Geomorphology 276 (2017) 257–279

Contents lists available at ScienceDirect

Geomorphology

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

Assessing channel changes of the Ganges-Padma River system in Bangladesh using Landsat and hydrological data

Ashraf Dewan [a,*], Robert Corner [a], Ashty Saleem [a], Md Masudur Rahman [b], Md Rafiqul Haider [c], Md Mostafizur Rahman [d], Maminul H. Sarker [d]

[a] Curtin University, Department of Spatial Sciences, Perth 6102, Western Australia, Australia
[b] University of Dhaka, Department of Geography & Environment, Dhaka 1000, Bangladesh
[c] International Centre for Diarrhoeal Disease Research (ICDDR,B), Bangladesh
[d] Center for Environment and Geographic Information Services (CEGIS), Dhaka, Bangladesh

ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form 3 October 2016
Accepted 10 October 2016
Available online 13 October 2016

Keywords:
Landsat
Bankline movement
Erosion and accretion
Channel pattern
Ganges-Padma system
Floods
Geospatial techniques

ABSTRACT

The Ganga/Ganges[1] is an important river system in South Asia which supports the life and livelihoods of millions of people both in India and Bangladesh. The system has a number of names throughout its length. Below its confluence with the Brahmaputra at Aricha it is known as the Padma, which in turn merges with the Upper Meghna at Chandpur below which the channel is known as the Lower Meghna. There is a growing concern about this large river system because its channels are subject to frequent migration, threatening engineering structures and resulting in various environmental and social consequences which may be compounded by climatic variability, land use change, and agricultural intensification as the basin experiences rapid population growth. Concerns have been expressed that the construction of a barrage just upstream of the Indo–Bangladesh border has adversely affected the Ganges reach in Bangladesh. Partly in order to investigate this, the planform changes of the Ganges and the Padma within Bangladesh was analysed over the period 1973 to 2011 using multitemporal Landsat images and long–term flow data in eight epochs with an average duration of 4.5 years. The Padma reach is less affected by the barrage and provides a useful control study. Areas of erosion and deposition were determined from sequential changes in the bankline positions. Mean channel width, sinuosity and braiding index were analysed using a Geographic Information System (GIS). Flood frequency, duration and magnitudes were studied using long-term discharge records. Generally, channel planform evaluation indicated that both the Ganges and the Padma experienced contraction, expansion and readjustment in configuration over the last 38 years. Erosion and deposition statistics of the Ganges indicate that 57 km^2 of land was lost along the right bank whereas around 59 km^2 has been gained along the left bank during the assessment period, suggesting that the erosion and accretion of both banks is roughly balanced with a general movement towards the right bank. The width of the Ganges varied from a maximum of 5.36 to a minimum of 3.23 km during the observation period. Changes to sandbar area are, in general, much more radical than changes to the overall width and area of the channel. Measurement of areas of erosion and accretion showed that both banks of the Padma experienced considerable loss of land. The total net loss for left bank and right bank was 155 and 28 km^2, respectively. The Padma is approximately twice the width of the Ganges and the changes to its channel area are not as temporally dynamic as the Ganges. The relationship between bank curvature and erosion/accretion of the river banks for both rivers was analysed and the results contradict established meander theory. Regression analysis between bank erosion rates, annual average discharge and mean flood flow data showed that bank erosion was significantly correlated with annual average discharge for the Padma ($r^2 = 0.6283$) and that the Ganges bank erosion rate is influenced by mean flood flow ($r^2 = 0.6738$). The flood frequency shows generally good stability across the first eight of the nine epochs for the Ganges but for the Padma the frequency showed even greater stability. We were unable to support the widely held belief that the upstream barrage has a deleterious effect on the Ganges but note that there is a slight effect due to the periodic release of sediment through scour sluices.

* Corresponding author.
E-mail addresses: a.dewan@curtin.edu.au (A. Dewan), R.Corner@curtin.edu.au (R. Corner), ashty.saleem@postgrad.curtin.edu.au (A. Saleem), masud_ra0171@yahoo.com (M.M. Rahman), cslraju@yahoo.com (M.R. Haider), mdmorahman@gmail.com (M.M. Rahman), msarker@cegisbd.com (M.H. Sarker).

[1] Nomenclature is always a problem with international rivers. The river known as the Ganges in Bangladesh is known as the Ganga in India. In this paper the system will be called the Ganga but that section with at least one bank in Bangladesh will be called the Ganges. Similarly, the Brahmaputra is sometimes referred to in Bangladesh as the Jamuna.

http://dx.doi.org/10.1016/j.geomorph.2016.10.017

1. Introduction

Rivers are highly sensitive to environmental conditions (Eaton et al., 2010; Rozo et al., 2014), and alluvial channels can respond or readjust at a range of rates to the variations caused by water and sediment inputs, active tectonics and human activities at a range of spatial and temporal scales (Sinha and Ghosh, 2012; Heitmuller, 2014). Any changes, whether natural or anthropogenic, can initiate a departure from a state of dynamic equilibrium (Winterbottom, 2000; Petts and Gurnell, 2005). This may, in turn, result in channel instability causing changes in channel form and pattern (Yang et al., 1999; Surian and Rinaldi, 2003; Wellmeyer et al., 2005; Richard et al., 2005; Li et al., 2007; Kummu et al., 2008; Yao et al., 2011; Ramos and Garcia, 2012; Gupta et al., 2013; Midha and Mathur, 2014).

The Ganges river system, with a catchment area of 1.09 million km^2, originates at the Gangotri glacier in the Himalayas and is one of the largest river systems in the world. Along its 2526 km course to the confluence with the Meghna, it crosses China, Nepal, India and Bangladesh, making it a quintessential international river. India has the largest share (79.1%) of its entire catchment whilst only 4.3% lies within Bangladesh (equivalent to 32% of the area of that country) (Mirza, 2004). The river has a central place as a holy river to millions of Hindu's (Sanghi and Kaushal, 2014), and provides a lifeline to millions of people distributed over four countries; all with rising populations (Mirza, 2004; Das, 2014). The population density of the catchment is also high (roughly 550 km^2, Sanghi and Kaushal, 2014), 74% of whom reside in rural areas, with a total harvested arable area of close to 68 million hectares (Mha), of which only 52% is rainfed (Sulser et al., 2010). Thenkabail et al. (2005) showed that at that time 24.9% or 33.08 Mha of the Ganges basin relied on irrigation. Each year, around 114.4 km^3 of water is required to support the agricultural, domestic and industrial activities of the people in the Ganges basin (Sharma et al., 2010). The Ganges provides a potential foundation for the long–term sustainability and economic development of its riparian states, but its health is under threat from the activities of those states through over extraction of water, mismanagement of natural resources, flow regulation/diversion through dams/barrages, and deforestation. In addition, Moors et al. (2011) have predicted that water availability in the catchment could be at risk from climatic variability. The Ganges delta has distributaries in two neighbouring countries and has been internationally listed as "in peril" because of its anticipated imbalance caused by extreme population pressure, and rapid modifications of the landscape (Coleman et al., 2008; Syvitski et al., 2009).

Large untamed rivers have existed for millennia in situations in which their courses have altered in response to changing climates, tectonic factors, landslides etc. Rudra (2010) argues that the Ganges has a tendency to range over a large meander belt over a period of three centuries and to reoccupy its former courses as it migrates between the limits of that belt, but it is difficult to determine the specific time interval of these reversals. The pressures on large "wild" rivers have changed over the past several hundred years. Firstly, the population dependent on them has increased to the extent that the resource can no longer be considered as infinite; secondly, engineering advancements have made it possible for one nation to impound the waters of the river, thus, controlling its flow in downstream nations. Such situations can lead to conflict (Gleick, 1993).

In the 16th Century, a natural eastward movement of the river caused a greater amount of water to be diverted down the Ganges–Padma branch at the expense of the Bhagirathi–Hooghly branch (Parua, 2009). There was concern before and during the period of British colonial administration that this change of flow was affecting the navigability of the Port of Kolkata/Calcutta and a number of reports on the subject were compiled between 1853 and 1971 (Hossain, 1998; Parua, 2009). Some of those reports studied the feasibility of diverting water to the Bhagirathi–Hooghly by means of a barrage at Farakka, 18–km upstream from the point at which the river enters Bangladesh.

In 1975, India completed construction of the Farakka barrage, and since then there have been concerns for the river's health downstream of that point. Diversion of water at Farakka has been governed by a range of agreements (Table 1), which have not been continuous over the period since 1975 and have not all been fully adhered to. However, it appears (PRIO, 2013) that since the 1996 treaty, Bangladesh has been receiving a fair allocation of the flow at Farakka. Over time, the flow upstream from Farakka has diminished.

A popular supposition, at least in Bangladesh, is that the problems experienced by the Ganges in that country are all caused by the operation of the Farakka barrage. One of the objectives of this paper is to examine that issue objectively. In addition, an in–depth analysis of how the geomorphology of the river system has evolved and reacted to change, at a range of spatio–temporal scales, will provide an understanding of the nature, rates and causes of channel change (Gilvear et al., 2000).

Activities that harness and manipulate the flow of water for the benefit of humans have increased dramatically with the increase in global population (Wellmeyer et al., 2005), with a range of consequences including channel pattern alteration, increased flood risk, navigation constraints and changes to aquatic and riparian ecosystems (Li et al., 2007). Geomorphological effects such as massive bank erosion and accretion cause population displacement, introducing additional problems, including loss of livelihood and degradation of arable land (Rudra, 2010; Das, 2011).

The Ganges system in Bangladesh,[2] including the Ganges and the Padma, is one of the largest rivers in the world and its catchment receives an average annual rainfall of 1200 mm (Sulser et al., 2010). It is therefore subject to high seasonality and recurrent floods of large magnitude (Gupta, 1995; Sharma, 2005) with 80% of the annual total discharge volume occurring during the monsoon season (July–Oct) (Kale, 2003). Migration of the river through bank erosion and bed scouring is common and is believed, by many, to have been aggravated in recent times in response to increased human activities (Sharma et al., 2010). Although water shortages caused by diversion at Farakka are reported to have increased erosion (CEGIS, 2003; Hossain et al., 2013), the impact of floods on river dynamics remain largely unclear since flooding in the Ganges system is also believed to be one of the major drivers of channel degradation (Geddes, 1960; Jain et al., 2012). This uncertainty over the causes of recent morphological changes is therefore one of the reasons

Table 1
Periods of various agreements over the sharing of the Ganges water between India and Bangladesh.

Period	Years	Activities
Pre–Farakka period	Before 1975	No diversion at Farakka
Ad–hoc MoU period	1975–1976	Water extraction commenced in 1975 under a temporary 41–day agreement. Unilateral diversion of water began in 1976 by India
	1977–1982	First water–sharing agreement in 1977
	1982–1987	Memoranda of Understanding (MOU) signed in 1982 and 1985 with slight modifications of the 1977 agreement
No–treaty period	1988–1996	Unilateral withdrawal by India
Treaty period	1997–present	A 30-year treaty was signed in December 1996 with lower Bangladeshi allocation than 1977. Arrangements failed in the first year since then minimum flow provision have applied

Source: Mirza (2004).

[2] In this study, we refer to the reach above Aricha (Fig. 1) as the Ganges and the lower reach as the Padma. However, we refer to the continuous stream from the Indo–Bangladesh border to Chandpur, as the Ganges–Padma system.