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Environmental Flow Assessment of Rivers using Ecohydrology Methods (Case study: Mahabad Chay, Lake Urmia Basin)

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ABSTRACT

This study aimed to estimate the minimum environmental flow (MEF) of the Mahabad-Chay River, located south of Lake Urmia. The research focused on two main tributaries, Bytas and Koter, as well as the mainstream Gerd-Yaghub. The EF demand for the river was assessed and compared using five hydrological methods, leading to the selection of the most appropriate method. The minimum EF requirements were estimated to be 0.35 m³/s for Bytas, 1.17 m³/s for Koter, and 1.15 m³/s for Gerd-Yaghub. Additionally, the annual average flows were recorded as 1.73 m³/s, 6.17 m³/s, and 4.42 m³/s at the Bytas, Koter, and Gerd-Yaghub hydrometric stations, respectively. Based on these results, the Flow Duration Curve (FDC) shifting method at class C was recommended as the best approach for estimating the minimum EF for the Mahabad-Chay River due to its requirement for fewer data and its ability to rapidly analyze accessible data compared to other methods.

Keywords:
Tributaries
DRM
FDC-shifting
Hydrometric Station

1. Introduction

There are ongoing debates about the vital resources needed to preserve rivers and maintain estuarine ecosystems. The quality and quantity of water flow play a critical role in both ecosystems and human livelihoods (Wu et al., 2010; Acreman et al., 2014). Key questions arise regarding the amount of water each ecosystem type requires to survive and the issues that arise when natural seasonal flow patterns are altered by dam construction. To manage specific rivers effectively on a daily basis, information on 'environmental flow' (EF) requirements—also known as 'environmental water allocations', 'ecological water demand', or 'eco-environmental water consumption'—is essential (Arthington, 2012). The complexity of river systems and related issues has led to the development of various disciplines, such as ecohydrology, hydroecology, and ecohydraulics, each addressing specific components of these systems (Gosselin et al., 2019).

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According to the primary definition of environmental flow assessment (EFA), a minimum volume of the flow regime in both place and time is required in a river to maintain its ecosystem's specified features (King et al., 1999). Many global EF methods exist, categorized into hydrological, hydraulic rating, habitat simulation, and holistic methods, among other approaches (Tharme, 2003). Additionally, some local standards have been developed to estimate environmental flow based on local hydrology, where recorded flow hydrographs play a crucial role (Opdyke, 2014). However, due to emerging questions about the uncertainties in determining governing parameters, climate change, and the dynamic nature of ecosystems, conventional methods are evolving (Acreman et al., 2014). Borde et al. (2020) developed an ecohydrological method for investigating the flow regime in tidal rivers. Environmental water regime prescriptions from the available building block method (BBM) applications have been grouped according to river hydrology to extract more general hydro-ecological principles, such as the desktop reserve model (DRM) in South Africa (Hughes and Hannart, 2003). Richter et al. (2009) introduced the framework called The Ecological Limits of Hydrologic Alteration (ELOHA) for assessing environmental requirements for many rivers. Investigations by Mikhailov et al. (2001) and Gao et al. (2012) revealed multiple changes over time in the Yangtze River flow regimes. Similarly, the Yellow River flow regimes underwent significant modifications due to the construction of several hydroelectric dams (Yang et al., 2010). Climate change impacts are another reason for seasonal and annual variations in river water regimes (Dzhamalov et al., 2013). Belmar et al. (2013) analyzed EF on a regional scale by clarifying the relationships between the hydrologic regime and physical habitat in Mediterranean basins. Guswa et al. (2020) conducted large-scale teamwork to identify nature-based solutions to the challenges of water resource management and factors contributing to stream flows.

Various parameters affect the environmental flow requirements (EFRs) of rivers, in addition to the river ecosystems and the hydrological properties of the river basin (Sanz et al., 2005). Increasing water demands in basins alter the natural regime of rivers. To estimate natural flow adaptive to the native ecosystem, the correct time step must be considered in hydrological data analysis (Blythe and Schmit, 2018). Kenjabayev et al. (2020) confirmed that irrigation demands severely impact water management and the supply of ecohydrological flows, especially in hot seasons. Constructing reservoirs on rivers also diverts the regime from its natural state, leading to smoother flow peaks (Fiala et al., 2020). Additionally, land use changes in riparian areas alter the CN values of river basins, changing the natural river flow regime from past decades (Pavelková Chmelová et al., 2007). Variation in the surface runoff coefficient affects not only the ecohydrology of rivers but also other landscapes, such as urban and rural areas (Lepeška, 2016). (Li and Kinzelbach, 2020) developed a multi-objective robust decision-making framework to address the conflicts between various effective factors in water management, studying the Heihe River Basin in China, which faces issues like unsustainable irrigation projects and ecosystem crises downstream. (Freed et al., 2019) showed that tributaries fed by small springs could be susceptible to climate change. Thus, a wide variety of parameters should be considered when investigating sustainable hydrogeological flow requirements. (Tonkin et al., 2017) employed ecohydrological solutions to determine flow requirements for the Great Ruaha River in Tanzania by improving irrigation systems and reducing evaporation rates with floating vegetation, extending water flow from one month to two months in the dry season. Danielaini et al. (2018) defined rural-urban interfaces for understanding ecohydrological processes, presenting six indicators to quantify ecohydrology at the rural-urban interface. While most methods for estimating environmental flow are based on ecological and hydrological factors, Sanz and Atienzar (2018) developed a method based on geological and lithological characteristics of the basin to determine minimum environmental flow in dry seasons, requiring minimal data. This method has been used in the Ebro Basin in Spain. In some cases, environmental flow cannot be established due to quantitative and qualitative degradation in river flow regimes, as reported for the Halda River in Bangladesh (Akter and Ali, 2012). Realistic environmental flow estimation requires comprehensive modeling of hydro-systems to overcome stresses imposed on water basins, from large to small scales (Krysanova and Arnold, 2008).

In the Lake Urmia basin in Iran, rivers primarily direct water supplies toward wetlands and lakes through suitable ecological distributions. There are ten main rivers with permanent flows in the surface flow network to Lake Urmia, including Nazlu-Chay, Aji-Chay, Zariineh-Rud, Simineh-Rud, Mahabad-Chay, Gadar-Chay, Baranduz-Chay, Shahr-Chay, Rozeh-Chay, and Zola-Chay. According to Yasi (2015) and Yasi and Ashouri (2017), four main rivers play a critical role in supplying water to Lake Urmia: Zarineh-Rud (41%), Simineh-Rud (11%), Aji-Chay (10%), and Nazlu-Chay (6%), contributing about 70% of the total surface flow. Among these rivers, the Mahabad-Chay River is the focus of this study. This study primarily aimed to estimate the EF in this river reach based on its current condition. Although the natural flow of rivers in Iran has been classified based on hydrological viewpoints (Tavassoli et al., 2014) using long-term recorded data, this classification does not apply to rivers influenced by dams. To determine the EFs in the Mahabad-Chay River, five different ecohydrological models were employed: flow duration curve shifting (FDC-shifting), DRM, Tennant, Tessman, and Smakhtin. Given that ecological conditions include a broader set of flow requirements, the recommended environmental flow does not directly represent the needs of ecological flow requirements.

2. Materials and Methods

2.1. Studied region

The Mahabad-Chay River basin, approximately 842 km² in area, is part of the Lake Urmia basin and is located in northwest Iran, flowing through the city of Mahabad. This river's basin ranks as the fourth largest sub-basin by area within the Lake Urmia basin. The area experiences variable precipitation, averaging around 434.8 mm annually, primarily occurring from March to June. The potential evaporation rate is approximately 1,246 mm per year. The river basin has a semi-arid cold climate. The downstream section of the Mahabad-Chay River below the dam extends for 43 km and is flanked by diverse water basins, including Gadar Chay basin to the north, the Persian Gulf basin to the south, and the Lake Urmia basin along with the Zarineh-rud and Simineh-rud Rivers to the east. The river is located between the coordinates 44°45' to 45°56' east longitude and 36°22' to 37°10' north latitude. It includes two main tributaries, Bytas and Koter, as well as the sub-branch Dehbakr.

Figure 1 illustrates the satellite photo and location of the stations and tributaries of the Mahabad-Chay River basin. Three hydrometric stations are located upstream and downstream of the Mahabad-Chay River. Bytas and Koter stations, with accessible data spanning 43 years (1971-2014), are located upstream of the Mahabad Dam. The Gerd-Yaghub station, with data over 26 years (1988-2014), is situated downstream of the Mahabad Dam, with no data available prior to 1988, the year of the dam's construction. These three stations were the primary focus of the analysis in this study. Table 1 presents the information related to these three stations.

Table 1. Specifications and position of three stations in the Mahabad-Chay River

River Name	Hydrometric Station Name	Observations	Distance from Lake Urmia (Km)	Elevation (m)	Basin Area (Km^2)	Mean Flow (m^3/s)	Average Annual Flow (10^6 m^3)
Mahabad-Chay	Bytas	Upstream of Mahabad Dam	52	1420	203	1.73	54.56
Mahabad-Chay	Koter	Upstream of Mahabad Dam	58	1380	415	6.17	194.58
Mahabad-Chay	Gerd-Yaghub	Downstream of Mahabad Dam	4.5	1280	1625	4.42	139.38

2.2. Hydrological methods

As previously mentioned, EF methods are categorized into hydrological, hydraulic rating, habitat simulation, and holistic types. Hydrological methods as the simplest methods are widely used. In this study, these methods were employed using data from three main hydrometric stations to estimate the EFRs. Due to the lack of sufficient ecological information for the studied river, five different hydrological methods (i.e., Tennant, Tessman, Smakhtin, FDC-shifting, and DRM) were analyzed and compared to estimate the appropriate amount of EF for the Mahabad-Chay River, in accordance with its current ecological condition.

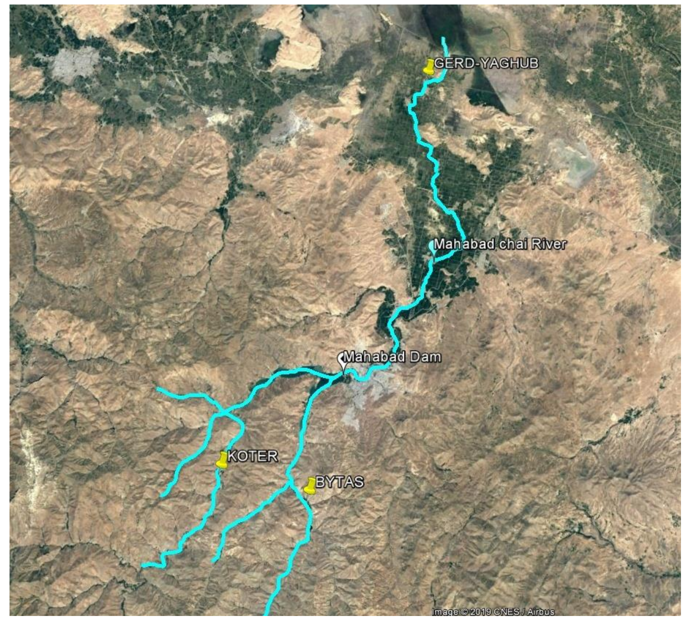

Figure 1. Aerial photos and view of stations and branches of the Mahabad-Chay River basin

The Tennant method, also known as the 'Montana method' (Tennant 1976), is considered the simplest and most common hydrological method used in many countries. It recommends specific percentages of the mean annual runoff (MAR) as the relevant EF based on the ecological circumstances of the river. This technique calculates a proportion of the MAR for two periods of the year (October-March and April-September) to define flow limits suitable for fishery, wildlife, recreational, and environmental resources. In Iran, the April-September and October-March periods are considered low and high-flow periods, respectively. However, April and May are considered high-flow periods, while June and March are regarded as low-flow periods for the Mahabad-Chay River. The modified Tennant method suggests the percentages of MAR for the Mahabad-Chay River's conditions as shown in Table 2.

The Tessman method combines mean monthly flow (MMF) and mean annual flow (MAF) to estimate the minimum required EF for a river. Unlike the Tennant method, which divides the year into two periods, Tessman (1980) classifies a hydrological year into 12 monthly periods and three categories based on the ratio of MMF to MAF. This method is suitable for areas with diverse hydrological and biological cycles (Adhikary et al. 2011). Table 3 provides the recommended minimum flow according to each category defined by this method.

Table 2. The modified Tennant method defined for the Mahabad Chay River

Flows' Description	Suggested Regime of Basic Flow MAR (%)	
	June-March (Low-flow periods)	April-May (High-flow periods)
Maximum	200	200
Optimum range	100- 60	100- 60
Outstanding	40	60
Excellent	30	50
Good	20	40
Acceptable	10	30
Minimum	10	10
High degradation	10>	10>

The Smakhtin method, developed by Smakhtin, Revenga, and Döll (2004), evaluates global water assessment conditions by estimating EFRs. It assigns two flow components for environmental water requirements: a low flow requirement (LFR set as Q90) for the needs of aquatic species, and a high flow requirement (HFR) to account for floods and channel geometry. The method uses the Q90/MAR ratio to distinguish flow regimes, where high and low values indicate unstable and stable regimes, respectively. Table 4 provides information related to this method.

Table 3. Recommended minimum flows related to three categories according to Tessman

Category	Recommended MMF
MMF > MAF	0.4 MMF
MMF > 0.4 MAF	0.4 MAF
MMF ≤ 0.4 MAF	MMF

To summarize, the Smakhtin method assumes that 90% of the time, the river system endures higher flows to adjust to everyday (low) flow conditions. Thus, the ecological system of the river may need a larger water allocation for survival. The FDC-shifting method, developed by Smakhtin and Anputhas (2006), analyzes the monthly discharge of the main stations of a river to calculate how much the flow can be modified for a specified desired condition. It defines environmental management classes (EMCs) A-F and establishes environmental FDCs from the reference condition (Hughes & Smakhtin 1996), considering the results of the monthly flow series of EFs.

Table 4. Smakhtin conceptual EFR method

LFR (Q90)	HFR	Comment
If Q90 < 10% mean discharge (MAR)	Then HFR = 20% MAR	Basin with highly variable flow regimes
If 10% MAR ≤ Q90 < 20% MAR	Then HFR = 15% MAR	-
If 20% MAR ≤ Q90 < 30% MAR	Then HFR = 7% MAR	-
If Q90 ≥ 30%MAR	Then HFR = 0% MAR	Extremely stable flow regimes. The flow is consistent during the year.

Class C represents the desired condition for the Mahabad-Chay River, as shown in Table 5. The FDC-shifting method was used to assess potential EFs in Mahabad-Chay with the GEFC (version 1) software, which calculates EFRs in river basins (Smakhtin & Eriyagama 2008). Monthly flow data collected over 43 and 26 years at Bytas and Koter stations, and Gerd-Yaghub station, respectively, were used to estimate flow requirements.

Table 5. The applied EMCs in the FDC-shifting Method

EMC	Most likely Ecological Condition	Management Perspective
C (moderately modified)	The habitats and dynamics of the biota have been disturbed while basic ecosystem functions are still intact; losing and/or reducing the extent of some sensitive species; the presence of alien species	Multiple disturbances (e.g., dams, diversions, habitat modification, and reduced water quality) associated with the need for socio-economic development

The DRM method, developed by Hughes and Hannart (2003) in South Africa, is based on hydrology and planning-type EFA. It uses monthly flows to estimate flow requirements similar to the FDC-shifting method. The DRM parameters were experimentally determined and may need modification for different conditions. For the Mahabad-Chay River, March-June and July-February are considered the wet and dry seasons, respectively. Therefore, input data were shifted by two months for accurate results.

3. Results and discussion

According to the modified Tennant method, April-May and June-March are considered high- and low-flow periods, respectively, for the Mahabad-Chay River. Using this method, environmental assessments were calculated as 0.53, 1.85, and 1.33 m^3/s for April-May (30% MAR) and 0.173, 0.6, and 0.44 m^3/s for June-March (10% MAR) at Bytas, Koter, and Gerd-Yaghub stations, respectively. The least EF in the three stations was estimated at about 10% of the MAR, which is not adequate for the river's condition. Using the Tessman method (Tables 6, 7, and 8), environmental assessments were calculated as 0.82 (47% MAR), 2.95 (48% MAR), and 2.3 m^3/s (52% MAR) at Bytas, Koter, and Gerd-Yaghub stations, respectively.

Table 6. Recommended minimum flows related to three categories according to Tessman in the Bytas station

Month	MAF	0.4* MAF	MMF	0.4* MMF	Suggested Estima
	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
October	1.73	0.69	0.055	0.022	0.055
November	1.73	0.69	0.63	0.25	0.63
Dec	1.73	0.69	0.94	0.386	0.69
January	1.73	0.69	1.23	0.49	0.69
February	1.73	0.69	1.94	0.778	0.778
March	1.73	0.69	4.34	1.73	1.73
April	1.73	0.69	6.75	2.7	2.7
May	1.73	0.69	3.63	1.45	1.45
June	1.73	0.69	0.87	0.35	0.69
July	1.73	0.69	0.21	0.083	0.21
August	1.73	0.69	0.08	0.03	0.08
September	1.73	0.69	0.037	0.015	0.037
Average	-	-	*1.73*	-	*0.82*

With the Smakhtin method (Table 9), the required environmental flow was computed as 0.346 (20% MAR), 1.234 (20% MAR), and 0.884 m^3/s (20% MAR) at Bytas, Koter, and Gerd-Yaghub stations, respectively, demonstrating a highly variable flow regime. The FDC-shifting method results (Table 10) indicated that 0.35 (20% MAR), 1.17 (19% MAR), and 1.15 m^3/s (26% MAR) are required at Bytas, Koter, and Gerd-Yaghub for the downstream environments of the river in class C condition, respectively. DRM results (Table 11) showed that 0.36 (just above 20% MAR), 1.30 (20.5% MAR), and 0.97 m^3/s (just above 22% MAR) are needed at Bytas, Koter, and Gerd-Yaghub stations for ecosystem living in class C condition, respectively.

4. Conclusions

The methods employed indicate the present diversity and future environmental requirements of the Mahabad-Chay River for preserving downstream environments. No single method is perfect under all conditions, so it is better to use a combination of methods. Region and climate require significant modifications to apply specific EFRs accurately. This study tested five hydrology-based and desktop EFR methods using Mahabad-Chay flows to the Lake Urmia basin in Iran. Due to insufficient ecological data, each method has its own definition and application.

Table 7. Recommended minimum flows related to three categories according to Tessman in the Koter station

Month	MAF	0.4* MAF	MMF	0.4* MMF	Suggested Estimation
	(m3/s)	(m3/s)	(m3/s)	(m3/s)	(m3/s)
October	6.17	2.47	0.55	0.22	0.55
November	6.17	2.47	2.36	0.94	2.36
December	6.17	2.47	3.8	1.52	2.47
January	6.17	2.47	5.4	2.16	2.47
February	6.17	2.47	13.25	5.3	5.3
March	6.17	2.47	4.35	1.74	2.47
April	6.17	2.47	24.67	9.87	9.87
May	6.17	2.47	15.16	6.06	6.06
June	6.17	2.47	3.55	1.42	2.47
July	6.17	2.47	0.94	0.38	0.94
August	6.17	2.47	0.24	0.1	0.24
September	6.17	2.47	0.22	0.09	0.22
Average	-	-	6.17	-	2.95

The FDC-shifting method rapidly estimates EFRs for different environmental classes (A-F) if monthly flow data are available. The DRM method also uses monthly flow rates but requires testing and re-calibration for other environments. Tennant, Tessman, and Smakhtin's methods are simpler but less precise than FDC-shifting and DRM methods. Figures 2, 3, and 4 compare and present EF rate predictions with MMF at three stations from each of the five methods, showing the least required water for the ecosystem each month. The FDC-shifting and DRM methods better classify the flow for maintaining the river at an acceptable ecological condition of Class C. The FDC-shifting method requires fewer data and is more conservative than the DRM method. Therefore, the FDC-shifting method at class C is recommended for estimating the minimum EF for the Mahabad-Chay River. Class C is appropriate as it considers 20-30%.

Table 8. Recommended minimum flows related to three categories based on Tessman in the Gerd-Yaghub station

Month	MAF	0.4* MAF	MMF	0.4* MMF	Suggested Estimation
	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
October	4.42	1.768	2.94	1.175	1.768
November	4.42	1.768	3.41	1.365	1.768
December	4.42	1.768	2.57	1.027	1.768
January	4.42	1.768	2.68	1.027	1.768
February	4.42	1.768	2.91	1.163	1.768
March	4.42	1.768	5.28	2.11	2.11
April	4.42	1.768	13.82	5.53	5.53
May	4.42	1.768	10.19	4.077	4.077
June	4.42	1.768	2.256	1.035	1.768
July	4.42	1.768	2.015	0.806	1.768
August	4.42	1.768	2.047	0.83	1.768
September	4.42	1.768	2.38	0.95	1.768
Average	-	-	4.42	-	2.3

Table 9. EFRs in three stations by the Smakhtin method

Stations	MAR (m^3/s)	LFR= Q90 (m^3/s)	HFR (m^3/s)	EWR (m^3/s)
Bytas	1.73	0.002	0.364	**0.364**
Koter	6.17	0.00	1.234	**1.234**
Gerd-Yaghub	4.42	0.364	0.884	**0.884**

MAR as the EF, maintaining the basic function of the ecosystem without significant changes, which suits managerial, agricultural, and drinking uses.

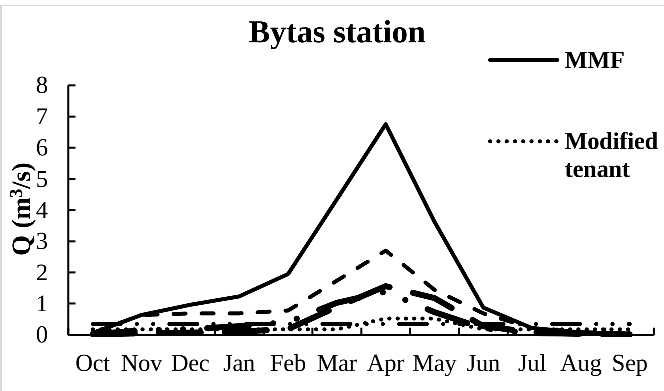

Figure 2. Comparison of environmental flow suggestion amounts of Mahabad-Chay River at the Bytas station by five methods

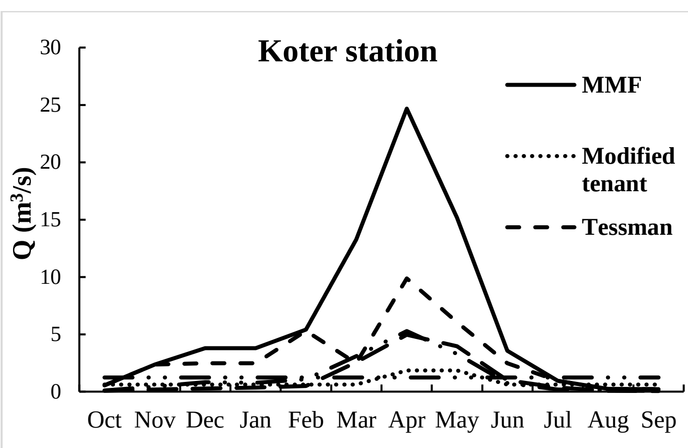

Figure 3. Comparison of environmental flow suggestion amounts of Mahabad-Chay River at the Koter station by five methods

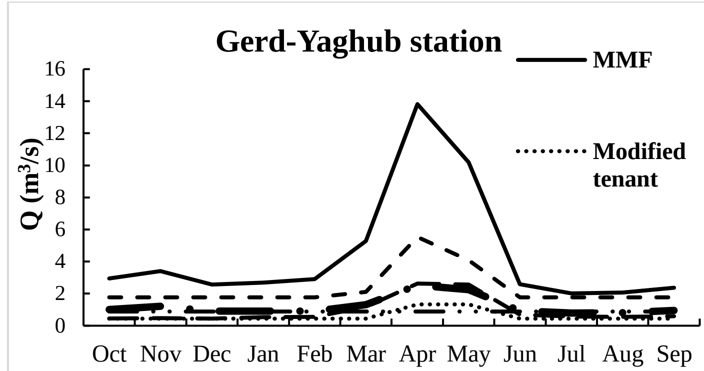

Figure 4. Comparison of environmental flow suggestion amounts of Mahabad-Chay River at the Gerd-Yaghub station by five methods

Table 10. Estimation of EF as a percent of MAR for different EMCs using the FDC-shifting method, Mahabad-Chai River

Station Name	Record Period	MAR (m3/s)	Long-term EF at Different EMCs (% of MAR)					
			Class A	Class B	Class C	Class D	Class E	Class F
Bytas	1971-2014	1.73	56.4	33.2	**19.8**	11.7	7	4.4
Koter	1971-2014	6.17	55.8	32.5	**19.1**	11.2	6.5	3.9
Gerd-Yaghub	1988-2014	4.42	59.7	38.2	**26**	18.9	14.3	11

Overall, the methods described in this study are not the ultimate solution for determining the minimum Environmental Flow Assessment (EFA) for this river. Desktop EFA methods, especially in the absence of ecological information, provide only low-confidence estimates of the EF. To achieve reliable results, the relationship between the river's flow and its ecological condition must be fully understood and documented. Therefore, besides hydrological methodologies, other types of methods—such as hydraulic rating, habitat simulation, and holistic approaches—should be analyzed in conjunction with hydrological methods to obtain the most accurate estimations.

Table 11. Estimation of EF as a percent of MAR for different EMCs using the DRM method, Mahabad-Chai River

Station Name	Record Period	MAR (m^3/s)	Long-term EF at Different EMCs (% of MAR)			
			Class A	Class B	Class C	Class D
Bytas	1971-2014	1.73	43.31	30.14	**20.27**	13.19
Koter	1971-2014	6.17	43.85	30.49	**20.5**	13.36
Gerd-Yaghub	1988-2014	4.42	48.82	33.22	**22.06**	14.38

Abbreviations: **m^3/s:** Cubic meters per second; **EF:** Environmental flows; **EFA:** Environmental flow assessment; **BBM**: Building block method; **DRM:** Desktop reserve model; **ELOHA:** Ecological limits of hydrologic alteration; **IHA:** Indicators of hydrologic alteration; **MK:** Mann-Kendall method; **HMA:** Hot mix asphalt; **YR:** Yellow river; **MMF**: Mean monthly flow; **LFR:** Low flow requirement; **HFR:** High flow requirement; **FDCA:** Flow duration curve analysis;

EMCs: Environmental management classes; **MAR:** Mean annual runoff; **MAER:** Mean annual environmental runoff; **FDC:** Flow duration curve; **EFR:** Environmental flow requirement; **Q90:** Annual flows equaled or exceeded for 90%.

References

1. Acreman, M.C., Overton, I.C., King, J., Wood, P., Cowx, I.G., Dunbar, M.J., Kendy, E., Young, W. The changing role of ecohydrological science in guiding environmental flows. Hydrological Sciences Journal, 59 (3–4): 433–450 (2014).
2. Adhikary, S. K., Atef, S.S., Gupta, A.D., Babel, S., Clemente, R.S., Perret, S. R. Potential impacts of incorporating EFR into multi – purpose reservoir operation policy and irrigation management in the Hari rod river basin, Afghanistan. Journal of Engineering Science, 2: 41–48 (2011).
3. Akter, A., Ali, M.H. Environmental flow requirements assessment in the Halda River, Bangladesh. Hydrological sciences journal, 57(2): 326-343 (2012).
4. Arthington AH. Environmental flows: Saving Rivers in the third millennium. University of California press (2012).
5. Belmar, O., Bruno, D., Martínez-Capel, F., Barquín, J., Velasco, J. Effects of flow regime alteration on fluvial habitats and riparian quality in a semiarid Mediterranean region. Ecological Indicators, 30:52– 64 (2013).
6. Borde, A.B., Diefenderfer, H.L., Cullinan, V.I., Zimmerman, S.A., Thom, R.M. Ecohydrology of wetland plant communities along an estuarine to tidal river gradient. Ecosphere, 11(9): 03185 (2020).
7. Blythe, T.L., Schmidt, J.C. Estimating the natural flow regime of rivers with long-standing development: The northern branch of the Rio Grande. Water Resources Research, 54(2):1212-1236 (2018).
8. Danielaini, T.T., Maheshwari, B., Hagare, D. Defining rural–urban interfaces for understanding ecohydrological processes in West Java, Indonesia: Part II. Its application to quantify rural–urban interface ecohydrology. Ecohydrology & Hydrobiology, 18(1): 37-51 (2018).
9. Dzhamalov, R.G., Frolova, N.L. & Kireeva, M.B. Current changes in river water regime in the Don River Basin. Water Resources 40, 573–584. (2013). https://doi.org/10.1134/S0097807813060043
10. Freed, Z., Aldous, A., Gannett, M.W. Landscape controls on the distribution and ecohydrology of central Oregon springs. Ecohydrology, 12(2): 2065 (2019).
11. Fiala R., Podhrázská J., Konečná J., Kučera J., Karásek P., Zahradníček P., Štěpánek P. Changes in a river's regime of a watercourse after a small water reservoir construction. Soil & Water Res., 15: 55-65 (2020).
12. Gao, B., Yang, D., Zhao, T., Yang, H. Changes in the eco-flow metrics of the Upper Yangtze River from 1961 to 2008. Journal of Hydrology, 448, 30-38 (2012).
13. Gosselin, M.P., Ouellet, V., Harby, A., Nestler, J. Advancing ecohydraulics and ecohydrology by clarifying the role of their component interdisciplines. Journal of Ecohydraulics, 4(2):172-187 (2019).
14. Guswa, A.J., Tetzlaff, D., Selker, J.S., Carlyle-Moses, D.E., Boyer, E.W., Bruen, M., Cayuela, C., Creed, I.F., van de Giesen, N., Grasso, D., Hannah, D.M. Advancing ecohydrology in the 21st century: A convergence of opportunities. Ecohydrology, 13(4): 2208 (2020).
15. Hughes, D.A., Smakhtin V.U. Daily flow time series patching or extension: a spatial interpolation approach based on flow duration curves. Hydrological Science Journal. 41(6):851-871 (1996).
16. Hughes, D.A., Hannart, P. A desktop model used to provide an initial estimate of the ecological instream flow requirements of rivers in South Africa. Journal of Hydrology, 270:167-181 (2003).
17. Kenjabaev, S., Arifjanov, A., Frede, H., Apakhodjaeva, T. Ecohydrology of the Syrdarya River under irrigation water management in the Fergana Valley. In IOP Conference Series: Materials Science and Engineering, 883(1): 12081 (2020).
18. King, J.M., Tharme, R.E., Brown, C.A. Definition and implementation of instream flows. Thematic Report for the World Commission on Dams (1999).
19. Krysanova, V., Arnold, J.G. Advances in ecohydrological modelling with SWAT—a review. Hydrological Sciences Journal, 53(5): 939-947 (2008).
20. Lepeška T. The impact of impervious surfaces on ecohydrology and health in urban ecosystems of Banská Bystrica (Slovakia). Soil & Water Res., 11: 29-36 (2016).
21. Li, Y., Kinzelbach, W. Resolving conflicts between irrigation agriculture and ecohydrology using many-objective robust decision making. Journal of Water Resources Planning and Management, 146(9): 5020014 (2020).
22. Mikhailov, V.N., Korotaev, V.N., Mikhailova, M.V. et al. Hydrological Regime and Morphodynamics of the Yangtze River Mouth Area. Water Resources 28, 351–363 (2001). https://doi.org/10.1023/A:1010472418566
23. Opdyke, D.R., Oborny, E.L., Vaugh, S.K., Mayes, K.B. Texas environmental flow standards and the hydrology-based environmental flow regime methodology. Hydrological Sciences Journal, 59(3-4): 820-830 (2014).
24. Pavelková Chmelová R., Šarapatka B., Dumbrovský M., Pavka P. Runoff processes and land use changes in the upper reaches of the Krupá river catchment during the last 70 years. Soil & Water Res., 2: 77-84 (2017).
25. Poff, N. Richter, B. Arthington, A. Bunn, S. Naiman, R. Kendy, E. Acreman, M. etc. The ecological limits of

hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards, Freshwater Biology, 55:147–170 (2009).

26. Sanz, D.B., Atienzar, I.P. A new method for environmental flow assessment based on basin geology: application to the Ebro Basin. Water Environment Research, 90(9): 826-834 (2018).

27. Sanz, D. B., del Jalón, D. G., Teira, B. G., Martínez, P. V. Basin influence on natural variability of rivers in semi-arid environments. International journal of river basin management, 3(4), 247-259 (2005).

28. Smakhtin, V.U., Revenga, C. Döll, P. A pilot global assessment of environmental water requirements and scarcity. Water International 29: 307-317 (2004).

29. Smakhtin, V.U., Anputhas, M. An assessment of environmental flow requirements of Indian River basins. IWMI Research Report 107. International Water Management Institute, Colombo, Sri Lanka, 36p (2006).

30. Smakhtin, V.U., Eriyagama, N., Developing a software package for global desktop assessment of environmental flows. Environmental Modelling & Software, 23(12): 1396-1406 (2008).

31. Tavassoli, H.R., Tahershamsi, A., Acreman, M., Classification of natural flow regimes in Iran to support environmental flow management. Hydrological sciences journal, 59(3-4): 517-529 (2014).

32. Tennant, D.L.1976. Instream flow regimens for fish, wildlife, recreation and related environmental resources. Fisheries 1: 6–10 (1976).

33. Tessman, S. A. Environmental Assessment, Technical Appendix E, in Environmental Use Sector Reconnaissance Elements of the Wester Dakotas Region of South Dakota Study. Water Resources Research Institute, South Dakota State University, Brookings, SD. (1980).

34. Tharme, R.E. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19: 97–441 (2003).

35. Tonkin, Z., Kearns, J., Lyon, J., Balcombe, S.R., King, A.J. and Bond, N.R., Regional-scale extremes in river discharge and localised spawning stock abundance influence recruitment dynamics of a threatened freshwater fish. Ecohydrology, 10(6): 1842 (2017).

36. Wu, J., Tian, X., Tang, Y., Zhao, Y., Hu, Y., Fang, Z., Application of Analytic Hierarchy Process-Grey Target Theory Systematic Model in Comprehensive Evaluation of Water Environmental Quality. Water Environment Research, 82(7): 633-641 (2010).

37. Yang, Y., Yang, Z., Liu, Q., Sung, T. (2010): Assessing effects of dam operation on flow regime in the lower Yellow river. Procedia Environmental Sciences 2: 507–516 (2010).

38. Yasi, M. Management of Rivers and Dams in Supplying and Delivering Water to Urmia Lake. Strategic Research Journal of Agricultural Sciences and Natural Resources, 2(1): 59-76. (2017).

39. Yasi, M., Ashori, M. Environmental flow contributions from in-basin rivers and dams for saving Urmia Lake. Iranian Journal of Science and Technology, Transactions of Civil Engineering, 41(1): 55-64 (2017).