Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Evaluation of hydrological flow regime alteration and its ecological consequences in the Gilgel Abay River Basin, Ethiopia

Endalh Mekonnen

endalhmekonnen@gmail.com

Amhara Agricultural Research Institute, Sirinka Agricultural Research Center https://orcid.org/0000-0003-2838-5160

Research Article

Keywords: Degradation, ecological health, fish migration, flow regime, hydrological flow alteration

Posted Date: July 28th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10486295/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: The authors declare no competing interests.

Abstract

Hydrological flow alteration is widely recognized as a critical approach for assessing river flow regimes and associated ecological health. Although this approach remains relatively new in Ethiopia, it holds significant potential for guiding future river management and conservation efforts. This study aimed to evaluate the ecological health of the Gilgel Abay River using hydrological flow alteration metrics. Flow alterations were analyzed using the Indicators of Hydrologic Alteration (IHA) model based on daily discharge data collected over a 42-year period (1979–2020). The results revealed a declining trend in both high-flow and low-flow durations, particularly for the 1-day and 90-day flow indices. Analysis of environmental flow components showed that only four major flood events occurred during the study period (1980, 1986, 1988, and 1994), with no large floods recorded after 1995. In contrast, the frequency of extremely low-flow events increased after 2002, while small flood events have been absent since 2008. The flow duration curve indicated that stream flow equaled or exceeded 15.81 m^3/s for 95% of the time, reflecting persistent low-flow conditions in the study area. Overall, the findings demonstrate substantial ecological degradation resulting from flow regime alteration, highlighting the urgent need for sustainable flow management strategies in the basin.

1. Introduction

Water plays a fundamental role in sustaining human societies and maintaining the structure and functioning of ecosystems. Freshwater systems support biological communities, regulate ecological processes, and underpin social, economic, and political development throughout history (Martin and Alister 1988; Karr and Chu 1999; Hooker 1996). However, sustainable development at the global scale is unattainable without adequate freshwater availability, both in quantity and quality (Lemma et al. 2018). In recent decades, anthropogenic activities such as dam construction, irrigation abstraction, land-use change, and urban expansion have profoundly altered the natural flow regimes of rivers worldwide (Nilsson et al. 2005). Alterations in river flow are widely recognized as one of the most significant drivers of ecological degradation, as they directly and indirectly affect water quality parameters (Munasinghe et al. 2021), aquatic biodiversity, community structure, and ecosystem functioning (Richter et al. 1996; Poff and Zimmerman 2010). Consequently, flow alteration poses a serious threat to the ecological sustainability of riverine ecosystems and the ecosystem services they provide (Tharme 2003; Finn et al. 2009).

Ethiopia faces comparable challenges related to water resource degradation and increasing water stress. Importantly, water scarcity in the country is not primarily caused by a lack of water resources but rather by inadequate management, inefficient allocation, and weak institutional governance (Lemma et al. 2018; Mekete 2022). These challenges highlight the urgent need for scientific based approaches that support sustainable water management while safeguarding aquatic ecosystems and livelihoods. Maintaining natural flow regimes is central to preserving river health, ecosystem integrity, and the socio-economic benefits derived from freshwater systems. Environmental flow assessment, which aims to determine the quantity, timing, and variability of water flows required to sustain freshwater ecosystems,

has therefore emerged as a critical and rapidly expanding field of research. Previous studies have demonstrated that ensuring minimum flow requirements is an effective management strategy for maintaining riverine ecological health and promoting sustainable water use (McClain 2013). Accordingly, environmental flow assessments have been applied in diverse river systems worldwide, including the East Rapti River (Smakhtin and Eriyagama 2008), the La Nga River in Vietnam (Babel et al. 2012), and the Huaihe River in China (Hu et al. 2008).

Among the tools used to evaluate flow alteration and ecological responses, the Flow Duration Curve (FDC) plays a critical role in assessing river health and ecosystem functioning (Booker and Snelder 2012). FDCs provide valuable information on flow variability across time and are closely linked to ecological responses of aquatic biota (Poff and Zimmerman 2010). Information derived from FDCs is widely applied in assessing physical habitat quality (Booker et al. 2004), evaluating the reliability of water supply and ecosystem protection (Snelder and Lamouroux 2011), and supporting integrated river health assessments (Booker and Snelder 2012). In systems undergoing major hydrological modifications such as large-scale irrigation developments, the Indicators of Hydrologic Alteration (IHA) framework recommends maintaining Environmental Flow Requirements (EFRs) of approximately 90% during low-flow periods and 50% during high-flow periods to protect ecological integrity and ecosystem services (Pastor et al. 2014). The Gilgel Abay River is an ecologically and socio-economically important river system in the Upper Blue Nile Basin, serving as a key migration corridor for fish spawning and supporting local livelihoods (Dagnew et al. 2021). Despite its importance, the river is increasingly affected by human-induced pressures, including water abstraction, land-use change, and watershed degradation (Arega and Dwarakish 2016). These pressures underscore the need for continuous ecological assessment and improved water management strategies (Adane 2006). Numerous studies have investigated the hydrology, watershed characteristics, and water quality of the Gilgel Abay River (Uhlenbrook et al. 2010; Yihun et al. 2013; Anwar et al. 2014; Arega and Dwarakish 2016; Yirga et al. 2016; Bitew et al. 2019; Hanibal et al. 2019; Habtamu et al. 2020; Temessgen et al. 2020; Dagnew et al. 2021). However, these studies largely focused on water quality and catchment processes, with limited consideration of hydrological flow alteration as a determinant of ecological health. Given that river flow regime is a master variable governing physical habitat availability, water quality dynamics, and biological integrity, the absence of flow-based ecological assessment represents a critical knowledge gap. Therefore, the present study aims to assess the overall ecological health of the Gilgel Abay River by applying ecologically meaningful hydrological alteration metrics and indicators. By integrating flow-based analysis into river health assessment, this study provides a more comprehensive understanding of ecosystem condition and generates scientifically robust evidence to inform water resource planning, environmental flow allocation, and sustainable river management in the basin.

2. Materials and Methods

2.1. Description of the Study Area

The Gilgel Abay River is located in central Ethiopia. It begins in the Gojjam highlands at latitude 37°7'E and longitude 11°48'N, and it extends from north to southwest Lake Tana. The Gilgel Abay has tributaries, such as the Ashar, Kelti, Jamma, and Koger. The Gilgel Abay River, with a catchment area of 5,004 km^2, is the largest river discharging into Lake Tana (Yihun et al. 2013). Moisture from the Atlantic and Indian oceans moves north-south in the inter tropical Convergence Zone, generating rainfall in the Gilgel Abay area and the Upper Blue Nile region (Mohamed et al. 2005). According to the Ethiopian climate classification, the Upper Gilgel Abay watershed experiences rainfall regimes that are monomodal. The study area's main rainfall season lasts from June to September and contributes for 70–90% of the annual rainfall (Tarekegn and Tadege 2006). The mean annual rainfall in the studied river ranged from 1,624 to 2,349 mm, while the average monthly maximum temperature fluctuated between 24.3 and 31.3°C in Wetet Abay (1994–2008). Additionally, the majority of the study region receives between 1,842 and 1,986 millimetres of rainfall annually (Anwar et al. 2014). Figure 1 illustrates the geographical location of the study area along with the sampling sites.

The Gilgel Abay River is home to a variety of biota, including ten fish species that belong to the Cypridae, Clarridae, and Cichilidae families and major plants such as Dockma (*S. guineense*), Girar (*Accacia*), Kaya (*C. anisata*), and Gemero (*C. tomentosa*), and other animals, for instance, Akustsa (Hardback) and different bird species like Yibera (*A. aegyptiaca*), duck, and Sabesa (*C. egret*) (Yibeletal et al. 2018).

2.2. Data Collection

2.2.1. Stream Flow

The hydrology of the river was analyzed for the entire Gilgel Abay River catchment using data obtained from gauging stations. Flow records for the period 1979 to 2013 were collected from the Ministry of Water, Irrigation and Electricity (MoWIE), while data for the period 2014 to 2020 were obtained from Climate Explorer.

2.3. Data Analysis

2.3.1. Flow Analysis Using IHA Software

Due to the absence of consistently recorded observed flow data, this study utilized the available records beginning from 1979. A total of 42 years of daily observed flow data, spanning from 1979 to 2020, were analyzed for the station. Among these, 22 years of daily flow data were obtained from the Ministry of Water, Irrigation and Energy (MoWIE), Ethiopia, while the remaining 20 years were collected from the Climate Explorer website. These data were used to assess river flow characteristics, including monthly flow patterns, flow duration indices, and five environmental flow components, using the Indicators of Hydrologic Alteration (IHA) software version 7.1 (The Nature Conservancy, 2009). Non-parametric statistical methods, particularly medians and coefficients of variation, were applied to compare variations in flow rates

2.3.2. Environmental flow components and Flow Duration Curve

The ecologically essential environmental flow component parameters; extreme low flows, low flows, small floods, high flow pulses, and large floods were examined applied IHA software (The Conservancy 2009). The 42-year period from 1979 to 2020 was utilized to estimate the flow duration curve (FDC) for the Gilgel Abay River, the formula is expressed in Eq. 1. According to (Langat et al. 2019), the FDC was computed using the formula:

$$\mathrm{F} = \left(\frac{R}{n+1} \right) * 100$$

1

Where F is the frequency of occurrence expressed as the percentage of time stream flow value is met or exceedance probability, R is the rank associated with the stream discharge rate, and n is the total number of days considered in the analysis. This methodology allows researchers to effectively evaluate the variability of stream flow patterns over the specified period, providing valuable insights for water resource management and planning.

3. Results

3.1. Flow Indices

3.1.1. Monthly Flows

The monthly flow analysis indicated that low flow conditions occur between February and April, with the lowest flow recorded in April. During this month, the median flow was 17.43 m³/s and the standard deviation was 4.95 m³/s. In contrast, high flow conditions were observed from June to November, with the peak occurring in September, when the median flow reached 268.6 m³/s and the standard deviation was 52.7 m³/s (Table 1). A high coefficient of dispersion (COD) was recorded in November and May, which correspond to the dry season (winter and spring), whereas a low COD was observed in September during the wet season (summer). Overall, the river flow during the study period exhibited a decreasing trend, as illustrated in Fig. 2a and 2b.

Table 1
Monthly median flows (m3/s) of the Gilgel Abay River for the recorded period from (1979–2020)

Months	Medians flows(Q50), m^3s^{-1}	Coefficient of Disp.(Q75 Q25)/Q50	Months	Medians flows (Q50), m^3s^{-1}	Coefficient of Disp. (Q75–Q25)/Q50
October	196.3	0.5347	April	17.43	0.3176
November	79.04	0.576	May	30.42	1.349
December	36.69	0.4107	June	90.36	0.3941
January	26.20	0.23	July	126.3	0.2526
February	22.89	0.22	August	185.2	0.3413
March	19.98	0.25	September	268.6	0.1728
NB; Q25 is flow that is exceeded 25% of the time, Q50 is the median and Q75 is flow exceeded 75% of the time					

3.1.2. Low and High flow

The 1-day, 30-day, and 90-day low flows showed a statistically significant decreasing trend over the study period, as indicated by the Mann–Kendall trend test ($p = 0.01$). Specifically, the 1-day low flow declined from 14.12 m³/s in 1979 to 13.98 m³/s in 2020. Similarly, the 30-day (monthly) low flow decreased from 16.23 m³/s in 1979 to 15.39 m³/s in 2019, while the 90-day (seasonal) low flow declined from 18.51 m³/s in 1979 to 17.78 m³/s in 2020. The minimum and maximum flow values are presented in Table 2. High flow conditions also exhibited a decreasing trend over time, similar to the low flows. Quantitatively, the 1-day high flow decreased from 579.1 m³/s in 1979 to 378.4 m³/s in 2020. Likewise, the 90-day (seasonal) high flow declined from 214.6 m³/s in 1979 to 211.3 m³/s in 2019. However, the reduction in the 90-day high flow was relatively small (Fig. 3).

Table 2
The minimum and maximum flows (m3/s) of the Gilgel Abay River during various time periods from 1979 to 2020

Duration	Medians flows (Q50), m3s − 1	Coefficient of Disp.(Q75–Q25)/Q50	Duration	Medians flows (Q50), m3s − 1	Coefficient of Disp.(Q75–Q25)/Q50
1-day minimum	13.91	0.3005	1-day maximum	548.1	0.5961
3-day minimum	14.07	0.28	3-day maximum	472.6	0.5863
7-day minimum	14.43	0.30	7-day maximum	389	0.3674
30-day minimum	15.97	0.27	30-day maximum	289.3	0.2666
90-day minimum	19.72	0.24	90-day maximum	208.3	0.2367

3.2. Environmental Flow Components (EFC)

The EFC analysis revealed four significant floods over the past 42 years, specifically in 1980, 1986, 1988, and 1994 (Fig. 4). However, after 1995, no large floods have been reported. Since 2002, the occurrence of extremely low flows has risen, and no small floods have been recorded since 2008. Nevertheless, large floods, low flows, and small flows all showed similar trends of decline (Fig. 4).

3.3. Flow duration curve

The flow values and exceedance probability for each month are presented graphically, organized from highest to lowest, in conjunction with the FDC results (Fig. 5). In this study, low flow conditions were characterized as situations where there is a 95% flow exceedance probability, meaning that the river experiences 15.81 m³/s discharges in most of the time. The impact is clear at a 100% exceedance probability, suggesting that low flow conditions may decrease during the dry seasons from 1979 to 2020 (Fig. 5b). During this season, the monthly flow duration curves for May indicate low flow conditions at a 99.99% exceedance probability, which is nearly 100% likely to occur with a discharge of 7.81 m³/s) (Fig. 5a).

In the low flow zone, the period from 1979 to 2020 recorded a minimum flow of 7.81 m³/s, which was equaled or exceeded 99.99% of the time. In contrast, the inter-annual high flow, defined as the flow that is equaled or exceeded less than 10% of the time (Q10), was 240.36 m³/s, indicating the conditions of high flows. The IHA analysis indicates that when significant changes, such as dam construction and extensive irrigation projects, occur within this river system, the discharge levels during low flow are between 18.47 m³/s at 90% of the time and 15.81 m³/s at 95% of the time. During high flow periods, the

minimum environmental flow requirements (EFRs) needed to sustain the river's functionality is 57.67 m^3/s at 50% of the time

4. Discussions

4.1. Flow Indices

4.1.1. Monthly flow

The results of the present study indicate that low river flows occur during the dry season, whereas high flows are recorded during the wet season. During the dry season, the coefficient of dispersion (COD) values were relatively higher for all flow durations, reflecting greater variability in monthly discharge. However, a comparatively lower COD value was observed in September, indicating reduced flow variability during that month (Table 3). Even minor variations in the flow regime can significantly affect the composition and abundance of certain plant and animal species (Wetmore et al., 1990). Seasonal flows during the dry season (February, March, and April), as presented in Fig. 2a, and during the wet season (July, August, and March), as shown in Fig. 2b, display a declining trend. This reduction is mainly attributed to increasing human activities, particularly water abstraction, pumping, and diversion for irrigation. Consequently, the ecological condition of the river, including the functioning of its aquatic ecosystem, is deteriorating.

This finding is consistent with results from a study conducted on the Gumara River (Wubneh et al. 2020), as well as with Lloyd et al. (2004), who reported that 45 (64%) of the 70 reviewed papers assessed flow alteration in relation to water abstraction or withdrawals for irrigation. Similarly, the results of the present study indicate that the ecology of the Gilgel Abay River, especially the functioning of its aquatic ecosystem, is declining due to reduced variability in “ecologically relevant” flows.

4.1.2. Low and High Flow

The extent and duration of flow changes are closely associated with stronger ecological responses (Poff et al. 2010). Analysis of low-flow statistics is therefore essential for understanding water quality conditions and the suitability of aquatic habitat niches. This finding is also consistent with feedback obtained from the local community. The reduction in low flow observed after 2003 may be attributed to increasing human activities affecting the Gilgel Abay River, including water abstraction through pumping, diversion for irrigation, and livestock trampling and grazing along the riverbanks.

The results of the present study show that the coefficients of dispersion (COD) are higher under low-flow conditions across all flow durations, indicating greater variability in low flows. High flow variability (i.e., a high coefficient of variation of daily flows) tends to favor species with generalized feeding strategies and preferences for silt (Poff and Allan 1995). Similarly, greater variability in low flow may promote species with generalized feeding strategies and silt preferences (Lloyd et al. 2004), facilitate the proliferation of non-indigenous species, and contribute to the loss of longitudinal and lateral connectivity between rivers

and floodplain wetlands. These processes ultimately influence the abundance, diversity, and composition of native species in river ecosystems (Poff et al. 2010; Pardo-loaiza et al. 2021). In contrast, relatively lower COD values (Table 4) were observed for high flows, indicating reduced variability in high-flow conditions. Variability in river flow regimes is generally driven by complex interactions between human interventions and natural factors (Min et al. 2011).

The findings also reveal a declining trend in the volumetric flow of the Gilgel Abay River. Similar to low flows, maximum flows have decreased during the study period. The 1-day maximum flow serves as a reliable indicator of significant reductions in flood events because it captures individual peak flows rather than averaging them over longer durations such as 3-day, 7-day, 30-day, or 90-day periods (Fig. 3 and Table 4). The reduction of both high and low flows can decrease infiltration rates, leading to reduced base flow and consequently affecting aquatic biota. These hydrological changes can reduce the abundance, distribution, and diversity of macroinvertebrates, as well as degrade spawning habitats for migratory fish and aquatic-riparian vegetation. Consistent with the current study, the abundance of migratory fish species in the Gumara River was negatively affected by excessive water abstraction for irrigation during the months of March to May (Eshete et al. 2013; Wubneh et al. 2020). Flow alteration can also have both direct and indirect effects on fish communities (Clarke et al. 2008). In agreement with this finding, Matthaei et al. (2010) reported that reduced river flow influences several ecological response variables. Changes in flow regimes can lead to declines in the richness and abundance of macroinvertebrates, fish, and riparian vegetation (Poff et al. 2006), which subsequently trigger various ecological processes (Zeiringer et al. 2018). Consequently, alterations in key hydrological parameters indicate that the ecological functioning of the Gilgel Abay River has been significantly affected.

4.2. Environmental Flow Components (EFC)

The river under study is increasingly experiencing flow alterations due to water extraction for domestic and agricultural purposes. These anthropogenic activities have significantly reduced the overall flow of many rivers, altered the seasonal flow patterns, and affected both the frequency and magnitude of flood events. Fluctuations in low-flow levels create critical limitations for aquatic communities because they determine the amount of available aquatic habitat throughout much of the year. Consequently, these changes can substantially influence the diversity and population size of organisms inhabiting the river.

Since 2002, extreme low-flow events have significantly influenced the structure of aquatic communities. Such events reduce habitat availability, resulting in lower diversity and abundance of sensitive species, modifications in life cycles, and shifts in community composition. In addition, low-flow conditions may promote the proliferation of invasive species and disrupt trophic interactions. They may also concentrate prey for certain predators or lead to the drying of floodplain areas. As a result, these processes can contribute to the development of an imbalanced aquatic ecosystem (Wubneh et al. 2020).

Beginning in 2008, the frequency of small floods has declined. This reduction has limited the movement of mobile organisms both upstream and downstream and has contributed to the disconnection of floodplains and inundated wetlands from other aquatic habitats. The decrease in these ecologically

important events, often referred to as “small floods,” has influenced the river’s aquatic communities by reducing the availability of suitable habitats. As a result, the biological and hydrological services provided by aquatic ecosystems have been negatively affected (Brown 2003).

The frequency of such ecologically relevant flow events is considered one of the key indicators for distinguishing between impaired river ecosystems and relatively pristine (less disturbed) systems, particularly in relation to alterations in the hydrological flow regime. Furthermore, after 1994, large flood events were no longer observed, resulting in the loss of longitudinal and lateral connectivity between the river channel and floodplain wetland ecosystems (Ward and Stanford 1995). This loss of connectivity can affect migratory fish spawning areas and reduce the ability of plant seedlings to maintain prolonged access to soil moisture (Junk et al. 1989). Consequently, these changes contribute to the decline of biodiversity and the loss of nursery and foraging habitats for many fish species and other vertebrates (Ward et al. 1999). The findings of this study are consistent with research conducted on the Gumara River (Wubneh et al. 2020). Similarly, Poff and Zimmerman (2010) reviewed 165 studies examining aquatic or riparian responses to flow regime alterations, of which 145 reported responses in terms of population or community changes. In addition, higher flows can contribute to channel widening through processes such as avulsion and sediment deposition (Langat et al. 2019).

4.3. Flow Duration Curve

The non-parametric framework analysis of the Flow Duration Curve (FDC) is useful for evaluating how different factors influence changes in the magnitude of streamflow (Langat et al. 2019). In the present study, a nearly flat slope was observed between the 15th and 90th percentiles of the FDC during the wet season (Fig. 5a). This pattern suggests that streamflow remains relatively stable within this percentile range, indicating limited variation in the river’s flow regime during the wet period. Similarly, Kotei et al. (2016) reported a relatively flat slope in the FDC between the 25th and 75th percentiles for the Sumanpa Stream, although their findings suggested that this stream is more strongly affected than the Gilgel Abay River. In contrast, the steep slope of the FDC during the dry season indicates a rapid decline in flow as the curve approaches its lower end, reflecting a substantial reduction in discharge during low-flow periods. Steep flow duration curves in tropical rivers of West Africa have also been reported to indicate high variability in river discharge, particularly during dry seasons (Ward et al. 1999). Such variability can negatively affect river ecosystems by disrupting aquatic habitats and altering water quality conditions. It can also affect agriculture, as inconsistent water availability may reduce crop productivity and threaten food security. Furthermore, communities that depend on the river as a water source may face increased vulnerability to water shortages during dry periods. The Gilgel Abay River may experience similar challenges during the dry season.

The slope of the FDC is commonly used as an indicator of flow variability in lotic systems (Belete et al. 2015). In this study, the steeper FDC slope observed during the dry season suggests greater variability in river discharge. This observation is consistent with the findings of Belete et al. (2015), who reported steep FDC slopes in rivers with ephemeral flow regimes. In contrast, the relatively flattened slope during the wet season indicates more stable flow conditions, which is characteristic of perennial rivers (Belete

et al. 2015). The greater variability observed during the dry season may be linked to increasing water abstraction for domestic use and irrigation within the catchment. In addition, changes in the shape of the FDC may result from land-use changes, climate variability, and infrastructure development, all of which can affect the physical, chemical, and biological characteristics of river systems and their ecological responses (Poff et al. 2010).

For example, the flows equaled or exceeded at probabilities of 5%, 25%, 50%, 75%, and 95% in the Sumanpa Stream were reported as 45.0 m^3/s, 13.82 m^3/s, 5.53 m^3/s, 2.83 m^3/s, and 0.14 m^3/s, respectively (Kotei et al. 2016), which are lower than the values observed in the present study for the Gilgel Abay River. It should also be noted that the shape of the FDC can be influenced by the length and timing of the data record used for analysis (McKay and Fischenich 2016). The current study provides a more comprehensive representation of watershed conditions because it utilized 42 years of recorded data, whereas the study by Kotei et al. (2016) used only 24 years of data to construct the FDC. Longer periods of record generally produce FDCs that more accurately represent watershed behavior, while shorter records may be strongly influenced by extreme climatic events, such as unusually wet or dry years (McKay and Fischenich 2016).

5. Conclusions

The findings of this study indicate a declining trend in both low and high flow regimes of the Gilgel Abay River over the past 42 years. The highest monthly variability in flow was observed in May, as indicated by a high coefficient of dispersion (COD). In addition, the probability of experiencing inter-annual low-flow conditions was nearly 100% across all months. During the past four decades, only four major flood events were recorded, and no large floods have occurred since 1995. Furthermore, the frequency of extremely low-flow events has increased since 2002, while small flood events have not been observed since 2008. These results indicate a clear downward trend in the selected flow regime metrics of the Gilgel Abay River. The Flow Duration Curve (FDC) for the river shows a sharper shape and steeper slope during the dry season, whereas it displays a flatter shape and gentler slope during the wet season throughout the observation period. Such hydrological changes may lead to negative ecological consequences, including reductions in the abundance, composition, and diversity of aquatic flora and fauna. The discharge values during low-flow (15.81 m^3/s) and high-flow (57.67 m^3/s) periods represent the minimum environmental flow requirements (EFR) recommended by the International Hydropower Association (IHA) to maintain the ecological health of the river and the ecosystem services it provides.

Based on the analysis of hydrological flow metrics, the study river appears to be in a degraded ecological condition. Hydrological alterations in the Gilgel Abay River may therefore have significant ecological consequences. These findings highlight the urgent need for sustainable water management practices. To protect ecosystem services and prevent further degradation of aquatic ecosystems within the river–wetland–lake connectivity, it is essential to closely monitor water resource use and implement integrated conservation and management strategies.

Declarations

Acknowledgements

I would like to express my gratitude to the Amhara Agricultural Research Institute (AARI), for their collaboration in providing the required logistical support.

Funding

This research was funded by Austrian Development Cooperation (ADC) project under grant number 0612-00/2021(AQUAHUB2). The authors acknowledge ADC for financing the joint master's program between Bahir Dar University, Addis Ababa University, Ethiopia and Egerton University of Kenya.

Data availability statement

All data generated or analysed during this study are included in this published article and the Supplementary material could be provided upon the response.

Declaration statement

The authors report there are no any financial or non-financial competing interests influenced our research work.

References

1. Adane S. 2006. Water quality and phytoplankton dynamics in Legedadi Reservoir. In Addis Ababa University, Addis Ababa, Ethiopia.
2. Anwar A, Assefa M, Seifu T, Shimelis G, Essayas K, Abeyou W, Tewodros A. 2014. Climate change projections in the upper Gilgel Abay River catchment, Blue Nile Basin Ethiopia. In Nile River Basin: Ecohydrological Challenges, Climate Change and Hydropolitics . 9783319027, pp. 363–388. https://doi.org/10.1007/978-3-319-02720-3_19.
3. Babel MS, Nguyen C, Akter R, Nanduri UV. 2012. Operation of a hydropower system considering environmental flow requirements : A case study in La Nga river basin , Vietnam. Journal of Hydro-Environment Research. 6: 63–73. https://doi.org/10.1016/j.jher.2011.05.006.
4. Belete B, Yilma S, Solomon S, Assefa M. 2015. Flow Regime Classification and Hydrological Characterization: A Case Study of Ethiopian Rivers. Water.7: 3149–3165. https://doi.org/10.3390/w7063149.
5. Booker DJ, Dunbar MJ, Ibbotson A. 2004. Predicting juvenile salmonid drift-feeding habitat quality using a three-dimensional hydraulic-bioenergetic model. Ecological Modelling. 177(1–2): 157–177. https://doi.org/10.1016/j.ecolmodel.2004.02.006.
6. Booker DJ, Snelder TH. 2012. Comparing methods for estimating flow duration curves at ungauged sites. Journal of Hydrology. 434: 78–94. https://doi.org/10.1016/j.jhydrol.2012.02.031.

7. Brown C. 2003. Environmental flows: concepts and methods. World Bank.
8. Clarke KD, Pratt TC, Randall RG, Dave A, Smokorowski KE. 2008. Validation of the Flow Management Pathway : Effects of Altered Flow on Fish Habitat and Fishes Downstream from a Hydropower Dam. Canadian Technical Report of Fisheries and Aquatic Sciences. 2784: 111.
9. Collischon W, Fan FM. 2013. Defining parameters for Eckhardt's digital baseflow filter. Hydrol. Process. 27: 2614–2622, doi:10.1002/hyp.9391.
10. Dagnew M, Minwyelet M, Abebe G, Wassie A. 2021. Impact of irrigation practices on Gilgel Abay, Ribb and Gumara fisheries, Tana Sub-Basin, Ethiopia. Heliyon. 7(3). https://doi.org/10.1016/j.heliyon.2021.e06523.
11. Eshete D, Vreven E, Wassie A, Abebe G. 2013. Habitat use and downstream migration of 0+ juveniles of the migratory riverine spawning Labeobarbus species (Cypriniformes: Cyprinidae) of Lake Tana (Ethiopia), Fifth International Conference of the Pan African Fish and Fisheries Association (PAFFA5).
12. Finn MA, Boulton AJ, Chessman BC. 2009. Ecological responses to artifi cial drought in two Australian rivers with differing water extraction. Fundamental and Applied Limnology Archiv Für Hydrobiologie. 175: 231–248. https://doi.org/10.1127/1863-9135/2009/0175-0231.
13. Hooker R. 1996. World Civilizations. Ancient china: The Yellow River Culture. http://www. Ancient China. The Yellow River Culture.htm.
14. Hu W, Wang G, Deng W, Li S. 2008. The influence of dams on ecohydrological conditions in the Huaihe River basin , China. Ecological Engineering. 3: 233–241. https://doi.org/10.1016/j.ecoleng.2008.04.003.
15. J BM. 1997. An experimental study of stranding of juvenile salmonids on gravel bars and in sidechannels during rapid flow decreases. 13: 395–401.
16. Junk WJ, Bayley PB, Sparks RE. 1989. The flood pulse concept in river floodplin systems.106: 110–127.
17. Karr JR, Chu EW. 1999. Restoring life in running waters: better biological monitoring. Island Press, Washington, DC. p.197-206.
18. Kotei R, Agyeiagyare W, Kyei-Baffour N, Atta-Darkwa T, Takyiatakora E. 2016. Estimation of Flow-Duration and Low-Flow Frequency Parameters for the Sumanpa Stream at Mampong-Ashanti in Ghana for the 1985-2009 Period. American Scientific Research Journal for Engineering. 15(1): 62–75. http://asrjetsjournal.org/.
19. Langat PK, Kumar L, Koech R, Ghosh MK. 2019. Duration Curve, Historical Data and Remote Sensing : Effects of Land Use and Climate. Water. 309(11): 1–20. https://doi.org/10.3390/w11020309.
20. Lemma A, Abebe G, Brook L. 2018. Changes in fish diversity and fisheries in Ziway-Shala basin : The case of Lake Ziway, Ethiopia. International Journal of Advanced Research in Biological Sciences. 5:165–177. https://doi.org/10.22192/ijarbs.

21. Lloyd N, Quinn G, Thoms M, Arthington A, Gawne B, Humphries P, Walker K. 2004. Does flow modification cause geomorphological and ecological response in rivers. A literature review from an Australian perspective. CRC for Freshwater Ecology. 57.
22. Martin KD, Alister JH. 1988. World land and water resources. Hodder & Stoughton.
23. Matthaei CD, Piggott JJ, Townsend CR. 2010. Multiple stressors in agricultural streams : interactions among sediment addition, nutrient enrichment and water abstraction. Journal of Applied Ecology. 47: 639–649. https://doi.org/10.1111/j.1365-2664.2010.01809.x
24. Mcclain ME. 2013. Balancing Water Resources Development and Environmental Sustainability in Africa : A Review of Recent Research Findings and Applications. p. 549–565.https://doi.org/10.1007/s13280-012-0359-1.
25. Mckay SK, Fischenich JC. 2016. Development and Application of Flow Duration Curves for Stream Restoration. ERDC TN-EMRRP-SR. 49: 1–12.
26. Mekete B. 2022. Chapter 24 : Policy , regulatory and institutional frameworks relevant to Ethiopian water governance. p. 519–544.
27. Min S, Zhang X, Zwiers FW, Hegerl GC. 2011. Human contribution to more-intense precipitation extremes. Nature. 470(7334): 378–381. https://doi.org/10.1038/nature09763.
28. Mohamed YA, Van den Hurk BJ, Savenije HH, Bastiaanssen WG. 2005. Hydroclimatology of the Nile : results from a regional climate model. Hydrology and Earth System Sciences. 9: 263–278.
29. Munasinghe DS, Najim MM, Quadroni S. 2021. Impacts of streamflow alteration on benthic macroinvertebrates by mini - hydro diversion in Sri Lanka. Scientific Reports. 11(546): 1–12. https://doi.org/10.1038/s41598-020-79576-5.
30. Nilsson C, Reidy CA, Dynesius M, Revenga C, Nilsson C, Reidy CA, Dynesius M, Revenga C. 2005. Fragmentation and Flow Regulation of the World ' s Large River Systems. Science. 308(5720): 405–408.
31. Pardo-loaiza J, Solera A, Bergillos RJ, Paredes-arquiola J, Andreu J. 2021. Improving indicators of hydrological alteration in regulated and complex water resources systems: A case study in the duero river basin. Water (Switzerland).13(19). https://doi.org/10.3390/w13192676.
32. Pastor AV, Ludwig F, Biemans H, Hoff H, Kabat P. 2014. Accounting for environmental flow requirements in global water assessments. Hydrology and Earth System Sciences. 18(12): 5041–5059. https://doi.org/10.5194/hess-18-5041-2014.
33. Poff NL, Allan JD. 1995. Functional Organization of Stream Fish Assemblages in Relation to Hydrological Variability Author (s): N . LeRoy Poff and J . David Allan Published by : Wiley on behalf of the Ecological Society of America Stable URL : https://www.jstor.org/stable/19412. Ecological Society of America. 76(2): 606–627.
34. Poff NL, Olden JD, Pepin M, Bledsoe BP. 2006. Placing global stream flow variablity in geographyic and geomorphic and Geomorphic contexts. River Res. Applic. 22: 149–166. https://doi.org/10.1002/rra.902.

35. Poff NL, Richter BD, Arthington AH, Bunn SE, Naiman RJ, Kendy E, Acreman M, Apse C, Bledsoe BP, Freeman MC, Henriksen J, Jacobson RB, Kennen JG, Merritt DM, O'Keeffe JH, Olden JD, Rogers K, Tharme RE, Warner A. 2010. The ecological limits of hydrologic alteration (ELOHA): A new framework for developing regional environmental flow standards. Freshwater Biology. 55(1): 147–170. https://doi.org/10.1111/j.1365-2427.2009.02204.x.
36. Poff NL, Zimmerman J. 2010. Ecological responses to altered flow regimes : a literature review to inform the science and management of environmental flows. Freshwater Biology. 55: 194–205. https://doi.org/10.1111/j.1365-2427.2009.02272.x.
37. Richter BD, Baumgartner JV, Powell J, Braun DP. 1996. A Method for Assessing Hydrologic Alteration within Ecosystems. In conservation Biology. 10(4).
38. Smakhtin VU. 2001. Low flow hydrology: A review, J. Hydrol. 240: 147–186.
39. Smakhtin VU, Eriyagama N. 2008. Environmental Modelling & Software Developing a software package for global desktop assessment of environmental flows. Environmental Modelling & Software. 23: 1396–1406. https://doi.org/10.1016/j.envsoft.2008.04.002.
40. Snelder T, Booker D, Lamouroux N. 2011. A method to assess and define environmental flow rules for large jurisdictional regions. Journal of the American Water Resources Association. 47(4): 828–840. https://doi.org/10.1111/j.1752-1688.2011.00556.x.
41. Tarekegn D, Tadege A. 2006. Assessing the impact of climate change on the water resources of the Lake Tana sub-basin using the WATBAL model. World. 30: 1–15.
42. Temesgen G, Abeyou W, Yihun T, Solomon A, Amare B, Gete Z. 2020. Evaluating potential impacts of land management practices on soil erosion in the Gilgel Abay watershed, upper Blue Nile basin. Heliyon. 6(8): 1–13. https://doi.org/10.1016/j.heliyon.2020.e04777.
43. Tharme RE. 2003. A global Perspective on Enviromental Flow Assessment: Emerging Trends in the Development and Application of Enviromental Flow Mthodologies for Rivers. River Res. Applic. 441: 397–441. https://doi.org/10.1002/rra.736.
44. The Conservancy N. 2009. IHA Software Version 7.1 User's Manual, The Nature Conservancy.
45. Uhlenbrook S, Mohamed Y, Gragne AS, Medani W. 2010. Analyzing catchment behavior through catchment modeling in the Gilgel Abay, Upper Blue Nile River Basin , Ethiopia. Hydrol. Earth Syst. Sci. 14: 2153–2165. https://doi.org/10.5194/hess-14-2153-2010.
46. Ward JV, Stanford JA. 1995. Ecological Connectivity in Alluvial River Ecosystems and Its Distruption by Flow Regulation. Regulated Rivers: Research & Management. 11: 105–119.
47. Ward JV, Tockner K, Schiemer F. 1999. Biodiversity of Flood plain River Ecosystems: Ecotones and Connectivity. Regul. RiTers: Res. Mgmt. 15:125–139.
48. Wetmore SH, Mackay RJ, Newbury RW. 1990. Characterization of the hydraulic habitat of Brachycentrus occidentalis , a filter- feeding caddisfly. J. N. Am. Benthol. Soc. 9(2):157–169.
49. Wubneh B, Seifu A, Michael M, Ayalew W, Minychl Gitaw, Teshager A, Demesew A, Steenhuis TS, Camp MV, Walraevens K, McClain ME. 2020. Hydrological foundation as a basis for a holistic

environmental flow assessment of tropical highland rivers in ethiopia. Water.12(547): 2–20. https://doi.org/10.3390/w12020547.

50. Wubneh B, Seifu A, Michael M, Ayalew W, Minychl G, Workiye W, Demesew A, Anwar A, Fasikaw A, Wuletaw A, Steenhuis TS, Mcclain ME. 2021. Ecological Status as the Basis for the Holistic Environmental Flow Assessment of a Tropical Highland River in Ethiopia. Water. 13(1913): 1–17.
51. Yibeletal A, Minwyelet M, Addis G. 2018. Diversity, Relative Abundance, Species Composition and Some Biological Aspects of Fishes in Gilgel Abay and Andassa Rivers, Blue Nile Basin, Ethiopia. Fish. Aqua. J. 9: 241. doi:10.4172/2150-3508.1000241.
52. Yihun T, Berndtsson R, Shimelis G. 2013. Hydrological Response to Climate Change for Gilgel Abay River, in the Lake Tana Basin - Upper Blue Nile Basin of Ethiopia Hydrological Response to Climate Change for Gilgel Abay River, in the Lake Tana Basin - Upper Blue Nile Basin of. PLoS ONE. *8*(10): 1–13. https://doi.org/10.1371/journal.pone.0079296.
53. Zeiringer B, Seliger C, Greimel F, Schmutz S. 2018. River Hydrology, Flow Alteration, and Environmental Flow. In Riverine Ecosystem Management;Aquatic Ecology Series. *8*: p. 67–89. http://www.springer.com/series/5637.

Figures

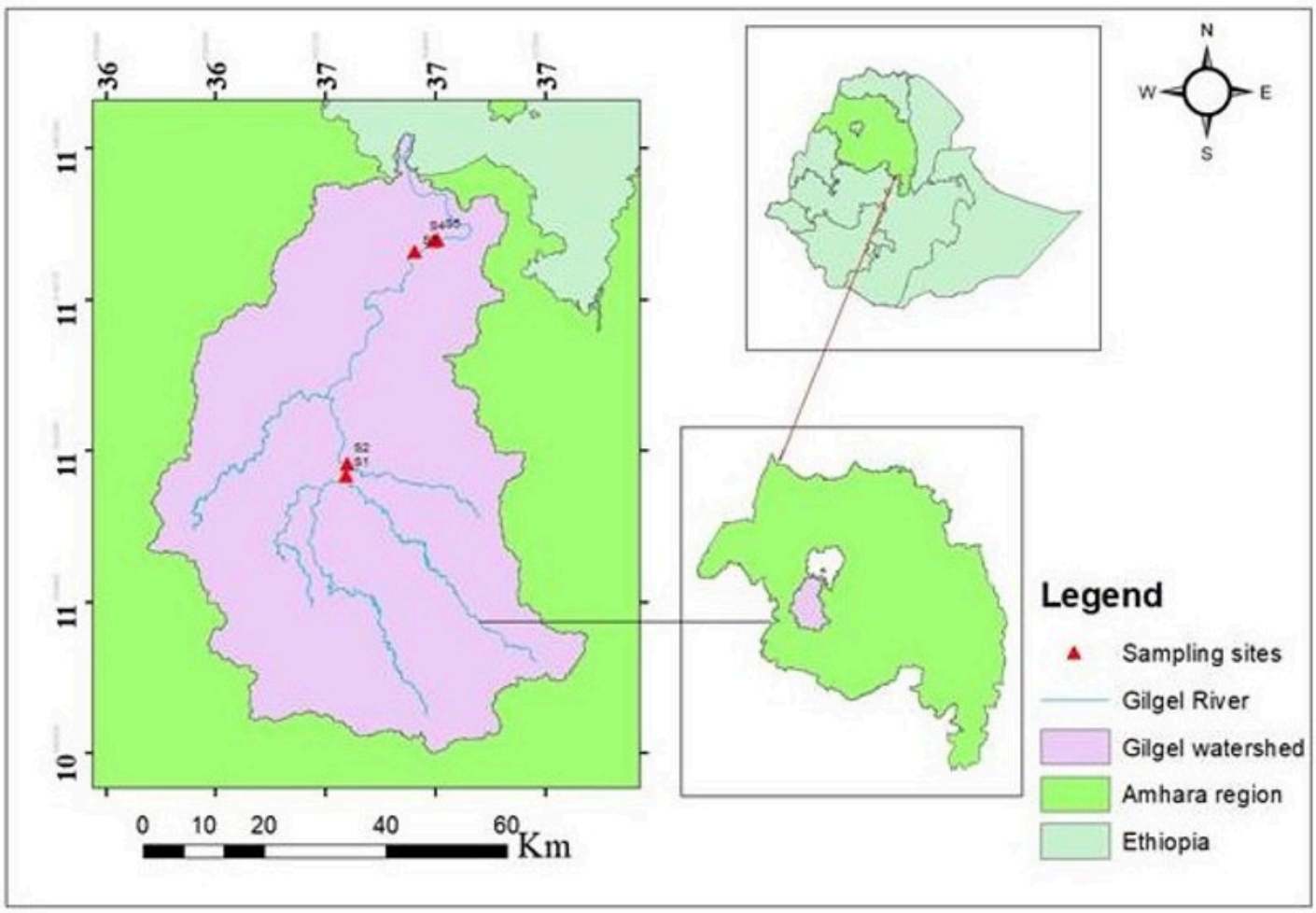


Figure 1

Map of the Gilgel Abay River with sampling sites

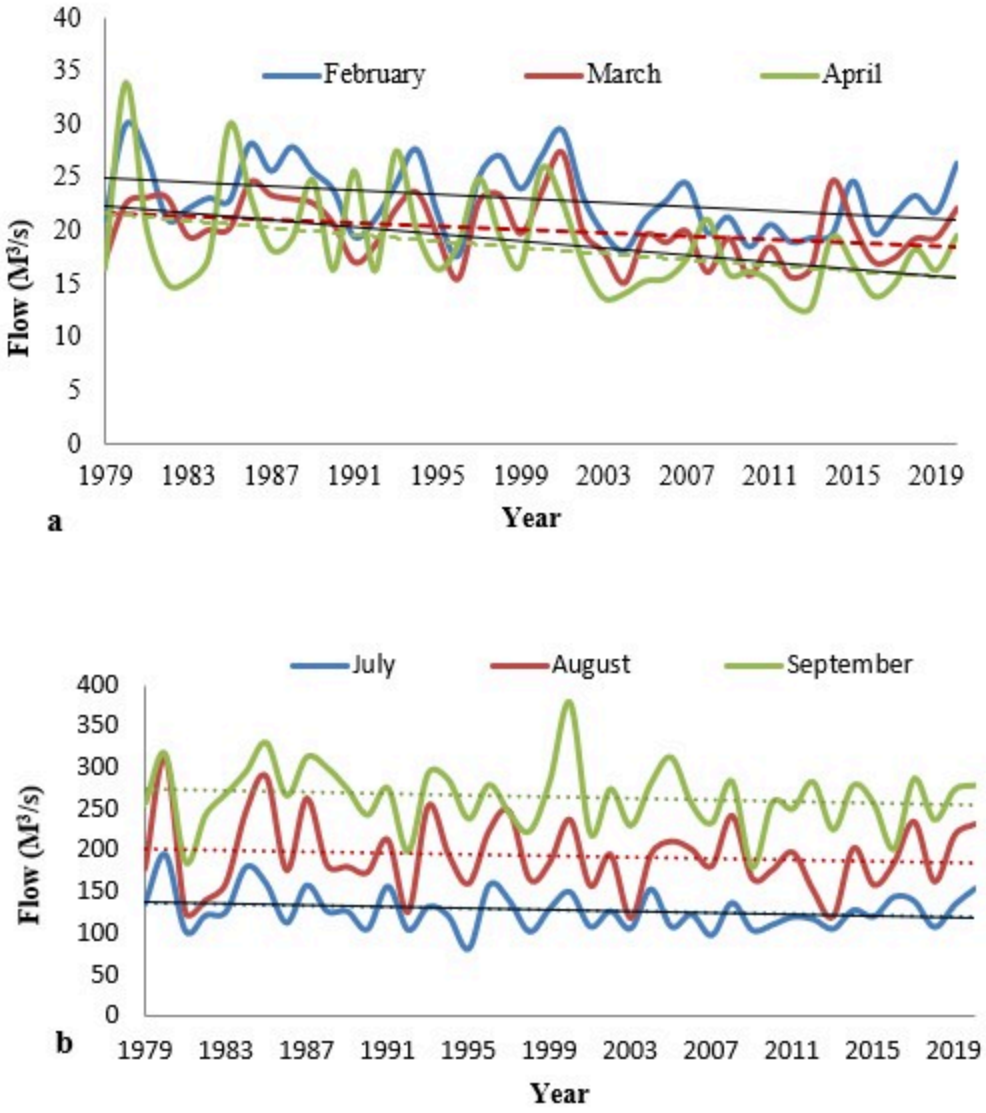


Figure 2

Monthly flow of Gilgel Abay River for the period from 1979–2020 (a) dry season (February, March and April), and (b) wet season (July, August and September).

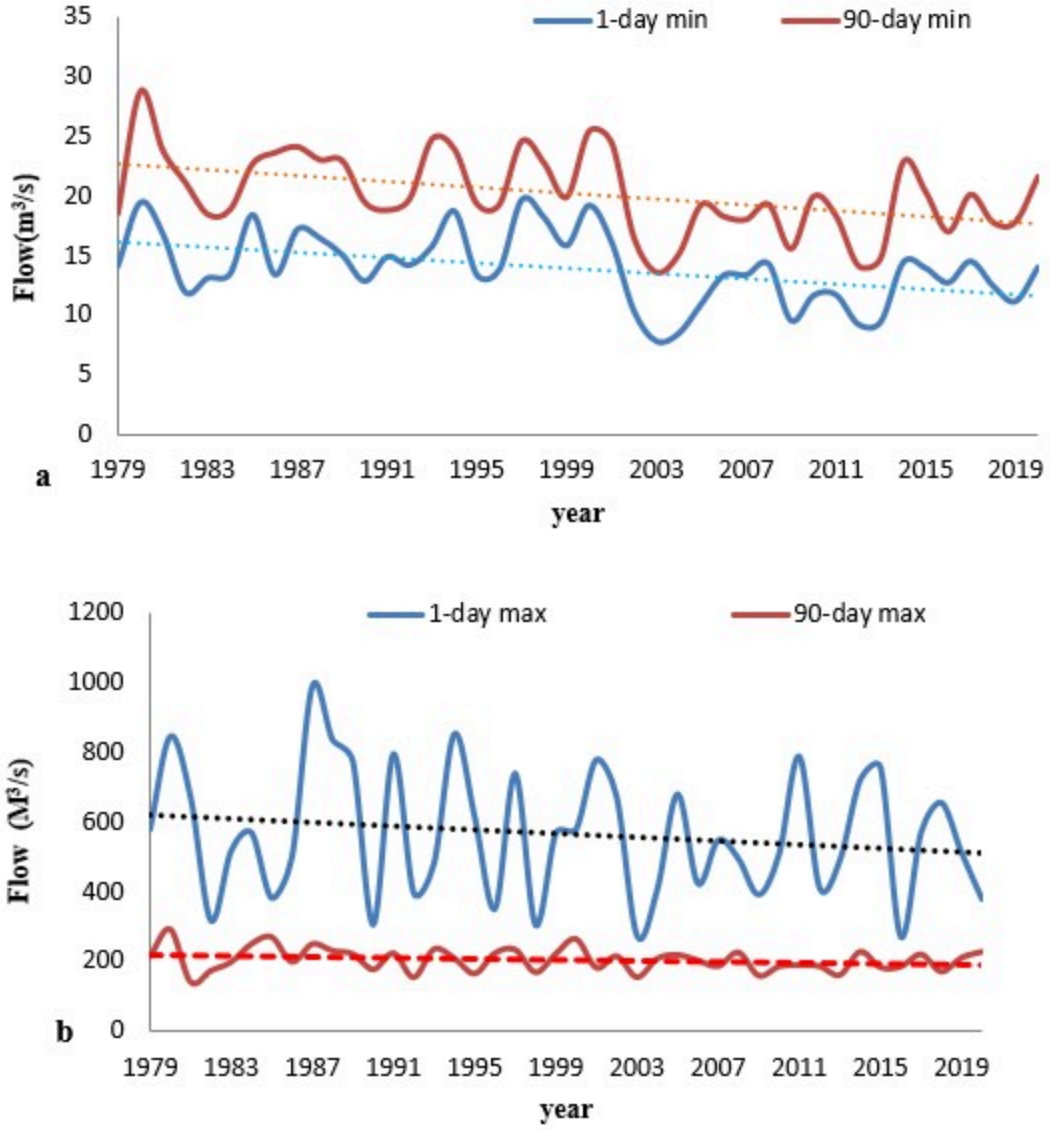


Figure 3

1-day and 90-day low flow (a) and high flow (b) of Gilgel Abay River (1979–2020).The figure depicts (a) the lowest flow from each individual day of the year as 1-day duration low flow and the lowest flow of average 90 days (seasonal) duration low flow and (b) highest flow from each individual day of the year as 1-day duration high flow; and highest flow of average 90 days duration high flow.

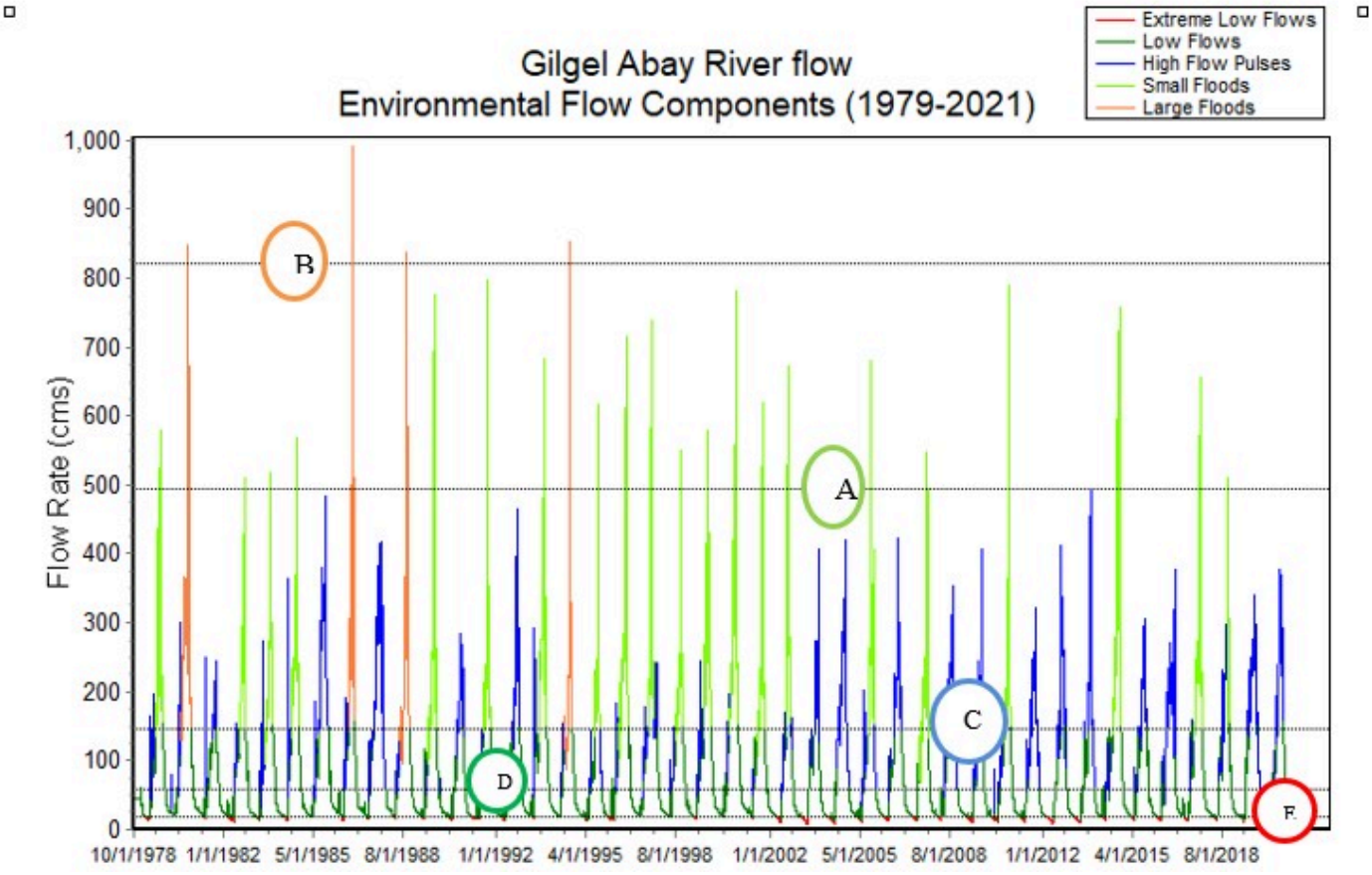


Figure 4

The five environmental flow components of the Gilgel Abay River: The horizontal line (a) shows the small flood minimum peak flow and the horizontal line (b) shows the large flood minimum peak flow, high flow pulse minimum peak flow (C), low flow minimum peak flow (D) and extreme low flow minimum peak flow (E).

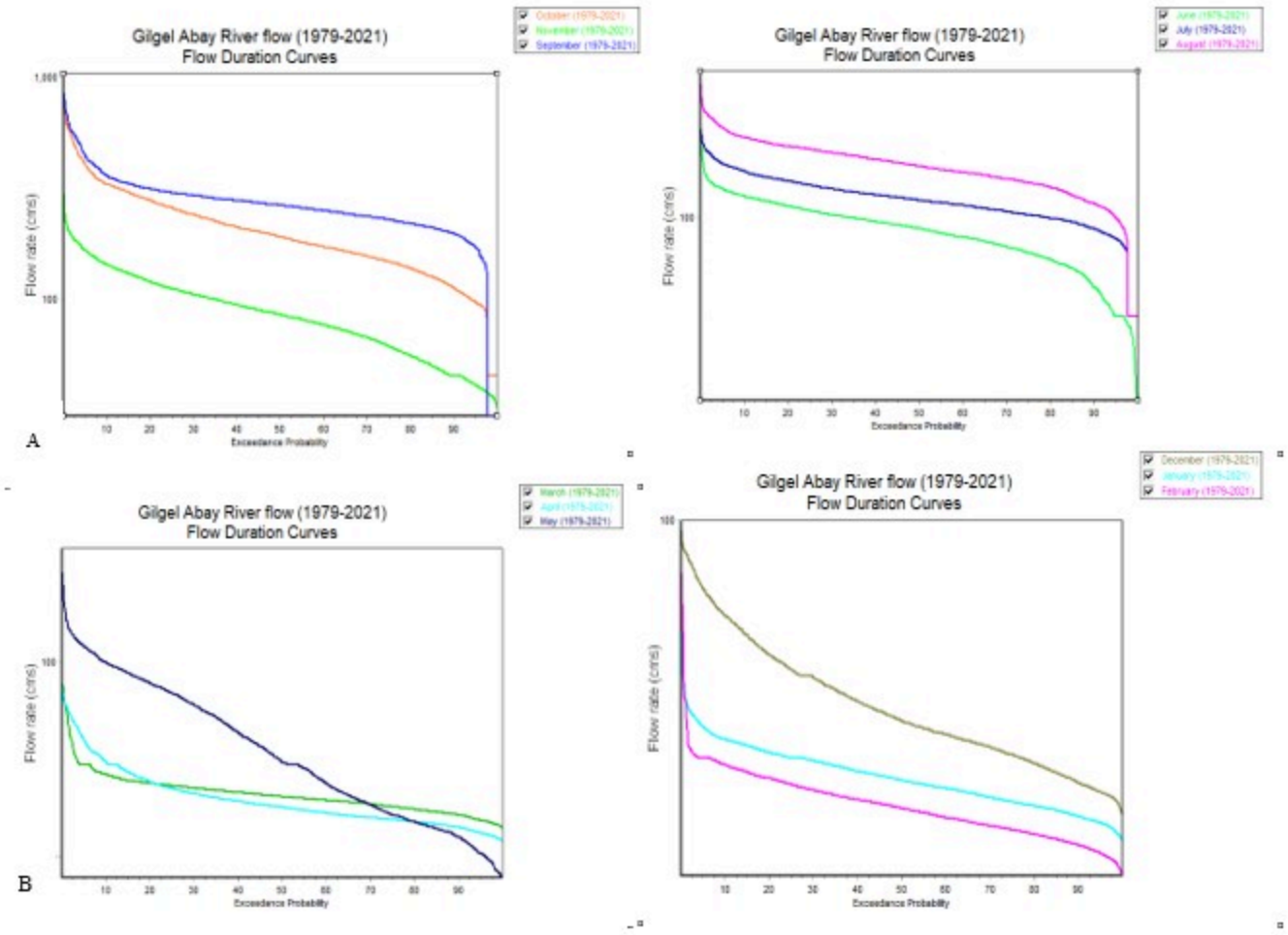


Figure 5

Flow duration curve for the Gilgel Abay during the wet season (A) and the dry season (B)