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Heavy Rainfall over a Basin Region, Dam Failure, Storm Surge, and Tsunamis Are Frequently to Blame for Flooding Occurrences: A Geographical Review

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ABSTRACT:

Floods are the world's most frequent and devastating natural hazards, wreaking havoc on human life and the environment (Berz et al., 2001; Sanyal and Lu, 2004). It is a powerful geomorphic agent that brings about significant changes on the surface of earth. Similarly, a large number of surficial earth processes are affected by floods. Milly et al. (2002), Bronstert (2003) and Christensen and Christensen (2003) have revealed that frequent floods occur due to land use changes worldwide, while Jonkman and Kelman (2005) and Tschakert et al. (2010) have associated the recurrent problem of floods with climate change and climate variability. Flooding kills more than 23,000 people each year across the world and impacts 140 million people. Floods are most often caused by heavy precipitation, monsoonal rains, and tropical cyclones. These three forms of floods have caused 91 percent of all floods and 99 percent of all people to be displaced (Few, 2003). In the last decade of the twentieth century, floods killed 100,000 people and affected 1.4 billion people around the world (Jonkman, 2005). Despite the fascinating advances of science and technology in the twentyfirst century, flood losses in developing countries continue to increase, hitting tens of billions of dollars and thousands of flood deaths per year in floodplains and fluviogeomorphologically fragile river basins (Alcantara-Ayala, 2002; Singh and Kumar, 2013; Singh and Kumar, 2017). Apart from this, floods have both primary and secondary effects. The primary consequences are loss of life and property, as well as disruption to infrastructure, ecosystems, cultural values, and roads and bridges, while secondary effects include disease outbreaks, soil fertility loss, drought, and poverty (Jonkman, 2005).

KEYWORD: Flood basalts—India, Geography, History and Geography, Social Sciences

INTRODUCTION

India, along with Bangladesh, is one of the world's most flood-prone countries. The number of people affected by floods overwhelmingly exceeds that of meteorological, climatological and geophysical disasters. Floods affect approximately 40 million hectares of land, which is roughly one-eighth of the total geographical area. Surprisingly, floods affect twenty-three of the thirty-two states and union territories. Among the states and union territories of India, Uttar Pradesh has the maximum flood prone area, while Pondicherry has the minimum area subject to floods. The tangible and intangible losses due to floods are increasing at alarming rate year after year due to increasing population and consequent encroachment of low-lying flood prone areas. The affected cropped area varies from 3.5million hectares during moderate floods to 10 million hectares during extreme floods on an annual basis. The flood-prone region has fluctuated in the past, ranging from 0.5 million hectares in 2006 to 17.5 million hectares in 1978. Singh and Kumar (2017), on the other hand, found no statistically significant monotonic increase or decrease in the flood-affected region. Conversely, Kale (2003) has observed a statistically significant increase in the flood affected population. On an average, floods have affected about 33 million people with more than 1500 human deaths annually during 1953-2009. Surprisingly, the number of human deaths in India due to floods accounts for around a quarter of the overall global death toll.

Climate change has increased the severity and intensity of floods in India, particularly in the last few years (Dhar and Nandargi, 2003; Gupta et al., 2003). Floods are caused by extreme spatial and temporal variations in rainfall, with approximately 75 percent of annual rainfall spilling over a short period of time (June-September), thereby resulting in higher discharge from the rivers. The Ganga and Brahmaputra River basins in northern and north eastern India have the highest flood capacity, followed by the Mahanadi, Narmada, Tapi, and lower Godavari rivers in central India. Besides, the basins of north western Indian rivers, namely Sutlej, Ravi, Beas, Jhelum, Chenab, and Ghaggar all originating from Himalayas carry quite substantial discharges along with large volumes of sediment in the season of monsoon.

Consequently, the stream beds are rising progressively leading to inundation. In Punjab and Haryana, the main issue at the moment is insufficient land drainage, which triggers flooding over large areas. Inadequate ability within riverbanks to contain high flows, riverbank flooding, silting of riverbeds, waterlogging, and changes in river regimes are some of the other causes of floods (Bhan, 2001). Floods are also caused by landslides that block flow, river course changes, flow retardation due to tidal and backwater effects, poor natural drainage, cyclone-related extreme rainstorm events, cloud bursts, snowmelt, glacial lake outbursts, and dam breaksThe state of Haryana is highly susceptible to floods and about 55 percent of its area is subject to flooding (Singh and Kumar, 2017). Further, its areas are hit hard by flash floods annually during south west monsoon season from the streams originating in the Siwalik Himalayas, namely Ghaggar and its tributaries such as Markanda and Dangri. These rivers breach their embankments all along their stretches and flood vast areas every year. Floodhydrology and its estimation these days are considered to be an extremely useful exercise in various water resource development and management projects. Flooding rivers, especially originating from Siwalik Himalayas in north western India are extremely dynamic and are characterised by their extremely large magnitudes, high frequencies and extensive devastations. Remarkably, very little is known with respect to causes and consequences of floods regarding the ephemeral streams originating from Siwalik Himalayas. Therefore, a study of the floods with respect to streams originating from Siwalik Himalayas in north western India is of special interest for the hydrologists, geomorphologists, hydraulic engineers and disaster managers to enhance the existing knowledge and to improve the forecasting and prediction capabilities based on past flood records so as to reduce the miseries of the residents in region.

Review of Literature

Flooding is a significant natural threat that happens on a daily basis. Some of the most unusual and unprecedented floods in recent decades have occurred along various rivers (Rakhecha, 2002; Herschy, 2002; Kale, 2003; Dhar and Nandargi, 2003, 2004; Singh and Kumar, 2017). The 1986 flood on the Godavari River was the largest flood on record in the Indian subcontinent, with a peak discharge of about 99,300 m3 /s (Rao, 2001; Kale, 2007). A thorough review of literature on following themes of floods have been conducted in the following sections:

Flood Hazard Mapping and Hydro-Geomorphic Aspects

Many researchers have carried out flood hazard mapping for flood-prone locations (Kumar and Chhonkar, 1989; Kundu and Kumar, 1995; Dhakal et al., 2002; Jain and Sinha, 2003; Jain et al., 2005; Chandran et al., 2006; Prasad et al., 2006; Bhatt et al., 2010). Saini and Kaushik (2012) have researched the Ghaggar's middle regions' flood susceptibility. Geographic information system (GIS) analysis of the river found drainage congestion, Agricultural operations, drainage confluence, discharge variability, a mild slope, and primary reason for flooding. Since 2013, Patel and Srivastava have utilized remote sensing and With a geographic information system, the Surat region's most flood-prone locations are marked.

Geomorphic Effectiveness of Floods and River Damming

River damming affects the flow rate, the sedimentary potential, the variability of the morphological parameters (total width, depth), the nature of the erosion, and the micro-level change in the long profile (Pal, 2016). Some of the most damaging floods have been caused by dam breaks, both natural and man-made (Kale, 2004). In the 20th century, human-built dams have broken and caused more than a dozen floods (Rakhecha, 2002; Kale, 2003; Cenderelli and Wohl, 2003; Singh and Kumar, 2013). River systems and flood plains have undergone major change as a result of numerous floods (Kale, 2003). Major flooding on some rivers seems to have longer-lasting effects. Recent studies (Kale, 2003; Kotoky et al., 2003; Mitra et al., 2005; Sinha, 2005; Sarma, 2005) have highlighted the geomorphic effects of floods on river bank erosion and expansion of channel, avulsion, and large-scale transport of sediments. According to Kotoky et al. (2003), Majuli Island, one of the largest river islands in the world, has been significantly damaged by yearly floods. Kale and Hire (2007) evaluated the changes over time in regard to the absolute power of the stream and the total energy that is available for geomorphic action in relation to the floods of the Tapi River in central India.

Objectives of the Study

In order to achieve the requirements of above stated preamble and rationale, following broad objectives have been set forth for investigation of the present study:
To delineate and evaluate the flood vulnerable areas based on linear, areal and relief properties of the Markanda River basin in north western India. To validate the flood vulnerable areas in the basin based on occurrence of past floods. To estimate the design rainstorm depths for different durations based on depthduration curves and depth-area-duration analysis. To analyse the spatial and temporal changes in the magnitude and frequency of flood peaks along with causative factors of floods. To examine the probability of peak flood magnitude and frequency for different return periods over the basin.

BASIN CHARACTERISTICS AND FLOOD VULNERABILITY

One of the most harmful hydro-meteorological phenomena is flooding, which claims many lives and results in enormous financial damages (Rahman and Khan, 2011, 2013; Jonkman and Vrijling, 2008). Over 70% of the world's population lives on land, which is under threat from floods (Aksoy et al., 2016). According to Jonkman and Kelman (2005), deluging causes harm to 140 million individuals each year and claims an average of 23,000 deaths. The largest floods, which jointly account for 91 and 99 percent of all floods and all displaced persons worldwide, are caused by high intensity rainfall, land use change, and cyclonic storms (Few, 2003).
Heavy rainfall, deforestation, and glacier melt that is occurring more quickly are all contributi ng factors to the increase in flooding episodes (Kundzewicz and Jania, 2007; Gujree et al., 20 17).
Future heavy rainfall events will result in an increase in the frequency of deadly floods (Mazz orana et al., 2009).High to extremely high rainfall causes flash floods with relatively significa nt amounts of flow, endangering human lives and habitations (Creutin et al., 2013; Gujree et al., 2017).
In addition, the physical characteristics of basins and subbasins are extremely important in de termining the likelihood of downstream flooding.A suitable and accurate vulnerability analysi s will help to lessen the aforementioned problems.

Computation of Basin Characteristics for Flood Vulnerability

Vieceli et al. (2015) concluded that different basin characteristics (morphometry) of natural drainage systems greatly influence the peak discharge and subsequently the flood vulnerability. Therefore, in order to assess the flood vulnerability, twenty basin variables (linear, areal, shape and relief) of Markanda and its sub-basins have been selected and computed based on firmly developed models given in Table 2.1. The basic basin characteristics such as geometric (perimeter, area, basin length, length of the main channel) and stream (length and number of streams) have been obtained from the natural drainage system layer. The length of the main channel and the distance from the top of the main channel to the basin boundary have been added together to get the basin length. (Altaf et al., 2013). The ordering of river network of Markanda and each of its sub-basins is based on Strahler’s scheme, which has been initially established by Horton and subsequently revised by Strahler (1952) and Schumm (1956).

ANALYSIS OF FLOOD PRODUCING RAINSTORMS

Amongst the hydrological hazards, floods referring to extreme rainstorm events are the most destructive due to their suddenness and unpredictability (Barredo, 2007). Extreme rainstorm events and resulting floods have a significant impact on agriculture, infrastructure (industry, roads, bridges, buildings, communication system etc.), food and water supplies, health, ecosystems and human lives, causing a serious concern in the society (Devereux, 2007; Middleton and Sternberg, 2013; Singh and Kumar, 2013, Das and Deka, 2017). As the severity and frequency of flooding, as well as the vulnerability of population and economy, have all increased rapidly in recent years, recurrent severe rainstorm events and increased flood threats have become the priority of society (Krausmann and Mushtaq, 2008; Hirabayashi et al., 2013; Zhou et al., 2017). Deadly floods will be more widespread in future with increasing extreme rainstorm events (Mazzorana et al., 2009). With the advent of climate change, flood threats from severe rainstorm events have increased, and the severity and creation of floods threaten many parts of the world (Jonkman and Dawson, 2012; Korah and Lopez, 2015). Furthermore, since localised severe rainstorm events occur within the context of changes in large-scale atmospheric processes, the relation between rainstorms and floods is diverse in intensity and location. The severity and length of the resulting flood are determined by the rainstorm's intensity, duration, and movement, which is determined by the location and movement of its corresponding synoptic structure in relation to the basin. Several tropical and sub-tropical countries are particularly vulnerable to changes in rainstorm patterns and the resulting floods (Anderson et al., 2015, Chadwick et al., 2015).

Data Sources

This study relies heavily on secondary data sources. Daily rainfall statistics for eight rain gauge stations (Dadhahu and Nahan fall in the territory of Himachal Pradesh, whereas Naraingarh, Ambala, Sahabad, Jansui, Jhansa and Gulha fall in the territory of Haryana) and annual peak discharge data available at the outlet of the basin were procured for the period 1996-2013 from Department of Land Records, Government of Himachal Pradesh, Shimla and Department of Irrigation, Government of Haryana, Panchkula. The area of the basin 49 represented by each rain gauge station is about 350 km2 . This network of rain gauges is fairly satisfactory when compared with the neighbouring basins of Chenab, Ravi, Sutlej, Beas and Yamuna and that of in United States of America (Dhar and Narayanan, 1965). However, there are gaps in rain gauge network in Markanda basin especially in north-west and central parts, where the distribution of rain gauges is not uniform. The Dadhau and Nahan rain gauge stations are located in Siwalik ranges of Himalayas, while others are located in alluvial plains of the basin. Additionally, Ambala and Jansui rain gauge stations fall in Dangri sub-basin, whereas Naraingarh, Shahabad and Jhansa fall in Markanda basin and Gulha rain gauge is just at the outlet point. The location and geographic characteristics of each rain gauge and flow measurement stations have been exhibited in Fig. 1.1 and Table 3.1. Generally, annual peak discharge measurements observed at the outlet of a basin is used as an indicator of floods. In this study, peak discharge occurring during rainy season (June-September) was considered. Furthermore, in the absence of discharge measurements at the outlet of basin, a sum of annual peak discharge measurements available at Jansui gauging station for Dangri river and at Jhansa gauging station for Markanda river were taken together to compute the annual extreme flow at the basin's outlet during the study period (Table 3.2). The data referred above is the only reliable and official source of data for the basin

Method

Computation of Percent Departure from Normal Rainfall

Percent departure from normal rainfall can be an excellent tool to understand the flood situation in a basin. As a result, in this study, percent deviation from normal rainfall has been calculated as the percentage deviation from the long-term mean of the normal rainfall, and it can be expressed mathematically as:

Percent departure from normal rainfall= po- long term mean of p/Long term mean of px100

where, Po is the maximum/minimum recorded rainfall in the basin, for example, month/season/year and P is the long-term average annual rainfall in the basin during a particular month/season/year.

Estimation of Design Rainstorm Depth for Different Durations

From the daily rainfall recorded in the basin, a design rainstorm depth for different durations was calculated by depth-duration method and depth-area-duration analysis. From the daily depths of storm rainfall, maximum depths of rainfall over the basin for durations of, say, one-day, two-day, three-day etc. were derived for each storm. Maximum values of rainfall thus obtained were then plotted against different durations and for each storm a depth-duration curve was drawn. Following that, an envelope curve was drawn to obtain the maximum rainfall depths for various durations such as one day, two days, three days, and so on. For depth-area-duration analysis, isohyets were constructed for rainstorms leading to major floods by interpolation between the rain gauge stations. **MAGNITUDE AND FREQUENCY OF FLOOD PEAKS**

Among the hydrological hazards, floods are probably the most common and devastating due to their suddenness and unpredictability (Barredo, 2007; Singh and Kumar, 2013). Annually, floods claim more than 20,000 lives and adversely affect about 75 million people worldwide, mostly through homelessness (Smith, 2001). The annual cost of flooding to the global economy is estimated to be between 50 and 60 billion dollars (Shrestha, 2008). Besides, high magnitude flood events may lead to catastrophic effects on the environment, individuals and society (Kale, 2003; Du et al., 2013; Markantonis et al., 2013). Flood threats have recently become a priority of society as the severity and frequency of floods, as well as the vulnerability of society and economy, have all risen rapidly (Krausmann and Mushtaq, 2008; Hirabayashi et al., 2013; Zhou et al., 2017). The magnitude and frequency of deadly floods might increase with more wildfires, anthropogenic actions (land use change etc.), volcanic eruptions and climate change (Mazzorana et al., 2009; Dong et al., 2009; Gaurav et al., 2011; Yue et al., 2012; Koplin et al., 2014). Over the last 25 or 30 years, the severity and frequency of destructive floods have risen as a result of climate change (Emanuel, 2005; Jonkman and Kelman, 2005; Tschakert et al., 2010; Shifeng et al., 2011). According to Sharma (2012), the number of flood events in Asia increased three-fold and six-fold between 2000 and 2009, compared to the 1980s and 1970s, respectively. In Europe, 264 flooding disasters were reported from 1973 to 2002, with the number increasing from 31 in the period from 1973-1982 to 179 during 1993-2002 (Dhital and Kayastha, 2013). The risk of severe flooding in the Mekong River has risen in the last two decades. (Delgado et al., 2010). Because of large-scale interannual variability in rainfall amount, intensity, and length, there will be substantial variance in the duration, volume, and severity of floods around the world from year to year and decade to decade (Kale, 1999). According to Latt and Wittenberg (2015), climate change will cause more severe flooding in basins in the future unless appropriate steps are taken to alleviate the influence of climate change.

Conclusions

This paper has revealed about the return periods and occurrence probabilities of Qmax based on GEV and LP-III distribution models over the Markanda River basin. The analysis of Qmax shows a high interannual variability over the Markanda River basin as Cv varies between 49 percent at Mullana station to 110 percent at Mahesh Nagar with a mean value of 35 percent. The Qmax and its deviation have shown a decreasing trend over the basin except at Mullana gauge and discharge site, which have witnessed non-significant positive trends. These rising trends at Mullana station are consistent with climate change hypotheses, implying that the region may see more severe weather in the future. The return period for the highest Qmax recorded at Jhansa (2670 m3 /s) station has been computed as 9.5 and 8.2-years using the GEV and LP-III distribution model, respectively. The Qmax and projected discharges have a positive relationship for 25-, 50-, 100-, and 200-year return periods, indicating that they are linked. The analyses have shown that GEV distribution model has produced the overestimated results in comparison to LP-III distribution model. FI values differ among different stations over the basin with an increase in return periods.

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