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REPLY

# Assessing the influence of watershed characteristics on the flood vulnerability of Jhelum basin in Kashmir Himalaya: reply to comment by Shah 2015

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This is a response to the comment made by Shah (2015) to the study carried out by Meraj et al. (2015), published in the Natural Hazards (doi:10.1007/s11069-015-1775-x). We thank the commentator for his comments on our manuscript. The original manuscript published by Meraj et al. (2015) focused on the influence of the geomorphology and land cover on flood vulnerability in two Himalaya watersheds: one each from the Pir Panjal and Greater Himalaya ranges. The 2014 floods were mentioned in the manuscript just to indicate the validity and correctness of the approach adopted to assess the vulnerability of these two watersheds in Kashmir basin (KB). KB is also synonymously used for Karewa basin or Jhelum basin as well. The downstream areas of both these watersheds were inundated during the 2014 floods up to varying depths and duration. The September 2014 floods in the KB were a consequence of the extreme rainfall event that was quite widespread in extent. The situation was exacerbated due to the loss of wetlands, unplanned urbanization, the siltation of water courses in KB and the inadequate flood control infrastructure (Romshoo 2015). The commentator has made most of the comments about the genesis of 2014 floods, which was not specifically the focus of the research published by Meraj et al. (2015), and hence the genesis of the 2014 floods was not addressed therein. It is therefore appropriate that the comments made in Shah (2015) are properly responded to point by point, in order to provide a balanced perspective to the readership of the journal, and are as follows:

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1. We would like to reiterate here that the work carried out by Meraj et al. (2015) assesses the flood vulnerability of the downstream areas of the two watersheds of the KB: one on the Pir Panjal and the other on the Greater Himalaya range. The study is based on the analyses of the influence of various morphometric and land cover parameters on the hydrological response at the watershed scale. From the integrated analyses of the morphometry and land cover factors at the watershed scale, the flood vulnerability of the two watersheds was assessed using multi-criteria analyses in GIS environment. The role of the time series of the satellite and rainfall data, as suggested by the commentator, is very limited for determining the changes in the slope and drainage as these two parameters are static at decadal timescales for hydrological and geological studies (Fernandes and Dietrich 1997; Roering et al. 2001). However, because of the differential geomorphology, lithology and land cover, the vulnerability of these two watersheds to flooding varies quite significantly. There are various studies that have already been cited in our manuscript, which suggest that the unique geomorphology and heterogeneous lithology influence the hydrological response at the basin scale (Strahler 1964; Chow 1964; Montgomery and Dietrich 1989, 1992; Brasington and Richards 1998; Ward and Robinson 2000; Rakesh et al. 2000; Hudson and Colditz 2003; Yildiz 2009; Bhat and Romshoo 2009; Diakakis 2011; Romshoo et al. 2012; Altaf et al. 2013; Meraj et al. 2013).
2. During the last 3–4 decades, KB has lost numerous wetlands to urbanization and there has been consequent increase in the imperviousness, particularly in the floodplains of Jhelum basin (Rashid and Naseem 2008; Kuchay and Bhat 2014a; Romshoo and Rashid, 2014). During this period, large tracts of the agriculture lands in the Jhelum floodplains have also been converted into horticulture and built-up areas (Bhat 2008; Kuchay and Bhat 2014b; Murtaza and Romshoo 2015). This loss of wetlands and the unplanned urbanization of the Jhelum floodplains are regarded as the single most important reason for the unprecedented flood damage to the infrastructure and businesses during the 2014 floods (World Bank 2015a, b). Though the trigger for the 2014 floods is the extreme rainfall witnessed during the week preceding the flooding, the authors do not believe that the climate change has exacerbated the flooding scenario in the KB as insinuated by the author in his comments on the manuscript under discussion. KB has been traditionally vulnerable to floods as is evident from the historical flood record (Table 1). It is believed that the 2014 flood is following the 50-year flood cycle; the previous two floods of almost similar hydrological magnitude were 1905 and 1959, and there is thus a flood cycle of 50 years in Jhelum which cannot be attributed to the changing climate. However, several studies worldwide (Romanowicz and Beven 1998; Lal et al. 2001; Kundzewicz et al. 2010) and in Indian Himalaya (Valdiya 2011; Mishra and Srinivasan 2013) have reported increasing

**Table 1** Major floods recorded in the recent history of Kashmir basin (KB)

| | | | | | |
|---|---|---|---|---|---|
| 2082 BC | 635 AD | 724 AD | 855 AD | 917 AD | 1122 AD |
| 1379 AD | 1573 AD | 1662 AD | 1735 AD | 1746 AD | 1770 AD |
| 1787 AD | 1836 AD | 1841 AD | 1844 | 1882 | 1893 |
| 1900 | 1902 | 1903 | 1905 | 1909 | 1912 |
| 1918 | 1926 | 1928 | 1929 | 1932 | 1948 |
| 1950 | 1954 | 1957 | 1959 | 1966 | 1969 |
| 1973 | 1976 | 1986 | 1987 | 1988 | 1992 |
| 1995 | 1996 | 1997 | 2004 | 2014 | |

frequency of the extreme rainfall and flooding, but from the available observed data over KB, there is no evidence of the increasing frequency of extreme rainfall events, though the observation records are available for around 40–50 years only.

3. There is nothing to contest about the argument on the earthquake-triggered landslides and floods in the KB. There have been a few more recent studies about the tectono-geomorphic evolution of KB that have discussed the sequence of the formation and draining out of the Karewa lake encompassing the Jhelum basin (Basavaiah et al. 2010; Dar et al. 2014). However, we feel that this comment is not relevant in the context of the theme and focus of the research work reported in Meraj et al. (2015).
4. Again, this is not a relevant comment in the light of what has been researched and reported in the manuscript under discussion. Definitely, the role of tectonics on the 2014 flood scenario in KB is not considered in the manuscript. The focus of the research is primarily about assessing the impacts of differential geomorphology, lithology and land cover on flood vulnerability of the two watersheds located on the Pir Panjal and Greater Himalaya range. The tectono-geomorphic evolution of KB, nestled between the Pir Panjal range and the Greater Himalaya range, has been studied to understand its tectono-geomorphic evolution and stands published by one of the co-authors (Dar et al. 2015). The authors have meticulously discussed the sequence of the events of the Karewa lake formation and its draining out during the era when the homo sapiens did not even inhabit the earth.
5. The authors do not negate the NE-dipping thrust fault theory. However, we disagree with the argument that the geological and tectonic history has shown that a number of destructive floods caused by earthquakes could result in significant drainage reversals and therefore the proposal of constructing an alternate flood bypass channel for the Jhelum River is not a balanced approach to dealing with any such future flood event. We must understand that constructing flood protection hydraulic structure such as flood spill channel cannot be put on hold simply because of the threat of it getting reversed during an earthquake whose exact timing, magnitude and location we are unable to predict (Sornette and Sornette 1989; Geller 1997; Scholz 2002; Weldon et al. 2004). In the light of this fact, strengthening the flood infrastructure to control floods has been a standard practice worldwide (Galat et al. 1998; Sommer et al. 2001; Hooijer et al. 2004). Further, even if such a reversal does take place after any big earthquake, probably it is the main trunk of Jhelum River that might get blocked (Hough et al. 2009) and at that time, the alternate flood channel, being proposed as a flood control measure in KB, might help in reducing the extent of flooding. As a matter of fact, there already exists a flood spill channel from Padshahibagh (Srinagar) to Hokersar wetland in the Jhelum basin, which was built after the devastating floods between 1893 and 1902 and is routinely used to bypass flood waters for almost a century now (EIA 2011). Fortunately, there have been no drainage reversals since it was constructed. However, there is a need for a detailed technical feasibility study to assess the viability and efficiency of the proposed alternate flood channel in KB.

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