Ecological Indicators 82 (2017) 327–343

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Alternative alert system for Ganga river eutrophication using alkaline phosphatase as a level determinant

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A R T I C L E I N F O

Keywords:
Alkaline phosphatase
Biomonitoring
Eutrophication
Ganga river

A B S T R A C T

Short-term variations in phosphorus (P) concentrations must be considered while assessing the long-term changes in trophic status and estimating the P load and export. Furthermore, given the challenges of conventional monitoring of river systems, a sediment-specific biomonitoring tool may be more successful inferring P related human controls. In this study, conducted along a 37 km river channel representing up-and downstream urban control, and through a trajectory from a major point source (Assi drain), we tested the patterns of concordance between alkaline phosphatase (AP) activity and soluble reactive-P (SRP) and between AP activity and trophic status in the Ganga River. To validate data comparison, we selected a reference site at Dev Prayag, situated ~1130 km upstream to the main study stretch. Samples were collected for three consecutive year (March 2013 to February 2016) with respect to atmospheric deposition, surface runoff, point source loading, river water and sediment analysis. For trajectory analysis, samples were collected from 15 locations starting from the drain outlet (zero distance) upto 1.5 km downstream with sampling location 100 m away from the preceding one. We found marked spatial and temporal variations in P concentrations which could be traced by quantifying the AP activity. The AP activity, recorded highest at reference site, declined with increases in P; and at drain mouth it was close to zero reflecting strong influence of P level on alkaline phosphatase activity in the river. We used canonical correlation analysis (CCorA) to test the degrees of concordance and similarity in different variables. Most of the environmental variables and indicators of eutrophy appear largely clustered at one side of the coordinate separating AP activity and dissolved oxygen towards opposite side of the axis. The dynamic fit function relating AP activity with different variables showed significant positive correlation with DO ($R^2 = 0.67$; $p < 0.001$) and negative correlations with BOD ($R^2 = 0.82$; $p < 0.001$), Chl ***a*** biomass ($R^2 = 0.52$; $p < 0.001$) and trophic status index ($R^2 = 0.54$ (Chl ***a***), 0.96 (DRP); $p < 0.001$). Furthermore, the enzyme activity did not show significant negative correlation with heavy metals in sediment. Because anthropogenic activities continue to enhance P loads; AP is inhibited directly by P availability; and eutrophy feedbacks sediment P release, our observations on P-AP activity relationship provide a valuable alternative means for detecting P related controls on water quality, trophic status and biogeochemical feedbacks in human impacted rivers.

1. Introduction

Eutrophication is among the most common water quality problems in surface waters and, on global basis, researchers have shown a strong correlation between phosphorus loads and eutrophication (Anderson et al., 2002). In most of the surface waters, nitrogen (N) and phosphorus (P) are the critical nutrients influencing the fluxes of energy and matter that are fundamental to all ecosystem processes including those that control biomass, abundance and distribution of organisms. Globally, it is predicted that, if the current trend of anthropogenic releases continues, there is possibility of approximately 2.4–2.7 fold increases in N- and P-driven eutrophication of freshwater, marine and terrestrial ecosystems in the near future (Kundu et al., 2015). Fluxes of nutrients and organic matter in rivers are driven pre-dominantly from terrestrial landscapes modified by factors that are subject to human-induced control. The amount and timing of such fluxes; which are highly variable depending upon the catchment geology, time and intensity of rainfall, and the nature and magnitude of anthropogenic pressure; influence autotrophic-heterotrophic links with concordant river responses on different spatial and temporal scales. The main sources of P input into the aquatic environment are household sewage containing detergents and cleaning materials, effluents from fertilizer, detergent and

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http://dx.doi.org/10.1016/j.ecolind.2017.06.061
Received 27 January 2017; Received in revised form 29 June 2017; Accepted 30 June 2017
Available online 14 July 2017
1470-160X/

soap industries, phosphorus mining, and agricultural runoff containing fertilizers and livestock releases. Rivers in urban areas particularly suffer with water quality problems associated with the common practice of discharging untreated sewage (Islam et al., 2015).

Water-saturated sediments that underline a river channel harbour a large microbial population that often dominate riverine biogeochemical cycling and may contribute to 76–96% of total respiration (Craft et al., 2002). However, human activities can alter sediment delivery and physico-chemical characteristics contributing to shift the microbial population and ecological degradation (Walling et al., 2003). Microbial functioning is extremely sensitive to changes in physico-chemical characteristics of sediments and can be used as a predictor of ecological integrity of river ecosystems (Feris et al., 2009; Gibbons et al., 2014). Thus, understanding the sediment metabolism along an environmental gradient will help how these ecosystems will change in response to human activities. Riverbed sediments are intensively colonized by microorganisms, especially bacteria, that contribute to carbon (C) and nutrient budget of aquatic ecosystems and can return nutrients to productive zone of water column during mixing or anoxia (Wetzel, 1981). Microbial processes in riverbed sediments, however, often suffer with episodic events driven by urban-industrial flushing, flow regulation, rain-driven lateral flow (surface runoff) and pulsed supply of sediments. Increased autotrophic growth (autochthonous C build-up) and enhanced input of allochthonous-C activate microbes and microbial processes in sediments. Therefore, total microbial activity is an important measure of organic matter turnover in natural habitats and variables such as respiration, active microbial biomass and fluorescein diacetate (FDA) hydrolysis are important measures of overall microbial activity (Schnurer and Rosswall, 1982; Costa et al., 2007; Pandey, 2011). More recent studies suggest the need for sediment specific biomonitoring tools to infer the cause and magnitude of ecological degradation (Turley et al., 2016).

During recent years, determinants such as biological oxygen demand, chlorophyll ***a*** biomass (Gholizadeh et al., 2016), phycocyanin (Ahn et al., 2007), microinvertebrates (Turley et al., 2016) and a substantial number of diatom indices (Kelly and Whitton, 1995; Potapova et al., 2004; Ponader et al., 2008; Rimet and Bouchez, 2012) have been developed as a narrative criteria in bioassessment of water quality in various geographic areas. The U.S. Environmental Protection Agency (U.S. EPA, 2000) considers benthic diatom species composition, which responds directly to nutrients (Pan et al., 1996), a more stable indicator of trophic state than measurement of nutrient concentration or algal biomass. Wide range of distribution of diatoms is considered as one of the major advantages of using diatom indices for monitoring eutrophication. Quantifying diatom ecology together with environmental variables that represent conditions during diatom growth discriminate better between sites and provide major source of information to assess the river water quality. Despite these merits, diatom indices developed in one geographic area are often found less suitable when applied in other geographic regions (Pipp, 2002). This reduces the universal applicability of diatom-based tools across geographic areas. This happens possibly because diatom species do not necessarily follow unimodal or symmetrical environmental distribution (Austin, 2002; Bere and Tundisi, 2011). Instead, there exists marked floristic difference among regions. Furthermore, some species exert stronger control over the ecological processes than other and a least dominant species may be highly sensitive to subtle environmental change (Cardinale et al., 2006).Therefore, a major challenge faced in bridging these narrative criteria to policy implementation; in addition to the specificity with respect to climate, geographic area, and nature and magnitude of human-induced control; is the variability in species sensitivity and functional control. Biological measures of eutrophication (diatom/algal growth) are generally used to assess the impact of nutrients on receiving waters (Ponader et al., 2008). But the relationships between biological variables such as algal biomass (chlorophyll ***a***) and nutrient concentrations are influenced also by other factors as climate, upstream basin size, river width and flow (U.S. EPA, 2000) that question the generality of data comparison.

The present study aimed to address the status of eutrophic condition along a 37 km segment of the Ganga River using alkaline phosphatase (AP) as a biomonitoring tool. The AP activity is used to address the status of phosphorus-driven eutrophication because AP is strongly influenced by P subsidies (Sayler et al., 1979; Johnson et al., 1998). Therefore, quantifying AP can be a practical approach in assessing the magnitude of human-driven P flushing, status of eutrophy and associated feedbacks in rivers and streams. The Ganges basin is most densely populated and urbanized river basin of India with intensive pressure on water quality of the Ganga River and its tributaries. Because P concentration is continuously increasing in the Ganga River, there is an emerging need to develop cost-effective methods for water quality assessment and to monitor P-eutrophication status in this river system (Pandey et al., 2014a,b). Because P enhances the eutrophy and the latter regulates sediment P release (Wetzel, 1995), our main objective was to investigate whether alkaline phosphatase could be used to give more detailed information concerning the P related changes in ecosystem resilience/ecological integrity of the river. In bioassesment of nutrient pollution, diatom indices generally explore two categories; low- and high- nutrient indicators. The AP activity, as a biomonitoring tool, is relatively advanced in the sense that it is applicable even for predicting the interfaces. Furthermore, biomarkers based on multiparameter/multi-species indices or molecular characterization either require extensive field visits and collection of environmental data used to quantify diatom ecology or need sophisticated techniques and, are often cost intensive. Here we propose P-AP relationship as an alternative alert system for monitoring P-eutrophication in the Ganga River. Since the analysis of AP involves simple analytical technique and is a single function predictor, it will be a cost-effective approach to be used as a biomarker of P-driven eutrophication. Using dynamic fit functions we tested the patterns of concordance between AP activity and soluble reactive-P (SRP) in riverbed sediment; and between AP activity and trophic status in the Ganga River. The merit of using this cost-effective biomonitoring tool is that it is sensitive to environmental stressors and can be easily integrated into standardized biological sampling methods; can be tested over full range of river ecosystem and have a strong relationship with human-induced control.

2. Materials and methods

2.1. Study area

The presented study was conducted for three consecutive years, from March 2013 to February 2016, along a 37 km segment of the Ganga River characterizing up- and downstream influences of Varanasi city (Fig. 1). The Ganga River basin (1,086,000 km^2) is the 4th largest trans-boundary river basin in the world. The river originates in the western Himalaya, flows through plains of north India and Bangladesh and finally empties in the Bay of Bengal (CPCB, 2013). Climatic conditions of the study area range from tropical monsoonal to humid subtropical. The year can be divided in three distinct seasons; a humid rainy (July-October) when relative humidity may reach close to saturation; a cold winter (November-February) when minimum temperature sometime drops below 4 °C, and a hot dry summer season (March- June) with temperature sometimes exceeding 46 °C. The region receives ~1050 mm average rainfall with over 85% occurs during monsoon season. The average monsoonal discharge remains almost 10 times higher than the average dry season discharge. The river is fed by the Himalayan snowmelt in summer and by rain-driven runoff in monsoon season. Soil of the region is highly fertile eutric cambisols and shallow luvisols (Jain, 2002). A large proportion of the basin constitutes farmlands which are intensively cultivated with large input of fertilizers.

Sampling stations differ with respect to land use, anthropogenic