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• PANCHKULA •

A DOUBLE BLIND PEER REVIEWED JOURNAL OF APG AND ISPER INDIA INDEXED IN SCOPUS

VOLUME 17 ISSN- 0973–3485 OCTOBER 2021

CAUSES AND CONSEQUENCES OF FLOODS IN MARKANDA RIVER BASIN: A HYDRO-GEOMORPHIC ANALYSIS

Doctoral Dissertation Abstract (2021)

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Floods are the most frequent and devastating natural disasters around the world with a significant impact on human life and the surrounding environment. Flooding on average claims more than 23,000 lives per year over the globe and adversely affects 140 million people each year. Heavy rains, particularly associated with monsoons and tropical cyclones are the most common cause of floods in India. Flood events caused by heavy rainfall over a basin area may lead dam failure resulting havoc for the mankind. Moreover, it is expected that the number of heavy rainfall events will increase and hydrological cycle may intensify, and consequently flooding events may rise in future due to global warming. Floods have both primary and secondary effects. Primary effects are loss of lives and property, damage to infrastructures, ecosystems, cultural values, roads and bridges, while secondary effects include the outbreak of diseases, loss of soil fertility, famine and poverty.

In India, floods are frequently occurring disasters and approximately 40 million hectares (ha) of land is prone to floods, of which about 8 million ha of land is affected by floods every year. About 2,443 flood events occurred in India have caused nearly 44,991 deaths with an average of 1,551 deaths every year from 1978 to 2006. An increase in frequency and duration of rainstorms has been observed over Indian region, especially during the monsoon season. Additionally, the severity and intensity of flood disasters has increased over large parts of India in recent years. Consequently, the adverse impacts of floods are likely to increase due to population growth, population migration and climate change.

The state of Haryana is highly susceptible to floods and about 55 per cent of its area is subject to flooding. Further, its areas are hit hard by flash floods annually during south-west monsoon season from the streams such as Ghaggar and its tributaries like Markanda and Dangri originating from the Siwalik Himalayas. These rivers breach their embankments all along their stretches resulting floods on vast areas every year. Markanda river basin has been purposively selected for investigation for the present study as a representative unit of the sub-tropical continental monsoon region of north-western India. This basin is a complete, clearly defined and an extremely fragile geomorphic unit which inundates its areas almost every year during June to September months. The basin has been worst flood-affected in the years 1960, 1962, 1964, 1968, 1971, 1976, 1977, 1978, 1983, 1988, 1993, 1995, 1998, 2001, 2004, 2008, 2010 and 2013. The nature

and extent of these floods has been alarmingly changing with respect to their spatio-temporal magnitude and frequency. Recently, the Markanda river basin has changed significantly due to rapid developmental activities. The flood management strategies adopted are not sufficient enough to mitigate the effect of floods. Therefore, this river basin has been selected for this study on account of availability of hydrological records, which generally are not available for such a smaller size basin such as of the Markanda river.

Objectives

Major objectives of the study are:

- to delineate and evaluate the flood vulnerable areas based on linear, areal and relief properties of the Markanda river basin;
- to validate the flood vulnerable areas in the basin based on occurrence of past floods;
- to examine the nature and distribution of flood generating rainstorms over the basin for the period 1996-2013;
- to estimate the design rainstorm depths for different durations based on depth-duration curves and depth-area-duration analysis;
- to explore the spatial and temporal variations in magnitude and frequency of flood peaks along with causative factors of floods and
- to examine the probability of peak flood magnitude and frequency for different return periods over the basin.

Database and Methodology

This study is based on a variety of data sources. Acquisition of basic data has been done from (i) Cartosat-1 digital elevation model having 30 m spatial resolution, downloaded from National Remote Sensing Centre, an open source geo-database; (ii) Global Mapper 19 to derive the detailed drainage network and basin boundaries; (iii) Survey of India (SOI) topographical maps on 1:50,000 scale for geometric correction and verification of drainage pattern; (iv) Indian Remote Sensing P6 Advanced Wide Field Sensor data with 56 m spatial resolution of July 9, 2010 to validate the extent of flood inundation areas of the basin with that of the model based flood susceptible areas and (v) For accuracy and validation of vulnerable areas data regarding past floods damages pertaining to number of affected villages, households and population (both male and female), economic losses, relief released, crop damages and human casualties have been collected from the Department of Revenue and Disaster management, Haryana, Himachal Pradesh and Punjab. Additionally, other collateral data pertaining to the causative factors of flood occurrence in the basin such as, groundwater levels, field photographs etc. have been collected and used in this study.

Apart from above, daily rainfall data for eight rain gauge stations (Dadhahu and Nahan fall in the territory of Himachal Pradesh and 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 have been procured for the period 1996-2013 from Department of Land Records, Government of Himachal Pradesh, Shimla and Department of Irrigation, Government of Haryana, Panchkula. Annual peak discharge measurements taken at the outlet of a basin are used as an indicator of floods. In this study, peak discharge occurring during rainy season (June-September) has been considered for flood forecasting.

Major Findings

Flood risk mapping is an indispensable tool for early flood warning, crisis management, and moderation of future floods. Depending on obtained results, the sub-basins of Markanda basin have been categorized into three classes according to the level of flood hazard. Analysis reveals that about 7, 21 and 72 per cent area of the basin is vulnerable to high, moderate and low levels of floods, respectively. High flood vulnerable areas are located in upper reaches where about 2.8 per cent of human population is settled. These reaches are characterized by steep slopes, impermeable and barren surfaces and high basin relief.

The accuracy of vulnerable areas has been assessed through secondary data pertaining to past flood damages such as number of villages, households and population affected, economic losses, relief released, crop damages and human casualties. The study reveals that three sub-basins have high degree of flood vulnerability, two sub-basins have low vulnerability and four sub-basins have medium degree of flood vulnerability. Subsequently, flood vulnerability of the sub-basins has been tested by using the satellite images and the spatial distribution of past flood casualties and economic losses.

Mean annual rainfall of the whole Markanda basin is about 95.7 cm. Monsoon (July to September) rainfall of the basin accounts for 82 per cent of the annual rainfall. The percentage departures of the maximum and minimum value from the mean annual are of the order of plus 45.4 and minus 29.5 per cent, respectively. South-western parts of the basin receive comparatively less rainfall as compared to the north-eastern parts, because moist wind currents are made to rise abruptly over the hills during the active south-western monsoon period.

Major months of flood occurrences in the basin are July followed by August and September. During the period 1996-2013, it has been witnessed that major floods exceeding 2000 m^3/s occurred four times in the month of July followed by thrice in August and twice in the month of September. Peak floods have hardly been witnessed in the month of June, which is one of the principal rainy months of Markanda catchment after July, August and September months.

Normally floods in this basin occur by monsoon depressions prevailing north-western region. Rainfall analysis of major flood producing rainstorms during the years 1996-2013 has shown that from 28 July to 3 August, 1997 rainstorm caused the maximum depths of the rainfall over the basin. This rainstorm produced a record peak discharge in the basin amounting to about 4000 m^3/s at the outlet. In this storm, the heaviest concentration of rainstorm has been witnessed on seventh, sixth, fifth and fourth day of the storm. Apart from this, it has been also observed that majority of the flood producing rainstorms affecting the Markanda catchment has been of 7-day duration.

During the study period i.e., 1990-2013, the basin experienced 84 floods in total encompassing 19 major floods (>1 m) at different gauge and discharge sites with an average of about more than 3 floods annually. Except the Mullana gauging station, the occurrence of highest observed annual peak floods at different gauge and discharge sites in the Markanda river basin has decreased since 1990. The highest flood in the basin occurred on August 11, 1999 at Kala Amb station when the difference between discharge level and highest flood level was recorded about 3.9 m above the danger level. Apart from this, Kala

Amb gauge and discharge site experienced eight major floods, out of the total 19 major floods, recorded in the basin during study period.

The longest duration of flood in the basin was experienced from September 4, 2010 to September 8, 2010 (5 days) at Mullana gauge and discharge site. The greatest occurrence of floods in the basin has been observed at Jansui gauge and discharge site over the Dangri river sub-basin and at Kala Amb gauge and discharge site. During the study period, maximum number of floods in the basin have been observed in the years 1995 and 2010 when 17 and 14 number of floods at different gauge and discharge sites have been witnessed, respectively. Similarly, the basin experienced maximum number of floods in the month of August followed by July which are the two rainiest months over the basin areas. Interestingly, a positive relationship between monsoon rainfall and occurrence of floods in the basin has been detected.

The analysis of Q_{max} shows a high inter-annual variability over the Markanda river basin as coefficient of variability varies between 49 per cent at Mullana station to 110 per cent at Mahesh Nagar with a mean value of 35 per cent. The box plots have revealed that the Q_{max} with respect to basin area is highest at Kala Amb gauge and discharge site with the lowest being at Shahabad, thereby revealing that the flood generation over the basin declines with increasing basin area. The Q_{max} and its deviation have shown a decreasing trend over the basin except at Mullana gauging station, which have witnessed non-significant positive trends. These increasing trends at Mullana station are consistent with the hypotheses of climate change, indicating that the area will experience more extreme events in future. These results have been duly authenticated by the plots of quadratic trend model in this study.

The probability distribution used for the estimation of return periods with the magnitude of estimated discharge shows that the exceedance probability decreases with increasing time. The comparison of the estimated discharges for 25-year return periods based on GEV-I and LP-III distribution models specifies that the estimated discharge (933 m^3/s) calculated using GEV-I distribution model is closer to the observed Q_{max} (940 m^3/s) at Raipur Rani gauge and discharge site. Apart from this, a comparison of the estimated discharge for the 2-year return period has been detected lesser than or equal to the Q_m over the entire Markanda River basin. Remarkably, GEV-I distribution model over-estimates the estimated discharge than LP-III distribution model at all gauge and discharge sites except Shahabad gauge and discharge site. The relationship between the Q_{max} and estimated discharges for 25-, 50-, 100- and 200-year return periods suggests that there is a positive correlation between them.

The CDF and P-P plots on the basis of KS and AD test reveal that the LP-III distribution model is best-fitted for maximum number of gauge and discharge sites in the study area as compared to the GEV-I distribution model. Flood regionalization curves reveal that on an average the expected flood may vary between 0.9 to 3.9 times the Q_m over the entire Markanda river basin. Finally, it can be concluded that the GEV-I and LP-III probability distribution models employed in this study can be helpful in floodplain management and for designing the dimensions of hydraulic structures over the Markanda River and its tributaries to mitigate the effects of recurring floods over the basin. The findings of this study may assist in adopting best management practices for flood vulnerable areas, for the socio-economic development of the people.

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