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Environmental flow requirements and impacts of climate change-induced river flow changes on ecology of the Indus Delta, Pakistan

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HIGHLIGHTS

- Environmental flows (E-flows) are essentially and constantly required to maintain current ecological management class (EMC) of Indus deltaic fresh water ecosystem.
- If current deterioration of Indus aquatic ecology continues then it will be irreversible to maintain present, or achieve higher EMC, regardless of any changes in river flows in the future.
- Need to build capacities and expand economic opportunities available to local communities for environmentally sustainable livelihoods in Indus Delta.
- Need to incorporate the concept of E-flows in the Indus Water Treaty for all rivers.

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ABSTRACT

Modification of Indus River flows to meet anthropogenic needs has seriously undermined the ecological benefits the river generates in the deltaic region. This paper provides an assessment of ecological conditions of the Indus Delta under different climate change scenarios by using ecological health of the Indus River as a proxy. First, we assessed the existing state of deltaic ecology and categorised it into an arbitrary environmental management class (EMC). Then, using Global Environmental Flow Calculator, we determined the Environmental Flows (E-flows) that are required for the Indus delta in (i) the present, and (ii) in the future under two climate change scenarios. Our analysis shows that due to inadequate and inconsistent release of E-flows downstream of Kotri barrage, deltaic ecosystems have deteriorated overtime. Our analysis reveals that under climate change Scenario 1, more flows may be available that can bring river flows close to natural E-flows. Under Scenario 2, there may be reduced river flows to the extent that E-flows required under prevailing conditions would not be possible. The study concludes that if the current deterioration of aquatic ecology continues, it will be challenging to maintain present, or achieve higher ecological management class (EMC), regardless of the changes in river flows in the future. In this light, there is a need to interlink economic and development needs of communities with environmental needs of Indus River in the deltaic region. Most importantly, there is a need for ensuring climate-compatible e-flows in water regulating sites such as Kotri Barrage.

1. Introduction

Globally, modification and exploitation of river flow regimes is detrimental to physical habitats and biotic composition of ecosystems that thrive in and around rivers (Bunn and Arthington, 2002). A number of studies indicate that modification of the Indus River during the 19th and 20th century has led to significant reduc-

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tion in downstream river flows in to the Indus Delta (Boon and Raven, 2012; Ghazanfar, 2009; Syvitski et al., 2013; Iftikhar, 2002; Qureshi, 2003). Some studies estimate a flow reductions up to 90% in the Delta (DasGupta and Shaw, 2013; Giosan et al., 2006). Thus alterations in the magnitude, frequency, duration, timing and rate of change of Indus river flows impact the range and spread of biodiversity—a persistent threat to freshwater ecosystems (Syvitski et al., 2013). The current situation poses numerous environmental challenges for Indus Delta. These include that include drastic reduction of sediments flux, increased salinity in agriculture fields and sea intrusion (including seawater flooding), soil erosion and coastal retreat (Syvitski et al., 2013). Further, there is a decline in mangrove cover and diversity, deterioration in marine and riverine resource base by lowering the reproduction potential of fishes, shrimps, crabs, etc., endangering riverine unique reptiles' species such as green turtles (GoP, WWF and IUCN, 2000). In this paper we seek to understand, *what is the current status of aquatic ecosystems in Indus Delta*? This question is essential for benchmarking environmental management classification to cross-compare with reported conditions in the literature.

Under the pressure of demographic growth, urban sprawl, and economic development, Pakistan's primary source of freshwater supply – the Indus River system – has become highly stressed. The competing water needs for water include, agriculture, domestic, energy and industrial sectors. Consequently, per capita water availability has decreased to 1000 m^3/person (GoP, 2007; Yu et al., 2013) in the country of 188 million. Consequently, the mainstream water management in the country has dictated river water for anthropogenic needs, thus silently compromising the needs of the freshwater ecosystems.

Unnatural changes in the river flows also undermine the numerous ecosystem services that humans derive from healthy rivers (Arthington et al., 2006; Syvitski and Saito, 2007), such as water for irrigation, consumption, fisheries, tourism and transport. Healthy rivers with functioning ecosystems also support livelihoods of millions of poor who depend on natural resources (Acreman and Dunbar, 2004). The situation is quite evident in the Indus Delta, as most of the dependent communities are marginalised and poor and characterised by low income diversification. They lack safe drinking water which has led to a high rate of human migration (Ghazanfar, 2009; Salik et al., 2015; World Bank, 2005). Many of also lost their shelter and access to essential services during river flooding and cyclones due to living in the fringes of creeks. For example, sea intrusion and erosion (which is about 20 m per year) in the Indus Delta has resulted to the town of Keti Bandar replaced west-wards thrice since 1952 (WWF-P, 2008a,b). Livelihoods that are largely based on fishery and agriculture sector, remain extremely sensitive and vulnerable to rising sea levels, increasing salinity and inadequate release of fresh water flows (Salik et al., 2015).

In order to reap benefits of healthy rivers and their ecosystems, river flows must meet environmental flow requirements (Poff et al., 2010). Environmental flows, or E-flows, are a management concept that determine the flow regimes required to maintain a river's ecosystems in a desired state. E-flow assessments, while beneficial in understanding flow regime dynamics, are also useful in measuring social, economic and ecological costs of development (Nel et al., 2011). Additionally, they can be a powerful environmental gradation tool to predict future resilience of deltaic and riverine ecosystems in light of climate change. This paper will analyse *what e-flows are required in Indus Delta under existing ecological conditions for sustainable deltaic ecosystems*?

For a country like Pakistan whose freshwater resources are highly vulnerable to the impacts of climate change, E-flows can serve as an important water management concept. Growing scientific evidence also suggests that climate change will impact water flows of the Indus River through shifts in temperature, extreme weather events, precipitation patterns, and glacial melting (Immerzeel et al., 2013; Rees and Collins, 2006). Despite this, little research has been dedicated for its understanding, this paper will look at *how climate-induced alterations in river flows will modify riverine and deltaic ecosystems that shelter millions of species fine-tuned to the natural rhythms of river flows*. Local research in hydrology and freshwater ecology is marred by additional gaps. While there are numerous studies and assessments in the Indus Delta on the interplay between flow regime and water quality, sediment deposition, vulnerability to extreme events, and aquatic habitat (Day et al., 1997; Valette-Silver and Scavia, 2003; WCD, 2000); these studies have been limited to a few ecological indicators and fail to provide an integrated picture of the Indus Delta.

This study has been designed to draw attention to the importance of E-flows. While a number of national policy documents recognise the need for ensuring 'minimal' E-flows, such as the Water Appropriation Accord of 1991, National Wetlands Policy 2009, draft National Water Policy, and the recent National Climate Change Policy (2012). Findings of this research are intended to inform the Government of Pakistan that is presently planning to implement the National Climate Change Policy. The study is also aimed at decision makers, scientists and development practitioners involved in policy planning, research, monitoring and forecasting on Indus river ecology to revisit the concept of E-flows in the light of predicted impacts of climate change.

2. Study site

The Indus Delta spreads 600,000 ha across south-eastern coast of Pakistan, from south of Karachi to Rann of Kutch beyond the India–Pakistan border. It is approximately 240 km in length and 200 km wide. Of this, the mangroves cover 158,000 ha (PFI, 2004) which is fragmented at most and of which only one-fifth is dense forest (Qureshi, 2003). Indus Delta supports livelihood of nearly 900,000 coastal population (Wood et al., 2013) and number of ecosystems that range from marshes, creeks and mudflats, to riverine forests, mangroves and lakes (GoP, WWF and IUCN, 2000). The fertile delta is home to innumerable avian, aquatic and terrestrial species, of which many are unique to the region e.g., South Asian Indus Dolphin and 22 of 147 fish species which are endemic to Pakistan (Wong et al., 2007). The mangrove ecosystem is unique in being the only arid mangroves of Asia remarkably resistant to extreme temperatures, high salinity and low precipitation (DasGupta and Shaw, 2013). However, the alarming disappearance of mangrove forest cover from the Indus Delta at a rapid rate of 2% per annum, makes them 'critically threatened' (DasGupta and Shaw, 2013). Scientific literature attributes this degradation to anthropogenic intervention and drastically reduced flows from the Indus River (Alongi, 2008; DasGupta and Shaw, 2013; Magsi and Atif, 2012).

The Indus River provides freshwater supplies to the Indus Delta. It is regulated by the Kotri Barrage, which is the last major hydraulic structure that was built across Indus River in 1955, (Fig. 1). Indus River is the lifeline of Pakistan, the 6th most populous country in the world. Most of the flow in Indus River (up to 70%–80%) are generated in the Upper Indus Basin (UIB) as a result of melting of the glacier and snow pack of Hindukush–Karakoram–Himalaya region (Wong et al., 2007). Since the construction of Tarbela Dam on the Indus River in 1976 (the most upstream major hydraulic structure on the River), downstream river flows have reduced considerably up to Kotri barrage (Fig. 2). As the river flows downstream of Kotri Barrage, it deposits 450 million tonnes of suspended deposits discharging 200 km^3 of water (GoP, WWF and IUCN, 2000).

The delta receives most of its annual rainfall during monsoon season (i.e. Jul–Sep), as evident from Karachi rainfall data (the gauging station situated closest to the study area and considered most representative) shown in Fig. 3.