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River flow analyses for flood projection in the Kabul River Basin

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Abstract
Flooding is one of the critical natural disasters in Afghanistan, causing huge social and economic losses on an annual basis. Due to lack of historical data and long gaps in the recorded data, flood predictions are usually associated with large uncertainties. The available hydrological data are collected before and after the Afghan civil war period. This long gap and climate change effects split the dataset and faces a challenge of using either dataset alone for predicting flood characteristics. In this study, first, the two datasets are compared to find river flow variation in terms of peak and frequency. Next, the river flow variation effects on flood peaks for each return period are analyzed to determine the flood projection. The results show that flood peaks have raised while the mean discharge in the basin is reduced during the second period. The frequency analyses show a change in high and low flow days in the recent period. In addition, the flood recurrence results show that the utilization of single period data for return period flood predictions yield huge variation, while the analyses using the combined dataset show a reasonable estimation of flood characteristics. Furthermore, the comparison of calculated flood peaks based on the first period and combined dataset show that flood peaks have an upward trend.

Keywords: River flow, variation, flood, projection, Kabul River Basin

Paper type: Research paper

1. Introduction

Every year, several large and medium scale floods occur in Afghanistan. According to Afghanistan Spatial Data Center (ASDC), 7.5 million people (22.3 % of the country population) and one million buildings are at flood risk. The Kabul River Basin (KRB), located in the central-east part of Afghanistan (Figure 1), is one of the most vulnerable region from flood disasters. This basin covers thirteen administrative provinces and is divided into seven watersheds. KRB is a densely populated basin in Afghanistan with 35 % of the Afghan

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population and 11 % of the areal extent of the country (Favre and Kamal 2004). 41 % of KRB's population live in the cities while 59 % live in rural areas near the rivers and cultivated land (NSIA 2018; World Bank 2010). The basin has a mountainous topography with higher altitudes in the north-east and lower altitudes in the south-western parts.

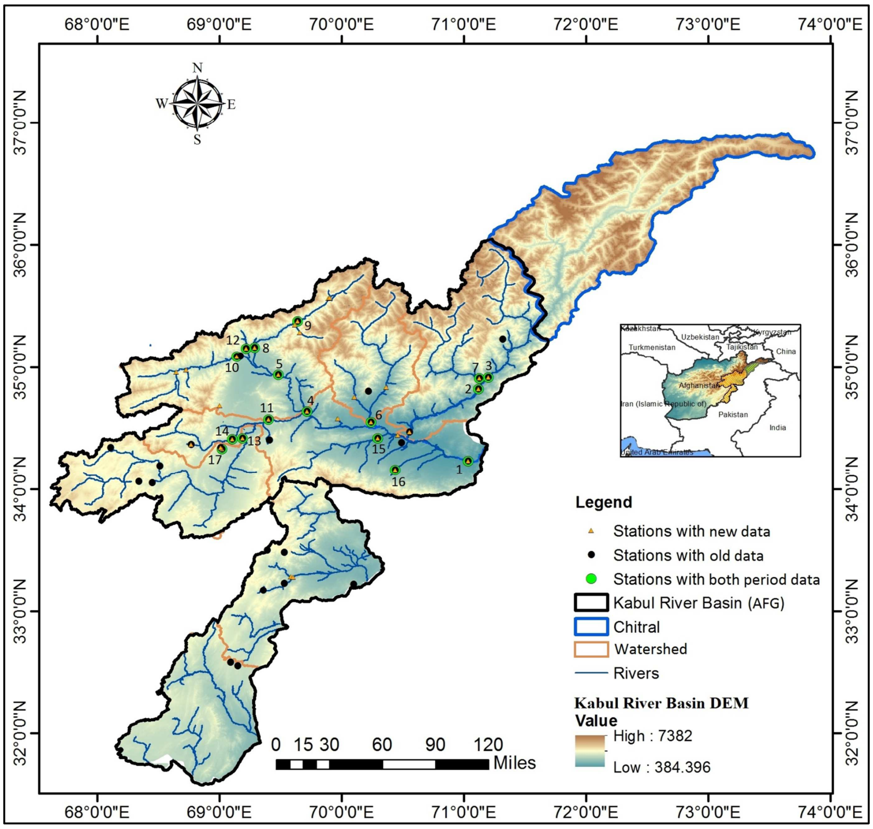

Figure 1. Kabul river basin map. The numbered stations' details are given in Table I.

The main sources of surface water in the Kabul River are glaciers and snow in the Hindu Kush mountains that are part of Himalayas (Vick 2014). According to Haritashya et al. (2009), glaciers in the Wakhan valley of Pamir Afghanistan considerably retreated and thinned. Similarly, Sarikaya et al. (2012) analyzed eastern Hindu Kush (higher altitudes of the KRB) glaciers between 1976 and 2007. Their results showed that 76% of the sampled glaciers retreated. In addition, the land use and land cover change analyses of Najmuddin et al. (2018) in the KRB from 2001 to 2010 revealed that cropland, grassland, water-bodies and urbanization areas increased, while forest, unused, and snow/ice areas decreased. Sadid et al. (2017) also reported an increase of suspended sediment concentrations by comparing 1965–1968 and 2012–2015 periods of measurements on the Maidan River partially due to land cover changes in the KRB. All of these factors might lead to a variation of discharge, flood peaks, and flood frequency in the study area. Besides, the international flood databases (CRED/EM-DAT data) and literature such as Alfieri et al. (2015) also reported the change in flood frequency, but the flood peaks and their effect on future floods predictions are not considered seriously or reported.

Floods management in Afghanistan have a short history. The systematic record of the river flow in the country first started in 1946 from the Helmand river basin (Westfall and Latkovich 1966). Subsequently, the network of hydrologic data collection was extended countrywide and recorded data until the 1980s. Following this period of data collection, the Afghan civil war destroyed all infrastructures including the hydrological data network, which caused a long gap in the water cycle dataset. In 2003, the hydrologic data collection in Afghanistan was restarted by the financial support of the international donors. The stations' record start and end dates have significant differences. The starting dates in the first period of the hydrological dataset were determined by the expansion of the hydrological network, but the finishing dates of the early part of the record are associated with security and war problems. In the second period, the start and ending dates of stations were influenced both by financial and security limitations.

The available hydrologic historical data in the KRB is related to pre- (1950 – 1980) and post- (2003 – 2018) Afghan civil war periods. The station records contain a gap of about three decades. During and subsequent to the period of missing data, intense global warming and climate change, urbanization, deforestation, and land cover changes effects on the river flow are not negligible in the region.

The long gap and environmental changes split the discharge time-series dataset into two parts. Due to the short record durations of each record periods, estimations of flood return periods are only feasible with the help of analytic methods. However, these methods also require a considerable duration of the records. Therefore, for longer return period predictions, using either a single period data is likely to result in huge variations and uncertainties; while using a combined full dataset will average over the effects of environmental changes that occurred after the first recording period. These challenges make the basin an ideal test case for determining flood projection using river flow analyses from the two discontinuous periods. Therefore, this paper first compares the river flow of both periods and later focuses on the flood problem and tries to identify the best practical method for long term flood estimation using the available discontinuous data.

2. Material and methods

2.1. Data

For flood projection analyses, instantaneous flood data does not exist. This means that the daily average discharge data must be used and the annual maximum daily value is considered as the flood situation. The water year in Afghanistan starts from the first of October. Thus, the annual statistical parameters of the flow are calculated for each water year in the period between October first and September 30th. There are 36 stations in the KRB with periods of record ranging from 3.7 to 21.0 years in the earlier (1950–1980) period of data collection, and from 3.8 to 15.5 years in the later second period (2003–2018). In addition to the issue of different starting and ending record dates, the locations of some stations in both periods have changed for unknown reasons. Thus, the number of stations having recorded data at the same location during both periods reduces to 20 stations with record durations of (3.7-21.0) and (5.9-15.5) years in the first and second periods respectively. The total record duration of both period is from 9.7 to 34.4 years. A list of these stations with location coordinates and recording duration details is provided in Table I. The gaging stations are shown on the basin map in Figure 1.

2.2.Methods

First, the data quality of both datasets was checked. Both periods' data were compared and those stations with illogical differences were identified as having errors. Further, spatial consistency of the stations recorded values was evaluated. The stations which do not match upstream and downstream stations were also removed from the calculation. In addition, the recorded values were evaluated for gage reading uncertainty. The existing data of some stations contained peak values from different times that were the same. For flood return period analyses, one maximum value from several equal discharge values in a year was selected. After quality control, 17 stations were finalized for the analyses. The stations removed from the analysis are highlighted in Table I.

Table I. Recording details of the stations with both period data in the Kabul River Basin. The stations are ordered according to maximum average discharge. Few stations have short missing data in the recording period which is marked by * in the duration column.

Station number	Station name	Station coordinates		1950 - 1980 period		Duration	Mean Discharge	Maximum Discharge	Minimum Discharge	2003 - 2018 period		Duration
		Latitude	Longitude	Start	End	Years	m^3s^{-1}	m^3s^{-1}	m^3s^{-1}	Start	End	Years
1	DAKAH	34.23071	71.03855	21-02-68	22-07-80	12.43	640.963	2970	63.4	01-04-07	30-09-18	11.50
2	KONAR RIVER AT NAWABAD	34.81969	71.12032	01-04-76	30-09-79	3.74	491.682	2000	80.6	21-03-07	30-09-18	11.54
3	KONAR RIVER NEAR ASMAR	34.91501	71.20172	23-02-60	30-09-71	11.61	378.294	1472	24.2	01-10-11	30-09-18	7.00
4	NAGHLU	34.63726	69.71704	01-10-59	30-09-80	21.01	112.205	880	10.5	11-08-08	30-09-18	10.14
5	PANJSHER RIVER AT SHUKHI	34.93617	69.48439	01-10-66	30-09-80	14.01	92.804	608	20.4	21-03-03	30-09-18	15.54
6	LAGHMAN RIVER AT PUL-I-QARGHAI	34.54698	70.24249	01-10-60	30-09-79	19.01	59.029	421	0.90	21-03-07	30-09-18	11.54
7	PECH RIVER AT CHAGHASARAI	34.90927	71.12884	23-02-60	28-02-79	19.02	58.566	505	2.34	21-03-07	30-09-18	11.54
8	PANJSHER RIVER AT GULBAHAR	35.15933	69.28868	01-10-59	30-09-80	21.01	54.488	461	6.43	01-10-07	30-09-18	11.01
9	PANJSHER RIVER AT OMARZ	35.37583	69.64085	01-10-62	30-09-80	17.67*	33.41	235	3.44	14-05-09	30-09-18	8.39*
10	GHORBAND RIVER AT PUL-I-ASHAWA	35.08880	69.14189	01-10-59	04-02-80	20.52	22.86	134	1.50	07-05-08	30-09-18	10.41
11	TANGI-I-GHARU	34.56988	69.40217	01-10-59	30-09-80	21.01	15.399	192	0.00	26-05-05	30-09-18	13.36
12	SALANG RIVER AT BAGH-I-LALA	35.15176	69.22051	01-10-61	29-02-80	17.73*	10.125	95.2	1.10	01-01-09	30-09-18	9.75
13	LOGAR RIVER AT SANG-I-NAWESHTA	34.41819	69.19113	01-10-61	30-09-80	19.01	9.632	93.8	0.00	23-07-05	30-09-18	13.20
14	TANGI SAIDAN	34.40898	69.10441	01-10-61	30-09-80	19.01	4.057	87.2	0.00	21-03-07	30-09-18	11.54
15	SURKHRUD RIVER NEAR SULTANPUR	34.41567	70.29584	08-03-68	31-03-80	11.78*	3.000	77.0	0.00	01-10-09	30-09-18	9.00
16	HAZARNAW RIVER AT SABAY	34.15458	70.44006	26-12-75	30-09-79	3.76	2.384	36.0	0.10	01-11-06	30-09-12	5.92
17	QARGHA RIVER ABOVE QARGHA RESERVOIR	34.34000	69.01000	16-04-63	30-09-80	14.01*	0.333	5.50	0.00	01-04-07	30-09-18	11.51
18	KONAR RIVER AT PUL-I-KAMA	34.46871	70.55703	28-12-66	30-09-79	12.76	482.21	2350	45.0	09-07-07	30-09-18	11.24
19	MATUN RIVER AT MATUN	33.23000	69.53000	23-12-62	20-05-79	16.42	0.801	16.0	0.01	01-01-15	30-09-18	3.75
20	BELOW QARGHA RESERVOIR	34.33000	69.02000	01-10-64	30-09-80	16.01	0.216	4.15	0.02	23-05-05	30-09-18	13.36

To find the difference of river flows over both periods, first, statistical mean, maximum and minimum of the selected stations were compared. As the periods of both records are not equal, the calculation interval for the longer period was set equal to the shorter period duration of the same station. Then the calculation interval was moved one year forward on longer period and the required statistics were recalculated. The process was continued until reaching the end of the longer period. Subsequently, the result of each calculation interval was compared with the shorter period data and the differences were calculated by using Equation 1. Then, the difference of mean, maximum and minimum discharges between the short period and each calculating interval of the longer period were averaged and 90 % confidence range for differences of each item were calculated. The summary of these analyses was used to explore trends in the mean, maximum and minimum flows.

For identifying the variation in discharge frequency, a constant ten intervals for each station of the first period (1950–1980) data were set from zero to the maximum discharge. Next, the frequency of daily discharge for each interval (discharge bin) was calculated. Then, the frequency of second period daily discharges was calculated based on the same discharge bins (intervals) as the first period, to compare the flow occurrence in every interval. The frequency of discharge in the second period (2003–2018) which exceeds the tenth interval due to rise in flow peak, were collected into the eleventh interval. Due to the difference in the duration of the two periods, first the frequency values were normalized over the recorded durations and then the difference of the second period relative to the first period was calculated by using Equation 1.

$$R_{\%} = \frac{f_{Q2} - f_{Q1}}{f_{Q1}} 100\% \qquad (1)$$

where $R_{\%}$ is the relative changes in percent between the first and second periods. f_{Q1} and f_{Q2} represent the first and second period items (mean, maximum, minimum discharges and normalized frequency values), respectively.

According to Equation 1, whenever the flow in a given bin has not occurred in the reference (first) interval, the frequency of occurrence value for this interval is equal to zero and the result of the relative change is undefined. In that case, the frequency of discharge in the second period is given with the percentage of its record duration in the brackets. This clarifies that flow occurred in this interval during the second period and the occurrence time is shown by percentage of the first period duration where the reference discharge interval value is zero. An interval with both periods having no occurrence of flow is kept blank, while zero percent (0 %) is used for intervals in which the discharge has occurred, but has not changed.

For evaluating the effects of flow variation on future flood peaks, the HEC-SSP (Brunner and Fleming 2010) software was used for the flood recurrence analyses. HEC-SSP is a statistical software developed by Hydrologic Engineering Centre (HEC) of the U.S. Army Corps of Engineers (USACE) that computes flood frequency analysis according to U.S. Federal agency guidelines reported in Bulletin 17B (Interagency Advisory Committee on Water Data 1982) and Bulletin 17C (England et al. 2015). Bulletin 17B uses the historical weighting procedure and Conditional Probability Adjustment (CPA) methods, while, Bulletin 17C uses Expected Moments Algorithm (EMA) methods for estimating the moment of Log-Pearson Type III frequency distribution (Bartles et al. 2016). Besides, both options have minor differences in low flood, confidence intervals, low outliers and plotting position calculating methods. In the analyses for this paper, the 17B methods option of the software was used because the Bulletin 17C (EMA methods) does not process data series which includes gap. Furthermore, as the regional skew value for stations in Afghanistan is unknown, the individual stations' skew values were used in the model. The remaining settings of the software were set to the default values. The analysis bundle contained three cases for flood peak recurrence estimations. The first and second cases corresponded to each single period individually and the third case was for a combination of all dataset including the gap in the time series. Estimated results were compared with first period results to evaluate effects of using each case on 10, 20, 50, 100, 200, and 500 year returning floods. As the result of stations with small discharge is critical to change in relative percentage, thus the final summary was achieved by combining the results of station with dominant discharge (stations 1–10).

3. Results and discussion

Data quality analyses identified errors in the Matun River at Matun and Below Qargha Reservoir stations. In addition, the Pul-e-Kama station on the Kunar River does not have spatial consistency. In view of these issues, these three stations were removed from the calculations. The record of several equal maximum values suggests that readings of gaging stations had uncertainty. This might originate from the conversion of flow depth or stage to discharge. This is explicit in many stations, especially in Sabay and Pul-e-Ashwa stations. It is assumed that the reading uncertainty did not significantly influence peak discharge values for the flood analyses so the data is accepted for the analyses presented here.

Statistical analyses result in Figure 2 indicates a small reduction of the mean discharge at the stations with larger discharges (Stations 1–10 average: -4.6 %). This trend is not clear for the rivers with lower discharges, which have large differences in variation between the early and later period data, as shown at stations like Sultanpur, Above Qargha Reservoir and Tangi-i-Gharu stations. The reason for this large variation in mean discharge is that these stations have smaller catchments and discharge values. Thus, a slight variation or uncertainty in gauge reading, results in a higher relative percentage value mathematically. In additions, the reduction in mean discharge originates to the occurrence of several droughts in the recent period. Omar (2018) identified droughts in the 2007–2009, 2011–2013, and 2016–2018 periods.

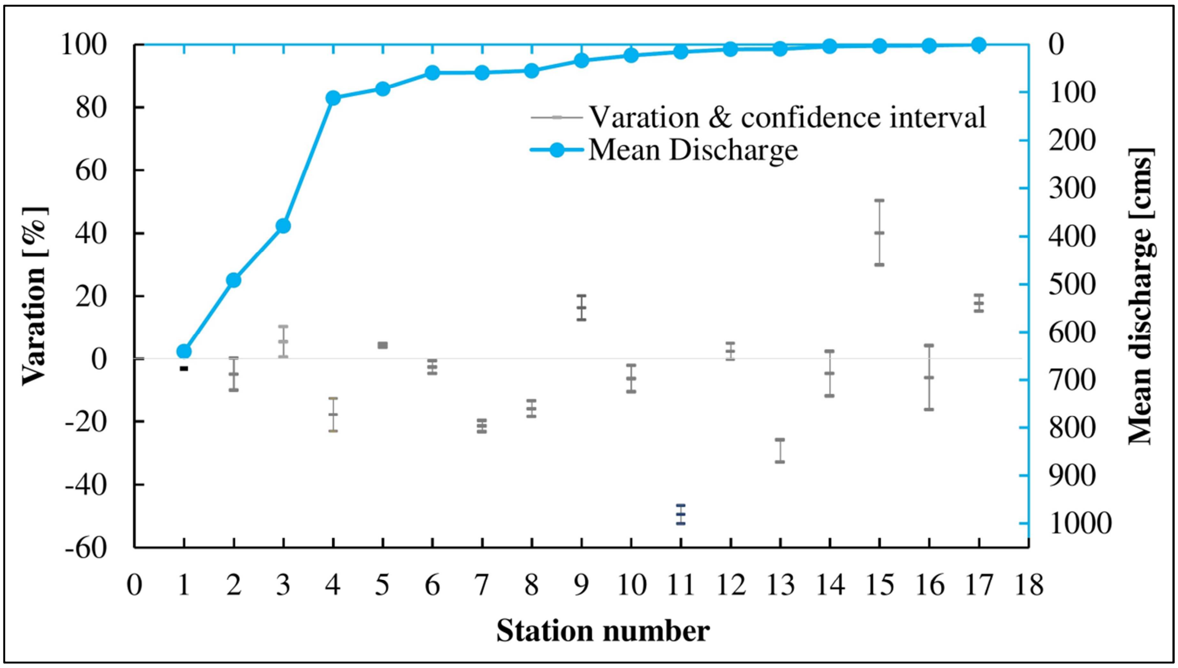

Figure 2. Variation of the mean discharge with 90 % confidence range between the recent and first periods, along with the station's average discharge. The numbered stations' details are given in Table I.

On the other hand, the analyses show (Figure 3) that peak discharge levels have mostly increased especially at the stations with larger discharges (Stations 1–10 average: 17.5 %). Rivers with smaller discharges show inconclusive results, as seen for the Sabay (Station 16), Sang-i-Naweshta (Station 13), Tangi Saidan (Station 14) and Tangi Gharu (Station 11) stations. The Chaghsarai (Station 7) has a smaller catchment, while the Asmar (Station 3) located near to Chaghsarai on the Kunar River has a larger catchment. Hence changes in the mean and maximum discharge values of these two stations are different. The stations with smaller discharge are located on tributaries and in the lower altitude and south-western areas, which receive less heavy precipitations. Thus, peak discharge values have also declined. Furthermore, WFP et al. (2016) reported that spring heavy precipitation events have increased 10–25 % in the mountainous areas of Hindu Kush and eastern part of the KRB. Thus, stations close to mountainous areas have higher increment percentage in the maximum discharge, while the stations located in the southern parts represent a decline or minor change in the maximum discharge.

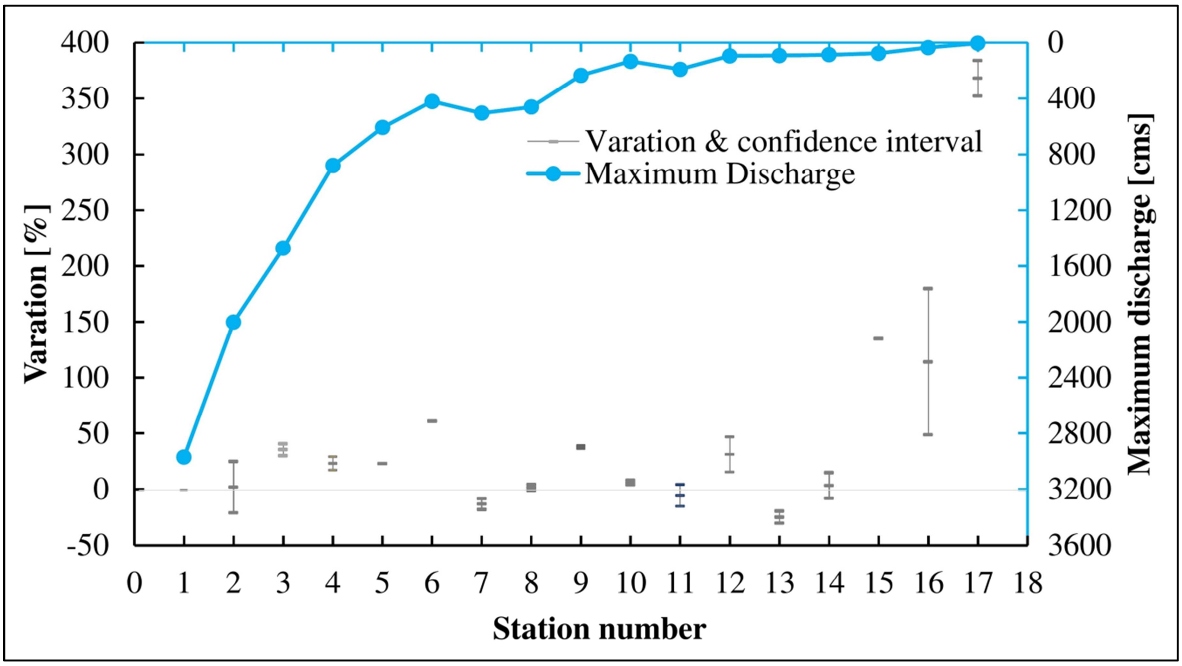

Figure 3. Variation of the maximum discharge with 90 % confidence range between the recent and first periods, along with the station's maximum discharge. The numbered stations' details are given in Table I.

Some rivers of the KRB are completely dry during the summer season, so the minimum discharge is zero and it is not possible to make a significant projection about minimum flows. However, the minimum discharge variation of most stations has a decline (Figure 4). According to the river network in Figure 1, the Kunar River is a large tributary of the Kabul River, thus flow changes in the Asmar (Station 3) leads to changes in the Dakah (Station 1). Therefore, the change of minimum discharge in these two stations is positive. The Pul-i-Ashwa (Station 10) and Sabay (Station 16) have very small mean and minimum discharges so a very slight change result to higher relative percentage compared to early period data.

Furthermore, the flow in northwest parts of the basin is controlled by a dam reservoir just before Naghlu (Station 4); so the minimum discharge released from the reservoir is essentially constant. Upstream station peaks are significantly reduced by this reservoir, however, the flow peak still raised at this station in the second period. The reduction of mean discharge at this station also suggests the change of the water balance in the upstream part of the basin.

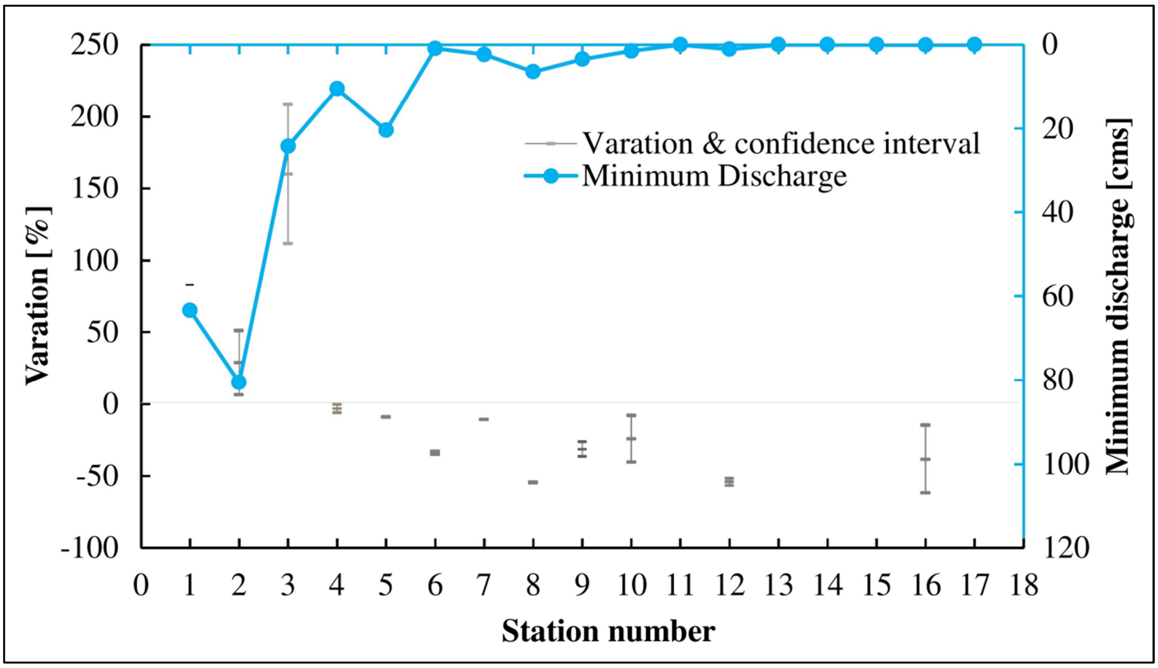

Figure 4. Variation of the minimum discharges with 90 % confidence range between the recent and first periods, along with the station's minimum discharge. The numbered stations details are given in Table I.

Moreover, the result of normalized frequency comparison analyses in Table II shows that high and low flow frequencies are increased (highlighted in Table II) in the second period in comparison to the first period. This is the result of significant increase in heavy precipitation reported by WFP et al. (2016) and increased snowmelt due to the rise of average temperature. The stations with reduced frequencies in the higher discharge interval are due to reduction of annual peak discharges discussed earlier and increment of consumption due to population growth. The increment of low flow frequencies suggests a change in flow regime and originate from droughts, rapid snowmelt and changes in precipitation pattern. The highlighted cells in Table II show the increment of river flow frequency in that interval.

Table II. Normalized frequency variation of the discharge intervals for the KRB stations between the first and second recording periods. The highlighted cells show the increment of river flow frequency in that interval. The values represent relative percentage of normalized flow frequencies. The flow range from low to high discharge is set in the first to eleventh interval.

Station number	Station name	Mean Discharge	Frequency intervals (Q$_{min}$)										(Q$_{max}$)
		m^{3}s^{-1}	1	2	3	4	5	6	7	8	9	10	11
1	DAKAH	640.963	-0.8%	7.1%	9.9%	21.1%	-9.1%	-2.9%	-57.8%	-68.3%	-60.5%	131.3%	
2	KONAR RIVER AT NAWABAD	491.682	-29.4%	93.2%	8.0%	12.6%	-8.4%	-55.6%	66.9%	37.6%	-84.8%	-89.9%	[1*329%]
3	KONAR RIVER NEAR ASMAR	378.294	-20.0%	56.0%	-1.2%	-15.4%	3.9%	-28.5%	-23.4%	-50.5%	63.0%	551.4%	[29*60%]
4	NAGHLU	112.205	6.6%	31.5%	-22.0%	-42.3%	-54.4%	-86.4%	-91.5%	-91.0%	-22.3%	55.4%	[2*48%]
5	PANJSHER RIVER AT GULBAHAR	92.804	4.63%	-5.78%	5.61%	48.01%	-20.45%	-78.26%	-83.92%	-96.18%	-90.91%	-100%	
6	LAGHMAN RIVER AT PUL-I-QARGHAI	59.029	-4.5%	17.0%	34.1%	39.7%	-13.6%	-5.2%	-33.6%	-73.9%	-74.4%	-75.3%	[5*61%]
7	PECH RIVER AT CHAGHASARAI	58.566	-0.9%	52.6%	-13.3%	15.0%	-68.8%	-73.2%	-95.7%	-100.0%		-100%	
8	PANJSHER RIVER AT SHUKHI	54.488	-5.63%	28.31%	7.29%	-1.27%	35.47%	12.18%	-25.26%	-22.08%	-41.30%	-62.88%	[12*111%]
9	PANJSHER RIVER AT OMARZ	33.41	-7.14%	3.30%	2.44%	11.12%	56.22%	115.47%	-8.81%	-27.01%	-54.85%	-9.71%	[18*47%]
10	GHORBAND RIVER AT PUL-I-ASHAWA	22.86	9%	-25%	24%	-10%	-21%	-10%	10%	-38%	-100%	-72%	[1*51%]
11	TANGI-I-GHARU	15.399	28.18%	-63.73%	-18.29%	-42.50%	-85.70%	-30.59%	-26.96%	-92.51%	151.71%	-100%	
12	SALANG RIVER AT BAGH-I-LALA	10.125	-2.4%	18.7%	-0.9%	-12.1%	-39.4%	107.8%	294.0%	991.0%	-9.1%	-100.0%	[1*54%]
13	LOGAR RIVER AT SANG-I-NAWESHTA	9.632	26.84%	-20.57%	-67.56%	0.71%	-2.99%	-0.66%	-54.51%	-60.72%	-100%	-100%	
14	TANGI SAIDAN	4.057	1%	0%	-9%	-46.1%	5.9%	-17.6%	-52.9%		229.5%	-100%	
15	SURKHRUD RIVER NEAR SULTANPUR	3.000	-8.5%	162.3%	-29.5%	-24.7%	141.0%	344.9%	161.7%	-56.4%	[1*76%]	30.8%	[6*76%]
16	HAZARNAW RIVER AT SABAY	2.384	6.8%	15.6%	-89.4%	-100%	-100%	-100%	[1*157%]			-100%	
17	QARGHA RIVER ABOVE QARGHA RESERVOIR	0.333	3%	-37%	-1%	2%	-18%	-23%	-13%	-29%	192%	168%	[43*82%]
AVERAGE OF STATIONS (1 – 10)			**-4.8%**	**25.8%**	**5.4%**	**7.8%**	**-10.0%**	**-21.2%**	**-34.3%**	**-53.0%**	**-51.8%**	**22.8%**	

Similarly, the flood recurrence results show that predictions using either of the single datasets are not reliable. These predictions show large variations, with overestimated and underestimated results especially for stations with shorter record durations. The comparison of the second period with reference to first period represent larger values for 10, 20, 50, 100, 200, and 500-year return flows at stations where maximum discharges are increased, such as in Pul-i-Qarghai (Station 6) and Naghlu (Station 4). This also shows a decline where peak flows are reduced, as in Sang-i-Naweshta (Station 13) and Chaghsarai (Station 7). The predictions based on the third case (combined full dataset including gap), showed smaller changes and better results compared to larger uncertainties in estimations using either single dataset. For example, predictions based on all three cases for (A) Naghlu, (B) Pul-i-Qarghai and (C) Nowabad stations are shown in Figure 5. The results show that using of single dataset is insufficient and yield unreasonable predictions, while the third case result has a logical trend and a better estimation. Significant variations based on single dataset were seen in most of the station analyses. The best results were found where the stations had longer periods of the record. Hence despite the effects of the environmental changes and long gap, application of the combined dataset is recommended for flood return period analyses.

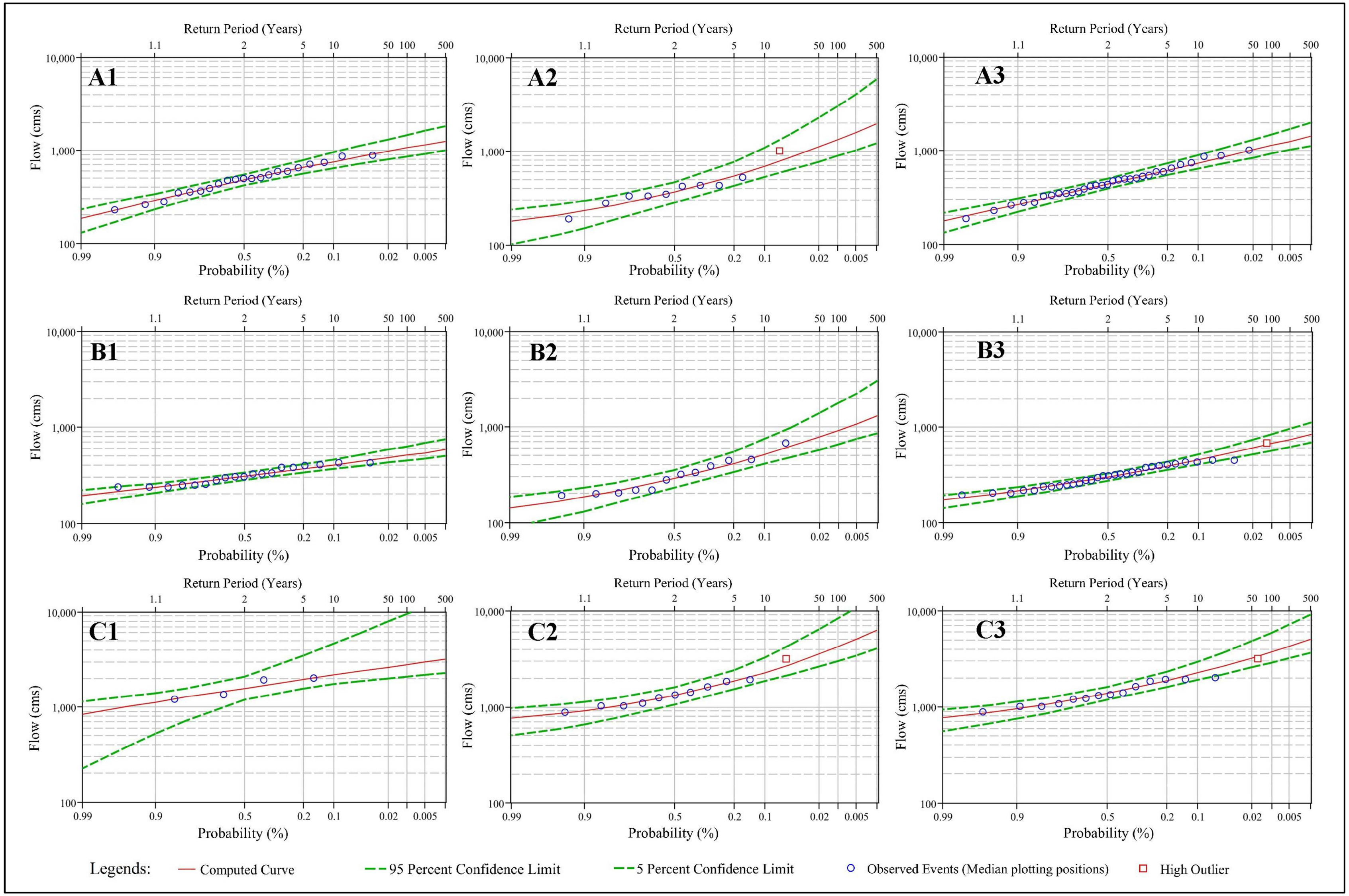

Figure 5. Flood return period estimations for (A) Naghlu, (B) Pul-i-Qarghai and (C) Nowabad stations for the first, second and third cases (1950-1980 period data, 2003-2018 period data and combined data including the long gap) respectively.

Finally, for identifying the flood peak projection, the estimated values for each return period based on the full dataset was compared to the first period results by using Equation 1. The result in Table III shows that estimated flood peak increased significantly in the stations where the maximum discharge peaks were raised and vice versa. The average percentage of the stations with significant discharge (Stations 1–10) shows an increment of 3.3–15.2 % in the 10–500 year return period floods. Table III also shows the change rate for every station individually. The highest change is observed in the longer return period, while shorter return period indicated smaller variation.

Table III. Variation of the estimated flood peaks between first (1950–1980) and combined (1950–2018) cases including the missing period. The highlighted cells show the increment of flood peak in relative percentage with reference to the first period.

Station number	**Station name**	**Return period [Years]**					
		500	**200**	**100**	**50**	**20**	**10**
1	DAKAH	6.91%	2.76%	-0.12%	-2.75%	-5.79%	-7.66%
2	KONAR RIVER AT NAWABAD	-25.94%	-19.18%	-13.85%	-8.41%	-1.20%	4.04%
3	KONAR RIVER NEAR ASMAR	51.17%	41.67%	34.76%	28.09%	19.60%	13.39%
4	NAGHLU	12.77%	9.13%	6.44%	3.78%	0.35%	-2.20%
5	PANJSHER RIVER AT GULBAHAR	27.79%	23.22%	19.80%	16.42%	11.94%	8.56%
6	LAGHMAN RIVER AT PUL-I-QARGHAI	44.34%	36.27%	30.32%	24.50%	16.91%	11.21%
7	PECH RIVER AT CHAGHASARAI	0.58%	-1.06%	-2.33%	-3.59%	-5.34%	-6.68%
8	PANJSHER RIVER AT SHUKHI	-11.03%	-8.65%	-6.90%	-5.24%	-3.35%	-2.39%
9	PANJSHER RIVER AT OMARZ	45.88%	39.21%	34.16%	29.12%	22.36%	17.06%
10	GHORBAND RIVER AT PUL-I-ASHAWA	-0.11%	-0.42%	-0.70%	-1.08%	-1.55%	-2.08%
11	TANGI-I-GHARU	13.62%	8.32%	4.35%	0.49%	-4.65%	-8.51%
12	SALANG RIVER AT BAGH-I-LALA	240.0%	228.61%	218.68%	207.58%	191.28%	175.68%
13	LOGAR RIVER AT SANG-I-NAWESHTA	-21.34%	-18.02%	-15.36%	-12.45%	-8.31%	-4.84%
14	TANGI SAIDAN	-1.98%	0.32%	2.01%	3.75%	5.87%	7.30%
15	SURKHRUD RIVER NEAR SULTANPUR	132.68%	112.99%	97.36%	81.38%	60.21%	44.90%
16	HAZARNAW RIVER AT SABAY	-19.52%	-15.71%	-13.55%	-12.48%	-13.01%	-16.05%
17	QARGHA RIVER ABOVE QARGHA RESERVOIR	602.94%	381.54%	264.52%	181.03%	94.44%	51.02%
AVERAGE OF STATION (1 -10)		**15.24%**	**12.30%**	**10.16%**	**8.08%**	**5.39%**	**3.33%**

4. Conclusion

The results of this study revealed that the flow peak is increased (17.5 %) in the basin from the early to the more recent period. Over the same period, the mean discharge exhibits a reduction (-4.6 %) due to several droughts in the recent period. In addition, the river flow frequency results suggest that peak and low flow frequencies have significantly increased. This indicates the increment of flooding and low flow days in the basin and may challenge the irrigation during the low and medium flow days. Furthermore, the flood recurrence analyses show that use of a single dataset for flood return period predictions is not appropriate, while the combined dataset including the gap duration analyses shown a reasonable result. This suggests that the environmental change effects are reflected by river flow variations and influenced subsequent results. Furthermore, the comparison of long-term flood peaks for each return period showed that flood peak has an upward trend. This originates to the recent variation of the flow peaks. Finally, the study also helps researchers who perform simulations using the first period data and calibrate or cross-validate their models using data from the more recent period, by defining the amount of flow change at each station.

5. Limitations

It is worth mentioning that floods are poorly studied in this region. The study was associated with a shortage of recorded data and limitations on the available data. Maximum efforts have been carried out to collect all available data. But, unfortunately due to war, the existing historical data has short durations in both the pre- and post-war periods. Using all these data, results obtained are sufficient for the purpose at hand and provide a better insight into the flood situation in the basin. For a more specific result, more data and detailed analyses are required.

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7. References

1. Alfieri, L., Burek, P., Feyen, L. and Forzieri, G., 2015. Global warming increases the frequency of river floods in Europe. *Hydrology and Earth System Sciences*. Vol. 19, pp. 2247–2260. Available at: https://doi.org/10.5194/hess-19-2247-2015.

2. ASDC. Afghanistan Spatial Data Center - ASDC/IMMAP (Web, map, dashboard, infographic). Afghanistan. Available online at: http://asdc.immap.org/. (Verified on 16 June 2019).

3. Bartles, M., Brunner, G., Fleming, M., Faber, B. and Slaughter, J., 2016. HEC-SSP Statistical Software Package User’s Manual, Version 2.1. ed. US Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA 95616. Available at: https://www.hec.usace.army.mil/software/hec-ssp/documentation.aspx.

4. Brunner, G. and Fleming, M., 2010. HEC-SSP Statistical Software Package. US Army Corps Eng. Inst. Water Resour. Hydrol. Eng. Cent. HEC. Available at: https://www.hec.usace.army.mil/software/hec-ssp/.

5. CRED/EM-DAT data. Centre for Research on the Epidemiology of Disasters (CRED) - International Disaster database (EM-DAT),. Available at: https://www.emdat.be/. (Verified on 16 June 2019).

6. NSIA, 2018. Afghanistan Statistical Year Book 2017 - 18. Issue 39. National Statistics and Information Authority (NISA). Kabul Afghanistan. Available at: https://www.nsia.gov.af:8080/wp-content/uploads/2019/04/Afghanistan-Statistical-Year-book-2017-18-3.pdf.

7. England Jr, J., Cohn, T., Faber, B., Stedinger, J., Thomas Jr, W., Veilleux, A., Kiang, J. and Mason, R., 2015. Guidelines for determining flood flow frequency. Bull. 17C US Geol. Surv. Tech. Methods. Available at: https://acwi.gov/hydrology/Frequency/b17c/archive/bulletin17c_draft_for_public_review.pdf.

8. Favre, A. and Kamal, G.M., 2004. Watershed atlas of Afghanistan. Kabul (Afghanistan). Available at: http://aizon.org/watershed_atlas.htm.

9. Hagen, E., Shroder Jr, J., Lu, X. and Teufert, J.F., 2010. Reverse engineered flood hazard mapping in Afghanistan: A parsimonious flood map model for developing countries. *Quaternary International*, Vol. 226, pp. 82–91. Available at: https://doi.org/10.1016/j.quaint.2009.11.021.

10. Hagen, E. and Teufert, J., 2009. Flooding in Afghanistan: A crisis, in: Threats to Global Water Security. Springer, pp. 179–185. Available at: https://link.springer.com/chapter/10.1007/978-90-481-2344-5_19.

11. Haritashya, U.K., Bishop, M.P., Shroder, J.F., Bush, A.B.G. and Bulley, H.N.N., 2009. Space-based assessment of glacier fluctuations in the Wakhan Pamir, Afghanistan. *Climatic Change*, Vol. 94, pp. 5–18. Available at: https://doi.org/10.1007/s10584-009-9555-9.

12. Interagency Advisory Committee on Water Data, 1982. Guidelines for determining flood flow frequency. US Geological Survey Reston, VA. Available at: https://water.usgs.gov/osw/bulletin17b/dl_flow.pdf.

13. Najmuddin, O., Deng, X., Bhattacharya, R., Najmuddin, O., Deng, X. and Bhattacharya, R., 2018. The Dynamics of Land Use/Cover and the Statistical Assessment of Cropland Change Drivers in the Kabul River Basin, Afghanistan. *Sustainability*, Vol. 10, No. 423. Available at: https://doi.org/10.3390/su10020423.

14. Omar, M.H., 2018. Drought analysis of the Kabul River Basin using hydrologic data (M.Sc. Thesis). Kabul Polytechnic University, Kabul Afghanistan.

15. Sadid, N., Haun, S. and Wieprecht, S., 2017. An overview of hydro-sedimentological characteristics of intermittent rivers in Kabul region of Kabul river basin. *International Journal of River Basin Management*, Vol. 15, pp. 387–399. Available at: https://doi.org/10.1080/15715124.2017.1321004.

16. Sarikaya, M.A., Bishop, M.P., Shroder, J.F. and Olsenholler, J.A., 2012. Space-based observations of Eastern Hindu Kush glaciers between 1976 and 2007, Afghanistan and Pakistan. *Remote Sensing Letters,* Vol. 3, pp. 77–84. Available at: https://doi.org/10.1080/01431161.2010.536181.

17. Vick, M.J., 2014. Steps towards an Afghanistan–Pakistan water-sharing agreement. I*nternational Journal of Water Resources Development*, Vol. 30, No. 2, pp. 224-229, Available at: https://doi.org/10.1080/07900627.2014.886471.

18. Westfall, A., Latkovich, V., 1966. Surface water resources investigations plan for Afghanistan. USGS. Available at: http://afghandata.org:8080/jspui/bitstream/azu/3547/1/azu_acku_pamphlet_hd1698_a3_w47_1966_w.pdf.

19. WFP, UNEP, NEPA, N.E.P.A., 2016. Climate change in Afghanistan: What does it mean for rural livelihoods and food security? Afghanistan. Available at: https://www.wfp.org/publications/climate-change-afghanistan-what-does-it-mean-rural-livelihoods-and-food-security.

20. World Bank, 2010. Afghanistan - Scoping Strategic Options for Development of the Kabul River Basin: A Multisectoral Decision Support System Approach. World Bank, Washington, DC. Available at: http://documents.worldbank.org/curated/en/319391468185978566/Afghanistan-Scoping-strategic-options-for-development-of-the-Kabul-River-Basin-a-multisectoral-decision-support-system-approach.