Evaluation of Tochi River for diversion of water to Baran Dam under the concept of Ecological Flow

Muhammad Ashraf Khan*, Mohammad Nafees* Asim Nawab* Asim Muhammad**

*Department of Environmental Sciences University of Peshawar, Khyber Pakhtunkhwa, Pakistan

**Department of Agronomy, The University of Agriculture Peshawar, Khyber Pakhtunkhwa, Pakistan

Abstract- When rivers are diverted to dams or small-scale hydroelectric projects, the quantity of water tends to diminish, which frequently has negative effects on the downstream ecology and livelihood opportunities. Keeping a specific ecological flow is thought to be an effective treatment, but simultaneously, it may also have an impact on the social and economic benefits of dam operation. Thus, to balance the relationship between these two, this research suggests using the concept of ecological flow to assess ecological flow demand in the dewatered river section. River data was tracked for eight years (2015–22), with the aim of calculating ecological flow. Results showed that the average natural flow over the course of eight years (2015–2022) is 7.9 m^3/sec. At present 1.9 m^3/sec is repudiated in the river and the remaining 6 m^3/sec is diverted toward the Baran Dame. But, during high flow season. In low flow season, this calculation is not followed. Water diverted irrespective of proper calculation will have negative impacts on the downstream ecology as well as socio-economic activities. It is therefore recommended to keep the river under the concept of ecological flow.

Keywords: River diversion, Ecological Flow, downstream ecology, Dam

I. Introduction

To meet the legitimate need for water resources for sustaining ecological and socioeconomic growth, the diversion of rivers to small hydropower or dams is a major challenge in developing countries, especially climate change-affected areas (Salik et al., 2016 and Auju et al., 2021). In this regard, ecological flow plays a vital role in determining the basis for water source conditions, maintaining the river flow, providing water for water-loving objects, and maintaining balance in social and economic use (Jiang et al., 2019 and Yu et al., 2021). The water ecosystem of any river is maintained by proper management of runoff. The hydrological regime is affected by human activities and by climate change that threatens the function of the river ecosystem (Zhang et al., 2010, Bănăduc, et al., 2021). The variation in the hydrological regime is important to determine the ecological flow for the downstream ecology to maintain the health of the river ecosystem (Karimi et al., 2017, Kattel et al., 2022). The diversion of the runoff downstream is extremely reduced, which has severe impacts on the natural habitat of plants and animal which create an alarming situation for the existence of aquatic organism especially fish (Han 2010). On the other hand, this situation degraded the quality of water due to an insufficient amount of water in the river and increased levels of pollution affected the river water environment and also disturbed the ecosystem of the water bodies (Perkin et al., 2015 and Issaka et al., 2017). As a result of the river diversion, the vegetation on both sides of the river is severely affected and also has negative impacts on domestic and drinking water for animals and humans (Qin et al., 2010). So it is important to determine the minimum discharge flow to protect the downstream ecological environment of the river (Yu et al., 2021 and (Nikghalb et al., 2016). Small flow rate and depth are the key factors for the spawning and breeding area of fish (Dumont et al., 2011). With these criteria, areas will be available for fish reproduction (Chollett et al., 2020). In order to complete their life history, fishes need different types of habitats for spawning, wintering, refuge, and migration (Benjamin et al., 2020 and Rothermel et al., 2020).

For this purpose, various types of techniques are used, such as habitat simulation, holistic method, hydrologic, and hydraulic methods, but all these require resources, field data, a large amount of workforce, a long process of calculation, lack of information and time consuming (Huang et al 2007 and Wei et al., 2022). Hydrological methods are used to calculate the average annual runoff, guarantee rate (GR) of the natural flow frequency curve, and ecological water flow demand, exceeding frequency on the flow duration curve (Guan et al., 2021). All these methods require high experience, data, and technical personnel and also have regional limitations (Li et al 2015).

As per these problems, the ecological water flow demand of the River is investigated in this study on the basis of basic ecological flow and variation (Shaeri et al,. 2012). In the first step, flow is calculated by using various recommended techniques to maintain the quality of the result (Fonarow et al., 2010). The monthly and daily extreme runoff of the River Tochi is calculated using mathematical equations, further modifying these calculations to calculate the recommended basic ecological flow, and establish the Annual Distribution method (ADM) (Suwal et al., 2020). The demands for water during inter and intra, seasonal, and monthly changes affects the water ecology and is considered to fulfill the requirements such as habitat and other life needs (Rehman, et al., 2020).

II. MATERIALS AND METHODS

This study was carried out on river Tochi which is located between 70.4364E; 32.94834N; in North Waziristan Khyber Pakhtunkhwa. This study aims to determine the ecological flow to gain the sustainability of the river Tochi and to maintain the river ecology. The targeted aims were gained successfully.

River Tochi is the main river of North Waziristan, which is made up of two main streams Mastoni and the Margha. Both the stream originates from Afghanistan then enter the Pakistan Khyber Pakhtunkhwa District North Waziristan and meet at Dwathoi. This river go downward and entered into Bannu District then called River Tochi. This river further goes downward and entered district Laky which is then also called the River Gambilla. The length of this river is about 373 km from the origin to the end when it joins the river Kuram (Rehman et al., 2020).

River Tochi is an important source of irrigation in large areas of land such as Dawar Valley, Bakka Khel Wazir, Mirali, Barakzai Bannuchis, and Takhti Khel Marwat (Wikipedia 2021). The total catchment area of the river Tochi is 1980 Sq. miles (5068 sq. Km) at Tangi post and 2126 Sq. miles (5442 sq. Km) up to the weir location. The River Tochi originates at an elevation of 4800 feet (1463 m). The early mean inflow of River Tochi at Tangi post for the period 1963 to 1995 was about 185351 Aft (Acer feet). River Tochi is a flooded river and their water is used for irrigation purposes in districts Bannu and Lucky Marwat. This water needs proper management to store properly and then use in an environmentally friendly a sustainable way. For this purpose, a Tochi Baran canal of 8.83 km is expected from the left side of the Tochi River which terminates on Baran Dam/Reservoir as shown in (Fig.1) (PC-1, Govt. of Khyber Pakhtunkhwa 2017). Baran Dam is located in Baran Nulah, about 13 km Northwest of Bannu City. Bannu district is about 192 Km situated in the south of Peshawar district. District Bannu has got a central position in the surrounding district of Karak, Lakki Marwat, North and South Waziristan agencies district Karak in the east north (Rehman et al., 2015).

To address the above issues, the River Tochi is the main source of water for irrigation purposes in the district Bannu and Lakki Marwat of Khyber Pakhtunkhwa Pakistan was selected as the study area (Ullah and Rahim 2022). This river originates from the Khost province of Afghanistan, and other tributaries join, making it heavier (Dawar and Farias Ferreira 2021). The topography of the river is suitable for diversion to conserve it in Baran Dam. Dam brings considerable benefits to the local area, but on the other hand, it creates severe threats to the downstream ecology. It is important to analyze the quantity, quality and fish fauna of the river before and after the diversion, to recover the downstream ecological environment based on the determination of the flow rate and the basic ecological flow. To maintain the downstream water environment a method is used called the Annual Distribution Method (ADM).

This method determines the average monthly flow, minimum monthly average flow, maximum monthly average flow, yearly average flow, yearly minimum average flow, yearly maximum average flow, seasonal average flow, seasonal minimum average flow, seasonal maximum average flow, and basic ecological flow of the year, month season and for fish breading months and season by using the proper mathematical equations. Based on this method the downstream area and water environment will be protected from degradation.

Data Acquired for Ecological Flow

Primary data of River Tochi flow/discharge data from 1961 to 2022 was collected from mile 16-gauge station no. 22 Hassan Khel Miran shah (NWTD) road, subdivision irrigation/hydrology office Bannu, and discharge data from 2015 to 2022 were collected from Gambilla gauge station. Month-wise calculation of river flow for eight years (2015-2022), of four different seasons to calculate ecological flow.

Hydrological Variation

In order to test the hydrological variation of any river/stream various methods are available, such as the Mann-Kendall and sliding t-test method was used to determine the downstream water requirements of Gangiang River (Chene et al 2015, Pirnia et al 2019 and T & Jiang 2023). The Weihe River flow was calculated by Mann- Kendall method by cumulative curve, sliding rank sum test (Yan et al., 2015 and Tan et al., 2018). There are so many other methods for detecting the required flow to maintain the downstream health of the water ecosystem (Acreman & Ferguson 2010). In this study, the Annual Distribution Method was used to analyze the flow of the River Tochi to maintain the downstream fish ecology. This method was used and determine the average monthly flow, minimum monthly average flow, maximum monthly average flow, yearly average flow, yearly minimum average flow, yearly maximum average flow, inter-annual variabilities, seasonal average flow, seasonal minimum average flow, seasonal maximum average flow and basic ecological flow of the year, month season and for fish breading months and season, by using the proper mathematical equations. On the basis of this method, the downstream area and water environment will be protected from degradation.

III. Flow data

The Annual Water Distribution

This method determines the average monthly flow, minimum monthly average flow, maximum monthly average flow, yearly average flow, yearly minimum average flow, yearly maximum average flow, seasonal average flow, seasonal minimum average flow, seasonal maximum average flow, and basic ecological flow, and environmental flow of a^{th} day b^{th} month by using the proper mathematical equations. Based on this method the downstream area and water environment will be protected from degradation.

Annual Distribution Method (ADM)

Annual Development Method (ADM) is used to determine the ecological flow through a series of mathematical equations and existing data from several years (Heymans et al., 2016). The proposed ADM is a new technique used to calculate even the daily environmental flow of the river Tochi. This technique gives good results as compared to other methods. ADM shows the relation of inter and intra-annual variation in flow, seasonal variation, and monthly variation and even determines the natural flow, by this way, the effect of the extreme high and low flow will be minimized up to some extent during the year distribution. This method determines the actual need for the runoff to maintain the water ecosystem and the need for domestic use.

ADM is used for the identification of the minimum flow/runoff, required for maintaining the ecology of the river. It is calculated from two averages of runoff i.e. annual average runoff and average minimal runoff. ADM helps to calculate the average monthly/ daily runoff we can maintain in river ecology. By doing so, the life of aquatic organisms is safeguarded and large-scale ecological disturbances can be avoided.

$$Q = \frac{1}{12}\sum_{a=1}^{12}\overline{q_a} \quad \text{———————} \quad (1)$$

$$\overline{q_a} = \frac{1}{n}\sum_{b=1}^{12} q_{ab} \quad \text{———————} \quad (2)$$

$$\overline{Q}_m = \frac{1}{12}\sum_{a=1}^{12} q_{m(a)} \quad \text{———————} \quad (3)$$

Source (Pan et al., 2013).
Where

q_a = is the average monthly discharge of b^{th} month during series of n years, $q_{m(a)}$ = is the minimum monthly discharge of a^{th} month for n years (m^3/s)
q_{ab} = is the average discharge of a^{th} month b^{th} year;
n= is the number of year data available.
Mean ratio index is calculated by (Equ.5)

$$\text{Mean ratio index } \eta = \frac{\text{Minimum annual average discharge (Qm))}}{\text{Annual average discharge (Q)}} \text{ ---------------- } (5)$$

For basic ecological flow (Q_E) use the following. (Equ. 6)

$$Q_E = \bar{q}_a \times \eta \text{ -- } (6)$$

Where (a) is the month, i.e., i = 1, 2, 3 – 12. (Zhang et al., 2019).

For daily environmental flow use the following equation (Equ.7)

$$Q^a_{env,b} = \frac{Q^a_{n,b}}{Q^a_n} \, X \, Q^a_{env} -------- \quad (7)$$

Where
$Q^a_{env,b}$ = Minimum environmental flow on b^{th} day of a^{th} month,
$Q^{ia}_{n,b}$ = Natural flow on the b^{th} day of the a^{th} month,
Q^a_n = Natural flow of the a^{th} month,
Q^a_{env} = Minimum environmental flow of a^{th} month. (Wałęga and Kuriqi, 2021).

Ecological Flow

The ecological flow of any river is based on the flow regime before going to any uncertain condition/mutation, but still, there is no universal method for calculating the ecological flow and its definition. The growth and reproduction of organisms and the sustainability of the ecosystem by the highest frequency of environmental factors are described in the theory of ecological suitability (Mackenzie 2001). In this study the method ADM was used to calculate the magnitude, frequency, and index of the basic ecological flow for sustainability of the downstream ecology.

Basic Ecological Flow (BEF)

Basic Ecological Flow (BEF) refers to the minimum amount of water that should be maintained in a river or stream to sustain the health of the aquatic ecosystem and the fauna and flora that depends on it. The minimum flow is important to support various ecological activities and processes like habitat creation, maintenance of water quality, breading space providing, and nutrient cycle (Hoque et al., 2022 and Acreman & Ferguson 2010). Protecting basic ecological flow is important for maintaining the productivity and health of the river, on the other hand, it gives benefits, provide recreation, water supply, and fisheries to human (Postel & Richter 2012 and Opperman et al., 2011). The BEF was calculated in m^3/sec, m^3/month, m^3/Season, and m^3/year.

Seasonal variation.

In Pakistan a year is divided into four seasons such as Season 1 December-February (cool dry winter), Season 2 March-May (hot dry spring), Season 3 June-September (monsoon period), Season 4 October-November (retreating monsoon period) (Ali et al., 2019). The seasonal flow was calculated in m^3/sec, m^3/month, m^3/Season, and m^3/year.

IV. RESULTS AND DISCUSSION

Hydrological Characteristics from 1961 to 2022

The Figure 1 showed hydrological sequence of the River Tochi from 1961 to 2022 that there is a major variation in the flow rate. The minimum flow was recorded in 1988 and noted a value of 67063 Acre-feet/year and the maximum value was 1030849 Acre-feet/year in the year 1971. The average discharge find out from 1961 to 2022 was 268540 Acre-feet/year as shown in Fig.1 In this hydrological sequence the flow was showing up and down ranges to the average flow. From 1963 to 1969 the flow was in decreasing status to average flow except in 1965, in 1970 the flow was near to the average. In 1971 the flow of the river shows a peak value which is also the maximum flow in the given data. Flow of the River Tochi shows decreases value as to average flow and remains till 1995 in these years only 1974 and 1983 show above the average flow. The flow range from 1996 to 2013 shows that the flow was recorded above the average range, in this tenure the year 1998, 1999, 2009, and 2011 flow was below the average range. From 2014 to 2022 the flow was observed below the average range.

Month wise max, min and average flow of river Tochi during 1961-2022 in Acer-feet/month

It is clear from table 1 that the average, minimum, and maximum flow of each month from January to December during the series of 1961-2022 of the River Tochi at Thangi post Hasan Khel Gauge station, it was observed that in the average discharge from 1961 to 2022 the minimum average discharge was recorded during the month of December which was (8597–acre-feet) whereas, the maximum average discharge was in August (46262–acre-feet). In the minimum discharge from 1961 to 2022 the maximum discharge was noted as (4106 –acre-feet) in August and minimum (198–acre-feet) in the month of April. In maximum discharge, the minimum and maximum values were noted as (24499, 518762-acre feet) in December and September respectively. This high deviation from average flow to minimum and maximum discharge was due to climate change and different seasons in Pakistan.

Monthly, Seasonal, Average, and annual discharge m^3/sec Acer-feet/month, Season, and Year from 2015 to 2022

We selected the sample of the eight-year flow from 2015 to 2022 from the available data as shown in the table 2. The general flow of River Tochi is calculated in m^3/sec, Acre-feet/month, Acre-feet/season, and Acre-feet/year. The discharge of River Tochi shows that the maximum discharge was recorded in the month of August at 18.4 m^3/sec and the minimum discharge at 2.7 m^3/sec in October, the remaining month shows moderate to good flow. The overall average discharge is 7.9 m^3/sec. Month-wise discharge show that the month of August has a maximum discharge of 38665 Acre-feet/month and a minimum discharge was noted in the month of October 5674 Acre-feet/month and the monthly average discharge during the series of 2015-2022 is

16583 Acre-feet/month. Among the four seasons, the season.3 has the maximum flow of 92250 Acre-feet/season and the season.4 has the minimum flow of 14289 Acre-feet/season, whereas the seasonal average is 49750 Acre-feet/season. The yearly average discharge from 2015 to 2022 is 199000 Acre-feet/year. The intra annual comparison shows that the year 2021 have the minimum discharge of 132696 Acre-feet/year during series of 2016 to 2022, while the year 2020 shows the maximum discharge of value 271616 Acre-feet/year, rest of the year shows from moderate to good flow, total discharge from 2015 to 2022 is 1590579 Acre-feet. Discharge from 2015 to 2022 shows a higher deviation in the total as well as in the average annual discharge. The year 2015, 2017, 2018, and 2021 annual flow is below the average, and the year 2016, 2019, 2020, and 2022 are above the average level.

Causes of Variation

Such variation in the annual discharge of river Tochi is due to climate change and human activities. The climate change factor is very effective in the above annual discharge from 2015 to 2022 because of the variation in the flow. The flow level in 2017 and 2018 nearly remains the same but 2019 and 2020 show a gradual increase and 2020 shows a high pick value as compared to the previous years flow. Again, the situation changes to very low flow as compared to the previous years and creates nearly drought conditions in the irrigated area of the river Tochi. The situation once again creates a new phase as the flow becomes in high pick in 2022 as compared to all the previous years which creates a flood situation in the surrounding area.

Monthly, seasonal and annual BEF m^3/Sec Acer-feet/month, season and year during 2015 to 2022

The BEF (Basic Ecological Flow) of each month during the series of 2015-2022 show the various value in table 3. The maximum BEF in April is 2.6 m^3/sec, 5464 Acre-feet /month and minimum in October 1.03 m^3/sec, 2164 Acre-feet/month rest of the month show moderate to good flow. The seasonal Basic ecological flow shows that the season 4 (retreating monsoon period) having the minimum value of 5926 Acre-feet/season followed by season 1 (cool dry winter) of value 11263 Acre-feet/season than to season 3 (monsoon period) 14394 Acre-feet/season and the season 2 (hot dry spring) has a maximum value of 15193 Acre-feet/season. The late (hot dry spring) and the (monsoon period) are the fish breading season that needs good Ecological Flow, the present flow is suitable for fish breeding.

Monthly, Seasonal, and annual average discharge towards Baran Dam m^3/Sec, Acer-feet/month, Season, and year from 2015-2022

The flow towards the Baran Dam varies each month depending on the monthly average flow as shown in table 4. The maximum flow towards the Baran Dam was noted during August 16.4 m^3/sec, 34462 Acre-feet/month and the minimum in December was 1.1 m^3/sec, 2312 Acre-feet/month. During the various season, season 3 (monsoon period) shows a maximum value of 77751 Acre-feet/season, and season 4 (retreating monsoon period) have a minimum flow of 8405 Acre-feet/month towards the Baran Dam. The annual flow towards the Baran Dam is 152140 Acre-feet/year during the series of 2015-2022.

During the month of January minimum and maximum Natural and Environmental flow m^3/sec by date ath month bth day during 2015-2022

In this study, we took the first months of the year January during a series of eight years from 2015 to 2022 to calculate the flow of a^{th} month b^{th} day. In this scenario, we took the minimum and the maximum flow of January from 2015 to 2022 each month. In January, the minimum flow was noted as 0.31 m^3/sec on 30^{th} January 2021, and a maximum flow was noted as 31.86 m^3/sec on 22^{nd} January 2015.

The minimum environmental flow for one specific month and day was calculated in the month of January each month during a series of years from 2015 to 2022. In this duration, we calculate the minimum and the maximum environmental flow on the concerned day. The minimum environmental flow was noted on 30^{th} January 2021 which was 0.07 m^3/sec and the maximum was noted as 3.40 m^3/sec on 22^{nd} January 2015. The minimum environmental flow ranges from 0.07 to 3.40 m^3/sec in January from 2015 to 2022.

Conclusion

In order to calculate the ecological flow of River Tochi need historical flow data. The overall scenario of 1961 to 2022 shows that the flow of river Tochi is feasible to divert to Baran Dam. The flow is suitable to divert all over the year. The Monsoon is the highest flow season and in some flooding situations, it is important to store the excess amount of water and then use it in a sustainable way. The proposed ADM offers a better solution to the diversion of River Tochi towards the Baran Dam and to maintain the downstream water health and ecosystem by the calculated Basic Ecological Flow. By using this method several variations in flow were recorded. This variation is due to human activities and climate change which was noted in 2022 in the month of July and August. The basic ecological flow also decreases in such variation which affects the downstream ecosystem. The inter-annual, intra-annual, and seasonal flows reflect to determine the basic ecological flow in the same way. The late (hot dry spring) and the (monsoon period) are the fish breading season that needs good Ecological Flow, the present flow is suitable for fish breeding. The ADM can be used to determine the ecological flow throughout the year before and after the variation occurrence. This information set a platform for the study of rivers to protect the downstream health and ecosystem of the river. The diversion of River Tochi to Baran Dam and to gain sustainability in both the River Tochi and in the Baran Dam, for this purpose the flow towards the Baran Dam determined for every month.

References

1. Acreman, M. C., & Ferguson, A. J. D. (2010). Environmental flows and the European water framework directive. Freshwater biology, 55(1), 32-48.
2. Acreman, M. C., & Ferguson, A. J. D. (2010). Environmental flows and the European water framework directive. Freshwater biology, 55(1), 32-48.
3. Ali, M., Geng, Y., Robins, D., Cooper, D., Roberts, W., & Vogtländer, J. (2019). Improvement of waste management practices in a fast expanding sub-megacity in Pakistan, on the basis of qualitative and quantitative indicators. Waste Management, 85, 253-263.

4. Anju, A., Ravi S, P., & BecKuriqi, A., Pinheiro, A. N., Sordo-Ward, A., Bejarano, M. D., & Garrote, L. (2021). Ecological impacts of run-of-river hydropower plants-Current status and future prospects on the brink of energy transition. Renewable and Sustainable Energy Reviews, 142, 110833.
5. Bănăduc, D., Sas, A., Cianfaglione, K., Barinova, S., & Curtean-Bănăduc, A. (2021). The role of aquatic refuge habitats for fish, and threats in the context of climate change and human impact, during seasonal hydrological drought in the Saxon Villages area (Transylvania, Romania). Atmosphere, 12(9), 1209.
6. Benjamin, J. R., Vidergar, D. T., Dunham, J. B., (2020). Thermal heterogeneity, migration, and consequences for spawning potential of female bull trout in a river-reservoir system. *Ecol. Evol.* 10 (9), 4128–4142. https://doi.org/10.1002/ece3. v10.910.1002/ece3.6184

Table- 1 Month-wise max, min, and average discharge of river Tochi from 1961 to 2022 in Acer Feet/month

Month	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Octo	Nov	Dec
Average	13240	17006	27635	27473	26059	10597	43658	46262	26668	12615	8729	8597
min	570	2601	328	198	714	476	1607	4106	833	833	833	946
max	94581	121918	151476	138171	300062	39242	488867	229376	518762	185275	39958	24499

1Acre feet = 1233.48 m^3

Tabl.2 m3/sec, Monthly, Seasonal, Average, and annual discharge in m^3/sec Acer-feet/month, Season, and Year from 2015 to2022

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Ave
m^3/sec	4.2	4.4	11.4	11.2	9.9	4	17.3	18.4	4.2	2.7	4.1	2.9	7.9
Season.	Season. 1			Season. 2			Season. 3				Season.4		-------
Month	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	-----
Acer-feet/month	6094	8826	9246	23956	23535	20804	8405	36354	38665	8826	5674	8616	16583
Acer-feet /season	24166			68295			92250				14289		49750
Acer-feet /year	199000												
Year	2015	2016	2017	2018	2019	2020	2021	2022	Ave	min	max	Total	
Discharge	177291	242127	157151	155230	206521	271616	132696	247946	198822	132696	271616	1590578	

Acre-feet = 1233.48 m^3

Table.3 Monthly, seasonal, and annual BEF m^3/sec, Acer-feet/month, season, and year During 2015 to2022

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Average
BEFm3/sec	2.19	1.4	2.5	2.6	2.13	1.8	1.59	2	1.46	1.03	1.79	1.77	1.86
Season.	Season. 1			Season. 2			Season. 3				Season.4		------
Month	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	-------
Acer-feet/month	3719	4602	2942	5253	5464	4476	3782	3341	4203	3068	2164	3761	3898
Acer-feet/season	11263			15193			14394				5926		11694
Acer-feet/year	46776												

Acre-feet = 1233.48 m^3

Table.4 Monthly, Seasonal, and annual average discharge towards Baran Dam m^3/sec, Acer-feet/month, Season, and Year From 2015 to 2022

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Average
m^3/sec	2	3	8.9	8.6	7.8	2.2	15.7	16.4	2.7	1.7	2.3	1.1	6
Season.	Season. 1			Season. 2			Season. 3				Season.4		------
Month	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	------
m3/month	2312	4203	6304	18702	18072	16391	4623	32992	34462	5674	3572	4833	12678
M3/season	12819			53165			77751				8405		38034
M3/year	152140												

Acre-feet = 1233.48 m^3

Table.5 During the month of January minimum and maximum Natural and Environmental flow m^3/sec by date ath month bth day during series of 2015 to 2022

Day/Month/ Year	Min- Natural Flow	Max- Natural Flow	Min- Eco-Flow	Max- Eco-Flow
5, 22- Jan. 2015	5.97	31.86	0.64	3.4
4, 7- Jan. 2016	2.55	7.22	0.65	1.83
3, 24- Jan. 2017	1.56	7.22	0.43	1.99
4, 12- Jan. 2018	1.56	7.22	0.56	2.58
4, 30- Jan. 2019	0.48	3.09	0.32	2.06
12, 14- Jan. 2020	1.56	5.97	0.55	2.11
30, 10- Jan. 2021	0.31	6.46	0.07	1.37
3, 8- Jan. 2022	0.79	14.5	0.18	3.22

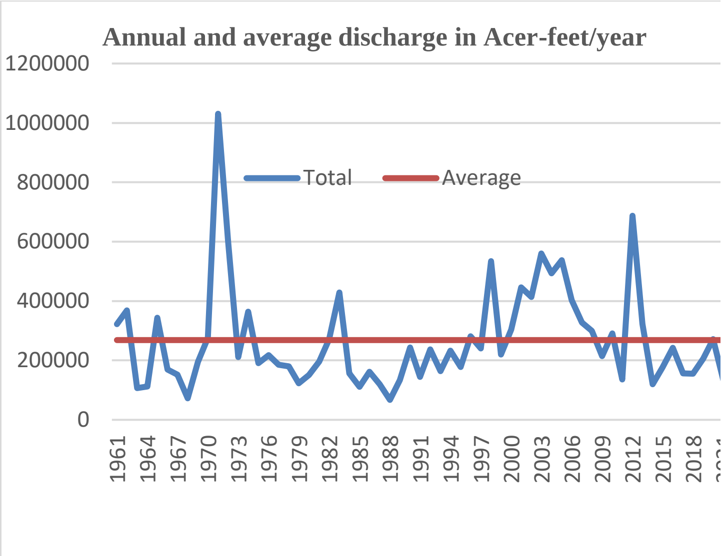

Fig.1 **Annual and average discharge in Acer-feet/year**

7. Chen, C. C., Wang, L. C., Yao, X., & LI, Y. (2015). Hydrological variation of low flows influenced by large size (I) reservoir construction in the Ganjiang river basin. *China Rural Water and Hydropower*, *9*, 1-6.
8. Chollett, I., Priest, M., Fulton, S., & Heyman, W. D. (2020). Should we protect extirpated fish spawning aggregation sites. *Biological Conservation*, *241*, 108395.
9. Dawar, A. I., & Farias Ferreira, M. (2021). New winners and losers in North Waziristan: Understanding tensions between top-down projects and local knowledge in the post-conflict setting (2015–2019). *Cogent Social Sciences*, *7*(1), 1909209.
10. Dumont, P., D'Amours, J., Thibodeau, S., Dubuc, N., Verdon, R., Garceau, S., & Fortin, R. (2011). Effects of the development of a newly created spawning ground in the Des Prairies River (Quebec, Canada) on the reproductive success of lake sturgeon (Acipenser fulvescens). *J. App. Ichthyology*, *27*(2), 394-404.
11. Fonarow, G. C., Albert, N. M., Curtis, A. B., Stough, W. G., Gheorghiade, M., Heywood, J. T., & Yancy, C. W. (2010). Improving evidence-based care for heart failure in outpatient cardiology practices: primary results of the Registry to Improve the Use of Evidence-Based Heart Failure Therapies in the Outpatient Setting (IMPROVE HF). Circulation, 122(6), 585-596.
12. Government of Pakistan. (2017). Project Commission of Raising of Baran Dam, Department of irrigation Bannu.
13. Guan, X., Zhang, Y., Meng, Y., Liu, Y., & Yan, D. (2021). Study on the theories and methods of ecological flow guarantee rate index under different time scales. Science of The Total Environment, 771, 145378.
14. han, S. (2010). Water pollution with special reference to pesticide contamination in India. Journal of Water Resource and Protection, 2010.
15. Heymans, J. J., Coll, M., Link, J. S., Mackinson, S., Steenbeek, J., Walters, C., & Christensen, V. (2016). Best practice in Ecopath with Ecosim food-web models for ecosystem-based management. Ecological modelling, 331, 173-184.
16. Hoque, M. M., Islam, A., & Ghosh, S. (2022). Environmental flow in the context of dams and development with special reference to the Damodar Valley Project, India: a review. Sustainable Water Resources Management, 8(3), 62.
17. Huang, Q., Li, Q., Zhang, Z. Z., Wang, Y. M., & Li, Y. B. (2007). Improvement Tennant method and application, it to compute eco-environmental water requirement in Yellow river. Journal of Hydrodynamics (Ser. A), 22(06), 774-781.
18. Issaka, S., & Ashraf, M. A. (2017). Impact of soil erosion and degradation on water quality: a review. *Geology, Ecology, and Landscapes*, *1*(1), 1-11.
19. Jiang, X., Liu, Y., & Zhao, R. (2019). A framework for ecological compensation assessment: A case study in the Upper Hun River Basin, Northeast China. Sustainability, 11(4), 1205.
20. Karimi, S., Salarijazi, M., & Ghorbani, K. (2017). River environmental flow assessment using Tennant, Tessman, FDC shifting and DRM hydrological methods. Iranian journal of Eco hydrology, 4 (1), 177-189.
21. Kattel, G. R. (2022). Climate warming in the Himalayas threatens biodiversity, ecosystem functioning and ecosystem services in the 21st century: is there a better solution. Biodiversity and Conservation, 31(8-9), 2017-2044.
22. Li, C. W., Kang, L., Zhang, S., & Zhou, L. W. (2015). A modified FDC method with multi-level ecological flow criteria. *J. Yangtze River Sci. Research Institute*, 32(11), 1.
23. Nikghalb, S., Shokoohi, A., Singh, V. P., & Yu, R. (2016). Ecological regime versus minimum environmental flow comparison of results for a river in a semi Mediterranean region. *Water resources management*, *30*, 4969-4984.
24. Opperman, J. J., Royte, J., Banks, J., Day, L. R., & Apse, C. (2011). The Penobscot River, Maine, USA. A basin scale approach to balancing power generation and ecosystem restoration. Ecology and Society, 16(3).
25. Pan, Z. R., Ruan, X. H., & Xu, J. (2013). A new calculation method of instream basic ecological water demand. *J. Hyd. Engg*, *44* (1): 119-126.
26. Perkin, J.S., Gido, K.B., Cooper, A.R., Turner, T.F., Osborne, M.J., Johnson, E.R., Mayes, K.B. (2015). Fragmentation and dewatering transform Great Plains stream fish communities. Ecol. Monogr. 85 (1), 73–92. https://doi.org/10.1890/14-0121.110.1890/14-0121.1.sm.
27. Pirnia, A., Golshan, M., Darabi, H., Adamowski, J., & Rozbeh, S. (2019). Using the Mann–Kendall test and double mass curve method to explore stream flow changes in response to climate and human activities. *J. Water and Climate Change*, *10*(4), 725-742. Yu, Y., Zhao, R., Zhang, J., Du, S., Zhou, T., Fu, X., & Jiang, S. (2023). Identification and restoration of hydrological processes alteration during the fish spawning period. Scientific Reports, 13(1), 11307.

28. Postel, S., & Richter, B. (2012). Rivers for life: managing water for people and nature. Island press.
29. Qin, B., Zhu, G., Gao, G., Zhang, Y., Li, W., Paerl, H. W., & Carmichael, W. W. (2010). A drinking water crisis in Lake Taihu, China: linkage to climatic variability and lake management. Environmental management, 45, 105-112.
30. Rehman, H. J. U., Khabir, M. N., Khan, A. S., Hassan, Z., Khan, I., & Khan, M. K. 2020. 49. Morphometric measurement, relative abundance and effect of physico-chemical parameters of water on ichthyofaunistic diversity of River Tochi District North Waziristan (Newly Merged District), Khyber Pakhtunkhwa. Pure and Applied Biology (PAB), 9(1), 501-506.
31. Rehman, H. J. U., Khabir, M. N., Khan, A. S., Hassan, Z., Khan, I., & Khan, M. K. (2020). 49. Morphometric measurement, relative abundance and effect of physico-chemical parameters of water on ichthyofaunistic diversity of River Tochi District North Waziristan (Newly Merged District), Khyber Pakhtunkhwa. Pure and Applied Biology (PAB), 9(1), 501-506.
32. Rehman, H., A. Wahab., M. Fayaz., M. Zakir., N. Akbar., I. Gul., N. Gul., T. A. Faran., H. Rashid., & M. Alamzeb. (2015). An assessment study of physico-chemical analysis of water and soil of Baran dam and Sarki Lawaghar dam of district Bannu and Karak, Khyber Pakhtunkhwa Pakistan and effect of parameters on fish growth. Global Veterinaria 14(6), 892-896.
33. Rothermel, E. R., Balazik, M. T., Best, J. E., Breece, M. W., Fox, D. A., Gahagan, B. I., & Secor, D. H. (2020). Comparative migration ecology of striped bass and Atlantic sturgeon in the US Southern mid-Atlantic bight flyway. Plos one, 15(6), e0234442.
34. Salik, K. M., Hashmi, M. Z. U. R., & Ishfaq, S. (2016). Environmental flow requirements and impacts of climate change-induced river flow changes on ecology of the Indus Delta, Pakistan. Regional Studies in Marine Science, 7, 185-195.
35. Shaeri Karimi, S., Yasi, M., & Eslamian, S. (2012). Use of hydrological methods for assessment of environmental flow in a river reach. *Int. j. env. Sci. tech*, *9*, 549-558.
36. Suwal, N., Kuriqi, A., Huang, X., Delgado, J., Młyński, D., & Walega, A. (2020). Environmental flows assessment in Nepal: the case of Kaligandaki River. Sustainability, 12(21), 8766.
37. Tan, G., Yi, R., Chang, J., Shu, C., Yin, Z., Han, S., & Lyu, Y. (2018). A new method for calculating ecological flow: Distribution flow method. Aip Advances, 8(4).
38. Ullah, R., & Rahim, N. (2022). Socio-Economic Development and Rehabilitation in North Waziristan in Post Military Operations Era. *Ind. J. Eco. Bus*, 21(2).
39. Wałęga, A., & A. Kuriqi. (2021). Preface to Advances in Sustainable River Management: Reconciling Conflicting Interests under Climate Extremes. Sustainability, 13 (18): 10087.
40. Wei, N., Xie, J., Lu, K., He, S., Gao, Y., & Yang, F. (2022). Dynamic simulation of ecological flow based on the variable interval analysis method. *Sustainability*, *14*(13), 7988.
41. Yan, A. L., Da, L. J., & Cui, Y. C. (2015). Variation diagnosis during hydrological processes in the Weihe river basin. *Yellow River*, *37*(9), 8-10.
42. Yu, Z., Zhang, J., Zhao, J., Peng, W., Fu, Y., Wang, Q., & Zhang, Y. (2021). A new method for calculating the downstream ecological flow of diversion-type small hydropower stations. Ecological Indicators, 125, 107530.
43. Zhang, H., J. Chang., C. Gao., H. Wu., Y Wang., K. Lei., R. Long., & L. Zhang. (2019). Cascade Hydropower Plants Operation Considering Comprehensive Ecological Water Demands. Energy Conversion and Management, 180, 119–133.
44. Zhang, Q., Xu, C. Y., Zhang, Z., & Chen, Y. D. (2010). Changes of atmospheric water vapor budget in the Pearl River basin and possible implications for hydrological cycle. Theoretical and applied climatology, 102(1), 185-195.