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Changes in geomorphic units alter nitrogen fixation in a large lowland tropical river

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Abstract The present investigation was carried out over 50 km reach the Padma River of Bangladesh, downstream of the confluence of the Ganges and Brahmaputra rivers. The study area is highly dynamic, with various geomorphic units (GUs) such as primary and secondary channels (C&S) islands (VI), bars (L, T and SB), vegetated bank (EK), dry channel (ED) and water depression (WD). A field study was carried out in low flow (dry/winter) season to measure the nitrogen fixation rate (NFR) in each type of GUs. Later NFR was upscaled in different seasons based on the surface area of GUs. Principal component analysis was applied considering the seasonal variation of GUs (surface area and number) and the distribution of nitrogen fixation estimated in GUs in different seasons. Results showed that changes in the number and surface area of GUs across seasons could alter NFR. This systematic investigation of the spatial and temporal distribution of geomorphological and NFR measuring and monitoring will help plan river restoration and ecosystem management programs.

Keywords: Geomorphology, biogeochemical process, Seasonal variation, Large lowland river, Bangladesh

1. Introduction

Nitrogen fixation is a biogeochemical process that plays a vital role in river ecology and can occur in sediments and soils (Rai et al. 2000; Paerl 2017). Accumulation of sediments/soils in lowland rivers can result in geomorphic units, which are considered building blocks of the river (Rinaldi et al. 2016). In large rivers, enormous water and sediment transport occur due to high water velocity, which can alter channel morphology (Best 2018; Eisner 2017), resulting in geomorphic units (GUs). In-channel GUs are also prevalent and amplified by river bank erosion, flooding and other extreme events. These GUs represent the land portion of the river and can act as riparian or floodplain zones (Gani et al. 2022), thus can exhibit a potential site for nitrogen fixation. Nitrogen fixation can impact the river ecosystems where GUs is one of the dominant features. The addition of nitrogen in the GUs can have beneficial effects. For example, nitrogen fixation can increase soil fertility and proliferate crop production. In addition, to assess the river's health, nitrogen accumulation through fixation should be considered due to the effect of nitrogen on aquatic organisms.

Therefore, nitrogen fixation provides valuable ecosystem service. Moreover, to better estimate the nitrogen budget of large rivers, consideration of nitrogen fixation is essential, especially in the case of large lowland rivers where GUs play a pivotal role. So, the present was conducted in a large lowland tropical river with a geomorphic complexity. The main aim of the study was to determine the N fixation rate (NFR) in different GUs of the river and to show how changes in GUs impact NFR.

2. Materials and methods

2.1. Study area

The study area is 50 km reach from a large lowland river Padma River in Bangladesh (Fig. 1). The area is highly dynamic, showing the formation of different GUs such as primary & secondary channels (C&S), vegetated islands (VI), sidebar (SB), longitudinal bar (L), transverse bar (T), dry channels (ED), unvegetated bank (EK) and water depressions (WD). Variation of discharge is the responsible factor for altering GUs in different seasons (Gani et al. 2022).

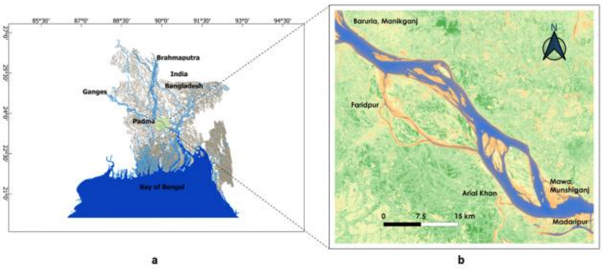

Figure. 1 a, b. Map showing the study area of the Padma River in Bangladesh. b) Enlarge the view of the study area. The area starts from Baruria, Manikganj and ends in Mawa Munshiganj.

2.2. Field samplings

Field samplings were carried out during the dry/winter season (February 2020). Sediment/soil samples were collected from the identified GUs. A total of 211 samples were collected, of which 156 samples were collected from 0-5 cm depth, and the rest were collected from 5-10 cm depth. Immediately after collection, all the samples were transported in the cold, using an icebox, to the research laboratory in the Department of Botany, Jagannath University, Bangladesh.

2.3. Lab analysis

In the laboratory, NFR was measured by the acetylene inhibition method, as described by Grimm & Petrone (1997). Here, acetylene was introduced to the samples, and the nitrogenase enzyme converted acetylene to ethylene. Samples were placed in gas-tight flasks that were made anaerobic by evacuating and flushing the headspace with nitrogen. Then, purified acetylene was added, and flasks were placed on a rotary shaker at 125 rpm for incubation for 4 hours. Gas accumulated in the flask was removed by hand inserting a syringe, then injected into evacuated gas vials (15 mL) and stored for later analysis of ethylene. After processing, the gas vials were transported to IHE Delft Institute for Water Education, the Netherlands, for gas chromatography (GC). In GC (Bruker GC-456), ethylene was quantified using a flame ionisation detector (FID) at 175 °C, and the runtime was 2.5 mins. Finally, the NFR was calculated as mg $N_2\,m^{-2}\,d^{-1}$.

2.4. Data analysis

At first, paired t-tests were performed between the samples from 0-5 cm and 5-10 cm depth. No significant difference was observed between the samples from the two depths. After that, NFR was considered an integration of 0-10 cm depth for the rest of the analysis. The R function "prcomp" was used for the PCA analysis, R function "ggbiplot," which is available on GitHub ("vqv/ggbiplot"), was used to visualise the PCA plot. All the analysis was performed in R v4.1.2 (R Core Team 2021).

3. Results and Discussion

Box plots showed different mean and median values of NFR in GUs. The highest mean was found in EK (4.15 mg $N_2\,m^{-2}\,d^{-1}$), followed by L (3.46 mg $N_2\,m^{-2}\,d^{-1}$), T (3.47 mg $N_2\,m^{-2}\,d^{-1}$), VI (3.3 mg $N_2\,m^{-2}\,d^{-1}$), ED (2.83 mg $N_2\,m^{-2}\,d^{-1}$), SB (2.94 mg $N_2\,m^{-2}\,d^{-1}$) and, WD (2.46 mg $N_2\,m^{-2}\,d^{-1}$). The ranges of NFR in EK, SB and T were highly variable, mainly depending on vegetation and soil types, as shown by the other researchers (Lawrence 1989; Vitousek et al. 2013). The highest value of NFR was found in EK, and the lowest was in T (Fig. 2). This might be due to the shape of GUs, which can be an important factor in this variation (Gani et al. 2022).

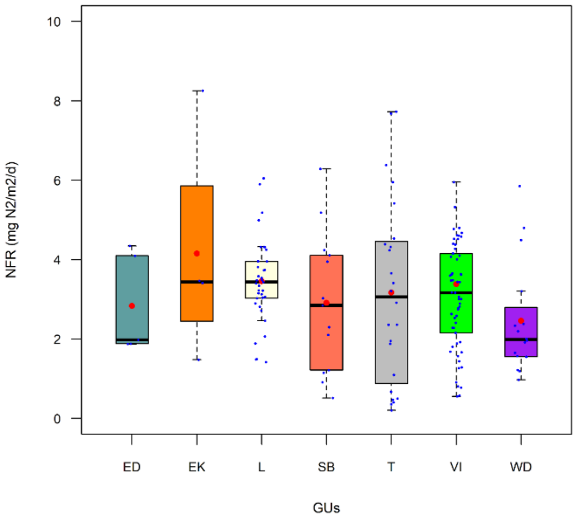

Figure 2 NFR (Nitrogen fixation rate) at 0-10 cm depth from different geomorphic units in the Padma River of Bangladesh. The large red dot inside the box plot indicates the mean value of each type of GUs, and the smaller blue dot indicates the number of samples of each GU.

The upscaled NFR showed that during dry/winter, the highest NFR occurred, and the lowest value was observed post-monsoon. Such a result was found due to the variation of the surface from season to season. Among GUs, the maximum NFR occurred in VI due to vegetation cover, followed by L, T and SB. The highest number of WD was found post-monsoon, so the maximum NFR was observed during that time (Fig. 3).

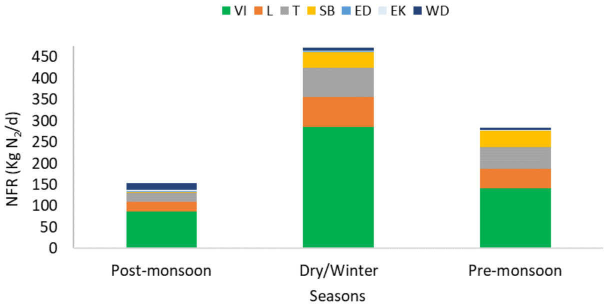

Figure 3. Upscalled NFR (nitrogen fixation rate) in different GUs during post-monsoon 2019, dry/winter 2020 and pre-monsoon 2020 in the Padma River of Bangladesh.

The first two axes (PC1 and PC2) were explained in PCA by 83.5% of the total variance. And eigenvalues of PC1 and PC2 were 1.84 and 1.56, respectively. PC1 positively correlated with EK (r=0.82), ED (r=0.89) and WD (r=0.88) while negatively correlated with VI (r=-0.74) and SB (r=-0.73). L (r=0.94) and T (r=0.95) negatively correlated with PC2. PCA plotted three groups based on the NFR, area and number of GUs.which showed that N, both area and number of GUs, could influence NFR. However, in L, T, EK, ED and WD, the number of GUs can impact NFR, and for VI and SB, the area of GUs can impact NFR in different seasons (Fig. 4).

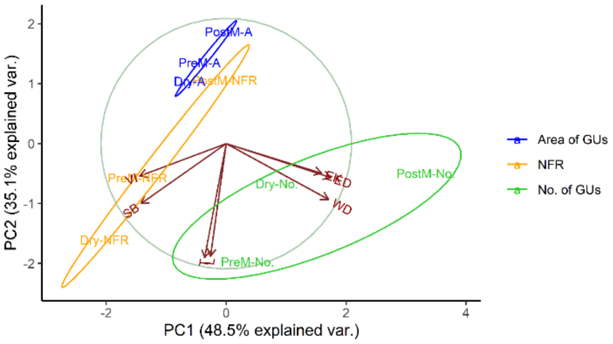

Figure 4. PCA (principle component analysis) of the surface area of GUs (geomorphic units), No. of GUs and NFR (nitrogen fixation rate) in different GUs (L, T, SB, VI, ED, EK and WD) during post-monsoon (PostM), dry/winter (Dry) and pre-monsoon (PreM) seasons in the Padma River of Bangladesh. A and No. represents the area and number of GUs, respectively.

The present study also supported the tool of identifying and mapping nutrient retention/export relevant GUs developed by Gani et al. (2022), where using remote sensing data, a potential area of GUs can be identified and separated. In future, this type of analysis can be incorporated with a geomorphological mapping tool to estimate better different biogeochemical processes using remote data.

4. Conclusion

NFR is a crucial biogeochemical process in the GUs of the large lowland river. In the present study, we found that the seasonal variation of GUs enhanced the alteration of NFR and can vary primarily due to the number and surface area of GUs. So, to estimate the nitrogen budget of large lowland rivers, NFR should be counted as it can influence overall assessment. In addition to determining sources of nitrogen pollution, NFR in GUs should be considered; thus, better river monitoring and management programs can be implemented.

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