

Article



Detection of Spatial Shift in Flood Regime of the Kabul River Basin in Pakistan, Causes, Challenges, and Opportunities

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Abstract: Recent evidence of regional climate change impacts on hydrological cycle directed us to study the floods in a high elevated and rapidly urbanized river basin, the Kabul River basin (KRB), Pakistan, which is susceptible to frequent flooding. Therefore, we analyzed the changes in flood regime at various spatial and temporal scales and their possible causes, which is accomplished by using flood indicators, trend analysis, change point analysis, and hydrological modeling. The results showed that the northern and northwestern parts of the KRB were more exposed to flood hazard than the southern parts under long-term scenario (1961/64-2015). However, after the change points, the flood risk decreased in the northern and increased in the southern regions. This spatial shift increased the vulnerability of population to the flood hazard, because the majority of population resides in the southern region. The extreme precipitation has also increased, especially the maximum one-day rainfall and maximum five-day rainfall throughout the basin. Particularly, the major cause of the decrease in different flood indicators in the northern parts of the KRB is the corresponding decrease in the annual and monsoonal rainfall and corresponding positive mass balance of glaciers in the northern region after the occurrence of change point in flood regime. However, the major cause of the increase in flood hazard on the southern part of the KRB is associated with maximum five-day rainfall. A 68% variability of annual maximum flood for the Kabul River at Nowshera and an 84% variability of annual maximum flood for Bara River at Jhansi post are explained by maximum five-day rainfall. In addition, a considerable decrease in forests (-5.21%) and increase in the urban area (88.26%) from 1992–2015 also amplifies the risk of higher flood peaks. The results of hydrological modeling suggest that the six-hourly flood peak increased by 6.85% (1992–2010) and 4.81% (2010–2015) for the extreme flood of 2010 for the Kabul River at Nowshera. The flood peak per decade will increase by 8.6%, as compared to the flood peak under the land use scenario of 2010. Therefore, consideration of proper land use planning is crucial for sustainable flood management in the KRB.

Keywords: flood regime; sustainable flood management; extreme precipitation; LUCC; Kabul River basin; Pakistan

1. Introduction

The global mean surface temperature is predicted to increase by 0.3–0.7 °C for the near future 2016–2035 relative to 1986–2005 [1]. The warming climate can intensify the hydrological cycle at global as well as regional scales [2,3]. Observed variations in extreme weather and climate events since the 1950s suggest increased risks of floods and



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). droughts because of more extreme precipitation, lengthening dry span, high peak flows, and increased intensity of most extreme tropical cyclones [1,4–6]. Climatic extremes are the key drivers of meteorological and hydrological hazards, such as floods and droughts [7]. The changes in climatic extremes, especially in temperature and precipitation, may alter the occurrence, duration, and intensity of floods and droughts [6,8,9]. Climate models also suggest that extreme precipitation events will become more common [9]. In recent years, losses due to catastrophic natural hazards have aroused public awareness of extreme events [10,11].

Notably, South Asia is highly vulnerable to climate change. The average temperatures in the region have increased in the last sixty years and will continue rising in future. Rainfall is becoming more erratic, and some areas will experience more droughts, and others, more flood. Not only temperature extremes but also precipitation extremes related to the monsoon are very likely to increase in East, South, and Southeast Asia. More than 85% of CMIP5 models showed an increase in mean precipitation in the East Asian summer monsoons, while more than 95% of models projected an increase in heavy precipitation events. All climate models projected an increase in both the mean and extreme precipitation in the Indian monsoon under all scenarios. These two regions also showed an increase in the interannual standard deviation of seasonal mean precipitation [12].

Consequently, Pakistan ranked fifth most vulnerable to weather and climate extremes as per the Climate Risk Index (CRI) [13]. From the regional perspective, Pakistan experienced 66 flood events from 1985–2015. Among them, sixteen were long-duration floods, and fifty were short-duration floods [14,15]. Eighty-six percent of disasters in Pakistan were related to floods from 1985–2011 [16]. Floods are the most frequently occurring and damaging natural hazards in the country. The flood of 2010 was the most devastating in nature, which caused about 2000 casualties, damaged 1608,184 houses, affected 17,553 villages, and inundated an area of 160,000 km². This event was the worst in terms of the area affected and second worst in terms of lives lost in the flooding history of Pakistan [17]. The temporal and spatial extent of 2010 heavy rainfall event was described by Anjum et al. [18].

The nature of flooding varies according to geography. Fluvial floods in the Indus plain prove most devastating, as the terrain is flat, densely populated, and economically developed. Hill torrents (flash flooding) are the second most destructive type of flood. Hill torrents threaten large areas of the country and claim human lives most frequently. Floods due to cyclones and intensive localized rain are dominant at other locations [19].

The present study has focused on the Kabul River basin (KRB), Pakistan, because the whole KRB was flooded during the 2010 flood, and ten districts within the KRB were severely affected [20]. After 2010, Pakistan has been experiencing floods each year. Flood-related deaths and injuries were 470 and 428, respectively, from 2012–2018 in the Khyber Pakhtunkhwa province, Pakistan. A total of 4602 houses were damaged; among them, 2727 were partially, and 1917 were entirely damaged. About 70% of these casualties and damages to the homes were in the catchment area of the KRB [21]. The population in the KRB has also increased by 42.9% during 1998–2017, with an average annual growth rate of 2.26%.

Various studies were also reported in the KRB, and its sub-basins related to meteorology, hydrology, flood mapping, and water resources. For example, Ahmad et al. [22] studied trends in monthly precipitation in the Swat River basin. Ahmad et al. [23] also developed a bi-level model for the Swat River basin, illustrating the optimal allocation of water resources among competing for water demand sectors. Ahmad et al. [24] analyzed the spatial and temporal extent of snow cover and its linkage with hydrological, climatological, and topographical factors across the Chitral River basin. Bahadar et al. and Khattak et al. [25,26] studied the flood hazard assessment and prepared maps of flood-prone areas for the floods of different return periods for the Swat River and the Kabul River, respectively. Aziz et al. [27] performed the rainfall–runoff modeling for the whole transboundary KRB between Afghanistan and Pakistan using IFAS. Sayama et al. [28] also performed the rainfall runoff inundation mapping for 2010 flood event in the KRB, Pakistan. Mehmood et al. [29] performed the non-stationary modeling of annual maximum flood regime. Furthermore, some studies explored the causes of floods and their socio-economic damages [30–33]. However, all these studies were either limited to a single flood event or performed at sub-basin scales. The previous studies in the KRB were limited to inundation mapping of flood-prone areas. [25–28,34]. Moreover, the previous studies regarding land use change and precipitation were also limited to one city or one sub-basin in the KRB. However, no study was reported which critically emphasized the changes in flood regime in the basin.

Keeping in view the absence of any detailed study on floods, their probable causes, and studying the flood regime under changing environment, the present study was designed to explore the following objectives: (1) to explore the spatial and temporal trends in flood regime at the annual-, seasonal-, and peak over threshold (POT)-based flood indicators in the KRB, Pakistan; (2) to explore the probable causes of floods in the basin; (3) to analyze the impact assessment of land use cover changes on the extreme flood of 2010 in the past and the future for the KRB by using HEC–HMS model; and (4) to provide suggestions for flood management.

This paper is structured as follows: in Section 2, details on study area and data are described, Section 3 focuses on methods and approaches, Section 4 illustrates the results, Section 5 sheds light on necessary discussions, and finally, Section 6 highlights the major findings as conclusions of study.

2. Study Area and Data Description

2.1. Study Area

The Kabul River basin (KRB), Pakistan, stretches from 71°1′55″–72°56′0″ east to 33°20′9″–36°50′0″ north, covering an area of 40,064 km². The Kabul River starts at the base of Unai pass from the Hindu Kush Mountains in Afghanistan and flows eastward and covers a distance of 700 km to drain into the Indus River, Pakistan [35]. The whole basin covers an area of 87,499 km². The elevation in the basin varies substantially from 249 m.a.s.l to 7603 m.a.s.l. High elevation mountains are mainly located in the north. The average temperature and average precipitation vary significantly across the river basin. The average temperature is about 13 °C. Most of the precipitation occurs in the northern mountains and highlands, reported up to 1600 mm [36].

This study explores the part of KRB that contributes to flooding. The flood problem arises mainly as the Kabul River enters in Pakistan. Warsak dam is also located on Kabul River in Pakistan. The study area is further divided into four sub-basins: the Kabul River basin, Chitral River basin, Swat River basin, and the Bara River basin. The Chitral River originates from the Hindu Kush Mountains in Pakistan, enters in Afghanistan, and joins the Kabul River. The Kabul River then enters in Pakistan. The Golen Gol hydro-power project (HPP) was recently completed on the left tributary of the Chitral River, having an installed capacity of 108 MW, as shown in Figure 1. The digital elevation model–Shuttle Radar Topography Mission (DEM–SRTM) of 30 meter and the geographical location of KRB and its sub-basins, along with different hydraulic installations, are illustrated in Figure 1.



Figure 1. Description of location of KRB, DEM-SRTM (meters), climate, and hydrological stations in the KRB, Pakistan.

Population in the KRB

The population is the key driver of anthropogenic activities and has continuously been increasing in the basin since the inception of the country in 1947. The first population census was conducted in 1951. Figure 2 demonstrates the population (no. of inhabitants) from 1951 to 2017. It is clear from Figure 2 that the population is continuously increasing within the KRB. From 1951 to 1981, during the initial thirty years, the total increase was 58%, while the population increase was more during the last thirty-seven years from 1981 to 2017, approximately 66%. The total increase in population was 85.7% from 1951 to 2017. Figure 2 also represents the average annual population growth rate, which was minimum during 1972–1981 and was maximum during 1951–1961. However, the average population



growth was very high (2.261) during the last two decades from 1998 to 2017. Figure 3a represents the population density in the KRB [37].

Figure 2. Total population and population growth rate in the KRB, Pakistan, from 1951 to 2017. Source: Pakistan Bureau of Statistics.



Figure 3. (a) Spatial distribution of population density in the KRB and (b) soil map of KRB, Pakistan.

2.2. Data

Various types of data, such as hydrological, meteorological, soil, and land use, were used for the current study. The details are presented under a separate heading for each data set.

2.2.1. Hydrological and Meteorological Data

Daily streamflow data on five hydrological stations were collected to study the flood regime of the KRB in details. The quality of the data was controlled before its release from "Surface Water Hydrology Project–Water and Power Development Authority" (SWHP–WAPDA) of Pakistan for the specific long period. The corresponding details are provided in Table 1. The spatial representations of flow gauge stations for SWHP are displayed in Figure 1.

Table 1. Basic information of SWHP flow gauges in the KRB, Pakistan.

Site#	River	Station	Flow Regime	Basin Area (km ²)	Record (Years)
1	Kabul	Nowshera	Rainfall-dominated	87,499	52 (1964–2015)
2	Chitral	Chitral	Seasonal snowmelt regime	11,396	52 (1964–2015)
3	Swat	Kalam	Seasonal snowmelt regime	2020	50 (1961-2010)
4	Swat	Chakdara	Seasonal snowmelt and rainfall	6066	55 (1961-2015)
5	Bara	Jhansi Post	Rainfall-dominated	1847	54 (1962–2015)

Meteorological data was collected from SWHP–WAPDA and Pakistan Meteorological Department (PMD). Daily precipitation and annual temperature data were collected. The temperature and precipitation data were consistent for almost all the stations. However, the precipitation record at Drosh was missing, and it was filled by mean value. The precipitation data were collected for ten stations, but three stations were discarded because of missing data and change of location for some rain gauges. Therefore, seven stations were included for analysis in this study. These seven climate stations reflect the regional climate, and the locations of climate stations cover the whole study area, as shown in Figure 1. The detailed information regarding the availability, duration of record, and elevation for each station is presented in Table 2. The use of satellite products was not helpful, because the satellite products are also unable to capture the spatial and temporal variability at various scales in the Hindukush region [18,38].

Table 2. Basic information of climate stations in the KRB, Pakistan.

Sr	Station	Record (Years)	Variables
1	Drosh	1961-2014	Precipitation & Temperature
2	Kalam	1961-2015 *	Precipitation & Temperature
3	Saidu Sharif	1974-2014	Precipitation & Temperature
4	Dir	1967-2014	Precipitation & Temperature
5	Chitral	1961-2015	Precipitation & Temperature
6	Cherat	1961-2015	Precipitation & Temperature
7	Peshawer	1961-2015	Precipitation & Temperature

* Temperature Record for Kalam was 2000-2015, only.

Therefore, six-hourly rainfall and flood hydrograph data for one season (2010 monsoon) were also collected from these organizations to model the extreme flood event of 2010 in the KRB.

2.2.2. Soil and Land Use Data

The soil data for the basin were obtained from the Harmonized World Soil Database (HWSD) with a resolution of 1 km, as shown in Figure 3b. This database was developed by the Food and Agriculture Organization (FAO) with the collaboration of International Institute

of Applied Systems Analysis (IIASA), the International Soil Reference and Information Centre (ISRIC), the Institute of Soil Science of Chinese Academy of Sciences (ISSCAS), and the Joint Research Centre (JRC) of the European Commission (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonizedworld-soil-database-v12/en/) (accessed on 20 July 2019).

Regional soils include sandy loams, loams, sandy clay loams, silt loams, silt, silty clay loams, and clay loams with less than 35% clay and less than 65% sand; the sand fraction may be as high as 82% if a minimum of 18% of clay is present. This soil is referred to as medium-textured soil. Table S1 represents the specifications of soil data in the KRB, Pakistan. The soil belongs to hydrologic soil group C in the basin.

Land use data were obtained from the European Space Agency climate change initiative (CCI) project. The data was available from 1992 to 2015, with a spatial resolution of 300 m. The detailed information about CCI map is presented in [39,40]. Moreover, an independent accuracy assessment performed at global scale represented an overall accuracy of 73% [41]. The images of 1992, 2000, 2010, and 2015 were downloaded and reclassified into seven land use classes for the study area of KRB, Pakistan. Table S2 describes the details of the original classes as well as re-classes.

3. Methods

3.1. Preliminary Analysis

3.1.1. Analysis of Annual, Seasonal, and Peak over Threshold Flood Regime Flood Indicators

Four flood indicators were used to evaluate the changes in flood regime at different scales. The details of these indicators are presented in Table 3. AMF and AMFsp were used to study the changes at annual and seasonal scale, respectively, while the POT series were used to study the changes in flood regime at different levels of thresholds. POT series was used to compensate for the limitation of annual maximum series, which provides the information about the largest flood in a hydrological year.

Table 3. Description of indicators for flood	n of indicators for floods
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Flood Indicators	Abbreviations	Description	Flood Characteristics
Annual maximum flow (m ³ /s)	AMF	Maximum daily flow during a hydrological year	Magnitude
Annual maximum flow from spring to pre-monsoon (m ³ /s)	AMFsp	Maximum daily flow including spring to pre-monsoon (March–15 June)	Magnitude
Peak over threshold POT3M magnitude (m ³ /s)		Flow peaks over the threshold that lead to an average of 2.4–3 events per year	Magnitude
Peak over threshold frequency (number of events per year)	POT3F	Annual number of flow events in POT3 series	Frequency

Independence of Flood Peaks

The flood peaks for the POT series-based flood indicators were separated according to the criteria by Zhang et al. and Lang et al. [42,43].

$$\begin{cases} D > 5 + \log(A) \\ Q_{min} < \frac{3}{4}min(Q_1, Q_2) \end{cases}$$
(1)

where *D* represents the time between two successive peaks in days, *A* denotes the catchment area in km², and Q_1 and Q_2 describe the magnitudes of two successive flood peaks, respectively, in m³/s.

Selection of Threshold for POT Series

The threshold for the POT series was selected when the mean number of flood events ranges between 2.4–3 [42], and POT series follow the Poisson distribution. The Chi-square test was performed at 10% significance level to check whether the POT series follows the Poisson distribution or not.

Meteorological Indices

Eleven extreme precipitation indices [42,44,45] and one temperature index were used to study the causes and factors affecting the changes in flood regime across the KRB. Table 4 describes the meteorological indices used in this study. Data quality control procedure for precipitation data was adopted as pre-requisite as suggested in guideline prior to calculate the extreme precipitation indices using RClimdex1.1 [46].

Table 4. Meteorological indices to study the changes in extreme precipitation.

Indicators	Abbreviations	Unit
Annual Mean Temperature	T _{mean}	°C
Maximum length of dry spell	CDD	d
Maximum length of wet spell	CWD	d
Annual total precipitation in wet days	PRCPTOT	mm
Annual count of days when precipitation $\geq 10 \text{ mm}$	R10	d
Annual count of days when precipitation $\geq 20 \text{ mm}$	R20	d
Annual count of days when precipitation $\geq 25 \text{ mm}$	R25	d
Annual total precipitation when "daily precipitation amount on wet day > 95th percentile"	R95PTOT	mm
Annual total precipitation when "daily precipitation amount on wet day > 99th percentile"	R99PTOT	mm
Monthly maximum 1-day precipitation	Rx1day	mm
Monthly maximum 5-day precipitation	Rx5day	mm
Simple precipitation intensity index; Let RR_{wj} be the daily precipitation amount on wet days, w ($RR \ge 1$ mm) in period <i>j</i> . If <i>W</i> represents number of wet days in <i>j</i> , then: $SDII_j = \frac{\sum_{w=1}^{w} RR_{wj}}{w}$	SDII	mm/d

3.1.2. Trend Analysis

Non-parametric rank-based Mann–Kendall (MK) test was used to detect trends in flood time series of different indicators, extreme precipitation indices, and mean annual temperature. For a time series $x_1, x_2, x_3, ..., x_n$, with n > 10, MK test statistic (S), the variance of MK test statistic V(S), and the associated standard normal test statistic (Z) are calculated as below [47–51]. To quantify the magnitude of detected trends, a frequently used non-parametric method, Sen's slope method [52], was applied in the present study. This method is robust against outliers in a time series. The details are provided in Supplementary Materials.

3.1.3. Change Point Detection for Flood Time Series

The change point detection is an important aspect to assess the period from which significant change has occurred in a time series. Pettit's test [53], Buishand's range test [54,55], and standard normal homogeneity test (SNHT) [56,57] are the most widely used tests for change point detection. These tests have been applied for change point detection in times series data of flood. The current study also utilized these tests for change point detection in different flood indicators. The details of these methods are provided in Supplementary Materials.

3.1.4. Flood Modeling with HEC-HMS

Many hydrological models have been developed for the event-based hydrological modeling such as Continuum [58,59] and KINEROS [60]. However, the HEC–HMS can also be used for event scale hydrological modeling to analyze the flood behavior of individual storm events, and event scale models are considered more suitable for estimation of flood peak flows [61–63].

3.1.4.1. Basin Model

Application of the HEC–GeoHMS [64] prior to using the model was completed for terrain processing. DEM–SRTM of 30 m resolution was used to simulate the stream network and to delineate the watershed into a series of interconnected sub-basins by HEC–GeoHMS, the GIS pre-processor for HEC–HMS coupled with ESRI's Arcview GIS Program 10.4. The entire watershed was dis-aggregated into nineteen sub-basins, and the drainage network was also delineated. The topographic attributes for each sub-basin (e.g., slope, area, and location) were derived by HEC–GeoHMS. The SCS curve number grid is mostly use by hydrologic models to extract the curve number for watersheds. The curve number represents the runoff potential of watershed. The land use maps and soil maps were processed together to create the curve number (CN) grid [65]. The CNgrid was prepared for years 1992, 2000, 2010, and 2015 (CNgrid 1992, CNgrid 2000, CNgrid 2010, and CNgrid 2015). The basin model represents the physical watershed. This basin model was then imported into the HEC–HMS.

3.1.4.2. Meteorological Model

The meteorological model calculates the precipitation input required by a sub-basin element. In this study, point precipitation data were used from six climate stations. Thiessen polygon [66] was created for these climate stations.

In order to determine the loss, transformation, and base flow, different methods are available in the model. SCS Curve Number method [67] was used to calculate losses; SCS unit hydrograph method [68] was used to determine transformation, and recession method was used to account for the base flow in the HMS model for the KRB [69]. Moreover, Muskingum routing was used for channel routing [70].

3.1.4.3. Calibration and Validation of HEC-HMS

The HEC–HMS model was calibrated for the extreme historical flood event of 27 July 2010. Data of rainfall and discharge were entered in the respective files. The rest of the parameters were kept constant in all files. The model was validated for the 7 August 2010 flood event.

3.1.4.4. Land Use Cover Change (LUCC) Impact on the Extreme Flood of 2010

The model was calibrated using the CNgrid2010 and rainfall of 2010. After that, the CNgrid for each year was changed from 1992, 2000, and 2015 to quantify the impact of LUCC on extreme flood in the past and future, while keeping all others parameter constant.

3.1.4.5. Assessment of Model Performance

The model performance was assessed by four evaluation criteria, including the Nash–Sutcliffe coefficient of efficiency (*NS*), coefficient of determination (R^2), the deviation of peak discharge (*Dp*), and absolute error of time to peak $|\Delta T|$. The equations for *NS*, R^2 , *Dp*, and $|\Delta T|$ are as follows [71]:

$$NS = 1.0 - \frac{\sum_{i=1}^{N} (Q_{si} - Q_{oi})^2}{\sum_{i=1}^{N} (Q_{si} - \overline{Q}_{oi})^2}$$
(2)

$$R^{2} = \frac{\sum(Q_{oi} - \overline{Q}_{oi}) - (Q_{si} - \overline{Q}_{si})}{\sqrt{\sum(Q_{oi} - \overline{Q}_{oi})^{2} - (Q_{si} - \overline{Q}_{si})^{2}}}$$
(3)

$$D_p(\%) = \frac{Q_{sp} - Q_{op}}{Q_{op}} \times 100 \tag{4}$$

$$\Delta T| = \left| T_{sp} - T_{op} \right| \tag{5}$$

where Q_{si} and Q_{oi} are the simulated and observed stream flow at time step *i*, respectively; \overline{Q}_{oi} is the mean observed stream flow over the simulation period; Q_{sp} and Q_{op} are peak discharges of the simulated and observed hydrograph over simulation period, respectively; T_{sp} and T_{op} are the time for the observed and simulated hydrograph peaks to arrive, respectively; and *N* is the number of time steps. A larger *NS* value indicates a better model performance, as does the D_p with absolute values closer to zero. \overline{Q}_{oi} and \overline{Q}_{si} are the mean observed and simulated flow, respectively.

4. Results

4.1. Analysis of Floods at Annual, Seasonal, and Peak over Threshold

4.1.1. The Decision of Threshold for POT-Based Flood Series

Threshold values for the POT-based flood series for the five hydrological stations are described in Table 5. POT flood series were selected to satisfying the condition of homogenous Poisson process, and the observed value of Chi-square was less as compared to the critical value, as shown in Table 5. The parameter lambda (λ) ranges between 2.4–3 for all the study sites under consideration. The threshold for the Kabul River at Nowshera was 2267 m³/s. Similarly, the threshold values for Chakdara, Kalam, Chitral, and the Bara River at Jhansi Post were 557 m³/s, 273 m³/s, 752.2 m³/s, and 22 m³/s, respectively.

Sr	Station	Lambda λ	Chi-Squared Critical Value	Chi-Squared Observed Value
1	Nowshera	2.6	15.51	13.17
2	Chitral	2.731	15.51	9.968
3	Kalam	2.51	15.51	5.113
4	Chakdara	2.4	15.51	14.736
5	Jhansi Post	2.585	15.51	11.6

Table 5. Chi-square test statistics for POT flood series.

4.1.2. Spatial and Temporal Trends in Flood Regime of the KRB (1961/64-2015)

The flood indicators explained in Table 3, were used to study the changes in the flood regime. Their corresponding temporal and spatial variations within the basin by considering the data series (1961/64-2015) are provided in Figure 4a and Table 6, respectively. Significant increasing trends were observed for Chitral River at Chitral, and a non-significant increasing trend was observed for Swat River at Chakdara for AMF, while significant decreasing trends were observed for the Bara River at Jhansi Post, and non-significant decreasing trends were observed for the Swat River at Kalam and the Kabul River at Nowshera for AMF, respectively.



Figure 4. (a) Spatial distribution of long-term trends in flood indicators by considering the entire data series. (b) Spatial distributions of trends in flood indicators after change points.

Sr	Station	AMF	AMFsp	РОТ3М	POT3F
1	Nowshera	-0.35	-1.27	-1.8 +	-0.59
2	Chitral	2.86 **	1.56	0.61	0.95
3	Kalam	-1.36	-1.45	-0.08	-2.35 *
4	Chakdara	1.03	1.41	1.73 +	-0.75
5	Jhansi Post	-2.31 *	-2.67 **	-0.5	-2.23 *

Table 6. Trends in flood indicators.

** Trend is significant at $\alpha = 0.01$, * Trend is significant at $\alpha = 0.05$, + Trend significant at $\alpha = 0.1$.

Similarly, Chitral and Chakdara also showed non-significant increasing trends for AMFsp, while Bara River at Jhansi Post showed significant decreasing trends, and all other flow gauge stations showed a non-significant decrease in AMFsp.

For the POT series, Swat River at Chakdara revealed a significant increase in magnitude, while the Chitral River showed a non-significant increase in POT3M. The Kabul River at Nowshera showed a significant decrease, while the other two flow gauge stations were also in a non-significant decreasing trend. A non-significant increase in POT events frequency (POT3F) was observed only for the Chitral River at Chitral, while all the other flow gauge stations showed either significant decrease or a non-significant decrease by considering the entire data series.

Two flow gauge stations (Chitral and Chakdara) on the northern part of the basin showed an increase for all the flood indicators except for the POT frequency (POT3F) at Chakdara, while the rest of the three flow gauge stations represented decreasing trends for all the flood indicators. The northern and northwestern parts of the KRB showed an increased risk of flooding, whereas the southern part of the basin showed a decreased risk under long-term scenario by considering the entire data series for flood indicators. The risk is associated with flood indicators based on magnitude, not on frequency.

4.1.3. Change Point Analysis

Change point analysis was also performed for the time series of different flood indicators. Table 7 describes the change point year for the flood indicators by using three different statistical tests for change point detection. For the Kabul River at Nowshera, all the flood indicators represented the change point occurrence during 1968–1969 except POT3M, which showed the existence of a change point in 1978 as per Pettitt's test. The results of Buishand's test and SNHT were comparable for AMFsp and POT3F, as shown in Table 7. On the other hand, the change point year was observed very late (2009) and very early (1965) for AMF and POT3M, respectively. The results of Pettitt's test were also found reliable for AMF and POT3M and comparable to Buishand's test.

Table 7. Change point year for flood	indicators
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Sr Station		AMF			AMFsp			POT3M		POT3F			
or outfold	Pettitt's	Buishand	's SNHT	Pettitt's	Buishand's	SNHT	Pettitt's	Buishand's	SNHT	Pettitt's	Buishand's	SNHT	
1	Nowshera	1968	2004	2009	1969	1969	1968	1978	1968	1965	1969	1969	1969
2	Chitral	1991	1991	1991	2000	1987	1964	1981	1981	1972	1992	1992	1965
3	Kalam	1997	1999	1999	1996	1998	1998	1997	1963	1963	1995	1995	1998
4	Chakdara	1987	1987	1987	1989	1989	1989	1991	1973	1973	1998	1998	2010
5	Jhansi Post	1994	1983	1967	1983	1983	1967	1991	2009	2009	1983	1976	1976

Bold: Change point significant at 0.1.

Similarly, the Chitral River at Chitral represented the occurrence of change point year for POT3M in 1981, and all the other indicators showed a change point year during 1991–2000, according to the Pettitt's test. For AMF, POT3M, and POT3F, Pettitt's and Buishand's yielded the same change point year, but SNHT yielded the change point much earlier for POT3M and POT3F. However, for AMFsp, all the three tests displayed different change point years, as shown in Table 7.

Similarly, for the Swat River at Kalam and the Swat River at Chakdara, all of the three tests displayed comparable results for AMF, AMFsp, and POT3F, except SNHT for POT3F time series, as shown in Table 7. On the other hand, Buishand's test and SNHT yielded similar results for POT3M for these two stations.

On the southern part of the basin, the Bara River at Jhansi Post also revealed the comparable results for change point detection by these three tests for AMFsp, POT3M, and POT3F time series. However, the change point year detected for AMF was different from these three tests. The change point year detected by the Pettitt's test was statistically significant.

Overall, the twelve times series of different flood indicators at different stations represented the statistically significant occurrence of change point year. These were the Kabul River at Nowshera in AMFsp, POT3M, and POT3F; Chitral River at Chitral in AMF; Swat River at Kalam in AMF, POT3M, and POT3F; Swat River at Chakdara in AMF and AMFsp; and the Bara River at Jhansi Post in AMF, AMFsp, and POT3F, respectively. The occurrence of the change point year in all other indicators was statistically insignificant.

4.1.4. Trends in Flood Regime Posterior to Change Point

The temporal and spatial variations trend in flood indicators after the occurrence of change point year are presented in Figure 4b and Table 8, respectively. Trends in flood regime posterior to the change point were estimated as per Pettitt's test change point detection, because the Pettitt's test yielded comparable results to Buishand's test. However, we relied on the Pettitt's test. Moreover, the change points detected by the other two tests were also consistent with Pettitt's test for most of the flood indicators. Therefore, Pettitt's test change point was adopted for trends estimation in flood regime. The Kabul River

at Nowshera indicated the non-significant increase for all the flood indicators after the change point. The Chitral River at Chitral showed the non-significant decrease in all flood indicators except POT3F, which showed almost no trend after the occurrence of change point year. Similarly, the Swat River at Kalam and the Swat River at Chakdara also exposed a non-significant decrease.

Sr	Station	AMF	AMFsp	РОТ3М	POT3F
1	Nowshera	1.06	0.24	1.39	0.41
2	Chitral	-0.74	-0.88	-0.66	0.1
3	Kalam	-0.89	-1.4	-1.24	-0.83
4	Chakdara	-0.34	-1.04	-0.91	-0.71
5	Jhansi Post	2.09 *	0.65	-2.22 *	0.72

Table 8. Trends magnitude posterior to change point for flood indicators.

* Trend is significant at $\alpha = 0.05$.

On the other hand, the Bara River at Jhansi Post revealed a significant increase in AMF after the change point year and a non-significant increase in AMFsp and POT3F, whereas POT3M decreased significantly. The overall analysis revealed the interesting fact that all the flood indicators decreased insignificantly on the northern part of the KRB, while the southern part of the KRB depicted an increase in all the flood indicators except in the magnitude of the POT-based flood series (POT3M) for the Bara River at Jhansi Post. It indicates a spatial shift that the flood risk has been increased on the southern part of the basin and decreased on the northern part after the occurrence of the change point.

4.2. Probable Causes of Floods in the KRB, Pakistan

4.2.1. Spatial and Temporal Changes in Mean Annual Temperature across the KRB

Initially, the entire data series was considered for each climate station. All the stations showed a significant or non-significant increase except for the Cherat, which showed a significant decrease in mean annual temperature at 0.01 significance level as presented in Figure 5a. On the other hand, while describing the temporal trends during the last thirty-five years from 1981 to 2015, four stations revealed significant increase, excluding the Cherat station, which showed a significant decrease, by considering the entire time series as shown in Figure 5b. One station showed a non-significant increase, while the rest were in non-significant decrease during the last thirty-five years. Warming sign was evident across the whole KRB, Pakistan. This increase in the mean annual temperature can cause an increase in extremes weather events. Temporal trends magnitude is presented in Table 9. Please note that data of Dir and Saidu Sharif stations do not reach back to 1961 for Figure 5a and Table 9.

Sr	Station	Entire Series	1981-2015
1	Drosh	0.22	-0.02
2	Kalam	0.22	0.22
3	Saidu Sharif	0.43	0.60
4	Dir	1.23	3.18 **
5	Chitral	1.92 +	2.00 *
6	Cherat	-1.68 ⁺	1.77 +
7	Peshawer	3.58 ***	1.82 *

Table 9. Trends on mean annual temperature across the KRB, Pakistan.

*** Trend is significant at $\alpha = 0.001$, ** Trend is significant at $\alpha = 0.01$, * Trend is significant at $\alpha = 0.05$, + Trend significant at $\alpha = 0.1$.



Figure 5. Spatial distribution of annual mean temperature in the KRB, Pakistan.

4.2.2. Spatial and Temporal Trends in Extreme Precipitation Indices

The temporal trends in extreme precipitation indices are described in Table 10, and their spatial representation is displayed in Figure 6a–k. Saidu Sharif, Peshawar and Cherat showed significantly increasing trends in PRCPTOT. However, Kalam, Chitral, and Dir also showed a non-significant/insignificant increase in PRCPTOT. (Here, significant, non-significant, and insignificant are referred to as strong, weak, and very weak signal of increase or decrease, respectively). Moreover, only Drosh showed a non-significant decrease in PRCPTOT.

T 11	Stations									
Indices	Chitral	Drosh	Kalam	Saidu Sharif	Dir	Peshawar	Cherat			
CDD	-1.62	0.52	-1.88 ⁺	1.66 +	0.78	0.2	-0.8			
CWD	0.48	-3.69 ***	-1.08	1.17	0.63	1.87 +	-0.6			
PRCPTOT	0.16	-1.38	1.13	1.95 +	0.19	2.87 **	1.66 +			
R10mm	0.55	-0.62	0.81	1.99 *	0.4	3.02 **	1.52			
R20mm	0.3	-0.13	0.29	1.51	0.49	3.44 ***	1.67 +			
R25mm	0.08	0.19	0.96	1.68 +	0	3.36 ***	1.70 +			
R95p	-0.18	0.33	1.66 +	1.52	-0.14	1.87 +	1.15			
R99p	-0.57	-1.32	1.97 *	0.22	0.65	0.98	2.73 **			
R1*Day	0.43	0.48	1.56	2.47 *	0.83	1.94 +	2.22 *			
R5*Day	1.07	0.11	2.09 *	2.37 *	1.32	2.23 *	1.58			
SDII	-0.28	2.95 **	-0.05	0.61	-0.53	2.14 *	1.21			

Table 10. Trends on extreme precipitation indices across the KRB, Pakistan.

*** Trend is significant at $\alpha = 0.001$, ** Trend is significant at $\alpha = 0.01$, * Trend is significant at $\alpha = 0.05$, + Trend significant at $\alpha = 0.1$.



Figure 6. Spatial distributions of extreme precipitation indices across the KRB, Pakistan.

In the case of CDD, significantly increasing trends were observed at the Saidu Sharif and a non-significant increase at Drosh, Dir and Peshawar (Table 10 and Figure 6b). However, a significantly decreasing trend was obtained at Kalam and non-significant decreasing trend at Cherat and Chitral. R10mm increased significantly at the Saidu Sharif and Peshawar and non-significantly on Chitral, Cherat, Kalam, and Dir. Only Drosh showed a non-significant decrease in R10mm. The spatial distribution of R10mm is shown in Figure 6c.

In the case of CWD, significantly decreasing trends were observed at Drosh, and a non-significant decrease was also observed at the Kalam and Cherat. However, significant

increasing trends existed at Peshawar and non-significant increasing trends at Chitral, Saidu Sharif, and Dir (Figure 6d).

Moreover, R20mm increased significantly at Peshawar and Cherat and non-significantly at Saidu Sharif, and Dir showed a non-significant increase, while all other stations in the basin showed an insignificant increase and decrease in R20mm, as shown in Figure 6e. Similarly, R25mm index showed significant increasing trends at Saidu Sharif, Peshawar, and Cherat, and all other stations in the KRB either showed a non-significant increase or insignificant increase in R25mm precipitation, as shown in Figure 6f.

In the case of R95p, significantly increasing trends were observed at Kalam and Peshawar and non-significant increasing trends at Saidu Sharif, Cherat, and Drosh. However, Chitral and Dir showed an insignificant decreasing trend in R95p. Furthermore, all the stations showed either significant increasing trends or non-significant increasing trends in R99p except Chitral and Drosh, which showed non-significant decreasing trends, as represented in Figure 6h.

Finally, all the stations showed significant increasing trends or non-significant increasing trends for R*1Day rainfall R*5Day rainfall in the entire basin. In the case of SDII, significantly increasing trends were exhibited at Drosh and Peshawar, and non-significant increasing trends were observed at the Saidu Sharif and Cherat. However, SDII was negative at Chitral, Kalam, and Dir. Figure 6i–k represents the spatial distribution of trends in R*1Day, R*5Day, and SDII indices.

Most of the stations showed positive trends for all the extreme precipitation indices, except fewer indices, which showed negative trends. The southern part of the KRB was found to be more vulnerable to extreme precipitation. The capital city of Khyber Pakhtunkhwa province, Peshawar, will be more vulnerable to extreme precipitation related disasters, because none of the extreme precipitation indicators were found to be negative.

4.2.3. Land Use Cover Changes in the KRB from 1992–2015

The changes in LUCC were also studied in the KRB during 1992–2015. The land use was reclassified from twenty classes to seven classes. Table 11 describes the seven classes and their areas and the relative changes in each land use class from 1992 to 2015.

Class Name	1992 (km ²)	2000 (km ²)	2010 (km ²)	2015 (km ²)	% (1992–2000)	% (2000–2010)	% (2010–2015)	% (1992–2015)
Forest	5839.56	5538.96	5542.56	5535.36	-5.43	0.06	-0.13	-5.21
Urban Areas	40.14	48.51	264.78	341.91	17.25	81.68	22.56	88.26
Grassland	17,680.1	17,776.7	17,685.4	17,688.3	0.54	-0.52	0.02	0.05
Agriculture	8795.25	8990.82	8874.63	8801.91	2.18	-1.31	-0.83	0.08
Water Body	33.12	33.12	33.03	32.94	0	-0.27	-0.27	-0.54
Snow Cover	1192.05	1192.05	1192.05	1192.05	0	0	0	0
Bare Areas	1964.7	1964.7	1952.37	1952.37	0	-0.63	0	-0.63

Table 11. Description of land use changes and Percentage of land use changes in the KRB, Pakistan.

Moreover, Figure 7a–d represents the spatial changes in land use classes from 1992 to 2015. It is clear from the results that forest area has decreased by 5.43% from 1992 to 2000, while the urban area has increased by 17.25%; grassland increased by 0.54% and the agriculture area has also increased by 2.18%. However, no change was observed for the water bodies, snow cover, and bare areas for the same period. On the other hand, from 2000 to 2010, there was a small increase in forest areas 0.06% (5 km²) and an abrupt increase in urban areas 81.68%, while all other classes showed a decrease except snow cover, which remains unchanged throughout the study period 1992–2015.



Figure 7. Spatial representation of LUCC from 1992 to 2015 across the KRB, Pakistan.

Similarly, the forest area also decreased from 2010 to 2015, while the urban areas continued to increase by 22.56%. Grassland also showed a minor increase of 0.02% while the agriculture areas and water bodies decreased by 0.83% and 0.27%, respectively.

The overall results of LUCC indicate that the forest area has been considerably decreased from 1992 to 2015 (–5.21%, 304.2 km²). Similarly, the water bodies and bare areas also decreased by (0.54%, 0.18 km²) and (0.63%, 12.33 km²), respectively. On the other hand, there was a considerable increase in urban areas (88.26%, 301.77 km²), followed by an increase in grasslands (0.05%, 8.23 km²) and agriculture area by (0.08%, 6.66 km²). Initially, the forest areas converted into agriculture areas, and then agriculture area converted to urban areas and grassland, as shown in Table 11. Most of the increase in the urban area occurred in the southern part of the KRB that is the place of Peshawar city, which is the capital city of KPK, Province. The increase in urban areas is linked with the population increase, which has been more than doubled during the last two decades, 1998–2017, within the KRB. This decrease in forest areas and the increase in urban areas can exacerbate the flood risk in the basin by ultimately increasing the runoff potential of the basin.

4.2.4. Calibration and Validation of HEC-HMS

HEC-HMS model was calibrated at six-hourly scale based on the observed flood hydrograph for the extreme flood of 27 July 2010 and validated for the extreme flood of 7 August 2010, as shown in Figure 8a,b, respectively. The calibration event was the highest flood event ever recorded since 1929 in the basin. A cumulative rainfall of 1024 mm was received from 29 July 2010 to 30 July 2010. The validation event was also greater than the hundred-year return period as per LP3 distribution, and a cumulative rainfall of 400 mm was received between 7 August 2010 and 11 August 2010. The parameters were optimized for the calibration event. The initial discharge was calculated from the observed flood hydrograph. Optimized parameters were described in Table S4. The model performed very well for both Nash efficiency of 0.86 and coefficient of determination (R^2) of 0.82 for the calibration event. The performance of the model was also found reliable for the validation event. Moriasi et al. and Mahmood et al. [72,73] stated that the Nash efficiency of 0.75–1.0 and R² value greater than 0.7 represents the model performance as "very good". The results were found to be very good for both calibration and validation events. During the calibration and validation events, the model also performed well to determine the flood peak flow. The percentage difference was less than 1% for calibration event and less than 7% for validation the event. However, the model performance was good to determine the time to peak for the calibration event, whereas for validation event, the model performance was satisfactory, as shown in Table 12.



(a) Calibration

(b) Validation

Figure 8. (a) Calibration and (b) validation of HEC-HMS model for the historical extreme flood of 27 July 2010 and 07 August 2010, respectively in the KRB, Pakistan.

	Peak Flow (m ³ s ⁻¹)	Time of Peak (Hours)	Nash Efficiency (NS)	Coefficient of Determination (R ²)			
Calibration Event 27 July 2010 to 5 August 2010							
Observed	9808	30 July 2010, 18 p.m.	-				
Simulated	9871	31 July 2010, 00 a.m.	0.86	0.85			
Difference Dp (%)	0.63%	6 h					
Validation Event 7 August 2010 to 14 August 2010							
Observed	7054	09 August 2010, 14 p.m.					
Simulated	6578	08 August 2010, 12 a.m.	0.84	0.83			
Difference Dp (%)	6.74%	26 h					

Table 12. Summary of results for calibration and validation of flood events at 6-hourly scale.

4.2.5. Impact of LUCC on Flood Peak in Past and Future

The LUCC impact was assessed on the flood peak of extreme historical flood of 2010 after calibrating and validating the HEC–HMS model.

Figure 9 represents the simulated hydrograph under different land use scenarios (1992–2015). The six-hourly flood peak of the extreme historical flood of 2010 (9808 m³ s⁻¹) was decreased by 6.85% (9136 m³ s⁻¹) under the 1992 land use scenario. The basin average CN values vary from 81.29 to 81.6 from 1992 to 2010. Figure 9 also describes the decrease in hourly flood peak under the 2000 land use scenario, which decreased by 6.4% (9178 m³ s⁻¹). There was a minor increase in the urban area from 1992 to 2000, and the forest area was converted into agriculture land in this period. Therefore, a minimal effect on peak flood was observed. On the other hand, there was a rapid increase in the urban area from 2000 to 2010, almost 81%. Thus, a very rapid increase in flood peak was observed for 2000–2010. Similarly, 4.81% (10304 m³ s⁻¹) increase of flood peak was also observed during 2010–2015, because the urban area also increased in this period by 22.56%, as shown in Table 10. The land use change has a considerable effect on the flood peak discharge of the extreme historic flood in the KRB. The results of the study were found to be comparable with Ali et al., Miller et al., Chen et al. and Mishra et al. [62,74–76].



Figure 9. Impact of LUCC on the extreme historical flood of 2010 in past and future.

Finally, Figure 9 also presents the land use change impact in future by considering the linear changes of CN in each sub-basin of the KRB, Pakistan. The average CN value for KRB was 81.6 in 2010; assuming the current rate of urbanization in each sub-basin, the per decade rise in the average CN value of the KRB will be 82.8, representing an average increase of 1.2 in the whole KRB. The flood peak per decade will increase by 8.6% (922 m³ s⁻¹), as compared to the flood peak under the land use scenario of 2010.

5. Discussion

5.1. Analysis of Annual, Seasonal, POT Series, and Probable Causes of Floods in KRB 5.1.1. Analysis Posterior to Change Point in Flood Regime

Trends in flood regime posterior to the change point were also estimated. The overall analysis after the occurrence of the change point revealed the interesting fact that all the flood indicators decreased insignificantly on the northern part of the KRB, while the southern part of the KRB depicted an increase in all the flood indicators except in the magnitude of the POT-based flood series (POT3M) for the Bara River at Jhansi Post. It indicates a spatial shift that the flood risk has been increased on the southern part of the basin and decreased on the northern part after the occurrence of the change point (Figure 4a,b).

The decrease in flood risk, especially related to AMF and AMFsp, is because of the corresponding decrease in monsoonal rainfall and annual rainfall, respectively, for the river basins dominated by seasonal snowmelt regime or seasonal snowmelt and rainfall regime. Latif et al. [77] also highlighted decreasing signal of flow for snow-fed basins such as Chitral, and their findings are consistent with the current study. Monsoon rainfall in the Chitral River Basin has decreased non-significantly, and annual rainfall decreased significantly, as shown in Table 13, after the occurrence of the change point in the flood regime in 1991. Similarly, for the Swat River basin, the annual and monsoonal rainfall has decreased after the occurrence of the change point in 1989, as shown in Table 7.

Table 13. Trends in annual and seasonal (monsoon) rainfall for Chitral and Swat River basins (northern part of KRB).

Sr 1	Chitral River Basin				Swat River Basin			
	Annual Rainfall		Monsoon Rainfall		Annual Rainfall		Monsoon Rainfall	
	ES	ACP	ES	ACP	ES	ACP	ES	ACP
1	0.55	-1.74 +	1.73 +	-1.06	1.58	0.28	1.79 +	0.06

ES: Entire series, ACP: After change point in flood regime, +: Significant trend at 90% confidence interval.

Recently, Gardelle et al. and Hasson et al. [78–80] reported that slight mass gain or balanced mass budget of glaciers in central Karakoram are confirmed for a larger area $(+0.10 \pm 0.16 \text{ mw.e. yr}^{-1})$ and also observed for glaciers in the western Pamir $(+0.14 \pm 0.13 \text{ mw.e. yr}^{-1})$ for the study period of 1999–2011. Thus, the "Karakoram anomaly" should be renamed the "Pamir–Karakoram anomaly", at least for the last decade. The overall mass balance of Pamir, Karakoram, and Himalayan (PKH) glaciers, $-0.14 \pm 0.08 \text{ mw.e. yr}^{-1}$, is two to three times less negative than the global average for glaciers distinct from the Greenland and Antarctic ice sheets.

Therefore, the major cause of decrease in different flood indicators in the northern part of the KRB is the decrease in annual and monsoonal rainfall and corresponding positive mass balance of glaciers in the region after the occurrence of the change point in the flood regime.

Furthermore, the flood risk has been increased in the southern part of the basin for the Kabul River at Nowshera and the Bara River at Jhansi Post. The reason for this increase in flood risk is associated with R*5Day (Maximum five-day) rainfall, as shown in Figure 10a,b. A 68% variability of AMF for the Kabul River at Nowshera and 84% variability of AMF for Bara River at Jhansi Post is explained by maximum five-day rainfall. Maximum five-day rainfall has been increased all over the Basin in the KRB. These basins possess rainfall-dominated flow regimes.



Figure 10. Regression of AMF by R*5Day Rainfall for Kabul River at Nowshera and Bara River at Jhansi Post.

5.1.2. Impact of LUCC on Extreme Flood of 2010 in Past and Future

Irrespective of the presence of risk due to increased temperature in the past and future [24,80,81] and extreme precipitation across different spaces and time in the KRB, the population increase has also intensified the human activities. Therefore, the considerable changes in LUCC have occurred during 1992–2015, as shown in Table 11 and Figure 7. The decrease in the forest area and a substantial increase in the urban areas also amplify the flood risk in the basin. The risk of flash flooding in the upper catchments, and as well as urban flooding in the lower catchment of the KRB, will be pronounced. The capital city of KPK, Peshawar, will be more vulnerable to urban flooding due to the significant increase in all the precipitation indices, increase in temperature, and increase in built-up areas in the last two decades. The increased population in the basin also increased the vulnerability of the population to the flood hazard. The six-hourly flood peak has been increased by 6.85% from 1992 to 2010 for the extreme flood of 2010 at the main outlet of the basin, the Kabul River at Nowshera. The six-hourly flood peak has also been increased by 4.81% from 2010 to 2015 for the same event. The results of hydrological model also suggest that flood peak per decade will increase by 8.6% (922 m³ s⁻¹) as compared to the flood peak under the land use scenario of 2010 for the extreme precipitation that resulted in the 2010 flood. Moreover, Iqbal et al. [82] also highlighted the increase in the intensity and frequency of floods in the KRB under different climate change scenarios.

6. Conclusions

While studying the temporal and spatial trends in the flood regime at annual, seasonal, and POT-based flood series of the KRB, the following major conclusions have been drawn:

The flood risk related to annual maximum flood (AMF), annual maximum flood during spring (AMFsp), and POT3M have increased for the catchments having seasonal snowmelt regime as well as seasonal snowmelt and rainfall regime under long term scenario by considering the entire data series (1961/64-2015).

Indeed, an important fact has also been revealed from the spatial perspective: the northern and northwestern parts of the KRB were found to be more exposed to flood hazard as compared to the southern part of the basin under long-term scenario, by considering the entire data series (1961/64-2015); however, after the change point occurrence, the flood risk has been decreased at the northern part of the basin and increased toward the southern part, where the majority of the population resides. This will ultimately increase the vulnerability of the population to the flood hazard.

In order to explore the probable causes of flooding in the KRB, the changes in temperature, extreme precipitation indices, and changes in LUCC and quantitative impact assessment of LUCC on the historical extreme flood of 2010 revealed following conclusions: Observation of significant increasing trends in the mean annual temperature across

the KRB indicated the pronounced warming at the regional scale.

The extreme precipitation has also increased especially the maximum one-day rainfall and maximum five-day rainfall, which ultimately increases the risk of flooding in the entire basin, as well as urban flooding in the main cities, such as the capital city of KPK, Peshawar.

Particularly, the major cause of decrease in different flood indicators in the northern part of the KRB is the respective decrease in the annual and monsoonal rainfall and the corresponding positive mass balance of glaciers in the region after the occurrence of change point in flood regime.

Furthermore, the major cause of increase in flood hazard on the southern part of the KRB is associated with maximum five-day rainfall. A 68% variability of AMF for the Kabul River at Nowshera and 84% variability of AMF for Bara River at Jhansi Post is explained by maximum five-day rainfall. Maximum five-day rainfall has been increased all over the basin in the KRB. These sub-basins possess rainfall-dominated flow regimes.

Finally, the considerable decrease in forest area (-5.21%) and a considerable increase in the urban area (88.26%) from 1992 to 2015 also increased the risk of higher flood peaks.

The six-hourly flood peak has increased by 6.85% from 1992 to 2010 for the extreme flood of 2010 at the main outlet of the basin, the Kabul River at Nowshera. The six-hourly flood peak has also been increased by 4.81% from 2010 to 2015 for the same event. The flood peak per decade will increase by 8.6% (922 m³ s⁻¹) as compared to the flood peak under the land use scenario of 2010.

Recommendations, Challenges, and Opportunities

Finally, the impact assessment of climate and LUCC change by using higher temporal and spatial resolution data is needed to understand the proportional contributions of changes that occurred in the flood regime due to the climate variability and LUCC. Particularly for LUCC impact assessment of floods, more data for observed extreme flood hydrographs (hourly scale) should be used, and more than one hydrological model should be considered for comparison in order to reduce the uncertainty caused by the hydrological model.

The government is constructing Mohmand Dam in the northern part of the KRB. Although the Dam will be helpful to control the flood peaks, the current study highlights that the southern part of the KRB will be exposed to the extreme precipitation-related hazard. Most of the population also resides in the southern part. This extreme precipitation hazard, especially the intensity of extreme precipitation on the southern part of the KRB, will remain a challenge in future. The Provincial Government of KPK started a project called the "Billion Tree Tsunami Project" to mitigate the deforestation in the region [83–85], but studies are required to assess how useful this project will be to controlling the flood peaks or rapid generation of runoff caused by the deforestation and extensive urbanization. At the same time, challenges are available for concerned organizations, and opportunities are also available to mitigate the extreme precipitation-related hazard on the southern region. Moreover, the spatial shift in flood regime is also critical for hydropower generation in the KRB, as indicated by Casale et al. [86].

Supplementary Materials: The following are available online at https://www.mdpi.com/article/ 10.3390/w13091276/s1, Table S1: Basic characteristics of soil data in the KRB, Pakistan, Table S2: Description of land use re-classes and original classes. Table S3: Critical values of test statistics for different change point detection tests, Table S4: Optimized parameters for HEC-HMS model (6–hourly scale). **Author Contributions:** A.M. and S.J. formulated the research design and plan and organized research flow and manuscript write-up; A.M. performed analysis; S.J. supervised research work and contributed to the interpretation of results and discussions. A.L., W.Z., R.M., M.S., and R.M.A. reviewed the article critically and provided some valuable suggestions to improve the article. All authors have read and agreed to the published version of the manuscript.

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