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Review

A review of atmospheric and land surface processes with emphasis on flood generation in the Southern Himalayan rivers

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HIGHLIGHTS

- Floods in the southern rim of the Indian Himalayas are a major cause of loss of life, property, crops, infrastructure, etc.
- In the recent decade extreme precipitation events have led to numerous flash floods in and around the Himalayan region. Sporadic case-based studies have tried to explain the mechanisms causing the floods.
- However, in some of the cases, the causative mechanisms have been elusive.
- The present study provides an overview of mechanisms that lead to floods in and around the southern rim of the Indian Himalayas.

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ABSTRACT

Floods in the southern rim of the Indian Himalayas are a major cause of loss of life, property, crops, infrastructure, etc. They have long term socio-economic impacts on the habitat living along/across the Himalayas. In the recent decade extreme precipitation events have led to numerous flash floods in and around the Himalayan region. Sporadic case-based studies have tried to explain the mechanisms causing the floods. However, in some of the cases, the causative mechanisms have been elusive. Various types of flood events have been debated at different spatial and temporal scales. The present study provides an overview of mechanisms that lead to floods in and around the southern rim of the Indian Himalayas. Atmospheric processes, landuse interaction, and glacier-related outbreaks are considered in the overview.

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1. Introduction

Five major flood events in the Himalayan region from Pakistan to Assam in the past 10 years have occurred, highlighting the increasing prevalence of floods, inadequacy of infrastructure to combat floods, incomplete understanding of flood forecasting mechanisms, and the lack of preparedness in the region. Managing the Himalayan floods is a challenging task, since the floods result from a combination of atmospheric and land surface processes. The 2010 July–August flood in Pakistan is considered to be the worst ever flood in the region caused by the mesoscale convective systems (Houze et al., 2011; Webster et al., 2011; Lau and Kim, 2012). This was followed by the Ladakh flood in August 2010, which was caused by multiple cloudbursts in a span of three days generated by the passing low pressure system (Rasmussen and Houze, 2012; Kumar et al., 2014; Thayyen et al., 2013). In 2012, the Brahmaputra flood was also generated by torrential rains over steep mountain slopes. In June 2013, the Kedarnath floods were caused by high intensity torrential rains coupled with Chorabari lake outburst (Dobhal et al., 2013). The Kashmir flood in September 2014 was caused by an unusual convergence of monsoon and westerly winds, whereas the 2015 Zanskar flood was caused by a Landslide Lake Outburst (LLOF) (http://www.nrsc.gov.in/Phutkal.html). Apart from these major flood events, many local floods were recorded across the Himalayas in the recent past as listed in Table 1. These recent flood events highlight the need for a better framework for flood hazard mitigation and disaster risk reduction in the region.

Geographically and geomorphologically, the Himalayas have a unique positioning, located along the Karakorum in the west to Assam in the east (Fig. 1a), blocking the monsoon and trade winds from the tropics in summer and from extratropics in winter. Within the Himalayas, climate and hydrology vary at the regional to sub-regional scale. The climate of western Himalayas is mainly driven by wintertime weather (Dimri et al., 2015; Yadav et al., 2013), the climate of central Himalayas is driven by summer and winter monsoon (Shrestha et al., 1999), and the climate of eastern Himalayas is dominated by summer monsoon (Jhajharia and Singh, 2011). The lifting of monsoon moisture along the steep southern slopes of the Himalayas is a major driver of floods in the region (Fig.1b). The principal non-monsoon flood regime of the Himalayas lies in the north-west of the monsoon regime, where major floods are also caused by glaciers and landslide damming. The high altitude glacier regimes are also the potential zones of non-monsoon floods, such as Glacial Lake Outburst Floods (GLOF). Hence, floods in the region have multiple geneses, offering a formidable challenge to flood management.

Our understanding of atmospheric and land surface processes that dictate flood characteristics in the Himalayan region have many gaps. This can be attributed to the complex geography and topographic interactions with large scale atmospheric flows and data gap/sharing issues. Conditions and physical processes that produce floods in the Himalayan region can be highly complex, comprising multiple geneses that often involve coupled and dynamic atmospheric and land surface processes (Barros et al., 2004; Dimri and Niyogi, 2012; Bookhagen and Burbank, 2006). Feedbacks between atmospheric, topographical, and geomorphological attributes may result in highly variable patterns and outcomes of water and sediment distribution in high altitude areas, including foothill and plain regions. Incomplete understanding of these processes often hinder effective flood management practices, especially flood forecasting.

Table 1
Flood events reported during the recent past in the southern Himalayas.

Number corresponding to Fig. 1	Flood event	Date	Dominant forcings
	Sutlej and Paree Chu	Jun 2005	Landslide lake outburst
5	Nepal, Kosi River	Aug 2008	Breach in the Kosi embankment
2	Myanmar	May 2008	Tropical cyclone - Nargis??
1	Pakistan, Indus River	Late Jul and early Aug 2010	European blocking and tropical-extratropical interaction
	Pakistan, Indus River	2012	
	Ladakh	Aug 2010	Cloudburst
	Zanskar, Ladakh	2015	Landslide Dam Outbursts
	Pokhara, Nepal	May 2012	Landslide + glacier melt + ???
	Uttarakhand (Kedarnath)	Jun 2013	Westerly-ISM monsoon + lake outburst
	Kashmir	Sep 2014	Torrential Rain???
	Assam, India Brahmaputra River	2012	Torrential rain
	Assi Ganga, India	2005	Cloudburst
	Rudraprayag, India	2006	Cloudburst
	Ukhimath, India	2008	Cloudburst
	Chenab, India	1996/1997	Monsoon flood
3	Bangladesh, Brahmaputra, Ganges, Meghna Rivers	1988, 1998, 2004, 2010	Monsoon flood
4	Bangladesh, Surma, Kushiyara Rivers	1998, 2004, 2007, 2010	Flash flood

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