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Original Research Article

Flow regime alteration due to anthropogenic and climatic changes in the Kangsabati River, India☆

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ABSTRACT

According to the 'natural flow paradigm', any departure from the natural flow condition will alter the river ecosystem. Flow regimes have been modified by anthropogenic interventions and climate change is expected to cause additional impacts by altering precipitation extremes. This study aims to evaluate the observed hydrologic alteration caused by dam construction and simulate alteration due to expected climatic changes in a monsoon dominated mesoscale river basin in India. To analyze the natural flow regime, 15 years of observed streamflow (1950–1965) prior to dam construction is used. Future flow regime is simulated by a validated hydrological model Soil and Water Assessment Tool (SWAT), using four high resolution (~25 km) Regional Climate Model (RCM) outputs for the near future (2021–2050) based on the SRES A1B scenario. Finally, to quantify the hydrological alterations of different flow characteristics, the Indicators of Hydrologic Alteration (IHA) method which is based on the Range of Variability approach is used. This approach enables the assessment of ecologically sensitive streamflow parameters for the pre- and post-impact periods. Results of our analysis indicate that flow variability in the river has been significantly reduced due to dam construction with high flows being reduced and low flows during non-monsoon months considerably enhanced. Streamflow simulated based on projected climatic changes reveals reduced monsoonal flows with marginal changes in non-monsoon streamflow. The combined effect will reduce flow variability, potentially affecting the ecosystem. We conclude that in such modified basins, adaptive river basin management will be necessary to maintain such an extreme river flow regime for the long term viability of riverine ecosystems.

1. Introduction

Amidst a growing understanding that sufficient water is essential for the sustainability of riverine ecosystems, significant stress has been placed on assessing important characteristics of the river flow regime needed to sustain ecosystem functions. Poff et al. (1997) have discussed how the ecological integrity of riverine ecosystems is a function of flow characteristics and their interactions with water quality, energy sources, physical habitat and biota. The

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natural dynamism of a river is demonstrated by the flow variability across hourly, daily, seasonal, annual and longer time scales. Primarily, five flow components; magnitude, frequency, duration, timing and rate of change, which have a significant influence on the ecological dynamics of river systems, have to be 'mimicked' in order to maintain ecosystem diversity and the diversity of organisms therein (Poff et al., 1997; Gibson et al., 2005; Arthington et al., 2006; Laizé et al., 2013).

Several studies over the past decade have discussed changes in river flow regimes brought about by human intervention (Gibson et al., 2005; Sun and Feng, 2012; Yang et al., 2012; Poff and Matthews, 2013). Dams are known to alter natural flow regimes of rivers when compared to the pre-impoundment period and have been found to homogenize distinct river flow regimes across broad geographic scales (Poff et al., 2007). Simplistic and static rules for delineating environmental flow requirements may be detrimental to the critical ecological functions of river flow variability and sustenance of ecosystems (Arthington et al., 2006). Dampened seasonality and interannual flow variability of rivers due to dams alters the habitat dynamics which makes assessment of these impacts critical from the point of view of biodiversity conservation (Poff et al., 2007). In their global analysis, (Döll and Zhang, 2010) find that along with ecological impacts of water diversion by dams, climate change induced flow alterations can have a strong impact on freshwater ecosystems. However, a strong regional variation in dam impacts may be observed in such studies, and also might have been underestimated. For an improved ability to gauge potential implications for riverine ecosystems, which experience different types of flow regimes across different regions, observed changes at a basin scale need to be analyzed, along with flow alterations caused by future climate change.

In this study, we analyze long-term observed and simulated streamflow at a location which lies downstream of a large earthen dam on the Kangsabati river to evaluate dam and future climate change induced flow alterations. This river, located in the lower Ganges basin, has been dammed to create the Kangsabati reservoir which provides flood/drought relief and diverts water for irrigation and domestic purposes in the command area. Flow regime changes due to dam construction could be exacerbated in the coming decades as future climate projections forecast a general decrease in precipitation, increase in temperature and an intensification of climatic extremes in the basin (Mittal et al., 2013). Use of hydrologic indicators for assessing environmental flow requirements. From the myriad hydrologic indicators available for assessing environmental flow requirements (Olden and Poff, 2003; Suen, 2010), we employ the Range of Variability Approach (RVA) (Richter et al., 1997) derived from aquatic ecology theory which involves a detailed assessment of the hydrological variability of river. This method is useful for detecting changes in the hydrological regime due to a known perturbation and for establishing flow-based river management targets (Chen, 2012) making it suitable for analyzing the impact of human intervention and climate change on the Kangsabati river basin.

2. Methodology

2.1. Study area

The Kangsabati river basin is located mostly within the Indian state of West Bengal, bounded by the 86° E and 87°30′ E longitudes and the 22°20′ N and 23°30′ N latitudes and having an approximate area of 5796 km^2. The Kangsabati river flow in a south-easterly direction before becoming the last contributing river to the Ganges river in India. The river basin is traditionally considered drought prone (Saxena, 2012), although it receives an average annual rainfall of 1200 mm. The high concentration of rainfall during monsoon (JJAS) months results in a skewed streamflow distribution with large differences in daily and monthly river flows within the natural flow regime. The Kangsabati river which originates in the uplands of the Chhota Nagpur plateau has caused highly eroded and gullied topography in the upper reaches where ephemeral 1st and 2nd order streams are dominant. This eroded landscape turns into undulating uplands towards the middle reaches and finally alluvial plains in the lower reaches. The Kangsabati reservoir project is located at the confluence of the Kangsabati river and its major tributary; the Kumari. This reservoir, built in two phases (1965 and 1973), receives inflow from both sub-basins. Along with the provision for irrigation and domestic water consumption needs the project also provides 246.7 million m^2 storage for flood relief. Along with these benefits, drought mitigation, pisciculture and recreational facilities are also a part of the project (Saxena, 2012). Some of the storage capacity has diminished over the past 40 years due to siltation. As a result, the current reservoir storage capacity is about 1/3rd of the annual reservoir inflow (Bhave et al., 2013b). Previous studies in this basin (Bhave et al., 2013a,b; Mittal et al., 2013) have discussed stakeholder experiences of past climatic changes. Moreover, projected climatic changes in mid-21st century demonstrate an amplification of the impacts due to changing precipitation extremes, particularly, consecutive dry days (CDD), highest five day precipitation (RX5D) and number of days with precipitation greater than 50 mm (PD50).

2.2. Analytical approach

Availability of long duration river discharge data is an essential requirement for assessing ecologically important characteristics of the natural flow regime. Kennard et al. (2010) suggest that hydrologic metrics should be based on more than 15 years of discharge data to reduce bias and increase accuracy. Mohanpur, a discharge gauging station of the Irrigation & Waterways Department, Government of West Bengal, approximately 80 km downstream of the Kangsabati reservoir has recorded and made available daily discharge data from 1950 onwards. Natural river flow conditions existed for a 16-year period between 1950 and 1965. The period between 1965 and 1973 constitutes an intermediate period between the completion of the Phase I and II of the Kangsabati reservoir project. The 37-year period from 1974–2010 marks the post-dam period where