Modeling implications of climate induced streamflow changes on the fish species of the Soan River, Pakistan

Muhammad Usman[1*], Christopher E. Ndehedehe[2], Burhan Ahmad[1] and Rodrigo Manzanas[3]

[1]Pakistan Meteorological Department, Pitras Bukhari Road, H-8/2, Islamabad, Pakistan

[2]Australian Rivers Institute and Griffith School of Environment & Science, Griffith University, Nathan, Queensland 4111, Australia

[3]Meteorology Group, Dpto. de Matemática Aplicada y Ciencias de la Computación, Universidad de Cantabria, 39005 Santander, Spain

Corresponding Author: Muhammad Usman (usman666.m@gmail.com)

Abstract

Climate change has significantly impacted the hydrological cycle in the rivers of Pakistan and the streamflow regimes of different rivers have witnessed noticeable flow alteration. These changes in stream flow affect aquatic biodiversity (e.g., freshwater fish species) and the productivity of freshwater ecosystems . This study therefore evaluates the streamflow alterations and their impacts on the fish species at the upstream and downstream of the Soan River in Pakistan. The hydrological model HBV-light was calibrated and validated for both up- (Chirah) and down- (Dhoke Pathan) stream gauged stations. The model was then forced with an ensemble of NEX-GDDP GCMs to simulate historic and future streamflow. Afterwards, changes in streamflow characteristics for two future periods against a historic period were assessed. Different ecologically relevant streamflow indices were used. The base flow at upstream and downstream was projected to increase under both the RCP 4.5 and RCP 8.5 emission scenarios for mid and end of century periods. Under the RCP 8.5, base flow was projected to increase with more inter-annual variability at upstream station, and changes depicted less variability for downstream under both emission scenarios. Number of high flow pulses were projected to decrease under both emission scenarios in both future periods for upstream and downstream, however, high variability was depicted for upstream than downstream area. Duration of high flow pulses was also projected to increase under the RCP 8.5 for end of century period for both upstream and downstream. These projections of streamflow characteristics may have a marked (positive) influence on the habitat and ecological conditions for the fish species of the Soan River.

Keywords: Hydrologic alteration, base flow, high flow pulse, NEX-GDDP GCMs, Aquatic habitat, Fish species.

Introduction

Natural hydrologic processes are substantially pertinent to the ecological integrity of rivers (Poff *et al.* 1997; Richter et al. 2003; Lytle and Poff 2004; Tharme 2003; Petts 2009). The base flow, high flow pulses, and duration of high flow pulses are considered as some of the most ecologically relevant components of streamflow (Poff et al. 1997). The chemical, physical and biological conditions that are crucial to sustain biological diversity of rivers are maintained by these hydrologic components in a number of ways (Poff et al. 1997; Bunn and Arthington 2002; Lytle and Poff 2004). There is an ample evidence of the significance that these streamflow characteristics have for river ecosystems (Dynesius and Nilsson 1994; Baxter 1977; Jansson et al. 2000; Bunn and Arthington 2002).

Globally, the biodiversity in the fluvial ecosystems is endangered by the variations in different streamflow characteristics like the magnitude, frequency, and duration of extreme water conditions (Poff et al. 2007; Döll et al. 2009). Sustainability and health of aquatic communities (e.g. fish species) are generally susceptible to variations in the streamflow regimes (Jalón et al. 2019). These alterations in streamflow however have a dependency on regional hydrological context and are location specific (McManamay et al. 2012). Variabilities in the streamflow are among the main drivers of ecosystem processes (Cid et al. 2017) and they play an indispensable role in the interaction between river structure, physical processes and ecological patterns (Naiman et al. 2008; Wohl 2012).

Climate change is a growing concern for the modern world and it has exacerbated in the recent decades, it is also among the major factors that have disrupted the hydrological cycle and have greatly altered the flow regime of many rivers throughout the globe (Petts 1984; Xenopoulos et al. 2005; Wang et al. 2012; Beaulieu et al. 2016; Chaemiso et al. 2016; Tesfaye et al. 2020; Usman et al. 2021a; 2021b).

More than 190 fish species are the inhabitants of different rivers in Pakistan (Rafique and Khan 2012). Competition for water resources and habitat modifications are some of the major stressors for fish assemblage (Kouamélan et al. 2003; Bremner et al. 2015; Crook et al. 2015) and are closely associated with the alteration of natural streamflow patterns. These stressors frequently become the reason for the extinction of delicate species, alterations and assemblage shift, decline in functionality and diversity of fish assemblages (Helms et al. 2009). Specifically, deterioration of hydrological regimes in Pakistani rivers has made some of the species critically endangered and some of them are extensively threatened (Rafique and Khan 2012).

Information about the spatial seasonal dynamics of fish assemblage is one of the requirements to assess the impacts of the aforementioned stressors (alterations in the natural streamflow characteristics) (Parks 2014). It is not a widely researched topic in a developing country like Pakistan, and in terms of different rivers of Pakistan, very limited studies are available addressing specifically the fish assemblage across these rivers and their relationship with the hydrological regimes of the rivers.

The Soan River is one of the important rivers of Pakistan, and it has undergone extensive victimization because of multiple natural and human induced stresses. Climate change is one of the major reasons for the alteration of hydrological regimes of the river. Changes in the streamflow characteristics of the river in past had a significant impact on the aquatic ecosystems, and water quality of the Soan River is extensively degraded under the effect of these stresses putting aquatic organisms in some tributaries of the river at ecological risk (Nazeer et al. 2016; Nazeer et al. 2014; Zamor et al. 2014).

A total of 22 freshwater fish species are found in the Soan River (Nazeer et al. 2016) and clear, turbulent water conditions are preferred by these fishes (Islam and Tanaka 2007; Bhatt et al. 2004). Natural breeding grounds for numerous fishes are provided by the upstream of the Soan River, however, these sites have already been dried either completely or partially (Nazeer et al. 2016). Climate change has significantly impacted the streamflow of rivers in Pakistan (Usman et al. 2021c; Burhan et al. 2020a) and as a consequence loss of habitat is evident. This habitat loss is one of the major reasons of the rapid decline in fish species of the Soan River.

Variations in temperature results in the modification of numerous aquatic processes, and these spatial-seasonal changes in temperature are associated with climatic conditions. Low flows are one of the most important issues in the Soan River especially in the downstream region and decreased natural base flow can result in drought like conditions, specifically in dry season. Alteration in streamflow considerably effects fish assemblage during drought like conditions either due to loss of habitat or decline in water quality (Geheber and Piller 2012).

In the developed regions of the world like North America, hydrologic alterations of most watersheds have already been described (Poff et al. 2006a, b). On the other hand in the Pakistani rivers basins negligible studies (Usman et al. 2021c) are found in literature where alterations of hydrologic regime under the influence of future climate change and its impacts on aquatic ecosystems have been studied. Pyron and Neumann (2008) emphasizes the need to study individual watersheds to assess the above mentioned characteristics of the river regime as they are helpful in examining the cause of local species extinction and assemblage changes that are attributed to hydrologic alterations. Periodic events like high (extreme) flows, duration of these flows, and base flow in a river play a vital role in structuring of fish assemblages (Pires et al. 1999). Flood pulse has also been reported to be a significant factor for seasonal variations in fish assemblages.

Therefore, this study aims to assess the alterations in hydrological regime of the Soan River due to climate change and its impacts on the freshwater fish species of the river at both upstream and downstream reaches at a longer temporal scales.

Material and Methods

Study area

The Soan River is one of the tributaries of the mighty Indus River. This study is conducted at the two gauging stations of the Soan River basin namely the Chirah (upstream) and the Dhoke Pathan (downstream) (Fig 1). Nearly 60% of the population is rural and cultivation is considered as one of the main sources of economy. See (e.g. Usman et al. 2019: 2021b) for a detailed description of the study area.

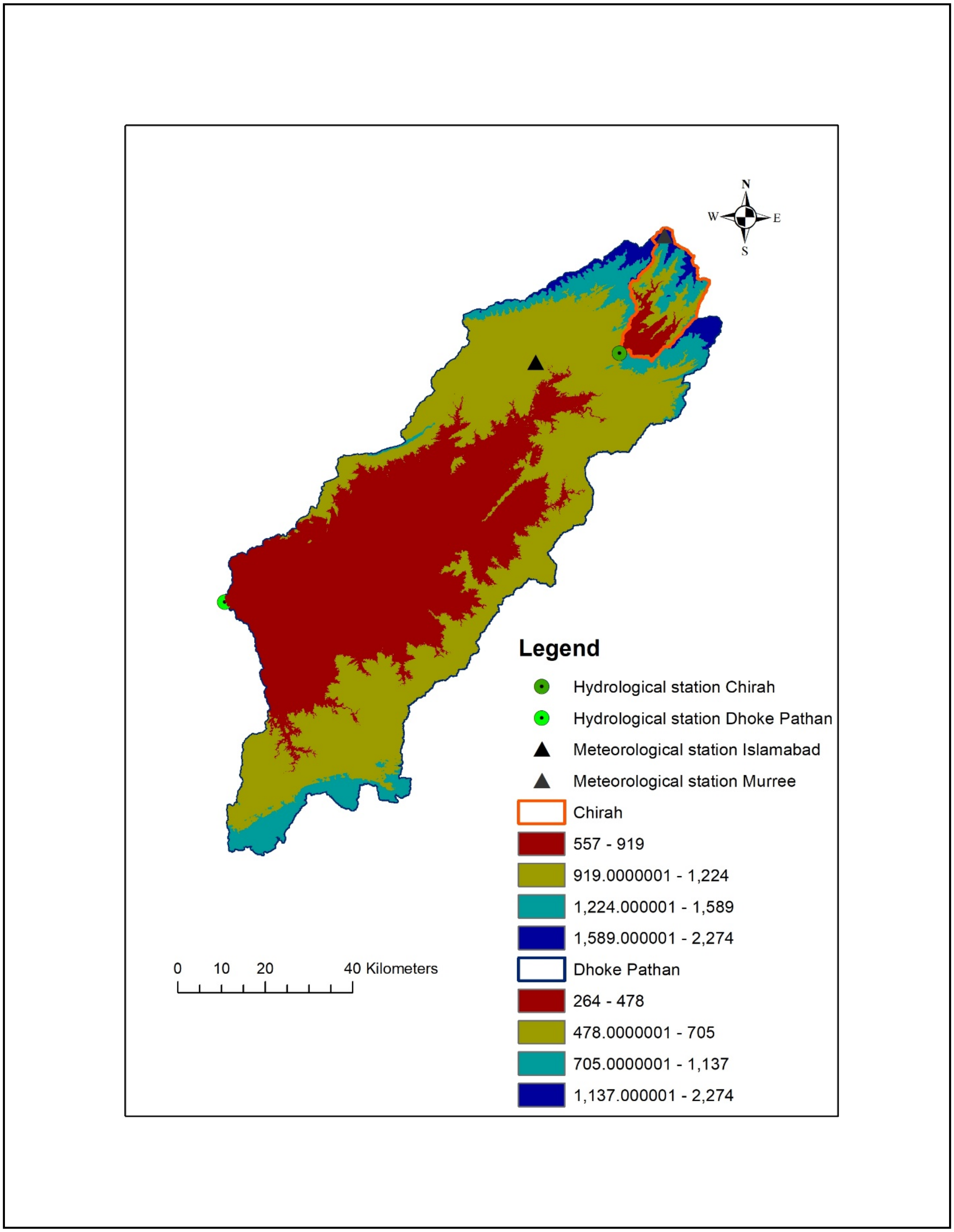

Figure 1. The study area.

Data description

Daily precipitation and temperature data were obtained from the Pakistan Meteorological Department for two stations namely Murree (Lat 33° 55' N, Lon 73° 23' E) and Islamabad (Lat 33° 42' N, Lon 73° 05' E) for the period 2001-2013. Daily streamflow data were provided by the Surface Water Hydrology Project (SWHP) of Water and Power Development Authority (WAPDA), Pakistan for the period 2001-2013. Potential evapotranspiration data of Climate Research Unit (CRU) was used in this study. Future climate projections of five different General Circulation Models (GCMs) from NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) for upstream and downstream Soan River were used in this study. The GCMs included were ACCESS1-0, CCSM4, CESM1-BGC, MIROC5, and MRI-CGCM3 for the Chirah hydrological station, and BNU-ESM, CCSM4, GFDL-CM3. IPSL-CM5A-LR, and NorESM1-M for the Dhoke Pathan hydrological station.

Methodology

The methodology adopted to assess the climate change induced changes in the streamflow and their potential impacts on the fish species of the Soan River is described in the following sections.

Hydrological model setup and development

The Hydrologiska Byråns Vattenbalansavdelning (HBV) model (Bergström 1976; Lindström *et al.* 1997) is a conceptual, semi-distributed hydrological model. In this study, HBV-light version (Seibert and Vis 2012) was used to simulate daily streamflow. Detailed description of the HBV model can be found in (Hakala et al. 2018, Bergström 1976; Burhan et al. 2020b, Seibert and Vis 2012). This model has successful applications in catchments with different climatic conditions and topographic features (Yacouba et al. 2019; Mutsindikwa et al. 2020; Asitatikie and Gebeyehu 2020; Usman et al. 2021b, d).

The model was calibrated for the period 2002-2006 with 2001 as a warm up period for the Soan River Basin at its upper and lower reaches. After the calibration, model was validated for an independent period 2009-2013. Different metrics were used to calibrate and validate the model, which includes visual inspection, the Kling Gupta Efficiency (KGE), and the mean difference (mm/year) between observed and model simulated streamflow. KGE was selected because it combines bias, variability, and correlation. It was introduced by Gupta et al. (2009) and has been extensively used ever since. It is also termed as the paramount score for streamflow simulation and hydrological models can be calibrated by optimizing this score (Brocca et al. 2020).

Indicators of Hydrologic Alteration (IHA) and Range of Variability Approach (RVA)

The indicators of hydrologic alteration (IHA) method was proposed by (Richter *et al*. 1996). It includes different ecologically pertinent indicators that could be used to determine stream health and its implications for aquatic ecosystem, and was used first to assess the climate induced streamflow alterations. In the Soan River, three key characteristics of the streamflow that includes base flow index, number, and duration of high streamflow pulses within each year have a strong influence on the fish species of the river. Therefore, these three indicators of streamflow regime alteration were selected in this study. There are five groups of IHA indicators and detailed description of these indicators could be found in (Richter et al. 1997). Base flow index is an indicator of streamflow regime alteration that belongs to the second group of IHA indicators that deals with the magnitude and duration of annual extreme water conditions. Variations in the base flow index have substantial implications for structuring of aquatic ecosystems (e.g. freshwater fish species), physical habitat conditions, and morphology of river channel. Base flow index is calculated as 7-day minimum flow/mean flow for year and plays a crucial role during the period of prolonged dry conditions. Number and duration of high streamflow pulses belong to the fourth group of IHA indicators that deals with the frequency and duration of high and low pulses and has a remarkable effect on the floodplain habitats availability for fish species and access for aquatic organisms to the sites where they could feed, rest, and reproduce.

At least twenty years should be used to carry out this kind of analysis as this period can represent natural climatic variability (Richter et al. 1997; Pfeiffer and Ionita 2017). Therefore, twenty five years (1980-2004) were selected as the pre-impact period and two additional twenty years period (representative of mid and end of 21st century) were selected as the post-impact period (2040-2064, and 2074-2098). Then the median changes in the post-impact period were assessed and analyzed as compared to pre-impact period.

Results

Hydrological model setup and development

Results of calibration and validation indicated that the model performance was very good for both upper and lower reaches of the Soan River (Fig. 2). KGE is a performance evaluation metric that has optimum value equal to 1; good performance of a model is achieved for KGE value between 0.7 and 1, and the model is considered to perform satisfactorily if the KGE achieved is between 0.4 and 0.7, and poor performance is exhibited if the values fall below 0.4. KGE values of 0.75 and 0.85 were achieved during calibration (2002-2006) and validation (2009-2013) period, respectively, for the Chirah hydrological station. For the Dhoke Pathan hydrological station KGE values of 0.8 were achieved during calibration and 0.9 for validation period, respectively. Annual difference in observed and simulated streamflow during the calibration was six percent while it was none during validation period, suggesting an even better performance during validation period.

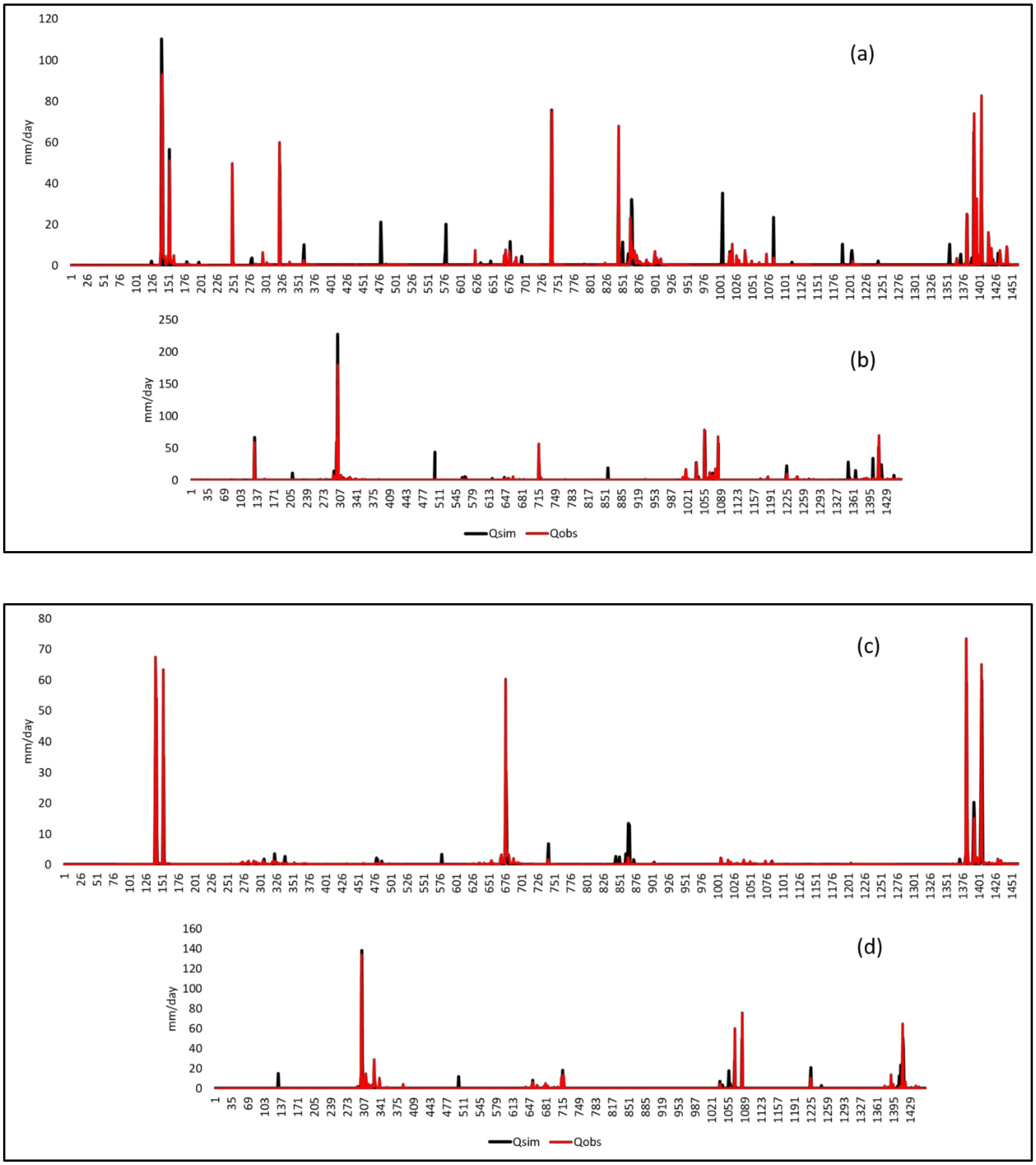

Figure 2. Simulated daily streamflow during calibration period (a,c (Chirah, Dhoke Pathan)) and validation period (b,d (Chirah, Dhoke Pathan)). Calibration period is from 2002 to 2006, and validation period is from 2009-2013.

Projected changes in base flow and their impacts on the aquatic ecosystem of the Soan River at Chirah

Base flow for Soan River at its upstream (Chirah) was projected to increase under both the average and extreme emission scenarios for the mid of century period (2040-2064) and end of century period (2074-2098) as shown in (Fig. 3). Projected range of base flow lies between 0.9 and 1 (and these values are pretty much consistent) under the RCP 4.5 emission scenario for the period (2040-2064) as opposed to the pre-impact period range which was 0.6 to nearly 0.9 (highly variable) (Fig. 4). Under the RCP 8.5 emission scenario base flow was also projected to increase, however, with more variability. Similar patterns were also observed for the period (2074-2098) in which a more consistent increase in base flow were projected under the average emission scenario and variable increase in base flow was projected under the extreme emission scenario.

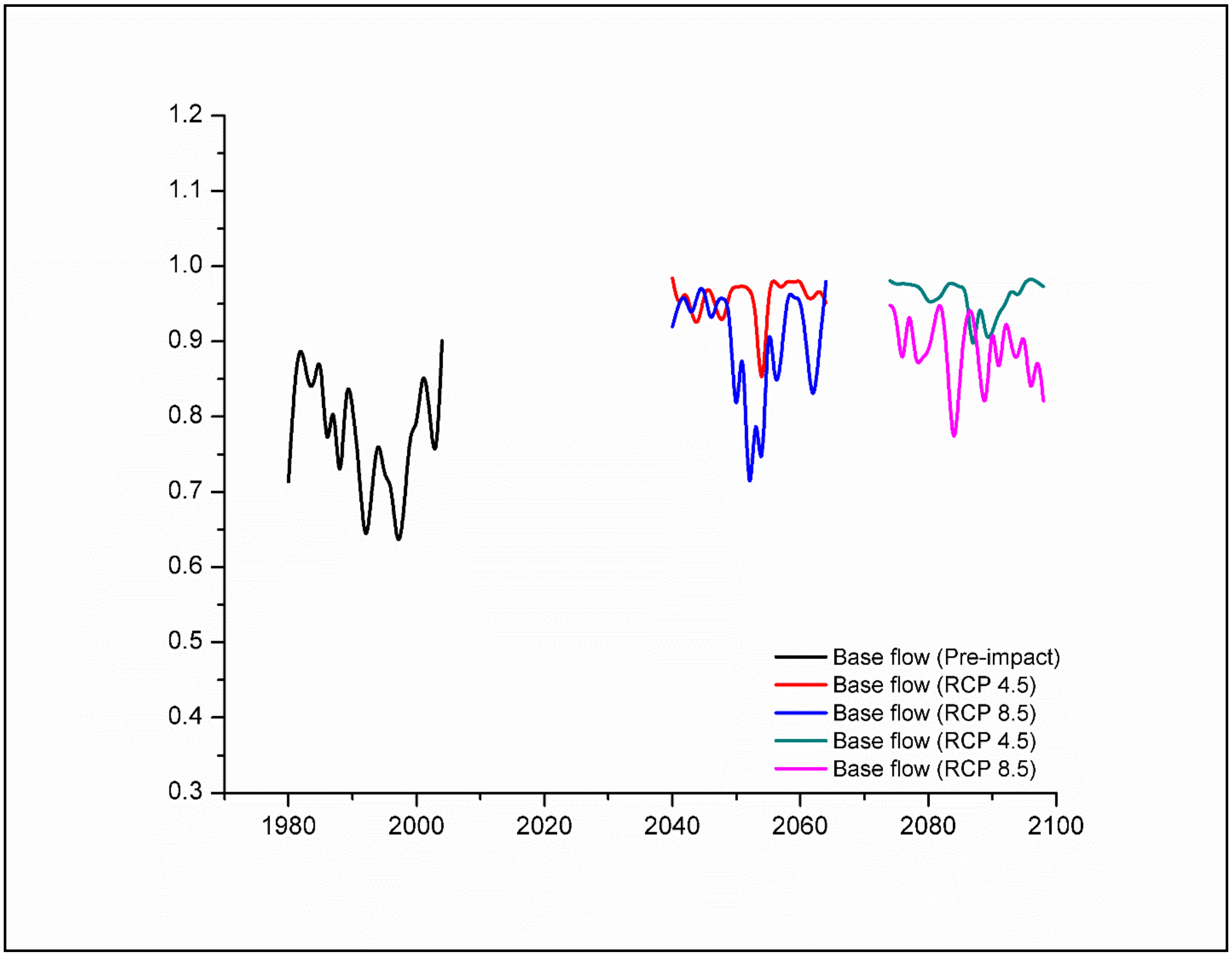

Figure 3. Projected changes in the baseflow for Soan River at Chirah gauging station. Black line shows the baseflow for pre-impact period (1980-2004), blue and red lines show the baseflow for near future post-impact period (2040-2064), and green and pink lines show the baseflow for far future post-impact period (2074-2098).

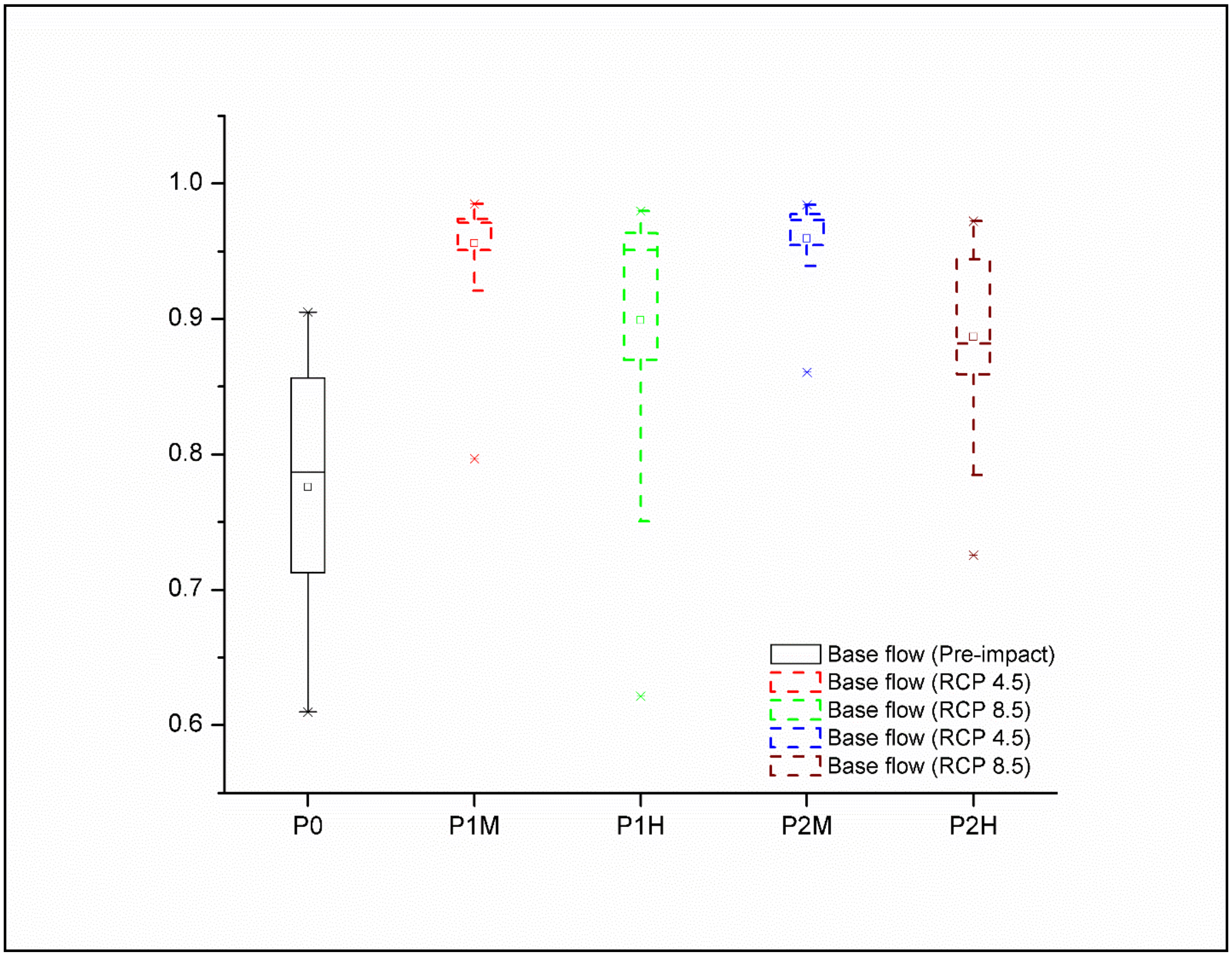

Figure 4. Box plots showing the magnitude of variability exhibited by projected changes in the baseflow for Soan River at Chirah gauging station. P0 denotes the variability in baseflow for pre-impact period (1980-2004), P1M and P1H show the variability in baseflow for near future post-impact period (2040-2064), and P2M and P2H show the variability in baseflow for far future post-impact period (2074-2098).

Projected changes in number and duration of high streamflow pulses and their impacts on the aquatic ecosystem of the Soan River at Chirah

Number of high flow pulses were projected to decrease under both the emission scenarios in both the future periods (Fig. 5), and high flow pulsing was projected to be less variable in the future as compared to pre-impact period (Fig. 5). Duration of high flow pulses was between 1.5 to 2 days during the pre-impact period is expected to remain (shorter) more or less similar for both future periods as compared to the pre-impact conditions, under the RCP 4.5 emission scenario. However, exceptionally prolonged pulses under the RCP 8.5 emission scenario towards the end of century period were projected (Fig. 6).

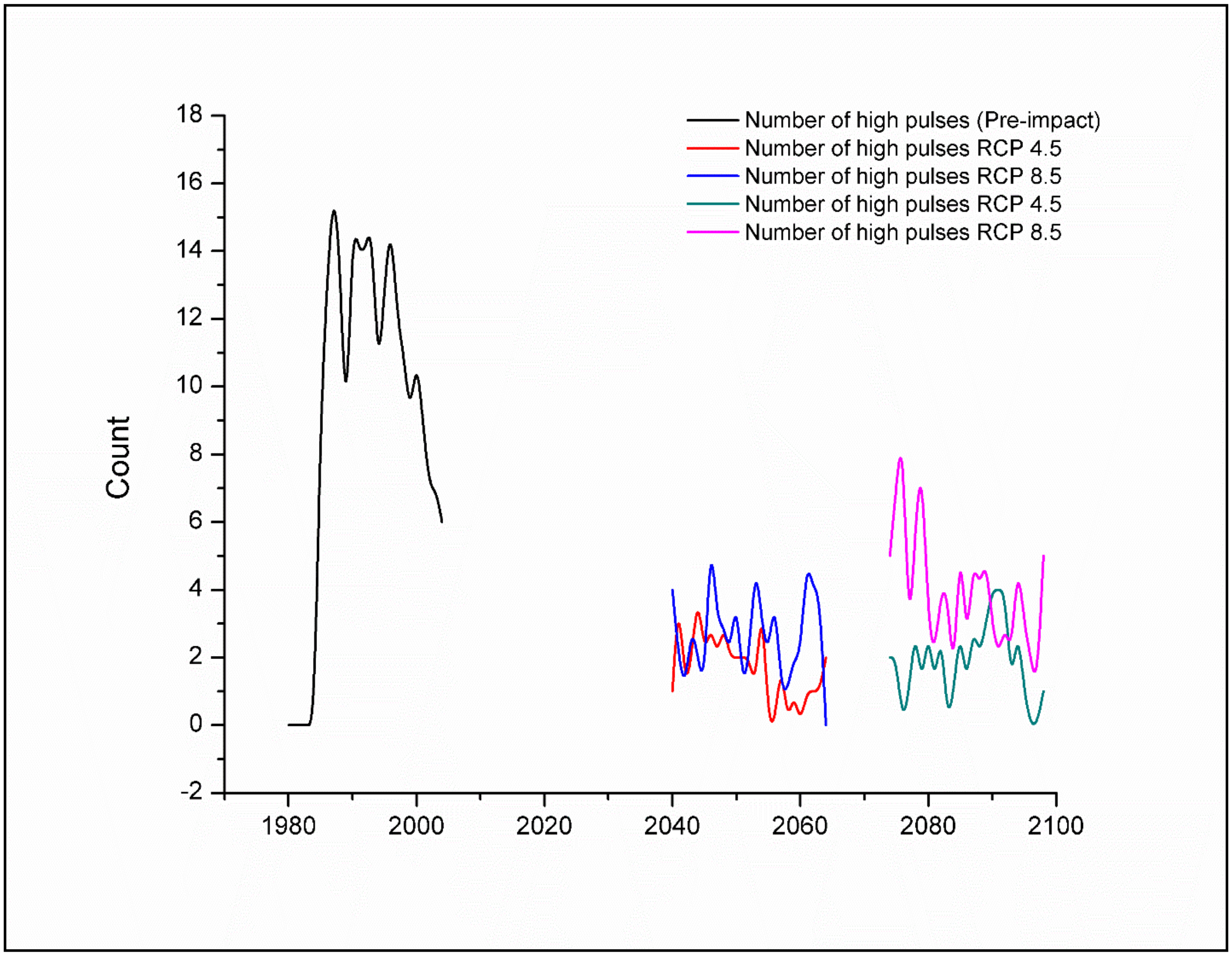

Figure 5. Projected changes in the number of high pulses for Soan River at Chirah gauging station. Black line shows the baseflow for pre-impact period (1980-2004), blue and red lines show the baseflow for near future post-impact period (2040-2064), and green and pink lines show the baseflow for far future post-impact period (2074-2098).

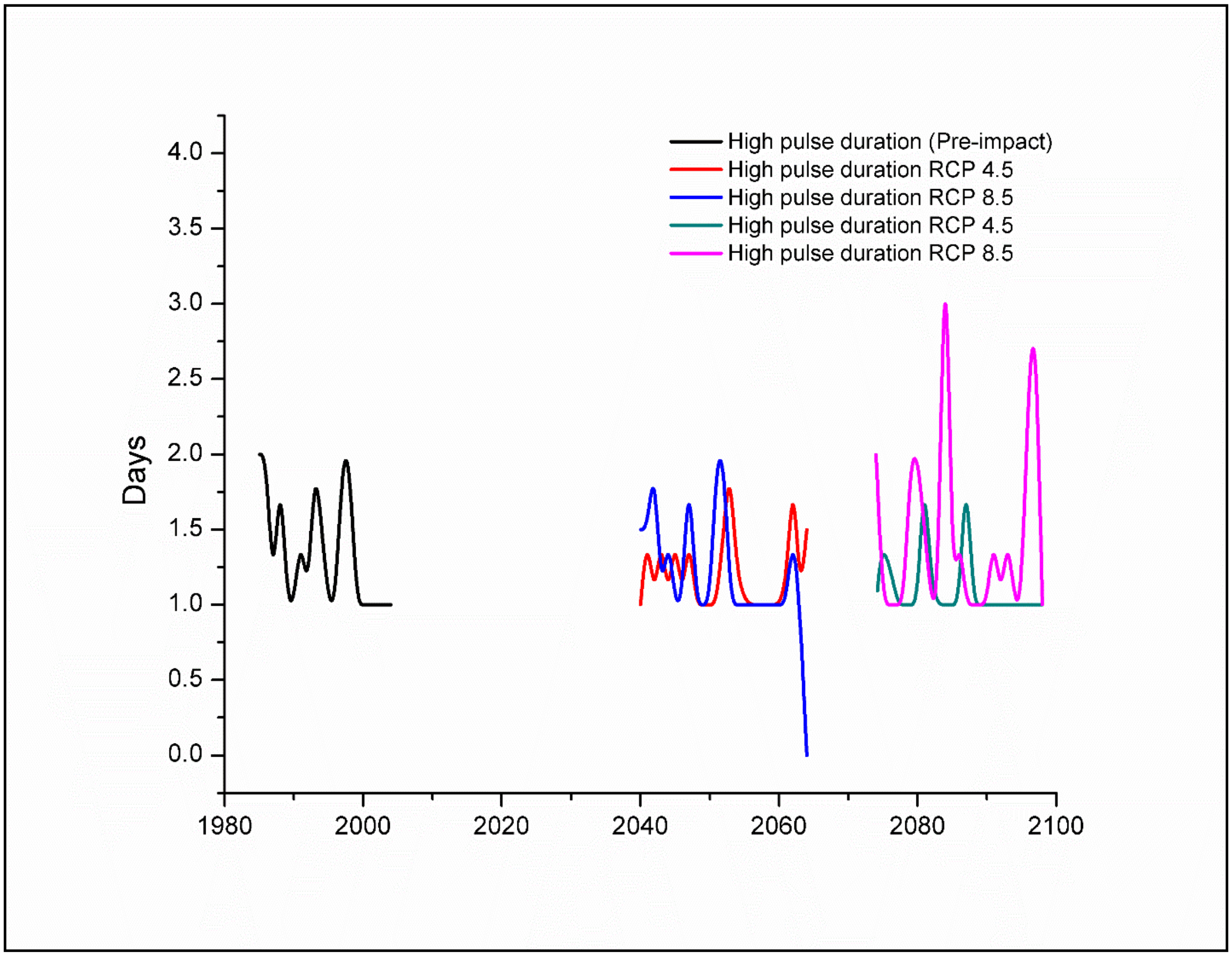

Figure 6. Projected changes in the high pulses duration for Soan River at Chirah gauging station. Black line shows the baseflow for pre-impact period (1980-2004), blue and red lines show the baseflow for near future post-impact period (2040-2064), and green and pink lines show the baseflow for far future post-impact period (2074-2098).

Projected changes in base flow and their impacts on the aquatic ecosystem of the Soan River at Dhoke Pathan

Base flow for Soan River at its downstream (Dhoke Pathan) was projected to increase under both the average and extreme emission scenarios for the mid of century period (2040-2064) and end of century period (2074-2098) as shown in (Fig. 7). Unlike the projected behavior of base flow at upstream Soan River, base flow was projected to increase and was highly consistent (with slight variations of low magnitude) (Fig. 7). This projected behavior of base flow might be an indicator that under the future climate change, in downstream Soan River there is low probability of drought like conditions and river might have stable conditions. Base flow index values were projected to be around 1.0 in near and far future under both the emission scenarios, and it implies that Soan River would be a stable river by exhibiting the geology that is relatively permeable and abundant groundwater (Tallaksen et al. 2004; Institute of hydrology report 1980).

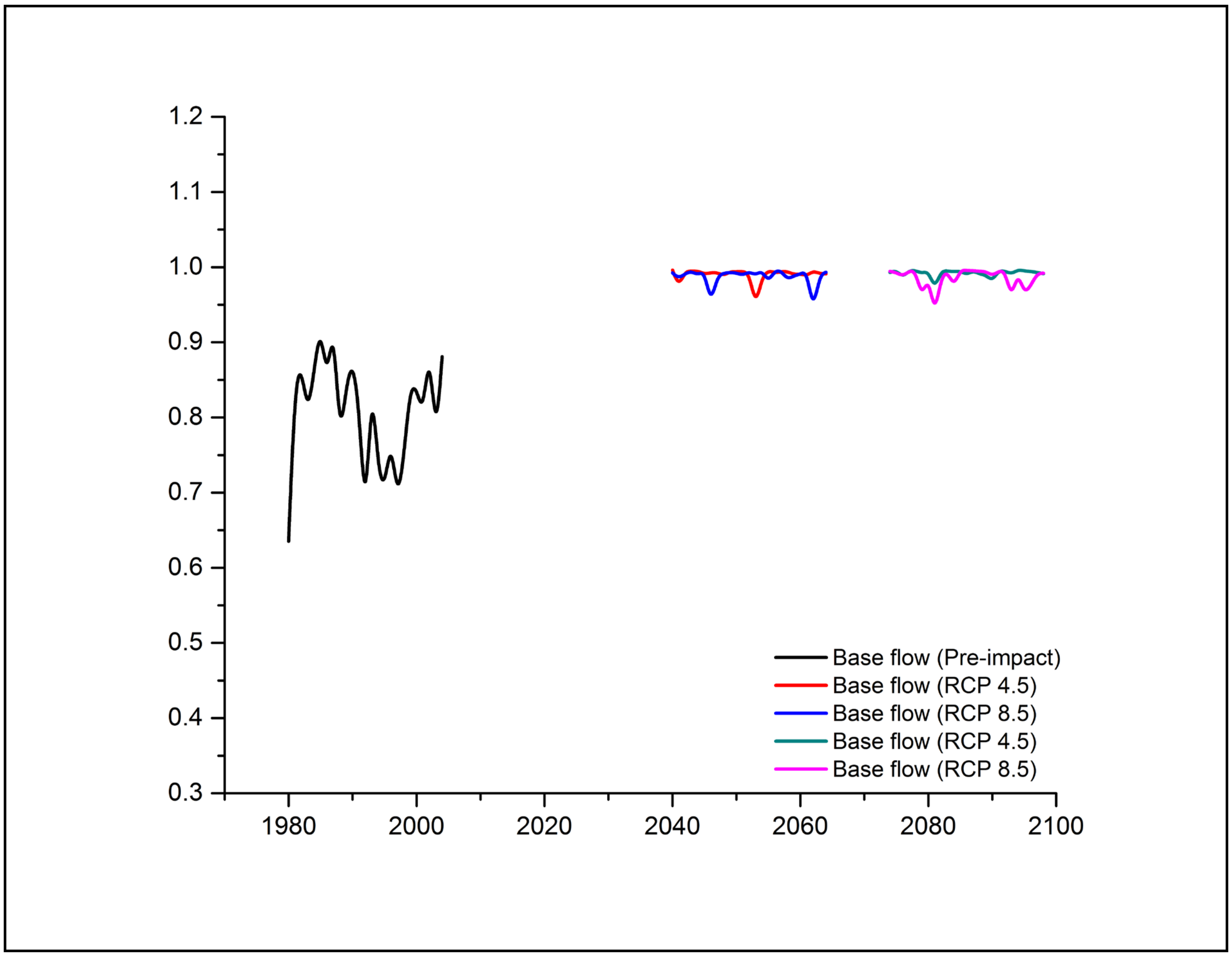

Figure 7. Projected changes in the baseflow for Soan River at Dhoke Pathan gauging station. Black line shows the baseflow for pre-impact period (1980-2004), blue and red lines show the

baseflow for near future post-impact period (2040-2064), and green and pink lines show the baseflow for far future post-impact period (2074-2098).

Projected changes in base flow at Dhoke Pathan also indicate a positive environment for the fish species of the Soan River at its downstream. Projected range of base flow index changes was mostly greater than 0.95 under both emission scenarios for the period (2040-2064) as opposed to the pre-impact period range which was 0.6 to nearly 0.9 (highly variable) (Fig. 8).

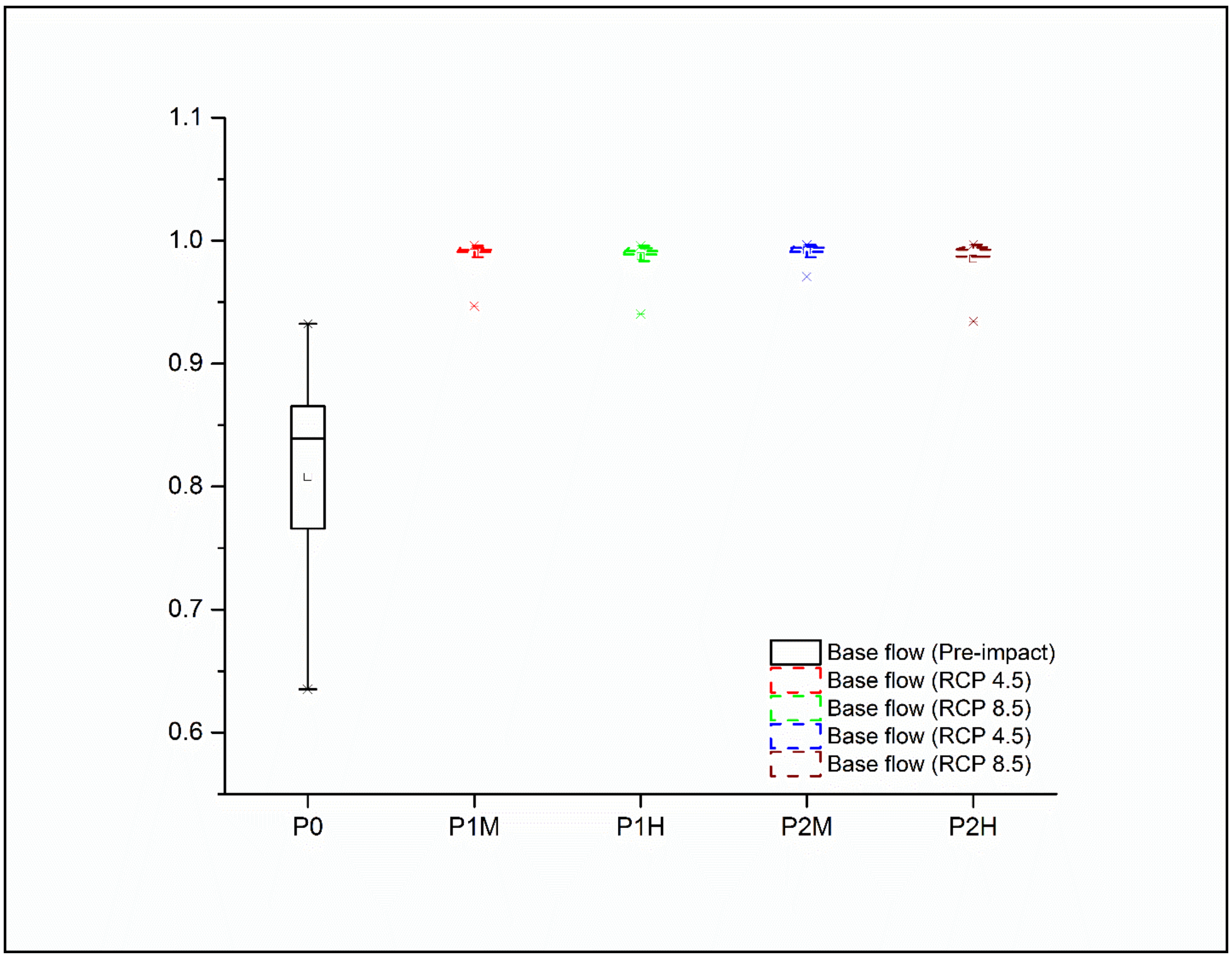

Figure 8. Box plots showing the magnitude of variability exhibited by projected changes in the baseflow for Soan River at Dhoke Pathan gauging station. P0 denotes the variability in baseflow for pre-impact period (1980-2004), P1M and P1H show the variability in baseflow for near

future post-impact period (2040-2064), and P2M and P2H show the variability in baseflow for far future post-impact period (2074-2098).

Projected changes in number and duration of high streamflow pulses and their impacts on the aquatic ecosystem of the Soan River at Dhoke Pathan

Number of high flow pulses during pre-impact period remained within 0 to 12 and were projected to decrease under both the emission scenarios in both the future periods (Fig. 9) with values ranging within 0 to 4. In addition, high flow pulsing was projected to be less variable in the future as compared to pre-impact period (Fig. 9). Duration of high flow pulses was projected to increase under the RCP 4.5 emission scenario in the near future period and under the RCP 8.5 emission scenario under the far future period, another important characteristic for these projected changes in high flow duration is the high variability (Fig. 10). Patterns of change in the high flow duration were projected to remain more or less similar to that of pre-impact conditions, under the RCP 8.5 emission scenario for near future period and RCP 4.5 emission scenario in the far future period, also, low inter-annual variability was a characteristic of this change.

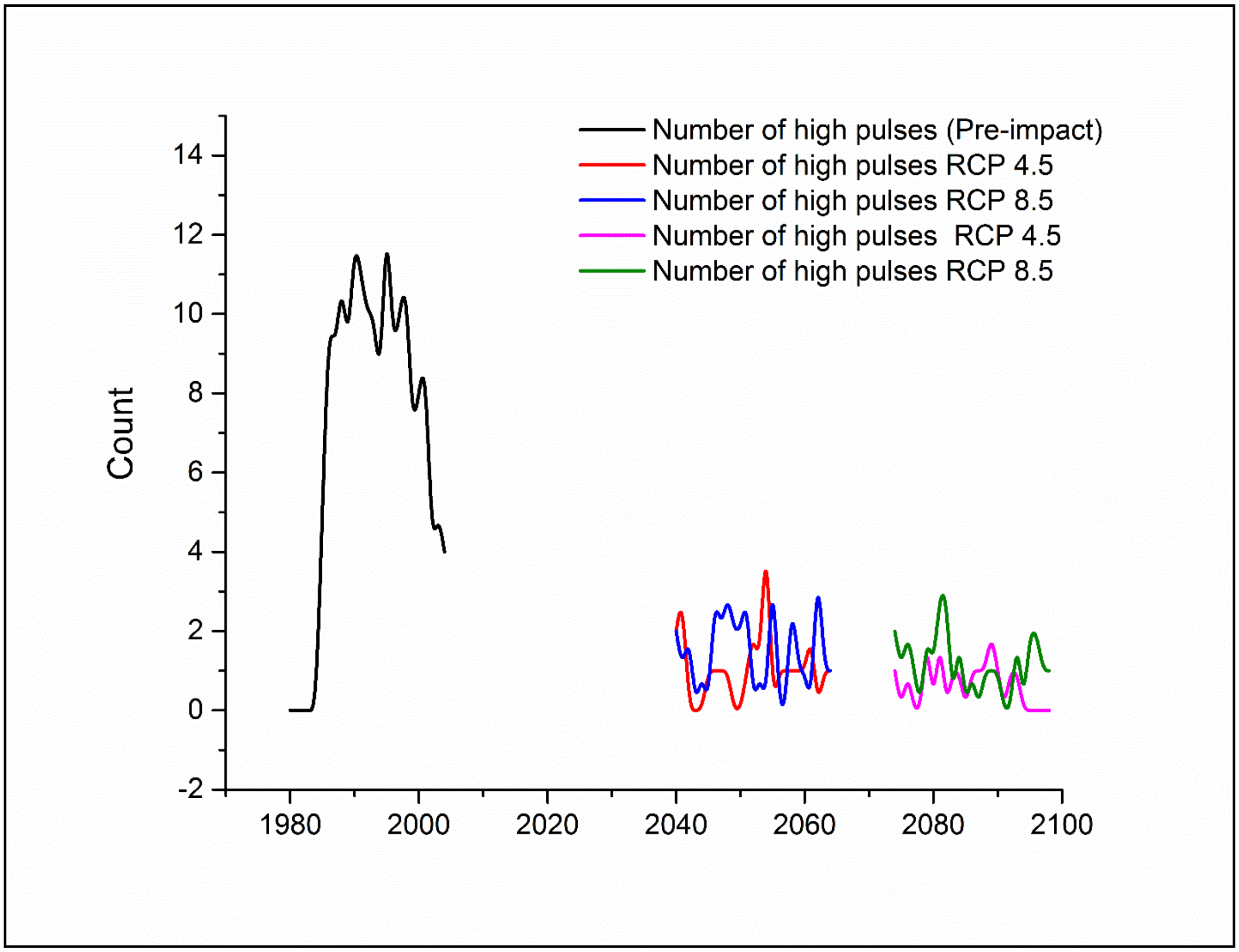

Figure 9. Projected changes in the number of high pulses for Soan River at Dhoke Pathan gauging station. Black line shows the baseflow for pre-impact period (1980-2004), blue and red lines show the baseflow for near future post-impact period (2040-2064), and green and pink lines show the baseflow for far future post-impact period (2074-2098).

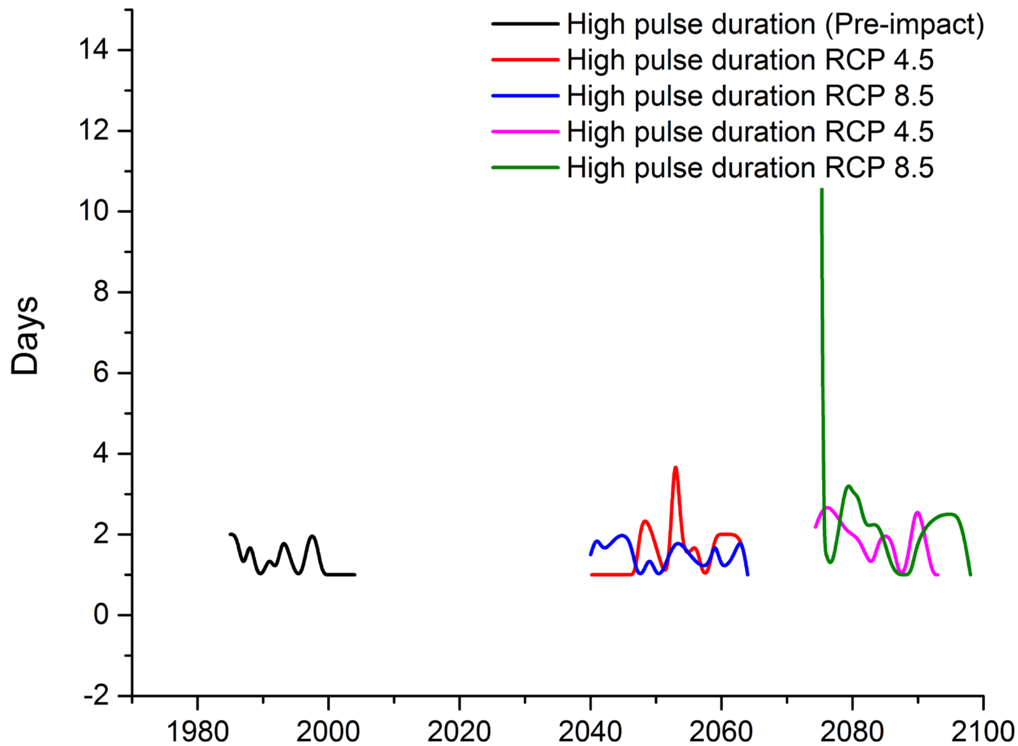

Figure 10. Projected changes in the high pulses duration for Soan River at Dhoke Pathan gauging station. Black line shows the baseflow for pre-impact period (1980-2004), blue and red lines show the baseflow for near future post-impact period (2040-2064), and green and pink lines show the baseflow for far future post-impact period (2074-2098).

Discussion

Base flow index is one of the most important hydrologic parameters and it has a substantial influence on the ecosystem of a river. It is the ratio of seven day minimum streamflow mean streamflow for a year (IHA user's manual). Interchange of nutrients between rivers and floodplains has a crucial role to play in ecosystem maintenance, and fluctuations in the base flow substantially effects the volume of this exchange of nutrients between floodplains and rivers. Another important concern for aquatic organisms is how long the stressful conditions (High streamflow, high streamflow pulses, low oxygen, and concentration of chemicals, etc.) prevail in the aquatic environments. When the weather conditions are dry, river flows have the tendency to be reduced substantially, in these scenarios, the importance of high base flow becomes more evident. These values (base flow index close to 1.0) are an indication in such events of dry weather conditions that river is sustained because of the groundwater inflow (Kelly et al. 2019).

Our results indicate and increase in the base flow for both up and downstream Soan River. This increase in base flow under the climate change at the upstream of the Soan River for near and end of century time period might provide preferable streamflow characteristics for the fish species and other aquatic inhabitants of the river.

When events of heavy rainfall occurs (which have relatively shorter duration), they have their own implications for a river, a rise in level of Soan River above its low streamflow levels will occur, these short term high flow events are termed as high streamflow pulses and provide important insight and necessary interruptions in low streamflow. High streamflow pulses with longer duration are more effective for ecosystem, however, these pulses does not have to be long enough to have an impact on aquatic environment, even a small "flush of fresh water" (IHA user's manual) is enough to provide all-important relief from high streamflow temperatures or conditions with low oxygen that are typical characteristics of the low-flow periods. These spell of fresh water can also provide a nurturing support of organic material/food to "support the aquatic food web" (IHA user's manual). High-flow pulses also provide fish and other mobile creatures with increased access to up and downstream areas.

One of the critical aspects of the lateral connectivity between a river and its floodplain are high streamflow pulses (Richter et al. 1998). Projected overall stability and a significant increase (under the extreme emission scenario, for end of century period) in duration of high pulses might provide suitable ecological functioning of floodplain wetland areas and feeding habitats for the endangered and prominent fishes of the Soan River like Tor putitora (regionally known as Mahseer). Mahseer is considered as the most important fish in the Asian sub-continent region (WWF 2002) and is also responsible for fifty percent of the total fish fauna in Pakistan (Nazeer et al. 2016). However, high variability in these changes might cause disruption in ecosystem functioning.

Conclusions

The study evaluated the plausible alterations in the streamflow characteristics of the Soan River at its upstream (Chirah gauging station) and downstream (Dhoke Pathan gaugin station). The hydrological model HBV-light was calibrated and validated for both up and downstream Soan River. After model setup and development, it was forced with an ensemble of five different GCMs for both Chirah and Dhoke Pathan gauging stations. Then the indictors of hydrologic alteration (IHA) method was implemented to see the changes in the streamflow characteristics for two future periods (2040-2064) and (2074-2098) against a pre-impact period (1980-2004). After this, the implications of these projected changes in streamflow for fish species of Soan River were assessed. Base flow for Soan River at its upstream (Chirah) was projected to increase under both the average and extreme emission scenarios for the mid of century period (2040-2064) and end of century period (2074-2098). Under the RCP 8.5 emission scenario base flow was also projected to increase, however, with more variability. This increase in base flow under the climate change at the upstream of the Soan River, for near and end of century time period might provide preferable streamflow characteristics for the fish species and other aquatic inhabitants of the river. Number of high flow pulses were projected to decrease under both the emission scenarios in both the future periods. Duration of high flow pulses was expected to remain more or less similar for both future periods as that of the pre-impact conditions, with exceptionally prolonged pulses under the RCP 8.5 emission scenario towards the end of century period.

Base flow index for Soan River at its downstream (Dhoke Pathan) was projected to increase under both the average and extreme emission scenarios for the mid of century period (2040-2064) and end of century period (2074-2098). Other than projected increase Baseflow was projected to be highly consistent. Number of high flow pulses were projected to decrease under both the emission scenarios in both the future periods and high flow pulsing was also projected to be less variable in the future. Duration of high flow pulses were projected to increase (and showed high variability) under the RCP 4.5 emission scenario in the near future period and under the RCP 8.5 emission scenario under the far future period. Patterns of change in the high flow duration were projected to remain more or less similar to that of pre-impact conditions, and depicted low inter-annual variability. The results of this study might be helpful for freshwater and aquatic ecosystem management.

Funding:

This study did not received any kind of funding from any Government or Private agency.

Conflict of Interest:

Authors declare no conflict of interest

Acknowledgements:

Authors are grateful to the Pakistan Meteorological Department and Surface Water Hydrology Project of Water and Power Development Authority, Pakistan for providing the hydrological and meteorological data for this study.

References

Asitatikie AN, Gebeyehu WZ (2020) Assessment of hydrology and optimal water allocation under changing climate conditions: the case of Megech river sub basin reservoir, Upper Blue Nile Basin, Ethiopia. Model Earth Syst Environ 1−14. https://doi.org/10.1007/s40808-020-01024-0

Baxter RM (1977) Environmental effects of dams and impoundments. Annu Rev Ecol Evol Syst 8:255−283. https://doi.org/10.1146/annurev.es.08.110177.001351

Beaulieu E, Lucas Y, Viville D et al (2016) Hydrological and vegetation response to climate change in a forested mountainous catchment. Model Earth Syst Environ 2:191. https://doi.org/10.1007/s40808-016-0244-1

Bergström S (1976) Development and application of a conceptual runoff model for Scandinavian catchments. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:smhi:diva-5738

Bhatt JP, Nautiyal P, Singh HR (2004) Status (1993-1994) of the endangered fish Himalayan Mahseer Tor putitora (Hamilton)(Cyprinidae) in the mountain reaches of the river Ganga. Asian Fish Sci 17:341−55.

Brocca L, Massari C, Pellarin T, et al (2020) River flow prediction in data scarce regions: soil moisture integrated satellite rainfall products outperform rain gauge observations in West Africa. Sci Rep 2710(1):1−4. https://doi.org/10.1038/s41598-020-69343-x

Bremner AM, Methven DA, Munkittrick KR, Frego KA (2015) Aug. Spatial and temporal variation in fish assemblages in three small unpolluted estuarine rivers and associated lagoons in Kouchibouguac National Park, southern Gulf of St. Lawrence, Canada. Can Field-Nat 129(2):121−33. https://doi.org/10.22621/cfn.v129i2.1692

Bunn SE, Arthington AH (2002) Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environ Manage 30(4):492−507. https://doi.org/10.1007/s00267-002-2737-0

Burhan AK, Usman M, Bukhari SAA, Khan MT, Malik K (2020a) Prognosis of Hydro-Meteorological Attributes based on Simulation and Projection of Streamflow in a High-Altitude Basin using Hydrologiska Byråns Vattenbalansavdelning (HBV) Model. Aquademia. 4(1):ep20015. https://www.aquademia-journal.com/article/prognosis-of-hydro-meteorological-attributes-based-on-simulation-and-projection-of-streamflow-in-a-8226

Burhan A, Usman M, Bukhari SAA, Sajjad H (2020b) Contribution of glacier, snow and rain components in flow regime projected with HBV under AR5 based climate change scenarios over Chitral river basin (Hindukush Ranges, Pakistan). Int J Clim Chang Res 4(1):24−36. http://www.conscientiabeam.com/journal/112/abstract/5965

Chaemiso SE, Abebe A, Pingale SM (2016) Assessment of the impact of climate change on surface hydrological processes using SWAT: a case study of Omo-Gibe river basin, Ethiopia. Model Earth Syst Environ 2:205. https://doi.org/10.1007/s40808-016-0257-9

Cid N, Bonada N, Carlson SM, Grantham TE, Gasith A, Resh VH (2017) High variability is a defining component of Mediterranean-climate rivers and their biota. Water 9(1):52. https://doi.org/10.3390/w9010052

Crook DA, Lowe WH, Allendorf FW et al (2015) Nov. Human effects on ecological connectivity in aquatic ecosystems: integrating scientific approaches to support management and mitigation. Sci Total Environ 534:52−64. https://doi.org/10.1016/j.scitotenv.2015.04.034

de Jalón SG, del Tánago MG, de Jalón DG (2019) A new approach for assessing natural patterns of flow variability and hydrological alterations: The case of the Spanish rivers. J Environ Manage 233:200−210. https://doi.org/10.1016/j.jenvman.2018.12.049

Döll P, Fiedler K, Zhang J (2009) Global-scale analysis of river flow alterations due to water withdrawals and reservoirs. Hydrol Earth Syst Sci 13(12):2413. https://doi.org/10.5194/hess-13-2413-2009

Dynesius M, Nilsson C (1994) Fragmentation and flow regulation of river systems in the northern third of the world. Science 266(5186):753−762. DOI: 10.1126/science.266.5186.753

Geheber AD, Piller KR (2012) Spatio-temporal patterns of fish assemblage structure in a coastal plain stream: Appropriate scales reveal historic tales. Ecol Freshw Fish 21(4):627−39. https://doi.org/10.1111/j.1600-0633.2012.00584.x

Gupta HV, Kling H, Yilmaz KK, Martinez GF (2009) Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling. J Hydrol 377(12):80−91. https://doi.org/10.1016/j.jhydrol.2009.08.003

Hakala K, Addor N, Seibert J (2018) Hydrological modeling to evaluate climate model simulations and their bias correction. J Hydrometeorol 19:1321−1337. https://doi.org/10.1175/JHM-D-17-0189.1

Institute of Hydrology. Low Flow Studies Report No 3; Institute of Hydrology: Wallingford, UK, 1980.

Helms BS, Schoonover JE, Feminella JW (2009) Feb. Assessing Influences of Hydrology, Physicochemistry, and Habitat on Stream Fish Assemblages Across a Changing Landscape 1. J Am Water Resour As 45(1):157−69. https://doi.org/10.1111/j.1752-1688.2008.00267.x

Islam MS, Tanaka M (2007) Mar. Threatened fishes of the world: Tor putitora Hamilton 1822 (Cypriniformes: Cyprinidae). Environ Biol Fishes 178(3):219. https://doi.org/10.1007/s10641-006-0021-5

Jansson R, Nilsson C, Dynesius M, Andersson E (2000) Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. Ecol Appl 10(1):203−224. https://doi.org/10.1890/1051-0761(2000)010[0203:EORROR]2.0.CO;2

Kelly L, Kalin RM, Bertram D, Kanjaye M, Nkhata M, Sibande H (2019) Quantification of temporal variations in base flow index using sporadic river data: application to the Bua catchment, Malawi. Water 11(5):901. https://doi.org/10.3390/w11050901

Kim BS, Kim BK, Kwon HH (2011) Assessment of the impact of climate change on the flow regime of the Han River basin using indicators of hydrologic alteration. Hydrol Process 25(5):691−704. https://doi.org/10.1002/hyp.7856

Kouamélan EP, Teugels GG, N'douba V, Bi GG, Koné T (2003) Sep. Fish diversity and its relationships with environmental variables in a West African basin. Hydrobiologia 505(1):139−46. http://dx.doi.org/10.1023/B:HYDR.0000007302.74296.84

Lindström G, Johansson B, Persson M, Gardelin M, Bergström S (1997) Development and test of the distributed HBV-96 hydrological model. J Hydrol 201(1−4):272−88. https://doi.org/10.1016/S0022-1694(97)00041-3

Lytle DA, Poff NL (2004) Adaptation to natural flow regimes. Trends Ecol Evol 19(2):94−100. https://doi.org/10.1016/j.tree.2003.10.002

McManamay RA, Orth DJ, Dolloff CA (2012) Revisiting the homogenization of dammed rivers in the southeastern US. J Hydrol 424:217−237. https://doi.org/10.1016/j.jhydrol.2012.01.003

Mutsindikwa TC, Yira Y, Bossa AY et al (2020) Modeling climate change impact on the hydropower potential of the Bamboi catchment. Model Earth Syst Environ 1−9. https://doi.org/10.1007/s40808-020-01052-w

Naiman RJ, Latterell JJ, Pettit NE, Olden JD (2008) Flow variability and the biophysical vitality of river systems. C R Geosci 340(9–10):629–643. https://doi.org/10.1016/j.crte.2008.01.002

Nazeer S, Hashmi MZ, Malik RN (2014) Heavy metals distribution, risk assessment and water quality characterization by water quality index of the River Soan, Pakistan. Ecol Indic 43:262−70. https://doi.org/10.1016/j.ecolind.2014.03.010

Nazeer S, Hashmi MZ, Malik RN (2016) Spatial and seasonal dynamics of fish assemblage along river Soan, Pakistan and its relationship with environmental conditions. Ecol Indic 69: 780−791. https://doi.org/10.1016/j.ecolind.2016.05.034

Olden JD, Poff NL, Bestgen KR (2006) Life-history strategies predict fish invasions and extirpations in the Colorado River Basin. Ecol Monogr 76(1):25−40. https://doi.org/10.1890/05-0330

Parks TP (2014) Jan. Historical changes in fish assemblage structure in midwestern nonwadeable rivers. Am Midl Nat171(1):27−53. https://doi.org/10.1674/0003-0031-171.1.27

Petts GE 1(984) Impounded Rivers: Perspectives for Ecological Management, Environmental Monographs and Symposia Series. John Wiley and Sons: Chichester;344.

Petts GE (2009) Instream Flow Science For Sustainable River Management 1. J Am Water Resour As 45(5):1071−1086. https://doi.org/10.1111/j.1752-1688.2009.00360.x

Pires AM, Cowx IG, Coelho MM (1999) Seasonal changes in fish community structure of intermittent streams in the middle reaches of the Guadiana basin, Portugal. J Fish Biol 54(2):235−49. https://doi.org/10.1111/j.1095-8649.1999.tb00827.x

Poff NL, Allan JD, Bain MB et al (1997) The natural flow regime. BioScience 47(11):769−784. https://doi.org/10.2307/1313099

Poff NL, Bledsoe BP, Cuhaciyan CO (2006a) Hydrologic variation with land use across the contiguous United States: geomorphic and ecological consequences for stream ecosystems. Geomorphology. 79(3−4):264−285. https://doi.org/10.1016/j.geomorph.2006.06.032

Poff NL, Olden JD, Merritt DM, Pepin DM (2007) Homogenization of regional river dynamics by dams and global biodiversity implications. Proc Natl Acad Sci 104(14):5732−5737. https://doi.org/10.1073/pnas.0609812104

Poff NL, Olden JD, Pepin DM, Bledsoe BP (2006b) Placing global stream flow variability in geographic and geomorphic contexts. River Res Appl 22(2):149−166. https://doi.org/10.1002/rra.902

Pyron M, Neumann K (2008) Hydrologic alterations in the Wabash River watershed, USA. River Res Appl 24(8):1175−1184. https://doi.org/10.1002/rra.1155

Rafique M, Khan NUH (2012) Distribution and status of significant freshwater fishes of Pakistan. Rec Zool Surv Pakistan 21:90–95. http://wwf.org.pk/pwp/record/17%20.pdf

Richter BD, Baumgartner JV, Braun DP, Powell J (1998) A spatial assessment of hydrologic alteration within a river network. Regulated Rivers: Research & Management: An International Journal Devoted to River Research and Management. 14(4):329−340. https://doi.org/10.1002/(SICI)1099-1646(199807/08)14:4%3C329::AID-RRR505%3E3.0.CO;2-E

Richter BD, Baumgartner JV, Powell J, Braun DP (1996) A method for assessing hydrologic alteration within ecosystems. Conserv Biol 10(4):1163−1174. https://doi.org/10.1046/j.1523-1739.1996.10041163.x

Richter B, Baumgartner J, Wigington R, Braun D (1997) How much water does a river need? Freshw Biol 37(1):231−249. https://doi.org/10.1046/j.1365-2427.1997.00153.x

Richter BD, Davis MM, Apse C, Konrad C (2012) A presumptive standard for environmental flow protection. River Res Appl 28(8):1312−1321. https://doi.org/10.1002/rra.1511

Richter BD, Mathews R, Harrison DL, Wigington R (2003) Ecologically sustainable water management: managing river flows for ecological integrity. Ecol Appl 13(1):206−224. https://doi.org/10.1890/1051-0761(2003)013[0206:ESWMMR]2.0.CO;2

Seibert J, Vis MJ (2012) Teaching hydrological modeling with a user-friendly catchment-runoff-model software package. Hydrol Earth Syst Sci 16(9):3315−25. https://doi.org/10.5194/hess-16-3315-2012

Shiau JT, Wu FC (2007) A dynamic corridor-searching algorithm to seek time-varying instream flow releases for optimal weir operation: Comparing three indices of overall hydrologic alteration. River Res Appl 23(1):35−53. https://doi.org/10.1002/rra.962

Tallaksen LM, Van Lanen HA (Eds.) (2004) Hydrological drought: processes and estimation methods for streamflow and groundwater. Amsterdam : Elsevier (Developments in water science 48) - ISBN 9780444516886 - 579

Tesfaye TW, Dhanya CT, Gosain AK (2020) Modeling the impact of climate change on the environmental flow indicators over Omo-Gibe basin, Ethiopia. Model Earth Syst Environ 6:2063–2089 https://doi.org/10.1007/s40808-020-00813-x

Tharme RE (2003) A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Res Appl 19(5-6):397−441. https://doi.org/10.1002/rra.736

Usman M, Ahmad B, Bukhari SAA (2019) Assessment of inter-seasonal, inter-annual and intra-annual variability in snow and rainfall recharged fresh water discharge under IPCC AR5 based climate change scenarios: a case study of Soan river basin, Potowar region, Pakistan. Clim Change. 5(20):264−326. http://www.discoveryjournals.org/climate_change/current_issue/v5/n20/A6.pdf

Usman M, Ndehedehe CE, Farah H, Manzanas R (2021a) Impacts of climate change on the streamflow of a large river basin in the Australian tropics using optimally selected climate model outputs. J Clean Prod 315:128091. https://doi.org/10.1016/j.jclepro.2021.128091

Usman M, Ndehedehe CE, Manzanas R, Ahmad B, Adeyeri OE (2021b) Impacts of Climate Change on the Hydrometeorological Characteristics of the Soan River Basin, Pakistan. Atmosphere 12(6):792. https://doi.org/10.3390/atmos12060792

Usman M, Pan X, Penna D, Ahmad B (2021c) Hydrologic alteration and potential ecosystemic implications under a changing climate in the Chitral River, Hindukush region, Pakistan. J Water Clim Change 12(5):1471−1486. https://doi.org/10.2166/wcc.2020.073

Usman M, Ndehedehe, CE, Ahmad B, Manzanas R, Adeyeri OE (2021d) Modeling streamflow using multiple precipitation products in a topographically complex catchment. Model Earth Syst Environ 1−11. https://doi.org/10.1007/s40808-021-01198-1

Wang LN, Shao QX, Chen X, H, Li Y, Wang DG (2012) Flood changes during the past 50 years in Wujiang River, South China. Hydrol Process 26(23):3561−3569. https://doi.org/10.1002/hyp.8451

WOHL E (2012) Identifying and mitigating dam-induced declines in river health: three case studies from the western United States. Int J Sediment Res 27(3):271–287. https://doi.org/10.1016/S1001-6279(12)60035-3

WWF (2002) Studies on resource base, ecological diversity and threats to Game Fish Mahsheer in Himalayan-Foothill River.

Xenopoulos MA, Lodge DM, Alcamo J, Märker M, Schulze K, Van Vuuren DP (2005) Scenarios of freshwater fish extinctions from climate change and water withdrawal. Glob Chang Biol 11(10):1557–1564. https://doi.org/10.1111/j.1365-2486.2005.001008.x

Yacouba Y, Aymar BY, Amadou K et al (2019) Failure of inland valleys development: a hydrological diagnosis of the Bankandi valley in Burkina Faso. Model Earth Syst Environ 5:1733–1741. https://doi.org/10.1007/s40808-019-00628-5

Yang P, Yin XA, Yang ZF, Tang J (2014) A revised range of variability approach considering the periodicity of hydrological indicators. Hydrol Process 28(26):6222–6235. https://doi.org/10.1002/hyp.10106

Yarnell SM, Petts GE, Schmidt JC et al (2015) Functional flows in modified riverscapes: hydrographs, habitats and opportunities. BioScience 65(10):963–972. https://doi.org/10.1093/biosci/biv102

Zamor RM, Franssen NR, Porter C, Patton TM, Hambright KD 2014 Jun. Rapid recovery of a fish assemblage following an ecosystem disruptive algal bloom. Freshw Sci 33(2):390–401. https://doi.org/10.1086/675508