



Hydrospatial Analysis

Homepage: www.gathacognition.com/journal/gcj3
<http://dx.doi.org/10.21523/gcj3>



Original Research Paper

Analysis of Discharge Variability in the Naryn River Basin, Kyrgyzstan



Merim Pamirbek K^{1,5}, Chen X^{1,5}, Sainath Aher^{2*}, Alamanov Salamat³, Pragati Deshmukh⁴, Choduraev Temirbek⁶

1. Xinjiang Institute of Ecology and Geography, Chinese Academy of Science, Urumqi-830011, China.
2. Department of Geography, S. N. Arts, D. J. M. Commerce and B. N. S. Science College, Sangamner-422605, India.
3. Research Center for Ecology and Environment of Central Asia, Bishkek-720040, Kyrgyzstan.
4. Department of Geography, H. P. T. Arts and R. Y. K. Science College, Nashik-422005, India.
5. University of Chinese Academy of Sciences, Beijing-100039, China.
6. Faculty of Geography, Ecology and Tourism I. Arabaev Kyrgyz State University, Bishkek-720026, Kyrgyzstan.

Abstract

Changing climate and land-use practices influencing the natural stream flow processes in the Naryn river basin of Kyrgyzstan. Variations in stream flow regime over 33-years (1980 to 2012) were investigated using daily discharge data of three hydro-stations (Naryn, Ych-Terek and Uzunakmat), located in the Naryn River Basin. Mean monthly discharge (MMD), mean annual discharge (MAD), standard deviation (SD) and coefficient of variation (CV) were calculated to know the spatio-temporal variability. Similarly, Pearson's correlation coefficient (r) was used to know the relationship between discharge and rainfall. Advanced time-series graph, exceedance probability and frequency distribution were computed using Hydrognomon (V.4.0.3) software to observe the variability and trends in discharge. The results from statistical calculations and software-based computations highlight the monthly, annual, and long term spatio-temporal discharge variability, extreme events, distribution and changes in stream flow records. This study preciously creates the frequency and trends of seasonal discharge, annual discharge cycle, and range of highest and lowest discharge flows. The weak and negative relationship (-0.2121, -0.4238) between rainfall and discharge propose for more investigation of climatic parameters and the topography of Tian Shan Mountain perhaps influencing discharge variability due to melting of glacier at high altitude. The flow regime of the Naryn river basin over the past 33-years perhaps changed due to climatic fluctuations, with the seasonal snowmelt timing (Post-Spring, Summer, Pri-Autumn), precipitations period (March-October), and large-scale land-use alterations.

© 2020 GATHA COGNITION® All rights reserved.

Article history

Received: 05 June 2020
 Revised: 12 July 2020
 Accepted: 12 July 2020

Keywords

Climate Changes;
 Discharge Variability;
 Frequency;
 Exceedance Probability;
 Time Series.

Editor(s)

P. S. Hire

1 INTRODUCTION

Land use changes in the world has invited significant scholarly attention in climate, water resources, and urban area (Foley *et al.*, 2005; Ng *et al.*, 2010, Gao *et al.*, 2015; Shinde *et al.*, 2020). Climate changes may impact on hydrological processes such as melting of glacier, evapotranspiration, soil moisture, water temperature, stream flow volume, timing and magnitude of runoff and frequency, and severity of floods (Zhang *et al.*, 2007). Besides, multifaceted processes in the river

basins affecting surface and sub-surface hydrology, channel geometry, soil erosion, chemical constituents, hydro-chemical characteristic, and land use activities (Singh *et al.*, 2005; Easton *et al.*, 2008, Deshmukh and Aher, 2016; Zolekar *et al.*, 2020). Therefore, studies of hydrological process and its temporal variations in stream power (Kale and Hire, 2007), and future trends are essential in the hydrological investigation. The hydrological behavior in the river basin is significantly

* Author address for correspondence

Department of Geography, S. N. Arts, D. J. M. Commerce and B. N. S. Science College, Sangamner-422605, India.
 Tel.: +91 9921223884

E-mails: merim90@list.ru (M. Kyz); chenxi@msxb.ac.cn (Chen X.); saigeo23@gmail.com (S. Aher -Corresponding author); s.alamanov@mail.ru (A. Salamat); dpragati30@gmail.com (P. Deshmukh); choduraev.temirbek@mail.ru (C. Temirbek).

associated with the climatic phenomena and regional topographical arrangement which is already validated from the discharge flow pattern (Srebrenovi, 1986; Linsley et al., 1988; Aher et al., 2017).

A discharge flow record is reflected the basin integration to natural dissimilarities and man-induced changes, like regulations of large dams and changes in land use / land cover within the basins (Yang et al., 2015). The discharge of the river varies over space and time (Akter et al., 2019) due to natural and man-induced factors. Investigating the long-term changes in river discharge from discharge record is a significant way for better management of water resource (Seyam and Othman, 2015; Shinde et al., 2020). Discharge record is significant as it characterizes the spatio-temporal analysis of climate change, basin-scale water balance, alterations of land use schemes over large spatial scales, and freshwater input to the ocean (Yang et al., 2015). Thus, it is essential to know the basic features like spatio-temporal variations in discharge flows regime at numerous time periods (daily, monthly, yearly to decadal time) and various places. Many studies related to discharge variability use daily, average monthly and yearly stream flow data to observe the hydrological changes within the river basin (Poff and Ward, 1989; Mapfumo et al., 2004; Kale et al., 2009; Garba et al., 2013; Yang et al., 2015; Aher et al., 2017; Higashino and Stefan, 2019).

The hydrological data collected in the past is used to find advance statistical parameters to predict future trends, probability and events that may be possibly happen in near future. However, it is a challenge in the identification of the suitable fitting, statistical distribution for examining the data and precise predictions of the selected database. Therefore, a probability distribution is a statistical tool widely used in discharge prediction and estimation (Garba et al., 2013). Similarly, advance software based computations, precise analysis of discharge, predicting future time series, trends, and probability can give innovative directions for hydrological studies. The study of precisely extremes the events, time series, and probability so rare and there are no comprehensive data, therefore it is a challenge to hydrologist (Garba et al., 2013). In the Kyrgyzstan, flood causing many difficulties and affect infrastructure, such as bridge collapse, building damage, and traffic problems. It is unbearable to circumvent risks of floods, reduce the impact, and their damages using early warning system, community based disaster management trainings, etc. to reduce the losses (Chymyrov et al., 2018).

Armstrong et al., (2019) have studied runoff from glacier ice and seasonal snow in high Asia and Kundzewicz et al. (2015) revealed the changes in climate and river discharge with seasonal runoff predictability in the Aksu River Basin. Akmatov et al. (2019) have reported the glacier runoff and regime of rivers with glacial power using case of study of Naryn River, Kyrgyzstan. However, the study of long-term

changes in discharge of Naryn river basin is not yet attempted. This study identifies the long-term changes in Naryn river basin stream flow where winter is more snowfall, high rainfall in spring and autumn, and more evaporation in summer. In this basin, formation of runoff and hydrographic network is greatly influenced by the topographic arrangement and local weather differences. The hydrological feature of Kyrgyzstan is divided into two areas - 1) runoff formation and 2) its dispersal. The first comprises the mountainous portion with more than 2000 m elevation and the area of dispersion of runoff is situated below the area of its formation, occupying the territory of foothill valleys and within the mountain. The objective of study are to examine the discharge process in the first and second parts those which associated with Naryn river basin and to investigate the possible causes of discharge variability. This study would be helpful to know the link of discharge with physical and meteorological drivers in the Naryn and other river basins which have similar hydro-meteorological characteristics.

2 STUDY AREA

The Naryn River basin (56210 km²) located in the middle Tien Shan mountain area of Kyrgyzstan (central Asia) which extent is 40°44'08.77" to 42°46'24.10" N latitudes and 71°61'03.78" to 78°35'57.87" E longitudes (Figure 1). The total length of Naryn River in the Kyrgyzstan is about 600 km (Dixon and Wilby, 2016). The maximum altitude in the basin is 5135 m and minimum is 413 m from mean sea level (MSL). Mountain ranges of Kyrgyzstan are barriers to moist air masses from the West, Northwest and North, and natural accumulators of atmospheric moisture. The Naryn river is formed due to local rainfall, seasonal snow and glacial melting process (Hill et al., 2017). The confluence of the Big and the Small Naryn rivers made the Naryn River after that which flows into Ferghana Valley, where it merges with Karadarya to form the Syrdarya River (Hagg et al., 2013). The Kichi-Naryn, At-Bashi, On Archa, Kadjyrt, Chychkan, Alabuga, Kökömeren etc. rivers are the main tributaries of the Naryn River (Welcome, 2020). About 2% of the Naryn river basin area is glacierized and these glaciers are concentrated in the eastern part of the basin (Gan et al., 2015).

The area has four seasons of the year due to the difficult orography and every season is different from each other. The climate of the area is influenced mainly by the mountains and associated glaciers, especially in the eastern part of the basin (Akmatov et al., 2019). The average temperature of the area is 10° C in July and -18° C in January. The average precipitation ranges between 280 mm and 450 mm annually (Gan et al., 2015). The overall climate of the area considered as continental climate that is significantly varied locally. In the basin area observed the dry and hot summer and cold winter (Gan et al., 2015). The land use and land cover are mostly associated with grass and shrub, with pastoral farming on mountain sides, and some arable crop and hay production in valleys which is sustained by local

irrigation (Samuel *et al.*, 2016). The elevated ridges of the Naryn River freezes in the winter season and flood situation happen in the river channel in the summer seasons (May to June). The entire stream flow system and allied flood and drought are determined by the stream flow features like rate, magnitude, duration, and timing (Djancharov and Street, 2003).

3 MATERIALS AND METHODS

3.1 Discharge Data and Statistical Calculation

Daily discharge (m^3/s) data of three hydro-stations (Naryn, Ych-Terek, and Uzunakmat), located in the Naryn River basin were collected for 33 years period (1980-2012) from the Hydro-Meteorological agency of Kyrgyzstan. Spatial information of hydro-station was shown in the Table 1. Yang *et al.* (2002) have used daily discharge data to study the variability and extreme of Mackenzie River discharge.

The preliminary checkup of discharge data was carried out and missing values of discharge filled by excel interpolation to form the complete data series. The statistical variables, i.e. mean monthly discharge (MMD), mean annual discharge (MAD), standard deviation (SD), and coefficient of variation (CV) which best signify the long-term variability of stream flow were then used to assess the long-term changes over the basin area (Table 2). The SD is useful to the measure the variability in the discharge data and CV is also useful to measure the relative variability of discharge data (Shinde *et al.*, 2020). Similar variables were also used by Seyam and Othman (2015) to study the long-term variability analysis of a tropical river's annual stream flow regime. The MMD of Naryn, Ych-Terek and Uzunakmat hydro-station was shown in Figure 2 and MAD, SD, and CV in table 2.

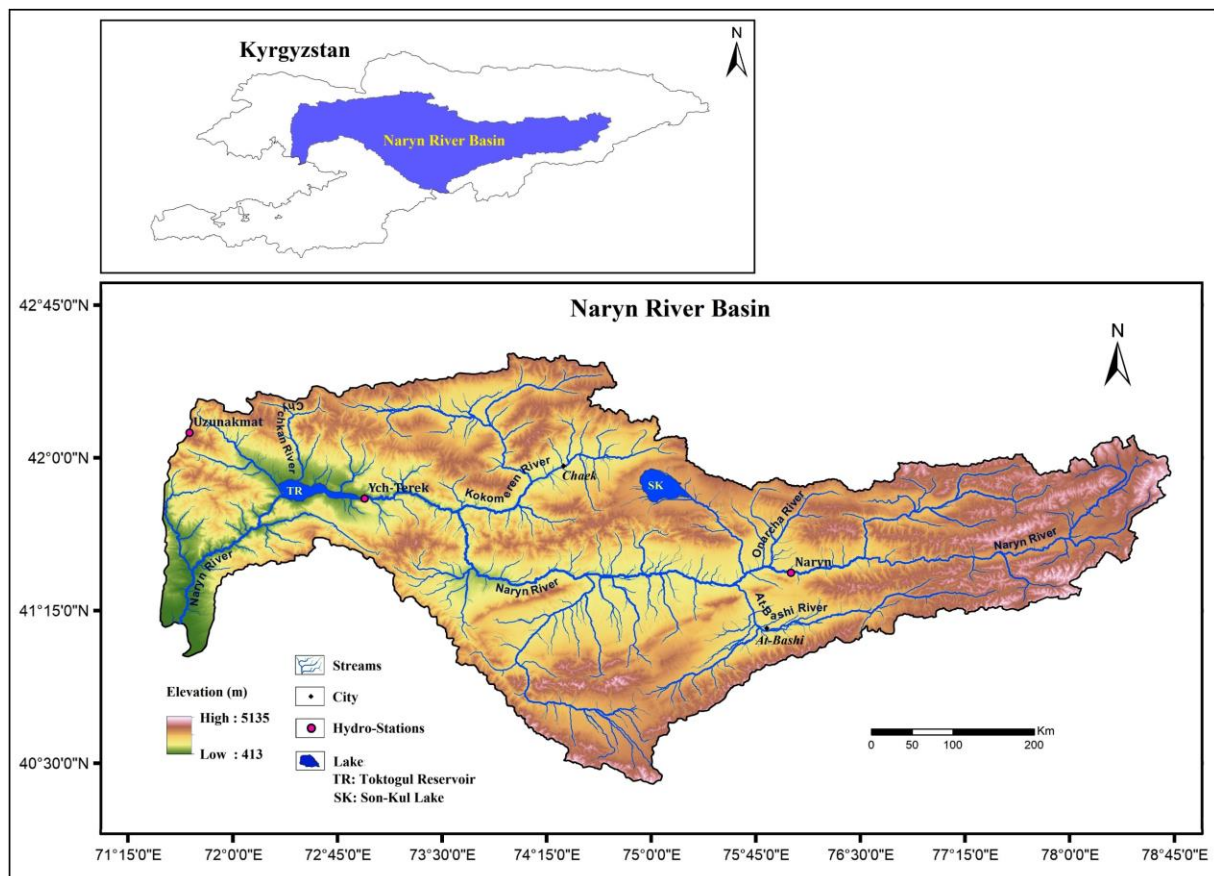


Figure 1. Study area: Naryn river basin with drainage network and topography

Table 1. Spatial information of hydro-stations

Hydro Station	Latitude	Longitude	Elevation (MSL)	Period
Naryn	41.4286N	75.9657E	2037	1980-2012
Ych-Terek	41.4605N	73.1743E	998	1980-2012
Uzunakmat	42.0559N	72.1830E	1879	1980-2012

Table 2. Calculated statistical variables from daily discharge data (m³/s)

Years	Naryn			Ych-Terek			Uzunakmat		
	MAD	SD	CV	MAD	SD	CV	MAD	SD	CV
1980	85.9	79.9	0.9	288.6	208.4	0.7	25.6	23.0	0.9
1981	107.9	115.5	1.1	322.3	245.5	0.8	30.4	23.2	0.8
1982	72.1	62.4	0.9	227.7	105.3	0.5	22.1	11.6	0.5
1983	90.0	87.9	1.0	301.5	215.2	0.7	27.6	20.5	0.7
1984	99.0	93.3	0.9	284.5	220.9	0.8	32.1	32.5	1.0
1985	76.9	71.0	0.9	278.0	185.5	0.7	23.4	18.4	0.8
1986	79.4	74.4	0.9	253.2	171.7	0.7	23.2	19.4	0.8
1987	105.0	98.2	0.9	403.6	361.0	0.9	37.1	31.9	0.9
1988	103.9	90.9	0.9	218.7	165.6	0.8	34.6	31.2	0.9
1989	72.6	65.4	0.9	309.8	194.9	0.6	22.5	19.8	0.9
1990	85.5	77.3	0.9	329.9	251.3	0.8	33.5	34.2	1.0
1991	77.9	73.4	0.9	282.9	177.0	0.6	29.6	26.7	0.9
1992	77.9	68.0	0.9	313.7	186.4	0.6	32.5	27.5	0.9
1993	108.4	104.8	1.0	370.4	298.0	0.8	32.1	27.7	0.9
1994	129.1	129.9	1.0	364.4	291.3	0.8	35.1	33.5	1.0
1995	102.3	96.0	0.9	357.2	288.8	0.8	20.3	14.4	0.7
1996	107.3	105.3	1.0	360.0	283.0	0.8	29.3	27.1	0.9
1997	102.2	86.0	0.8	295.4	164.2	0.6	22.6	17.9	0.8
1998	114.6	112.6	1.0	407.1	325.4	0.8	38.1	34.6	0.9
1999	122.2	116.1	1.0	413.5	292.6	0.7	35.9	30.1	0.8
2000	107.9	91.0	0.8	311.2	216.7	0.7	25.4	16.8	0.7
2001	116.5	102.5	0.9	342.0	221.7	0.7	28.5	21.8	0.8
2002	140.6	137.8	1.0	447.6	394.5	0.9	32.5	28.4	0.9
2003	119.1	109.7	0.9	449.3	350.4	0.8	30.1	24.9	0.8
2004	101.8	82.6	0.8	430.3	268.7	0.6	32.3	27.9	0.9
2005	100.9	81.9	0.8	416.6	263.5	0.6	27.8	25.0	0.9
2006	98.1	81.7	0.8	457.2	302.4	0.7	25.3	18.0	0.7
2007	89.3	66.0	0.7	312.3	161.7	0.5	32.1	27.9	0.9
2008	88.6	70.6	0.8	288.6	164.7	0.6	21.4	18.7	0.9
2009	102.0	80.4	0.8	395.8	274.3	0.7	30.1	19.4	0.7
2010	135.6	118.5	0.9	529.0	439.3	0.8	37.5	29.7	0.8
2011	97.7	77.3	0.8	415.7	313.1	0.8	32.1	26.2	0.8
2012	90.5	68.8	0.8	332.8	169.9	0.5	33.7	27.0	0.8

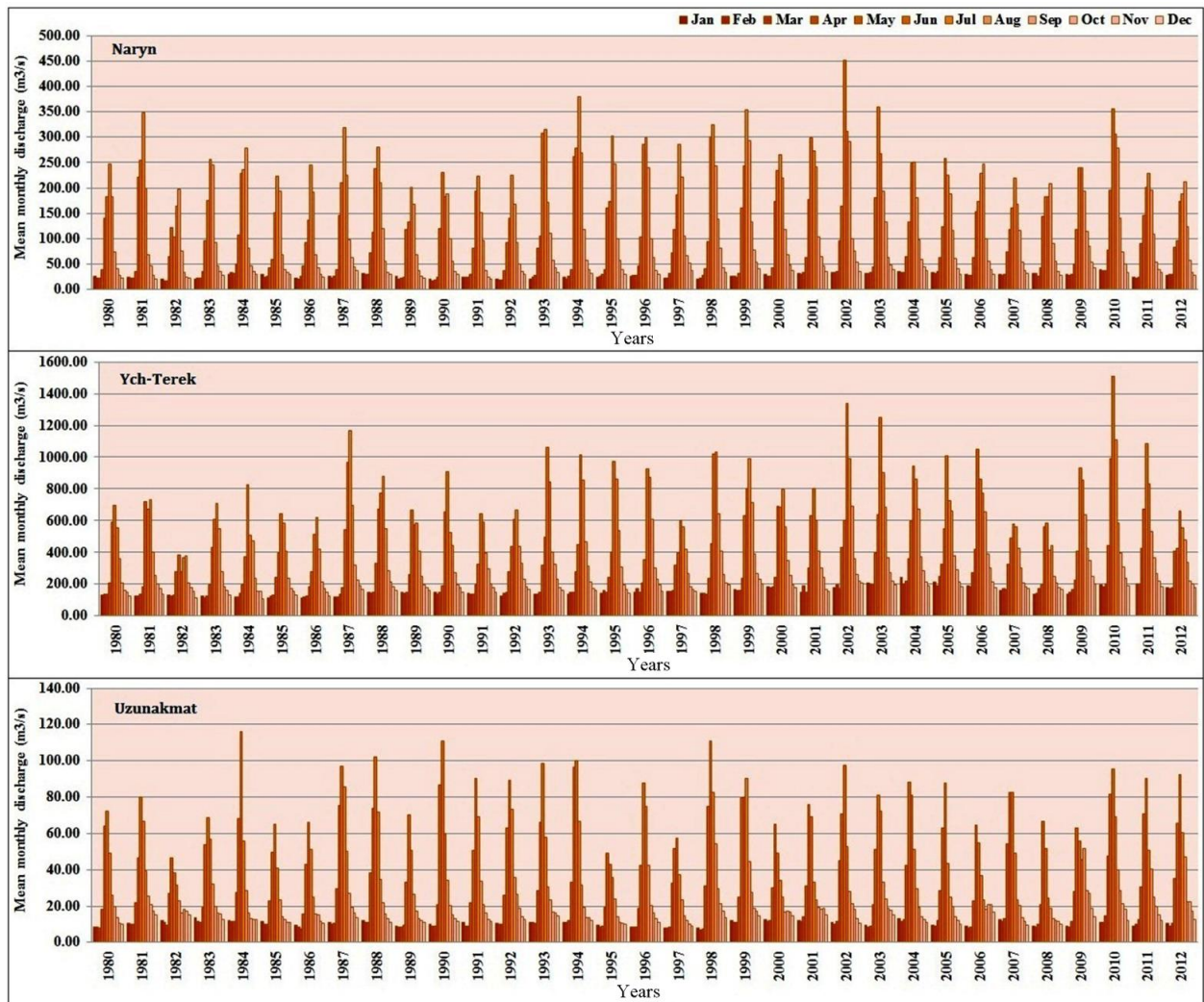


Figure 2. Mean monthly discharge at Naryn, Ych-Terek, and Uzunakmat hydro-stations

The average annual discharge of a river is imperative display to know the availability of water and flood situation for further water resource management (Higashino and Stefan, 2019). This varied range of hydrological variables can be support to measure the variations in the appearances of stream flow (Moliere et al., 2009). The SD and CV are quantitative statistical measures of dispersion in a selected data arrangement around its average. The CV of annual discharge data signifies the ratio of standard deviation to the average annual flow. Moreover, CV tallies the degree of dispersion and changes within the data (Boik and Shirvani, 2009; Albrecher et al., 2010). Thus, the calculated SD is the root of the variance which

highlighted here a degree of dispersion in selected mean discharge data. Spatio-temporal analysis of discharge data using statistical techniques (Shinde et al., 2020) is an important feature to describe the hydrological appearance. It helps to know the discharge variability and water availability within the basin to remark the river hydrology (Garba et al., 2013). The temporal changes in SD and CV of the Naryn, Ych-Terek and Uzunakmat hydro stations are shown in Figure 3, 4 and 5. Even though various methods have been used for trend and frequency analysis, the attempted analysis proposed to understand the spatio-temporal variation of discharge and the reasons for the variations.

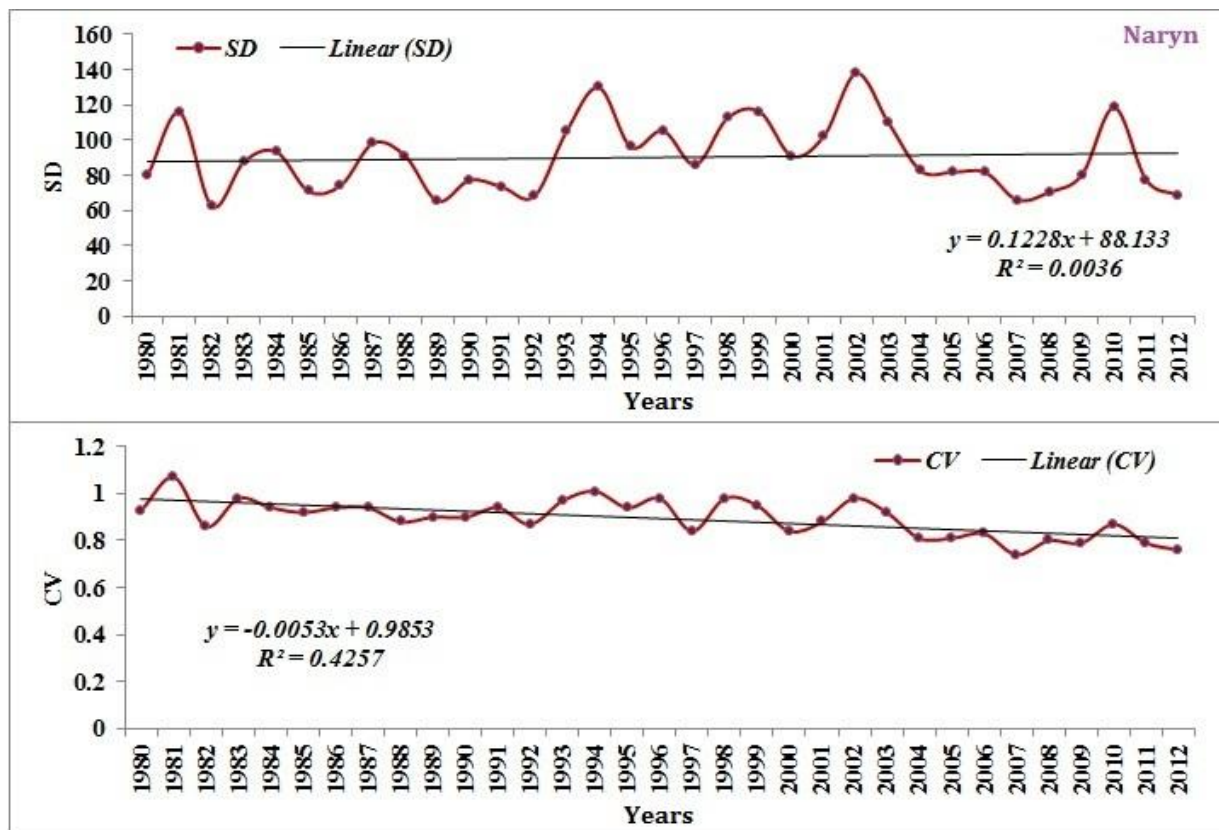


Figure 3. The changes in standard deviation and coefficient of variation: Naryn

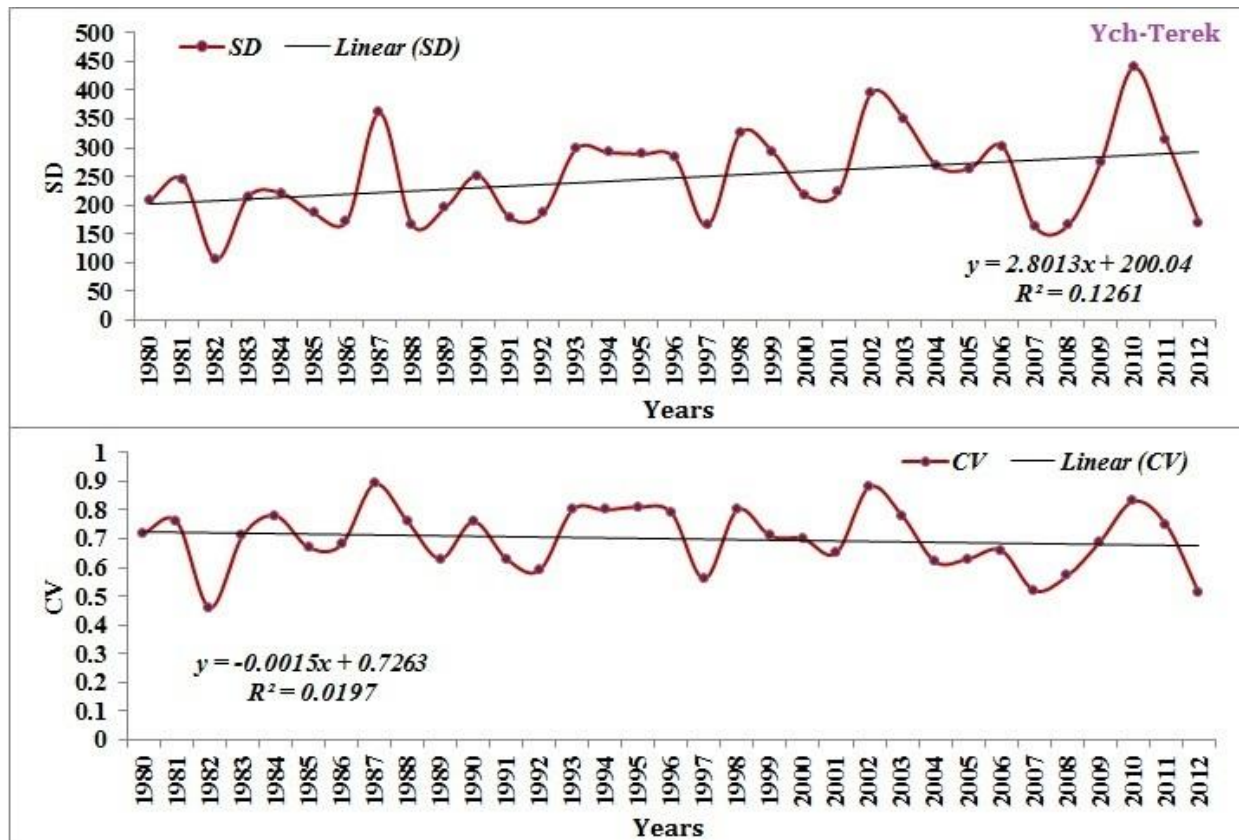


Figure 4. The changes in standard deviation and coefficient of variation: Ych-Terrek

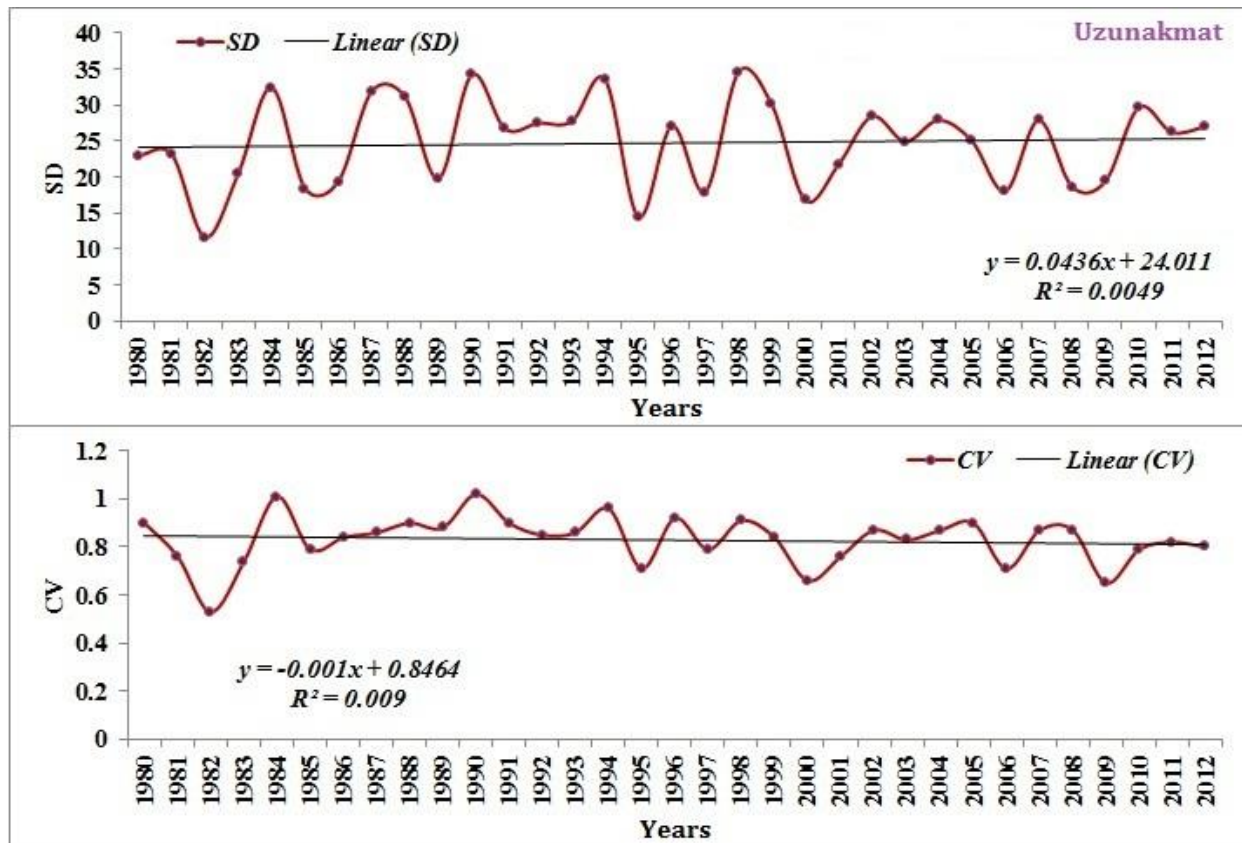


Figure 5. The changes in standard deviation and coefficient of variation: Uzunakmat

3.2 Rainfall Data and Pearson's Correlation Coefficient

Daily rainfall data of Naryn meteorological station was obtained and it converted in the mean annual rainfall. Pearson's correlation coefficient (r) was used to know the relationship between discharge (y) and rainfall (x). The Pearson's correlation coefficient (ranging from -1 to 1) signifies the degree of linear coherency between these two variables. The value 1 denotes a perfect positive correlation and the value -1 denotes a perfect negative relationship (Karlsson *et al.*, 2013; SSS, 2020). The correlation coefficient was calculated using Equation 1.

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2} \sqrt{\sum_i (y_i - \bar{y})^2}} \quad (01)$$

where, x_i and y_i are two variables (rainfall and discharge) at time i , $\bar{x}$ and $\bar{y}$ are the mean of rainfall and discharge, respectively.

Linear trend lines are plotted (Figure 6) to know the correlations between mean annual discharge (Naryn and Ych-Terek) and mean annual rainfall (Naryn).

3.3 Time Series Graph

Time series graphs were prepared to show the trends or pattern of discharge using recently developed Hydrognomon (V. 4.0.3) software (Figure 7). It is a publicly available package developed by the ITIA research team of National Technical University of Athens in 1997 for processing the hydrological data. Most of the time series models applied for stream flow predictions practice which are nearly linear models because it constructed under the assumption that they follows the normal distribution process, however maximum stream flow are nonlinear (Wang, 2006). In view of this, Hydrognomon software was used because it supports several time steps from the finest minute's scales up to decades for processing the hydrometric data and time-series data analysis (Kozanis *et al.*, 2010; Garba *et al.*, 2013). This software gained more and more popularity for plotting the time series graph of discharge and also supports to perform the frequency analysis among many other hydrologic tasks (Houessou-Dossou *et al.*, 2013). Time series graph presents the regular data measurements taken over fixed time intervals. Similarly, it highlights the trends in data series values over time. Therefore, the aim of the trend plotting was to fix if values of an MMD data series of stations have an overall increase or decrease with time.

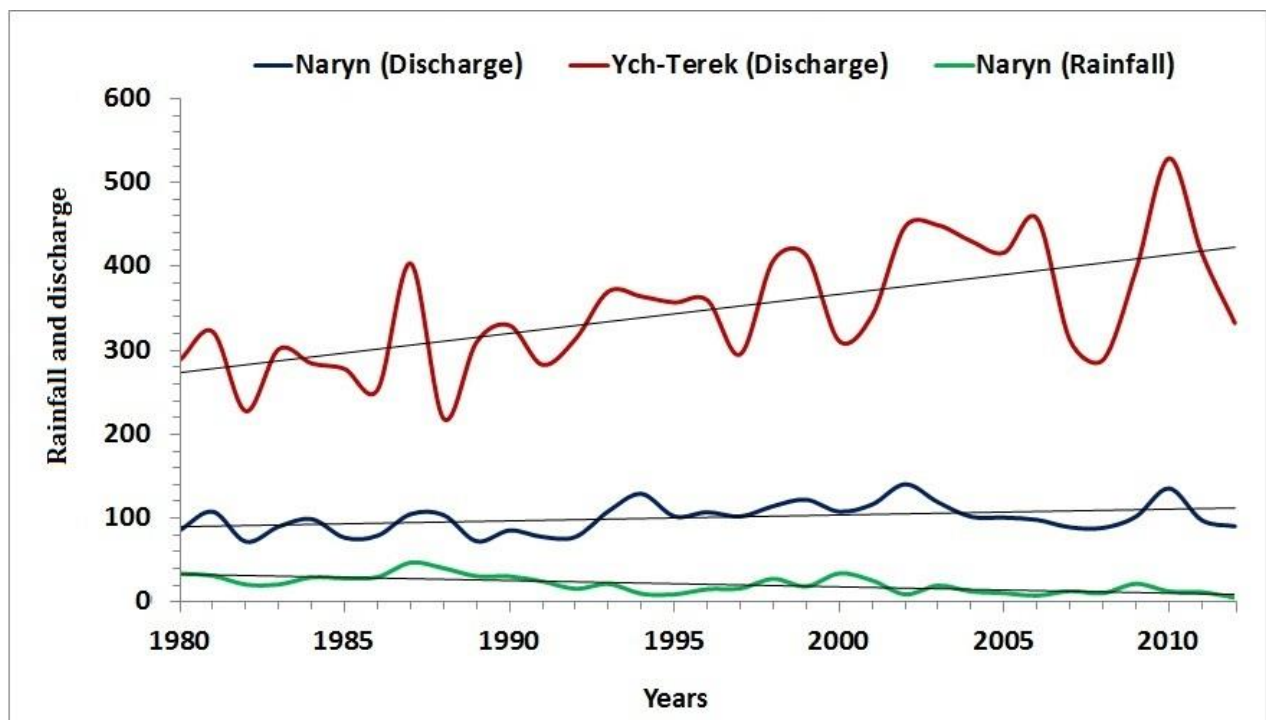


Figure 6. Linear trend line of rainfall and discharge correlation

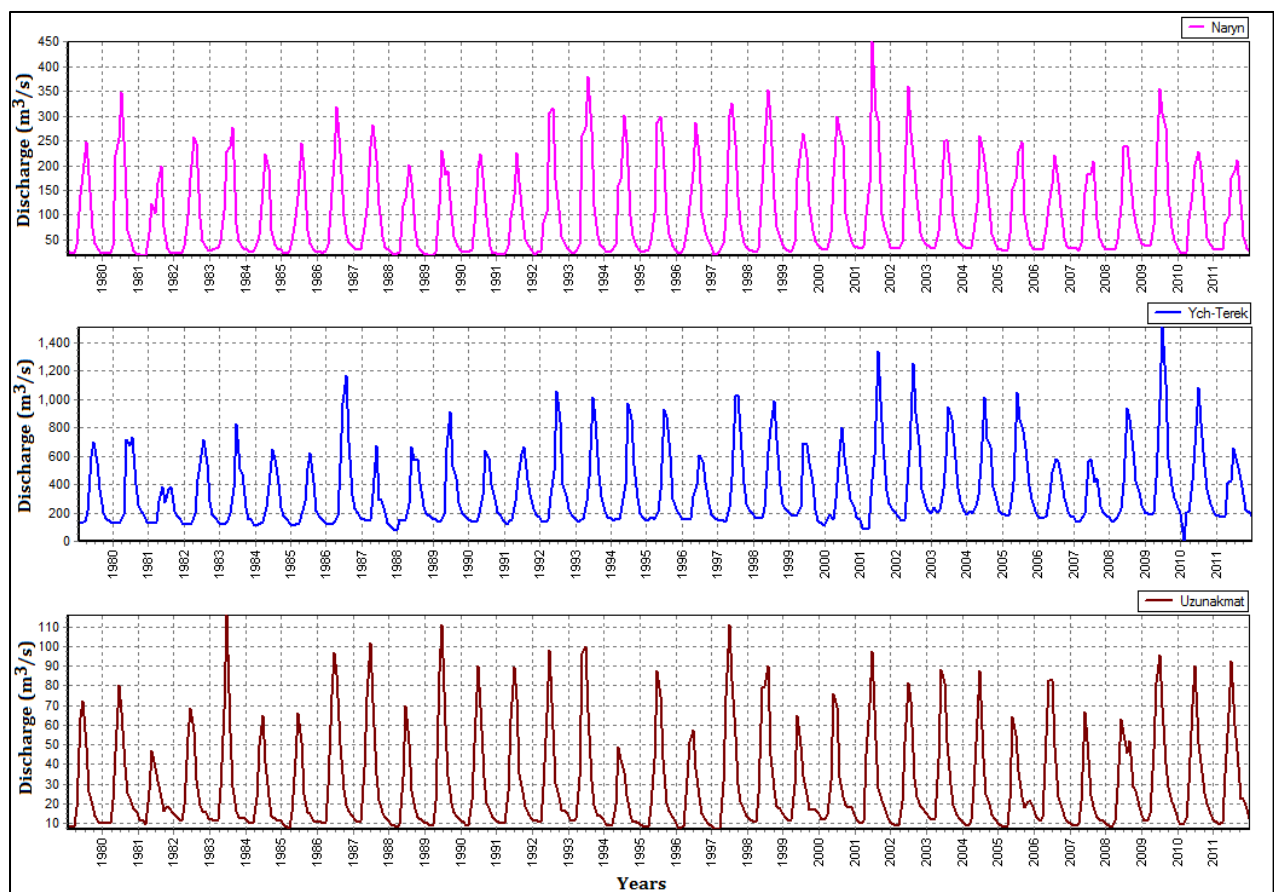


Figure 7. Time series graph highlights high and low discharge distribution

3.4 Exceedance Probability

Exceedance Probability (EP) of discharge data was plotted using advanced PYTHIA tool of Hydrognomon software for calculation of sample statistics and estimation of Normal and Gamma families. The distribution function of PYTHIA tool was used in order to plot the normal distribution and visualize the % EP of discharge data. The calculated statistical data are used to form the incidence distribution graphs that tell the likelihood of various discharges as a function of EP. A similar graph was also prepared by Garba et al. (2013) to know the discharge variability of Kaduna River. In the statistics, the normal distribution is the significant probability distribution which often used to represent the

real-valuable random variables whose distributions are unknown (George and Roger, 2001). In this attempt, EP plotting was shown based on two time scales, 1) Plotting of yearly changes and 2) Plotting of monthly changes (Figure 8, 9, 10). This work takes into account for the detection of the changes in the mean monthly and mean annually duration of high and low discharge. Computation of the monthly probability of maximum seasonal discharges is required to define the flood period. Thus, to know the maximum discharge in the Naryn river basin determination of EP distribution was carried out. This distribution analysis furthermore involved an examination of variability in monthly and annual duration for investigations of the trends of changes in the discharge over the 33-years.

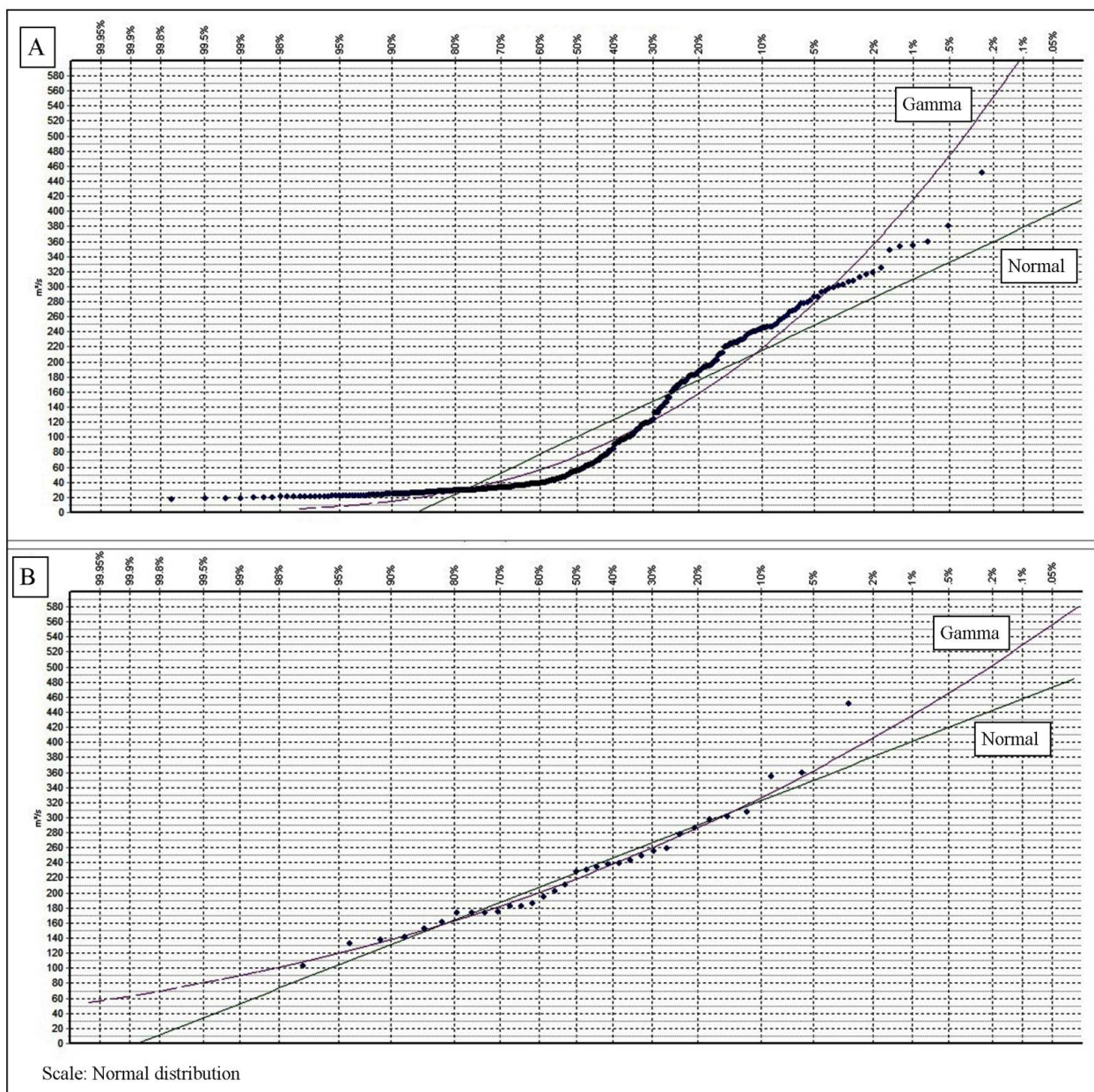


Figure 8. Exceedance probability for (A) all months and (B) June (Station: Naryn)

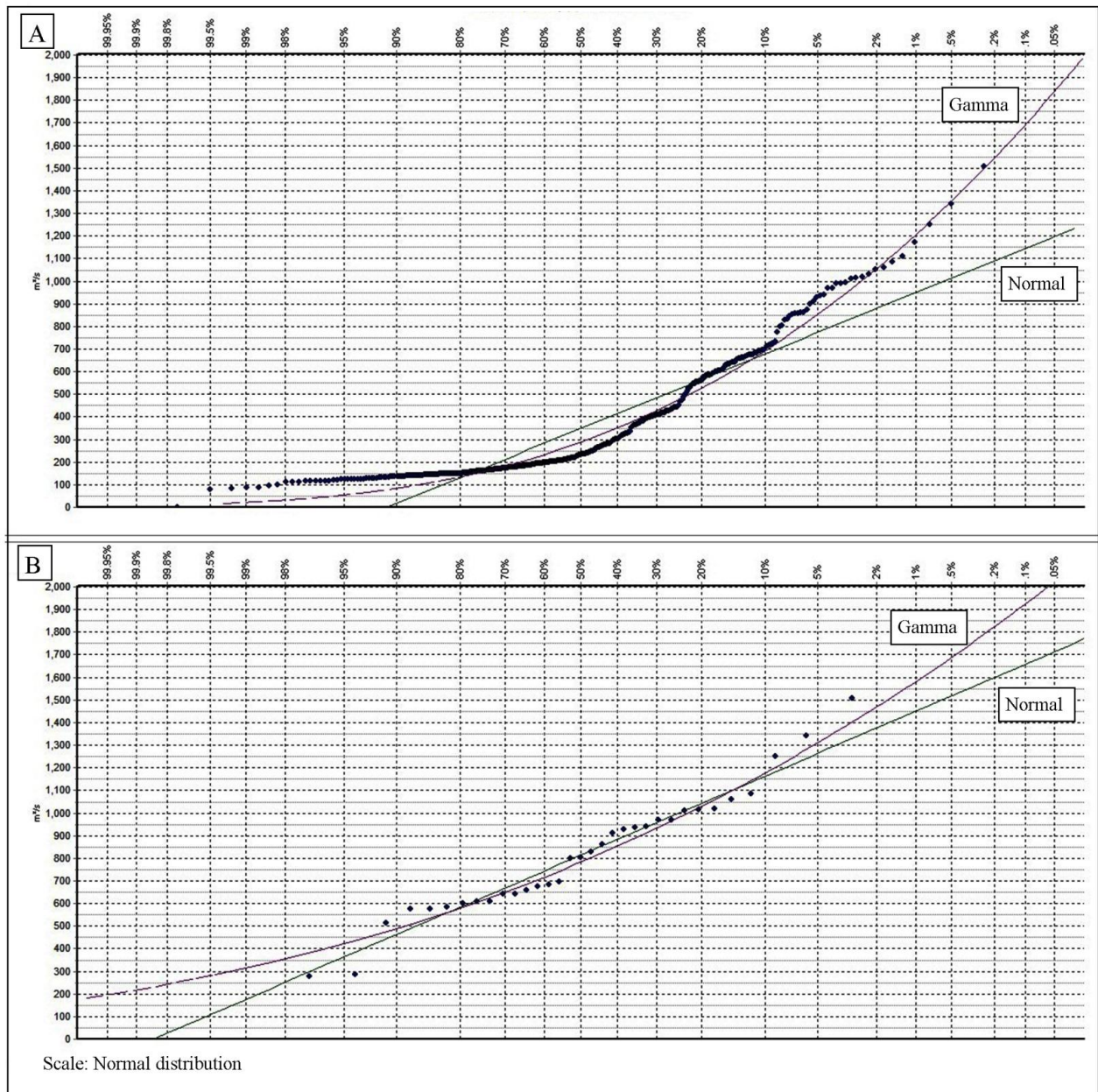


Figure 9. Exceedance probability for (A) all months and (B) May (Station: Ych-Terek)

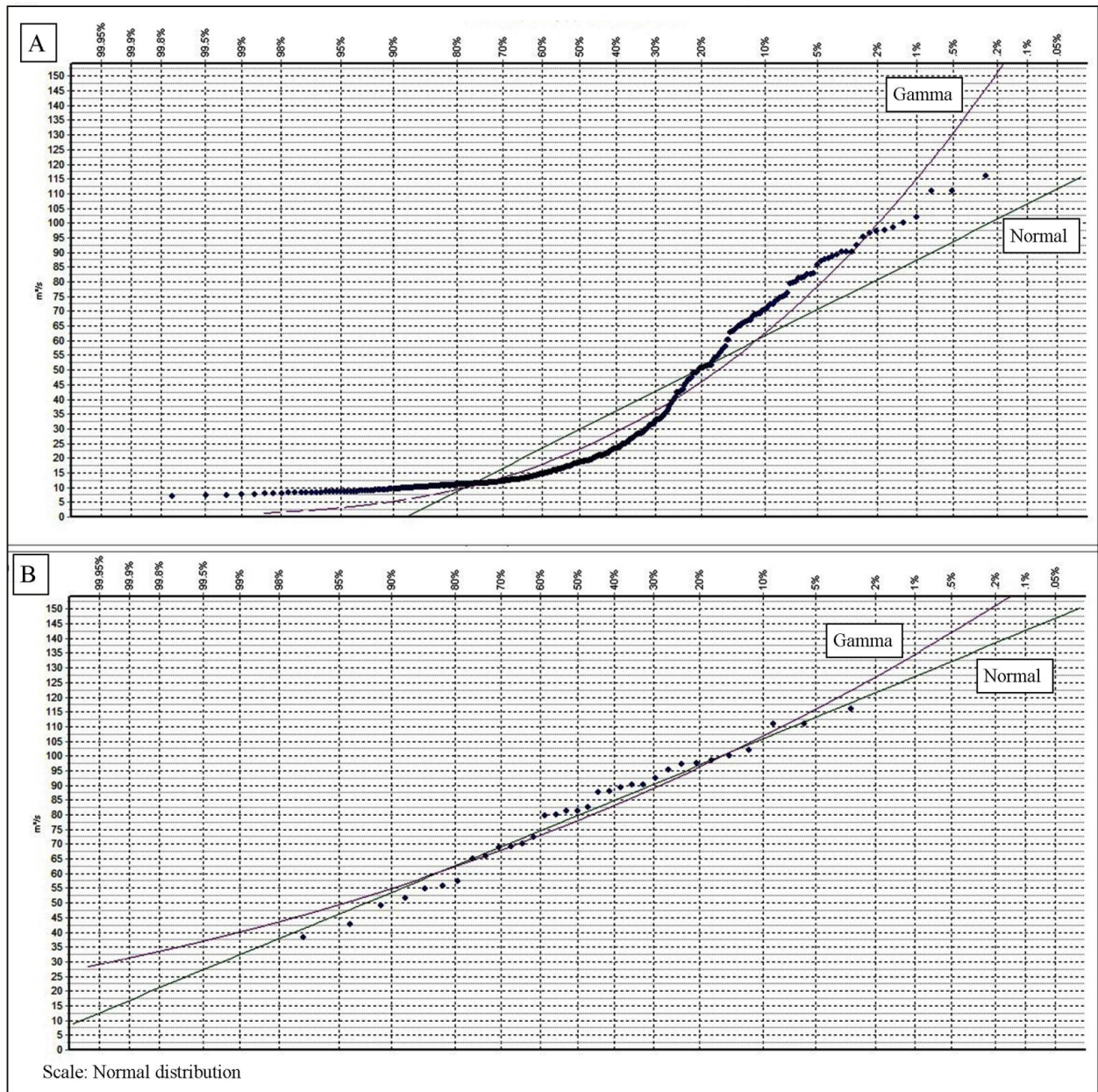


Figure 10. Exceedance probability for (A) all months and (B) June (Station: Uzunakmat)

3.5 Frequency Distribution

The PYTHIA tool of Hydrognomon software was used in order to visualize the river discharge more precisely using mean monthly time series data. Because, it is quite challenging to present the precise frequency analysis of a discharge using customary time series linear and nonlinear model methods (Wei *et al.*, 2012). Histogram was plotted to compare the frequency distribution of discharge data using same Hydrognomon software (Figure 11). This discharge frequency analysis

can be helped to predict the possible flood situations along the Naryn river channel, if any. Histogram representation is a graphical technique to check the normality for comparing the frequency distribution (histogram) of discharge records. The histogram can be visualized whether the selected data is fine-modeled by a normal distribution or not (Coin, 2008; Seyam and Othman, 2015). Such kind of long-term fluctuations in discharge flow can be identified using stream magnitude, rate, frequency, duration, timing, and rate of change characteristics (Poff and Ward, 1989).

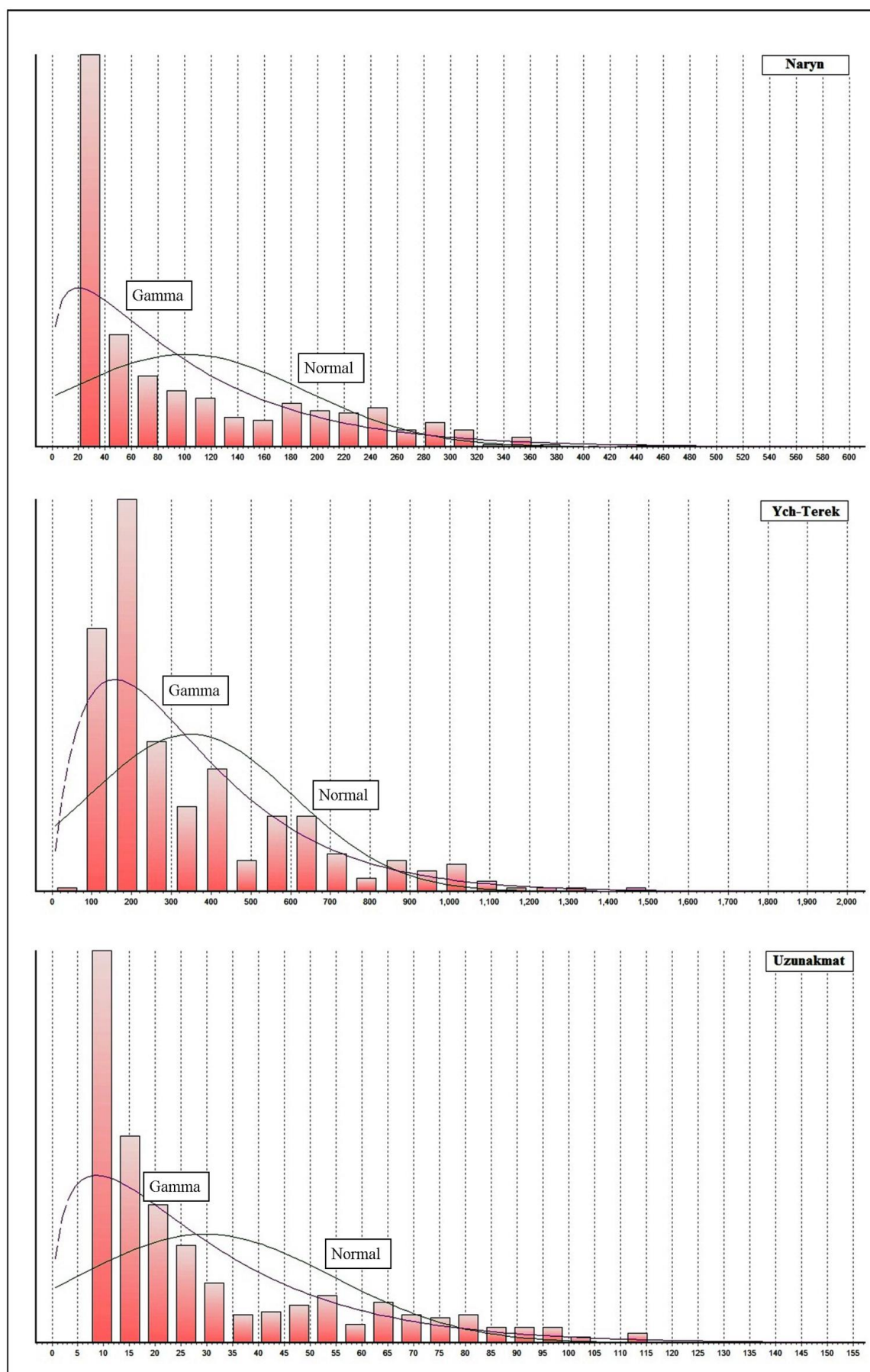


Figure 11. Discharge frequency distribution at hydro-stations

4 RESULTS AND DISCUSSIONS

4.1 Discharge Characteristics

4.1.1 Mean Monthly Discharge

The rate of MMD was observed higher in almost all June and July months in the selected periods due to seasonal changes. In each year observed the high magnitude of discharge in the summer season, i.e. June-July-August while low magnitude in the winter season, i.e. December-January-February (Figure 2). The snow in the high elevated mountain area melts especially in June that time maximum runoff occurred which contributes to the stream flows (Gan et al., 2015). Thus, the reasons behind high MMD have been a snow melting process, especially in the eastern margin of the Naryn basin, which particularly supplies the water to the river in summer season. In a 33 years period, sometime noticed high magnitude spikes of the discharge values may be because of local weather fluctuations. At the Naryn station observed the spikes of MMD in July 1981 (348 m³/s), July 1994 (380 m³/s), June 2002 (451 m³/s), and June 2010 (355 m³/s). Similarly, at Ych-Terek station observed three spikes of discharge in July 1987 (1170 m³/s), June 2002 (1340 m³/s), and June 2010 (1507 m³/s). At Uzunakmat station also observed the spikes in MMD in June 1984 (116 m³/s), June 1990 (111 m³/s), and June 1998 (111 m³/s). Such hydrological behaviors seen in the basin area are also due to the elevations of the hydro-stations (Naryn 2037 m, Ych-Terek 998 m, Uzunakmat 1879 m), from MSL and its associations with ice saturations and melting process. Generally, in the mountains area, moisture penetration prevents into central areas which resulting in low winter precipitation, with maximum sums occurring in June and July months (Aizen et al., 1995) due to snow melting process. According to Gan et al., (2015) the peak runoff in the Naryn basin will advance in May-June month, which will shift in runoff periods likely to increase the spring runoff average and decrease the summer average.

4.1.2 Mean Annual Discharge

In the average annual discharge data series seen the discharge variability which shown the annual rise and fall. At the Ych-Terek station observed the long term trend in the MAD graph where appeared higher discharge peaks and troughs seem to be increased each year up to 2010. More than 200 m³/s discharge was observed at Ych-Terek station as compared to other two stations. It is located in the downstream channel of the Naryn River basin area where meet the multiple channels (Figure 1). The characteristic of this discharge data series graph was cyclic nature and seem to raise long-term trend up to 2010. Instead of this, normal escalation was seen at the Naryn station in the 1994 (129.1 m³/s), 2002 (140.6 m³/s), and 2010 (135.6 m³/s) year might be due to local weather changes. A high MAD can be a good indicator of climate change and/or flood risk in the basin (Higashin and Stefan, 2019). Inter-annual variation in MAD in overall 33 years was noticed at the hydro-stations because of its relative

locations, altitude, and regional seasonal cycle. Higher discharge i.e. 38.1 m³/s (Uzunakmat) in 1998, 140.6 m³/s (Naryn) in 2002 and 140.6 m³/s (Ych-Terek) in 2006 whereas lower discharge, i.e. 20.3 m³/s (Uzunakmat) in 1995, 72.1 m³/s (Naryn) in 1982 and 218.7 m³/s (Ych-Terek) in 1988 was seen (Table 2). At the Ych-Terek station, significant increase in the magnitude and frequency of high discharge was recorded as compared to the past decades. The value of MAD was changed extremely after 2009 due to the relevant climatic changes. Furthermore, analysis revealed nearly negligible changes in MAD for Naryn and Uzunakmat stations. This kind of spatio-temporal changes in MAD can result of spatio-temporal differences in precipitation and spatial variations in the basin that decipher meteorological responses into the hydrological response (Burn and Elnur, 2002).

4.1.3 Standard Deviation

At the Naryn station seen the lower SD value (62.4) in 1982 and higher (137.8) in 2002 whereas at Uzunakmat station, low SD (11.6) in 1982 and higher (34.6) in 1998. The relative range of SD was recorded higher at Ych-Terek station. Here, recorded the higher SD value (439.3) in 2010 while lower (161.7) in 2007. Thus, the inter-hydro station and temporal variations in SD values indicated the discharge variability. The trend of SD was highly increased from 1980 to 2011 at Ych-Terek station. In 1980, it was 208.4 which increased up to 313.1 in 2011. Remaining two stations trends are not so far increased or decreased. Low SD values at the Uzunakmat station visualizes that the variations tend to be near to the average and high SD values at Ych-Terek station show that the variations spread out over a wider range of discharge values. Therefore, there was large variation in selected periods at all the hydro-stations in discharge data where these SD values can be used to form a benchmark for estimating the overall spatio-temporal variation (Shinde et al., 2020). The normal and linear SD lines showed the year-wise SD of discharge data of all gauging stations scores (Figure 3, 4, 5). The SD values of Ych-Terek station show a large variability, which reflected in a large deviation of the extreme annually discharge (Figure 5). Observed high SD at Ych-Terek station highlighted the mean discharge was not steady, which was changed over time.

4.1.4 Coefficient of Variation

The CV (Table 2) interprets the maximum discharge variability was seen in the 1981 year at the Naryn station (1.1) while minimum in 1982, 2007, 2012 at the Ych-Terek station (0.5) and Uzunakmat station (0.5) in 1982. It showed how much discharge data are dispersed around their mean in the selected stations and period (spatio-temporal variability). According to the discharge data series, more than 80% of the stream flow observed during the summer season (June-July-August) due to ice melting in the upper reaches of the basin. The reason behind low CV around Uzunakmat station is that its relative location in the western mountain part of the

basin. In this area, the orographic factors produce a common decline in precipitation and temperature along a northwest to southeast slope (Sorg *et al.*, 2012). Similarly, changes in temperature and allied snow and glacier melting process influenced this discharge process. Because, in this area more than 50% of the flow is originating from the snow and glacier melt sources (Savoskul *et al.*, 2003). Therefore, these spatio-temporal variations in discharge were strongly influenced from regional temperature, orographic influence, precipitations, and snow melting process.

4.2 Rainfall and Discharge Relationship

The Pearson's correlation coefficient (r) between Naryn station discharge and rainfall was -0.2121. Similarly, between Naryn station rainfall and Ych-Terek station discharge value was -0.4238. It means that, the result of correlation between discharge and rainfall was found negative, thus, the relationship between both the variables was weak. Therefore the possible glacier melting may be playing the significant role in the discharge variability process. The discharge pattern of the Naryn River doesn't highly depend on rainfall pattern. It is because of the possible glacier melting in the high elevated part, located in the eastern and south-east side (Figure 1). It was also validated from the trend of rainfall at Naryn station which was seen to decrease while the discharge trend was increase slightly at Naryn and highly at Ych-Terek station (Figure 6). It means that, discharge variability in the Naryn basin was possibly determined by glacier melting process as an influence of changing climate. The reasons behind increasing trend of discharge at the Ych-Terek station was its location where various streams/drainage are meet to Naryn River. Besides, the topography of the Tian Shan Mountain perhaps influences this variability, as it acts as an accumulation of glacier due to high altitude. This consequence is evident in the spatial variation of discharge. Thus, the overall discharge increases in the plain area around the Ych-Terek station.

4.3 Time Series Discharge Distribution Trends

Plotted time series distribution highlights the temporal variability in the discharge magnitude over 33 years' time period. Annual high and low discharge cycles were seen in the hydro-station where clearly, seasonal variations are recorded in the time series graph due to the seasonal cycles of spring, summer, autumn and winter months. In these discharge data series, clearly cyclical variation observed at these three hydro stations. The discharge manganite was seen higher, i.e. 1507 m³/s in June 2010 at Ych-Terek because of its relative location is in the lower channel section of the basin where possible amount of stream flow was higher. At the Naryn station the trends of discharge were started to increase from 1981 to 2001-2002. After that it was decreased up to 2012 except in 2009-2010 (Figure 7). At these stations probable discharge are high in summer and low in winter seasons due to seasonal variation in discharge cycles. At the Ych-Terek the trend was

increased from 1980-1981 to 2009-2010 due to ice-melting process and increasing surface runoff in the upper reach of the basin area. Descroix *et al.*, (2012) showed that the increase in the discharge flow of the river is directly proportional to the increased runoff coefficient. The general trends of discharge from a time series graph of Uzunakmat station was seen to decrease in the 33 years. Overall observed difference in discharge data from time series graphs was generally lower in the winter season (December- January- February) and higher in the spring (March-April-May) and summer melt season (Jun-July-August). Thus, it was observed that the regional seasonal cycles strongly influenced the discharge of the Naryn river basin.

4.4 Estimation of Exceedance Probability

At the Naryn station observed the maximum EP (99.7%, 17 m³/s) in 1982 while minimum (0.2%, 451 m³/s) in 2002. At this station, the trend of discharge was slightly increased after 40 m³/s where observed ~60% EP then it was raised. Similarly, at Ych-Terek observed the maximum EP (99.5%, 80 m³/s) in 1988 while minimum (0.3%, 1507 m³/s) in 2010. At this station, the trend of discharge was slightly increased after 200 m³/s where observed ~ 60% EP then it was raised. At the Uzunakmat station observed the maximum EP (99.7%, 6.8 m³/s) in 1998 while minimum (0.3%, 116 m³/s) in 1984. At this station, the trend of discharge was slightly increased after 13 m³/s where observed ~ 65% EP then it was raised (Table 3). It was interestingly noticed that with increasing the discharge values the EP was decreased (Figure 8, 9, 10). These trends are possibly produced due to continental types of climate in the present area. According to Gan *et al.* (2015) in the Naryn River Basin is observed the dry and hot summer and cold winter as a part of a continental climate. In this area, the average temperature is 10° C in July, - 18° C in January and precipitation ranges between 280 mm and 450 mm annually (Gan *et al.*, 2015). Thus, the distributed discharge data highlighted the possible correlations with % EP of the discharge.

4.5 Trends of Frequency Distribution

At the Naryn station discharge data distributed within the 20 to 360 m³/s where high frequency was observed (23 - 33 m³/s). At the Uzunakmat station discharge data was distributed within the 8 to 115 m³/s where high frequency was observed (8- 11 m³/s). The large variation in frequency was seen at the Ych-Terek station. Here the discharge data are distributed within the 20 to 1487 m³/s where high frequency was observed (171 to 206 m³/s) (Figure 11). These spatio-temporal variations in the discharge frequency were occurred due to regional climate and undulating nature of basinal topography. Hence, in this Naryn river basin the precipitations and melting of snow and ice affected the frequency of discharge which influencing the hydrological systems. The changing melting of snow and ice or rainfall pattern is changing overall hydrological schemes which influencing the associated

Table 3. Comparative Exceedance Probability (%) of hydro-stations

Hydro-stations	Years	Discharge (m ³ /s)	EP (%)	Probability
Naryn	1982	17	99.7	Maximum
	2002	451	00.2	Minimum
Ych-Terek	1988	80	99.5	Maximum
	2010	1507	00.3	Minimum
Uzunakmat	1998	6.8	99.7	Maximum
	1984	116	00.3	Minimum

water resources in the area (Jiménez *et al.*, 2014). There is observed the low precipitation in summer seasons. Moreover, glacier melting process in the higher elevated area are influenced the discharge frequency trends in the area. Because of about 2% of the basin area is glacierized and majority of glaciers are concentrated in the eastern part of the basin (Gan *et al.*, 2015). The average frequency trends of the Naryn and Uzunakmat hydro stations are considered normally distributed in overall 33 years.

5 CONCLUSION

The Naryn River basin is the major catchment of various rivers, and the human community of middle Kyrgyzstan is reliant on these rivers. Any changes in the glacier and rainfall significantly impact on the economy of this country. Hence, the present study highlighted stream flow in the Naryn River basin over 33 years to provide long-term variability in discharge regime. The used statistical variables helped to identify the long-term variability of Naryn River flow. This study also shows that Naryn River flow regime might be changed due to climatic fluctuations, with the seasonal snowmelt timing (Post-Spring, Summer, Pri-Autumn) and precipitations period (March-October). The use of advanced Hydrognomon software supported with various time steps from the monthly to annual time scales for processing the discharge data, time-series analysis, and frequency analysis. The results of the average annual aggregate time series analysis highlighted how the annual maximum discharge trend is likely to increase in the discharge frequency and intensity in coming years at Ych-Terek station. Correlations between rainfall and discharge was found weak and negative, thus, there is significant scope to investigate the other metrological parameters which determined the discharge variability. The area of the Naryn river basin is large where huge level of seasonal and inter-annual discharge fluctuations may be recorded due to precipitation pattern, melting of snow, and ice. Thus, the impact of climatic factors may influence the regional discharge variability. It was also found from the determined statistical and computational variables that chosen discharge are correlated with regional seasonal variability in the precipitation, snow-melting, and land-use patterns. The observed changes in the discharge variability validate the being of long-term changes in stream flow regime, which increase the possibility of floods and droughts in the near future.

This investigation is vital for the area, as the eastern side is dominated by glacier and the rivers originating from this region determine the water scenario in the middle and lower part of the basin. Therefore, there must be integrative monitoring of changing natural and man-induced aspects for precise water resource management in order to prevent the damaging effects of the possible variations in annual stream flow regime of the Naryn river basin.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

ACKNOWLEDGEMENTS

Merim Pamirbek kyzy is thankful for the Presidential Scholarship of the Chinese Academy of Sciences for their financial support to the Research Center for Ecology and Environment of Central Asia, the Chinese Academy of Sciences (Bishkek), for their support. Authors are thankful to Hydro-Meteorological agency of Kyrgyzstan for sharing the discharge data.

ABBREVIATIONS

CV: Coefficient of Variation; **MAD:** Mean Annual Discharge; **MMD:** Mean Monthly Discharge; **MSL:** Mean Sea Level; **SD:** Standard Deviation (SD).

REFERENCES

- Aher, S., Shinde, S., Gawali, P., Deshmukh, P. and Venkata, L. B., 2019. Spatio-temporal analysis and estimation of rainfall variability in and around upper Godavari River basin, India. *Arabian Journal of Geosciences*, 12(22). DOI: <https://doi.org/10.1007/s12517-019-4869-z>
- Aher, S., Shinde, S., Guha, S. and Majumder, M., 2017. Identification of drought in Dhalai river watershed using MCDM and ANN models. *Journal of Earth System Science*, 126(2), 21. DOI: <https://doi.org/10.1007/s12040-017-0795-1>
- Aizen, V. B., Aizen, E. M. and Melack, J. M., 1995. Climate, snow cover, glaciers and runoff in the Tien Shan, Central Asia. *Journal of the American Water Resources Association*, 31 (6), 1113-1129. DOI: <https://doi.org/10.1111/j.1752-1688.1995.tb03426.x>
- Akmatov, R., Alamanov, S., Choduraev, T. and Pochechun, V., 2019. Glacier runoff and regime of rivers with glacial power (a case of study: Naryn river, Kyrgyzstan). *IOP Conference Series: Earth and Environmental Science*. 321 012016

- Akter, S. M., Farhad, H., Ahmed, Z. and Chowdhury, T. R., 2019. The rainfall and discharge trends of Surma River area in North-eastern part of Bangladesh: An approach for understanding the impacts of climatic change. *Environ System Research*, 8 (28). DOI: <https://doi.org/10.1186/s40068-019-0156-y>
- Albrecher, H., Ladoucette, S. A. and Teugels, J. L., 2010. Asymptotics of the sample coefficient of variation and the sample dispersion. *J Stat Plan Infer.*, 140, 358-368. DOI: <https://doi.org/10.1016/j.jspi.2009.03.026>
- Armstrong, R. L., Rittger, K., Brodzik, M. J., Racoviteanu, A., Barrett, A. P., Khalsa, Raup, B., Hill, A. F., Khan, A. L., Wilson, A. M., Kayastha, R. B., Fetterer, f. and Armstrong, B., 2019. Runoff from glacier ice and seasonal snow in High Asia: Separating melt water sources in river flow. *Regional Environmental Change*, 19 (5), 1249-1261. DOI: <https://doi.org/10.1007/s10113-018-1429-0>
- Betrie, G. D., Mohamed, Y. A., van Griensven, A. and Srinivasan, R., 2011. Sediment management modelling in the Blue Nile Basin using SWAT model. *Hydrol. Earth Syst. Sci.*, 15, 807-818. DOI: <https://doi.org/10.5194/hess-15-807-2011>
- Boik, R. J. and Shirvani, A., 2009. Principal components on coefficient of variation matrices. *Statistical Methodology*, 6 (1), 21-46. DOI: <https://doi.org/10.1016/j.stamet.2008.02.006>
- Burn, D. H. and Elnur, M. A. H., 2002. Detection of hydrologic trends and variability. *J. Hydrol*, 255, 107-122. DOI: [https://doi.org/10.1016/S0022-1694\(01\)00514-5](https://doi.org/10.1016/S0022-1694(01)00514-5)
- Chymyrov, A., Betz, F., Baibagyshov, E., Kurban, A., Cyffka, B. and Halik, U., 2018. Floodplain forest mapping with sentinel-2 imagery: Case study of Naryn River, *Kyrgyzstan Vegetation of Central Asia and Environs.*, 335-347. DOI: https://doi.org/10.1007/978-3-319-99728-5_14
- Coin, D., 2008. A goodness-of-fit test for normality based on polynomial regression. *Comput Stat Data Anal*, 52, 2185-2198. DOI: <https://doi.org/10.1016/j.csda.2007.07.012>
- Descroix, L., Genthon, P., Amogu, O., Rajot, J. L., Sighomnou, D. and Vauclin, M., 2012. Change in Sahelian Rivers hydrograph: The case of recent red floods of the Niger River in the Niamey region. *Glob. Planet. Chang.*, 98-99, 18-30. DOI: <https://doi.org/10.1016/j.gloplacha.2012.07.009>
- Deshmukh, K. K. and Aher, S. P., 2016. Assessment of the impact of municipal solid waste on groundwater quality near the Sangamner city using GIS approach, *Water resources management*, 30, 2425-2443. DOI: <https://doi.org/10.1007/s11269-016-1299-5>
- Dixon, S. G., and Wilby, R. L., 2016. Forecasting reservoir inflows using remotely sensed precipitation estimates: A pilot study for the River Naryn, Kyrgyzstan. *Hydrological Sciences Journal*, 61 (1), 107-122. DOI: <https://doi.org/10.1080/02626667.2015.1006227>
- Djancharov, D. and Street, K., 2003. The use of irrigation systems for fish production in Kyrgyzstan. Fisheries in irrigation systems of arid Asia. *FAO Fisheries Technical Paper*, 430, 71-75.
- Easton, Z. M., Fuka, D. R., Walter, M. T., Cowan, D. M., Schneiderman, E. M. and Steenhuis, T. S., 2008. Reconceptualizing the soil and water assessment tool (SWAT) model to predict runoff from variable source areas. *Journal of hydrology*, 348 (3-4), 279-291. DOI: <https://doi.org/10.1016/j.jhydrol.2007.10.008>
- Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, C., Ramankutty, N., and Snyder, P. K., 2005. Global consequences of land use. *science*, 309(5734), 570-574. DOI: <https://doi.org/10.1126/science.1111772>
- Francesconi, W., Srinivasan, R., Pérez-Miñana, E., Willcock, S. P. and Quintero, M., 2016. Using the Soil and Water Assessment Tool (SWAT) to model ecosystem services: A systematic review. *Journal of hydrology*, 535, 625-636. DOI: <https://doi.org/10.1016/j.jhydrol.2016.01.034>
- Gan, R., Luo, Y., Zuo, Q. and Sun, L., 2015. Effects of projected climate change on the glacier and runoff generation in the Naryn River Basin, Central Asia. *Journal of Hydrology*, 523, 240-251. DOI: <https://doi.org/10.1016/j.jhydrol.2015.01.057>
- Gao, J., Wei, Y. D., Chen, W. and Yenneti, K., 2015. Urban land expansion and structural change in the Yangtze River Delta, China. *Sustainability*, 7 (8), 10281-10307. DOI: <https://doi.org/10.3390/su70810281>
- Garba, H., Ismail, A. and Tsoho, U., 2013. Fitting probability distribution functions to discharge variability of Kaduna River. *International Journal of Modern Engineering Research*, 3 (5), 2848-2852.
- Garba, H., Ismail, A., Olusoga, F. and Oriola, P., 2013a. Calibration of Hydrognomon model for simulating the hydrology of urban catchment. *Open J. Mod. Hydrol.* 3, 75-78. DOI: <https://doi.org/10.4236/ojmh.2013.32010>
- George, C. and Roger L. B., 2001. Statistical Inference (2nd ed.). Duxbury. Australia.
- Hagg, W., Mayer, C., Lambrecht, A., Kriegel, D. and Azizov, E., 2013. Glacier changes in the Big Naryn basin, Central Tian Shan. *Global Planet. Change*, 110, 40-50. DOI: <https://doi.org/10.1016/j.gloplacha.2012.07.010>
- Higashino, M. and Stefan, H. G., 2019. Variability and change of precipitation and food discharge in a Japanese river basin. *J Hydrol Regi Stud*, 21, 68-79. DOI: <https://doi.org/10.1016/j.ejrh.2018.12.003>
- Hill, A., Minbaeva, C., Wilson, A. and Satylkanov, R., 2017. Hydrologic controls and water vulnerabilities in the Naryn River Basin, Kyrgyzstan: A Socio-Hydro Case Study of Water Stressors in Central Asia. *Water*, 9 (5), 325. DOI: <https://doi.org/10.3390/w9050325>
- Houessou-Dossou, E., Gathenya, J. M., Njuguna, M. and Gariy, Z. A., 2019. Flood frequency analysis using participatory GIS and rainfall data for two stations in Narok Town, Kenya. *Hydrology*, 6 (4), 1-12. DOI: <https://doi.org/10.3390/hydrology6040090>
- Jiménez, C. B. E., Oki, T., Arnell, N. W., Benito, G., Cogley, J. G., Döll, P., Jiang, T. and Mwakalila, S. S., 2014. Freshwater resources, climate change 2014: Impacts, adaptation, and vulnerability. In: Barros VR et al., (eds) Part A: global and sectoral aspects, contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, 229-269.
- Kale, V. S. and Hire, P. S., 2007. Temporal variations in the specific stream power and total energy expenditure of a monsoonal river: The Tapi River, India. *Geomorphology*, 92 (3-4), 134-146. DOI: <https://doi.org/10.1016/j.geomorph.2006.06.047>
- Kale, V. S., Hire, P. S. and Baker, V. R., 2009. Flood hydrology and geomorphology of monsoon-dominated rivers: The Indian Peninsula. *Water International*, 22 (4), 259-265. DOI: <https://doi.org/10.1080/02508069708686717>

- Karlsson, I., Sonnenborg, T., Jensen, K. and Refsgaard, J., 2013. Evaluating the influence of long term historical climate change on catchment hydrology-using drought and flood indices. *Hydrology & Earth System Sciences Discussions*, 10 (2), 2373-2428. DOI: <https://doi.org/10.5194/hessd-10-2373-2013>
- Kozanis, S., Christofides, A., Mamassis, N., Efstratiadis, A. and Koutsoyiannis, D., 2010. Hydrognomon-open source software for the analysis of hydrological data. In *Proceedings of the European Geosciences Union General Assembly 2010, Vienna, Austria*, 12, 12419.
- Kundzewicz, Z., Merz, B., Vorogushyn, S., Hartmann, H., Duethmann, D., Wortmann, M. and Krysanova, V., 2015. Analysis of changes in climate and river discharge with focus on seasonal runoff predictability in the Aksu River Basin. *Environmental Earth Sciences*, 73 (2), 501-516. DOI: <https://doi.org/10.1007/s12665-014-3137-5>
- Kurban, A., Strobl, J., Amanambu, A., Khan, G. and Valentine, M., 2018. A Bivariate statistical technique with knowledge-based analytical hierarchy process for landslide susceptibility assessment in Naryn River Basin, Kyrgyzstan. *International Journal of Geoinformatics*, 14 (1).
- Kutuzov, S. and Shahgedanova, M., 2009. Glacier retreat and climatic variability in the eastern Terskey-Alatau, inner Tien Shan between the middle of the 19th century and beginning of the 21st century. *Global Planet. Change*, 69, 59-70. DOI: <https://doi.org/10.1016/j.gloplacha.2009.07.001>
- Linsley, R. K., Kohler, M. A. and Paulhus, J. L. H., 1988. *Hydrology for Engineers*. McGraw-Hill, London, 492.
- Mapfumo, E., Chanasyk, D. S. and Willms, W. D., 2004. Simulating daily soil water under foothills fescue grazing with the soil and water assessment tool model (Alberta, Canada). *Hydrological processes*, 18 (15), 2787-2800. DOI: <https://doi.org/10.1002/hyp.1493>
- Moliere, D. R., Lowry, J. B. C. and Humphrey, C. L., 2009. Classifying the flow regime of data-limited streams in the wet-dry tropical region of Australia. *J Hydrol*, 367, 1-13. DOI: <https://doi.org/10.1016/j.jhydrol.2008.12.015>
- Ng, T. L., Eheart, J. W., Cai, X. and Miguez, F., 2010. Modeling miscanthus in the soil and water assessment tool (SWAT) to simulate its water quality effects as a bioenergy crop. *Environmental science & technology*, 44 (18), 7138-7144. DOI: <https://doi.org/10.1021/es9039677>
- Poff, N. L. and Ward, J. V., 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of stream flow patterns. *Can J Fish Aquat Sci*, 46, 1805-1818. DOI: <https://doi.org/10.1139/f89-228>
- Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegard, K. L., Richter, B. D., Sparks, R. E. and Stromberg, J. C., 1997. The natural flow regime: A new paradigm for riverine conservation and restoration. *Bioscience* (47) 769-784.
- Richter, B. D., Baumgartner, J. V., Powell, J. and Braun, D. P., 1996. A method for assessing hydrologic alteration within ecosystems. *Un Metro Para Evaluar Alteraciones Hidrologicas Dentro de Ecosistemas*, 10, 1163-1174. DOI: <https://doi.org/10.1046/j.1523-1739.1996.10041163.x>
- Savoskul, O. S., Chevnina, E. V., Perziger, F. I., Vasilina, L. Y., Baburin, V. L., Danshin A.I., Matyakubov, B. and Murakaev, R. R., 2003. Water, climate, food, and environment in the Syr Darya Basin, in adaptation strategies to changing environments, institute for environmental studies. Amsterdam: Vrije University.
- Seyam, M. and Othman, F., 2015. Long-term variation analysis of a tropical river's annual streamflow regime over a 50-year period, *Theor Appl Climatol*, 121, 71-85. DOI: <https://doi.org/10.1007/s00704-014-1225-9>
- Shinde, S., Aher, S., Pawar, A. and Kantamaneni, K., 2020. Spatio-temporal variability of discharge over past 40 years in Krishna and Koyana river, India. *Iranian Journal of Sci and Tech, Transactions of Civil Engineering*. DOI: <https://doi.org/10.1007%2Fs40996-020-00375-z>
- Singh, J., Knapp, H. V., Arnold, J. and Demissie, M., 2005. Hydrological modeling of the Iroquois river watershed using HSPF and SWAT 1. *JAWRA Journal of the American Water Resources Association*, 41(2), 343-360. DOI: <https://doi.org/10.1111/j.1752-1688.2005.tb03740.x>
- Sorg, A., Bolch, T., Stoffel, M., Solomina, O. and Beniston, M., 2012. Climate change impacts on glaciers and runoff in Tien Shan (Central Asia). *Nature Climate Change*, 2, 725-731. DOI: <https://doi.org/10.1038/nclimate1592>
- Srebrenovir, D., 1986. *Primijenjena Hidrologija*. Tehnicka knjiga, Zagreb, 509.
- SSS, 2020. Social Science Statistics (Online). Assessed 30.6.2020.
- Wang, W., 2006. *Stochasticity, Nonlinearity and Forecasting of Streamflow Processes*, Amsterdam: IOS Press.
- Wei, S., Song, J. and Khan, N. I., 2012. Simulating and predicting river discharge time series using a wavelet-neural network hybrid modelling approach, *Hydrol. Process.* 26, 281-296. DOI: <https://doi.org/10.1002/hyp.8227>
- Welcome.Kg, 2020. Characteristics of the Rivers of Naryn River Basin (in Russian), assessed on 28.5.2020.
- Yang, D., Shi, X. and Marsh, P., 2015. Variability and extreme of Mackenzie River daily discharge during 1973-2011, *Quaternary International*, 380-381, 159-168. DOI: <https://doi.org/10.1016/j.quaint.2014.09.023>
- Zhang, X., Srinivasan, R. and Hao, F., 2007. Predicting hydrologic response to climate change in the Luohe River basin using the SWAT model. *Transactions of the ASABE*, 50 (3), 901-910. DOI: <https://doi.org/10.13031/2013.23154>
- Zolekar, R. B., Todmal, R. S., Bhagat, V. S., Bhailume, S. A., Korade, M. S. and Das, S., 2020. Hydro-chemical characterization and geospatial analysis of groundwater for drinking and agricultural usage in Nashik district in Maharashtra, India. *Environment, Development and Sustainability: A Multidisciplinary Approach to the Theory and Practice of Sustainable Development*, 1-20. DOI: <https://doi.org/10.1007%2Fs10668-020-00782-2>
