fossil fuel combustion and industrial processes contributed about 78% of that total GHGs emissions increase. Emissions of CO_2 from thermal power plants and cement industry are matter of concern because of their growing magnitude, the resulting increase in atmospheric concentrations of CO_2, the concomitant changes in climate, and the direct impact of increased atmospheric CO_2 on ecosystems and energy demand (Andres et al., 2012; Ciais et al., 2013). In 2012, fossil fuel combustion as well as cement industry contribute 9.7 ± 0.5 Pg C annually to the atmosphere which is 58% over 1990 (Le Quere et al., 2013; Peters et al., 2013). Reports also state that coal from thermal power industry shares the highest percentages (43%) towards global CO_2 emission while oil, gas and cement contribute the rest (Global Carbon Project, 2008). Despite decades of significant global warming, humanity is only now beginning significantly to address the reduction of CO_2 emissions caused by power generation and transport (IPCC, 2007). Hence, the reduction of CO_2 emissions must be humanity's paramount concern, and any cost-effective zero-carbon technology is preferable to a carbon emitting one. Strategy-makers have been developing many roadmaps to reach the carbon neutrality especially pertaining to the thermal power emission by undertaking different carbon offset projects. Biosequestration, the uptake of anthropogenic CO_2 by vegetation is one of such approaches.

Tropical forests processes about six times as much carbon as the anthropogenic emission. Changes in carbon dynamics in tropical forest with 50% contribution to global terrestrial gross primary production (GPP) (Grace et al., 2001) could alter the pace of climate change (Adams and Piovesan, 2005). Storing carbon as standing forests or from harvested wood has long been recognized as an atmospheric CO_2 mitigation option (also known as 'green carbon'). As for example, Schroeder (1992) estimated that 15–36 Pg C could be stored in tropical plantations and 50–100 Pg C sequestrated on a global scale (Winjum et al., 1992). A calculation by Lehmann (2007) indicates that an

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equivalent of about 10% of the US fossil fuel emissions may be harvested from biomass and stored as biochar. While the literature is vast regarding regional and tree-specific studies that shows global potential of carbon storage by the forests (Ni et al., 2016), there have been no attempt to our knowledge that addresses the same issue by the coastal habitats, in particular, mangroves. Mangrove forest accounts 0.7% of tropical forest (Giri et al., 2011) and in the coastal area it could be one of the possible sinks for the anthropogenic CO_2.

The Indian Sundarbans mangrove forest in the estuarine portion of the River Ganges is the largest delta on the globe (world's heritage site) and covers about 2.84% of the global mangrove area. Overall Sundarbans biosphere was found to act as a net sink of CO_2 sequestering 2.79 Tg C annually and ~96% of the sequestered carbon was stored in the live above and below ground biomass (1 Tg = 10^{12} g) (Ray et al., 2011, 2013). Given the high productivity and fast carbon sequestration rate (faster than Amazon rainforest), Sundarbans mangrove are supposed to take safe guard against the atmospheric pollution and CO_2 enrichment from the point sources like thermal power plant in Kolaghat and the heavily populated metropolis of Kolkata, both being present within 150 km from the mangroves. In fact, thermal power is the largest source of power in India. There are different types of thermal power plants based on the fuel used to generate the steam such as coal, gas, and diesel. However coal is the favorite fuel for the electricity generation in countries like India (also China) where coal and lignite based power plants have approximately 50–55% of the total electric power generation capacity (Chikkatur et al., 2011; Mittal et al., 2012). Kolaghat power plant, located in eastern India is one such coal fired thermal power plant. Nevertheless, there is a gap in understanding the capacity of the Indian Sundarbans to mitigate all the CO_2 emitted from the proximate thermal power plant. Given the contrasted environmental settings of these mangroves, power plant and the metropolis, a comprehensive knowledge about their atmospheric compositions, particularly CO_2 system is important to develop in the context of biosequestration.

Therefore, the main objectives of this study are: (1) to compare atmospheric compositions and CO_2 exchange fluxes between three different environments i.e. mangrove-power plant-metropolis, (2) to examine the need of extension of mangrove coverage to sequester CO_2 emitted from a proximate thermal power plant.

2. Material and methods

2.1. Study area

2.1.1. Indian Sundarban

The study site is located in the Indian Sundarbans (21°32' - 22°40′ N; 88°05' - 89°E, Fig. 1), which is a part of the estuary associated with the river Ganges and located at land ocean boundary of northeast coast of the Bay of Bengal. The Sundarbans, largest mangrove on the globe, cover an area of 10,200 km^2, of which 4264 km^2 of reserved forest is located in India and remainder in Bangladesh. In 1985, the Sundarbans was included in UNESCO's list of world heritage site. In 1989, India designated Sundarbans as a law protected forest. This natural mangrove is crisscrossed by the estuarine phases of several distributaries of the River Ganges: Hooghly, Mooriganga, Saptamukhi, Thakuran, Matla, Bidya, Gosaba and Haribhanga forming a sprawling archipelago of 102 islands out of which 54 are reclaimed for human settlement while the rest are in natural state. The study site, Lothian Island, is situated at the buffer zone of the Sundarbans Biosphere Reserve and covers an area of 38 km^2. This island is completely intertidal and occupied by thick dominant mangrove species, *Avicennia alba*, *Avicennia marina* and *Avicennia officinalis,* followed by other mangrove species like *Excoecaria agallocha, Ceriops decandra, Aegialitis rotundifolia*, etc.

2.1.2. Thermal power plant

Kolaghat is located approx. 55 km away from Kolkata city in the Purba Medinipur district, West Bengal (22°25.47′ N and 87°52.47′ E), on the western side of River Rupnarayan. The Kolaghat thermal power station is a major coal-based power plant of eastern India. This power project was established during the sixth plan period (1980–85). Now the plant has a total of six units with a capacity of 1260 MW (210 MW x 6). Kolaghat power station is managed by West Bengal Power Development Corporation Limited (WBPDCL), a department of the State Government of West Bengal. The plant is located on the fertile land of over 900 acres. This region is about 100 km away from the Indian Sundarbans.

2.1.3. City of Kolkata

This study area is located in the commercial and residential area of Ballygung in Kolkata (22°33′18.56″N and 88°21′0.38″E). Kolkata, formerly known as Calcutta (former capital of India), is one of the most populated cities of the world, ranking 3rd in India (~15 million). Kolkata stretches along the Hooghly River and at points is elevated between 1.5 and 9 m. Kolkata city has been selected as the study area in the present context due to several relevant factors. This includes the high traffic volume, the increased construction works, the growing population etc. Not many cities in the world are located near forests. Kolkata is an exception because there is the dense mangroves in the Sundarbans located ~150 km south of the metropolis, separating the city from the Bay of Bengal.

2.2. Sampling and analysis

Air sampling and micrometeorological monitoring were performed in three successive field works in Lothian Island (25–26 December, 2011), Kolaghat (2–3 January, 2012) and Kolkata (5–6 January, 2012). About 25 m observatory tower constructed inside the deep mangrove forest of the Lothian Island by the Ministry of Forestry, Govt. of West Bengal, were used for micrometeorological observation. For natural reason, the facility of such observatory towers was not available in Kolaghat and Kolkata where the same observations were carried out from the roof of multistoried buildings.

During three time series studies, air samples were collected from 10 m and 20 m height with the help of a portable air sampler (AS2-Technovarian) at a rate of 2 L min^{-1} at every 3 h interval covering 24 h cycle. The air was drawn into a pre-evacuated glass-sampling bulb of 150 ml capacity fitted with rubber septum. Soon after collection glass sampling bulbs were sealed properly with parafilm and kept in a cool and dry place and transported to the laboratory for the determination of CO_2 by gas chromatography (Varian 3800). GC consisted of chrompack capillary column (12.5 m × 0.53 mm) and a flame ionization detector (FID) and temperature were maintained at 50 °C and 150 °C, respectively. CO_2 was converted to methane after passing through Methanizer (Nickel catalyst system, Model No. MTN-1) maintained at 350 °C. Standard carbon dioxide (320 ppm), procured from EDT Instruments Ltd, UK was used for calibration. Finally mixing ratio of CO_2 in the air sample was determined by comparison of peak areas for samples and standard. The relative uncertainty on CO_2 measurement was found to be ± 0.063.

Temperature, relative humidity, pressure, wind speed and its direction were simultaneously recorded at two different heights (10 m and 20 m) using computerized weather station (Model: Davis 7440) connected with different probes and anemometer.

2.3. Estimation of community exchange of CO_2 fluxes

Biosphere-atmosphere CO_2 exchange flux (F) were calculated following Barrett (1998) formula: $F = V_C \Delta\chi$, where $\Delta\chi$ is the concentration difference between 10 and 20 m; V_C is the exchange velocity, defined as $1/(r_a + r_s)$ (r_a = aerodynamic resistance, r_s = surface layer). Negative F implies net uptake of CO_2 by the biosphere and positive F stands for net CO_2 emission. The flux values reported here are to be