

Collective Impact of Upstream Anthropogenic Interventions and Prolonged Droughts on Downstream Basin's Development in Arid and Semi-arid Areas: The Diyala Transboundary Basin

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Abstract The integrated management of transboundary waters has increasingly becoming a heavy burden facing decision-makers and water managers, especially in downstream countries. Human-intervention activities upstream combined with prolonged droughts have intensified the challenges encounter the water governance in a sustainable manner. This study quantifies the combined effects of upstream man-made modifications and basin-wide extended droughts on temporal river flow paradigms of the downstream riparian country. The Diyala watershed of about 32,000 km² shared between Iraq and Iran was chosen as an example case study. The Indicators of the Hydrologic Alteration (IHA) and the Range of Variability Approach (RVA) were adopted to characterise the streamflow alteration. Findings reveal that the joint impact has destructively influenced the development of the middle and lower portions of the basin in the downstream country, including the security of the irrigated agriculture, domestic and industrial water demands, and prompted people to leave their homes and lands coupled with growing conflicts between tribes. Prolonged severe droughts were marked between 1999 and 2015. The size and magnitude of the joint impact are anticipated to increase in the foreseeable future when under construction and future planned water withdrawal facilities upstream will be commissioned. The two successive acute droughts of (1999–2001) and (2008–2009) twinned with upstream regulation practices have hindered the socio-economic activities and deteriorated the environmental system of the middle and lower portions of the Diyala basin in the lower country.

Keywords Transboundary basin • Climate alteration • Hydrologic indicator • Sustainable management • Human-induced disturbance

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1 Introduction

Being a downstream riparian country across all of its transboundary rivers, with over 75% of its surface fresh water originating from outside its territory, Iraq has increasingly becoming vulnerable to the unilateral water abstraction and water policies of the upstream riparian countries, particularly Turkey and Iran. The climate change is making the level of vulnerability even worse. The IPCC (2014) reported that many arid and semi-arid areas (e.g., Mediterranean region, Western United States and South Africa) would encounter a decline in water resources due to potential impacts of climate change and climate variability. The growing water demands for agriculture, household and industrial purposes associated with climate change impacts have underlined the importance of a deep understanding of the adverse collective influence of upstream human pressures and climate alteration and variability at a regional scale on the runoff volume and quality of water of the downstream country (Al-Faraj and Scholz 2014; Al-Faraj and Al-Dabbagh 2015).

Increasing water demands in the territory of each riparian country and the differences in interests and water policies among riparian countries are expected to bring about increasing challenges to cooperation, possibly even increasing conflicts and tensions. For basins that entirely lie within the countries' territories, mitigation of the climate change impacts will be hard enough; however, when basins cross borders, bringing in multiple political entities and actors, integrated management of shared water resources in a changing climate and variability will be largely challenging. Iraq is a typical example of this second case. As more than 75% of its water resources originate in the upper riparian countries, Iraq is highly sensitive to the water withdrawal and regulation practices and unilateral management policies upstream.

This chapter examines the temporal streamflow alteration of the Diyala flow paradigm of the downstream country Iraq due to the mutual impact of a spectrum of upstream anthropogenic regulations and prolonged droughts at transboundary scale.

2 Materials and Methodology

2.1 Case Study Area

The Diyala basin is a transboundary river basin shared between Iraq and Iran (Fig. 1). The basin is intensively equipped with dams, extensive irrigation practices, fish farms, hydraulic water diversions and inter-basin water transfer tunnels. Moreover, Daryan dam, which is currently under construction primarily aims to divert a considerable amount of the river flow (about 1.4 billion m³/year) to the South-western part of Iran for irrigation, through the 48 km long Nosoud Water Conveyance Tunnel. The dam will also have a 210 MW hydroelectric power station. Both Daryan dam and Nosoud inter-basin water transfer tunnel are expected to be commissioned in 2018 (Al-Faraj and Scholz 2014, 2015).

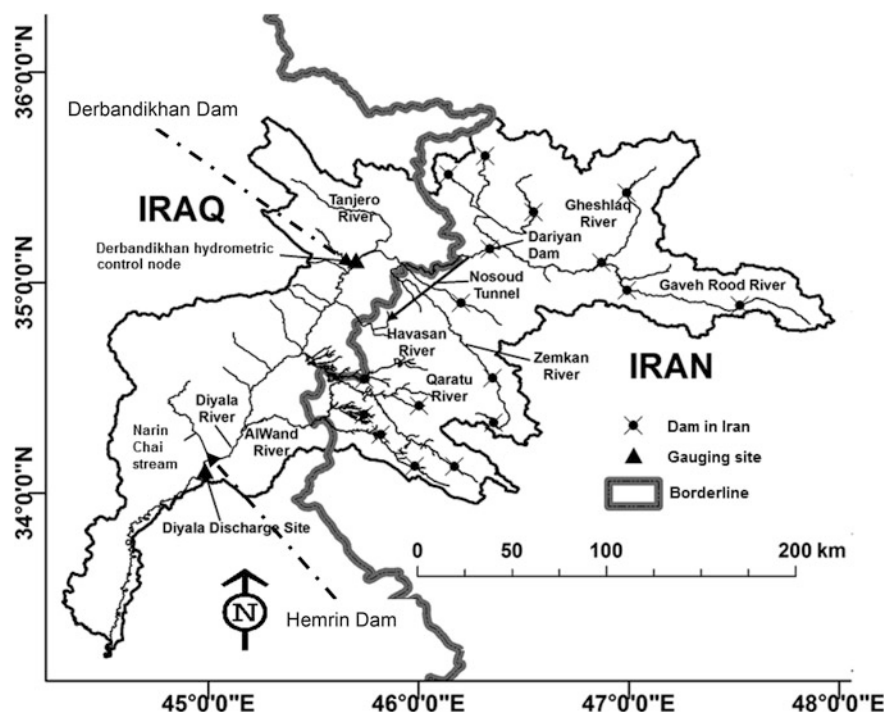


Fig. 1 The transboundary Diyala river basin (After Al-Faraj et al. 2015)

Precipitation usually falls between October and May, mainly spans November to April. The dry season usually extends from June to September. The basin lies between the latitudes 33.216°N and 35.833°N, and the longitudes 44.500°E and 46.833°E. It drains about 32,000 km², of which 43% (about 14,000 km²) lies in Iraq and 57% (approximately 18,000 km²) in Iran.

The upper portion of the basin drains about 17,900 km² of which approximately 25% stretches in Iraq. The upper portion is largely devoted to irrigated agriculture, fisheries, domestic and industrial water supply and water conveyance networks, including inter-basin water transfer tunnels to poor-water basins (Al-Faraj and Scholz 2014, 2015).

Concerning the downstream country Iraq, the main river corridor equipped with two key dams: the Derbandikhan dam, which controls the upper reach and Hemrin dam that monitors the most downstream site of the middle Diyala portion. Derbandikhan dam is located approximately 65 km southeast of Sulaimaniya and 230 km northeast of Baghdad. The middle Diyala stretches between Derbandikhan and Hemrin dams (Fig. 1), draining about 11,900 km² of the transboundary basin. It receives runoffs from three main water courses that emerge in Iran (Havasan, Qaratu and AlWand). Some seasonal streams on the right bank of the river (e.g., Narin Chai stream flowing into the Hemrin reservoir) in Iraq are slightly contributing to the total runoff of the river.

The three water courses are equipped with a web of dams and water diversions in Iran, which dedicated for irrigation, domestic and industrial water supply and fish farms. Irrigation projects are expanded across the banks of the river's main corridor in Iraq. The irrigation networks are directly benefiting from the middle reach of the river by gravity and pumping irrigation facilities (MoWR 2010; Al-Faraj et al. 2015).

The agriculture sector forms the largest water consumer of the transboundary waters, particularly, the upper and middle portions of the basin. Nearly 445,000 ha in Iraq and 131,000 ha in Iran are the projected areas to be put under irrigation facilities (Al-Faraj et al. 2015). A set of water pumps stretches on the left bank of the Tigris river in Iraq has been used to pump about 288 million m³/year of water from the Tigris river to the lower reach of the Diyala basin to compensate the water shortage. Moreover, it was recommended, yet has not been put in place, to annually transfer about 945.4 million m³ of water from the Lesser Zab river basin in Iraq to the Diyala basin (Al-Faraj et al. 2015).

The basin's development upstream and the critical level of vulnerability that the downstream country Iraq has reached have urgently called for investigating and assessing the hydrologic alteration induced by human interference upstream and climate change and variability. This chapter seeks to examine the combined impact of upstream human-induced interferences and climate alteration on the water resources availability of the lower riparian country.

2.2 Data Availability

Considering the availability of flow data, the Derbandikhan hydrometric station in Iraq was chosen as a promising control gauging site to examine the combined effect of the human pressures upstream and climate change on the flow regime of the downstream country. Daily runoffs observed between 1931 and 2013 were examined. The dataset covers both the unaltered flow condition (1931–1982) and the altered flow regime (1983–2013). The impaired period of 1999–2013 was more broadly analysed taking into account two acute drought periods (1999–2001) and (2008–2009). The data were gathered from various sources (Harza and Binnie 1958, 1959, 1963; USGS 2010; MoAg and WR-KRG 2013). The effective regulation of the river in the upper country began in 1983 (Al-Faraj and Scholz 2014). Thus, this year was used to split the time series (1931–2013) into natural (undisturbed) and disturbed flow regimes.

2.3 Characterization of Hydrologic Alteration

In this chapter, the Indicators of Hydrologic Alteration (IHA) associated with the Range of Variability Approach (RVA) was adopted to assess the hydrologic shift.

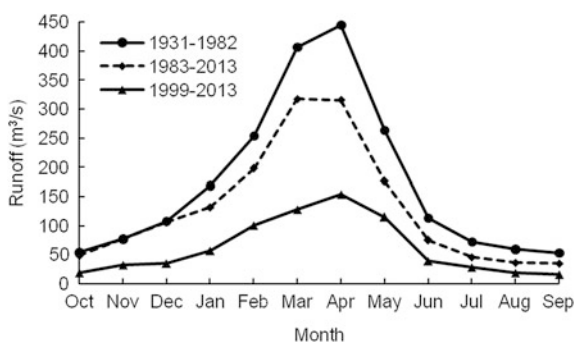
The IHA and the RAV are well documented in the literature (Richter et al. 1996, 1997, 1998; Shiao and Wu 2004a, b; Zuo and Liang 2015). The Indicators IHA are broadly used, which consider a full range of undisturbed natural flow variability, including magnitude, frequency, timing, duration and change rate; the 33 parameters of IHA were classified into five domains of hydrologic features. In order to obtain the flow regime target with IHA, the RVA method was introduced to assess the hydrologic anomaly attributed to hydraulic control works. The method for assessing hydrologic alteration is based on the differences in the flow paradigm between two defined periods at a certain hydrometric control node.

The long-term yearly average runoffs for the undisturbed natural condition (1931–1982), and the regulated periods (1983–2013) and (1999–2013) were $172.8 \text{ m}^3/\text{s}$ (5.45 billion m^3), $130.1 \text{ m}^3/\text{s}$ (4.10 billion m^3) and $77.8 \text{ m}^3/\text{s}$ (2.45 billion m^3), respectively. The corresponding drops in the long-term yearly average runoffs relative to the long-term yearly average runoff of the unimpaired flow regime were about -25 and -55% , respectively. The minimum, mean, maximum daily runoffs and the standard deviation of the natural flow regime over the period (1931–1982) were 1, 174.4, 5816 and $221.5 \text{ m}^3/\text{s}$, respectively. The prominent annual variations in the natural runoffs were primarily due to the nature of the water years (i.e. dry, normal and wet). The rate of alteration in the natural annual flow mainly depends on the degree of annual precipitation shift with respect to the long-term yearly average precipitation.

Concerning the impaired period (1983–2013), the corresponding values were 1, 130.1, 2446 and $163.8 \text{ m}^3/\text{s}$, respectively. The last fifteen hydrologic years (1999–2013) indicate significant drop where the minimum, mean, maximum daily runoffs and the standard deviation were 1, 77.8, 2446 and $106.8 \text{ m}^3/\text{s}$, respectively.

Figure 2 shows a comparison between the unimpaired and the impaired long-term mean monthly flows. The deviations of the long-term mean monthly flows for the altered period (1983–2013) are ranging from -7.2% observed in November to -36.1% perceived in September (Table 1). Remarkable anomalies were associated with the long-term mean monthly runoffs of the impaired period (1999–2013). The alterations were between -45.1% in November and -61.4% in September (Table 1). The considerable shifts associated with this period are

Fig. 2 A comparison between the long-term mean monthly runoffs of the undisturbed period and disturbed periods



attributed to the combined effects of droughts (1999–2001) and (2008–2009), and upstream river regulation arrangements and storage facilities.

2.4 Comparison of Monthly Percentiles Between Pre- and Post-alteration Periods

Table 2 shows the alterations in the flow percentiles over the periods of 1983–2013 and 1999–2013. Figure 3 compares the monthly percentiles (10, 25, 50, 75, and 90%) between the undisturbed and disturbed time series. The monthly 10th percentiles (Fig. 3a) presented a decline ranged from -33.4% in February to -70.6% in August for the period of 1983–2013, and drops between -37.2% perceived in February and -80.4% observed in August and September for the 1999–2013. For the monthly 25th percentiles (Fig. 3b), the first period of 1983–2013 was associated with departures between -23.1% in November to -45.4% in June. The corresponding shifts for 1999–2013 were between -45.6 and -76.9% . Concerning the monthly median flows (Fig. 3c), the anomalies associated with the 1983–2013 were ranged from -7.2% witnessed in November to -36.1% obtained in September. The corresponding alterations for 1999–2013 were between -45.1 and -61.4% . The alterations associated with the 75% flow percentiles for 1983–2013 ranged from -2.2% observed in October to -36.4% perceived in August. Unlike, November and December were accompanied by a positive shift of $+1.8$ and $+15.7\%$, respectively. The corresponding deviations associated with the period of 1999–2013 were between -27.2% observed in February and -74.7% noticed in September (Fig. 3d). As far as the 90% percentiles for the 1983–2013 are concerned, the shifts ranged from -12.6% perceived in March to -40.7% in August. November, December and January were associated with positive alteration between $+4.2$ and 58.5% . The deviations linked to the period 1999–2013 were between -0.5% obtained in October and -74.1% witnessed in September (Fig. 3e).

2.5 Magnitude of Annual Extreme Conditions

The results of the Range of Variability Approach (RVA) analysis are given in Table 1. Low to moderate deviation was linked to the post-impact period of 1983–2013. The moderate deviation was perceived in January, July and September. The corresponding hydrologic alterations were -34.1 , -35.9 , and -36.1% , respectively. The moderate degree of hydrologic alteration was also associated with the regulated period of (1999–2013). The hydrologic alterations were between (-45.1%) observed in November and (-61.4%) noticed in September.

The extreme minima flows of the period (1983–2013) experienced low to moderate deviations. High shift of -75% was linked to 1-day minima flow over the

Table 1 Statistics of the hydrologic alteration for the middle RVA category of the Diyala River

Parameter group #1	HA (%) (1983–2013)	Degree of alteration	HA (%) (1999–2013)	Degree of alteration	Parameter group #2	HA (%) (1983–2013)	Degree of alteration	HA (%) (1999–2013)	Degree of alteration
October	–25.0	Low	–56.8	Moderate	1–day minimum	–37.5	Moderate	–75.0	High
November	–7.2	Low	–45.1	Moderate	3–day minimum	–34.1	Moderate	–56.5	Moderate
December	–25.7	Low	–58.1	Moderate	7–day minimum	–34.4	Moderate	–55.4	Moderate
January	–34.1	Moderate	–54.2	Moderate	30–day minimum	–26.0	Low	–56.9	Moderate
February	–18.8	Low	–49.0	Moderate	90–day minimum	–28.7	Low	–59.3	Moderate
March	–31.9	Low	–60.4	Moderate	1–day maximum	–14.3	Low	–54.5	Moderate
April	–17.0	Low	–55.9	Moderate	3–day maximum	–25.4	Low	–51.0	Moderate
May	–27.9	Low	–46.5	Moderate	7–day maximum	–23.5	Low	–50.5	Moderate
June	–32.5	Low	–61.3	Moderate	30–day maximum	–11.5	Low	–47.6	Moderate
July	–35.9	Moderate	–57.3	Moderate	90–day maximum	–20.5	Low	–48.1	Moderate
August	–21.3	Low	–57.3	Moderate					
September	–36.1	Moderate	–61.4	Moderate					
Parameter group #3									
Julian date of annual minima	Pre-impact (275) Pre-impact (76)			Post-impact 1983–2013 (260) Post-impact 1983–2013 (78)			Post-impact 1999–2013 (251) Post-impact 1999–2013 (86)		
Julian date of annual maxima									
Parameter group #4									
Low pulse count	Pre-impact (2)			Post-impact 1983–2013 (8)			Post-impact 1999–2013 (6)		
Low pulse duration	Pre-impact (9.5)			Post-impact 1983–2013 (3)			Post-impact 1999–2013 (4)		
High pulse count	Pre-impact (6)			Post-impact 1983–2013 (6)			Post-impact 1999–2013 (5)		
High pulse duration	Pre-impact (3.5)			Post-impact 1983–2013 (3)			Post-impact 1999–2013 (2.5)		
Parameter group #5									
Rise rate	Pre-impact (2)			Post-impact 1983–2013 (8)			Post-impact 1999–2013 (4)		
Fall rate	Pre-impact (2)			Post-impact 1983–2013 (8)			Post-impact 1999–2013 (–5)		
Number of reversals	Pre-impact (2)			Post-impact 1983–2013 (8)			Post-impact 1999–2013 (177)		

Table 2 Alteration (%) in flow percentiles relative to the flow percentiles of the natural unimpaired flow regime

WY	Alteration (%)											
	1983-2013	1999-2013	1983-2013	1999-2013	1983-2013	1999-2013	1983-2013	1999-2013	1983-2013	1999-2013	1983-2013	1999-2013
Month	Percentiles											
	10%			25%			50%			75%		
October	-60.7			-27.6			-25.0			-2.2		
	-68.3			-69.5			-56.8			-22.7		
November	-35.3			-23.1			-7.2			+1.8		
	-54.7			-45.6			-45.1			-53.5		
December	-34.4			-41.7			-25.7			+15.7		
	-39.0			-48.3			-58.1			-49.0		
January	-43.3			-36.7			-34.1			-6.9		
	-51.7			-53.4			-54.2			-53.1		
February	-33.4			-40.7			-18.8			-13.0		
	-37.2			-49.7			-49.0			-27.7		
March	-40.6			-43.5			-31.9			-11.3		
	-49.1			-51.9			-60.4			-48.7		
April	-59.5			-33.8			-17.0			-21.1		
	-73.8			-67.4			-55.9			-47.8		
May	-64.7			-24.7			-27.9			-30.1		
	-72.0			-72.6			-46.5			-53.9		
June	-62.6			-45.4			-32.5			-31.6		
	-70.9			-76.9			-61.3			-60.7		
July	-65.0			-28.7			-35.9			-26.8		
	-79.4			-72.0			-57.3			-61.7		
August	-70.6			-29.0			-21.3			-36.4		
	-80.4			-70.1			-57.3			-60.9		
September	-69.9			-31.9			-36.1			-28.6		
	-80.4			-70.2			-61.4			-74.7		

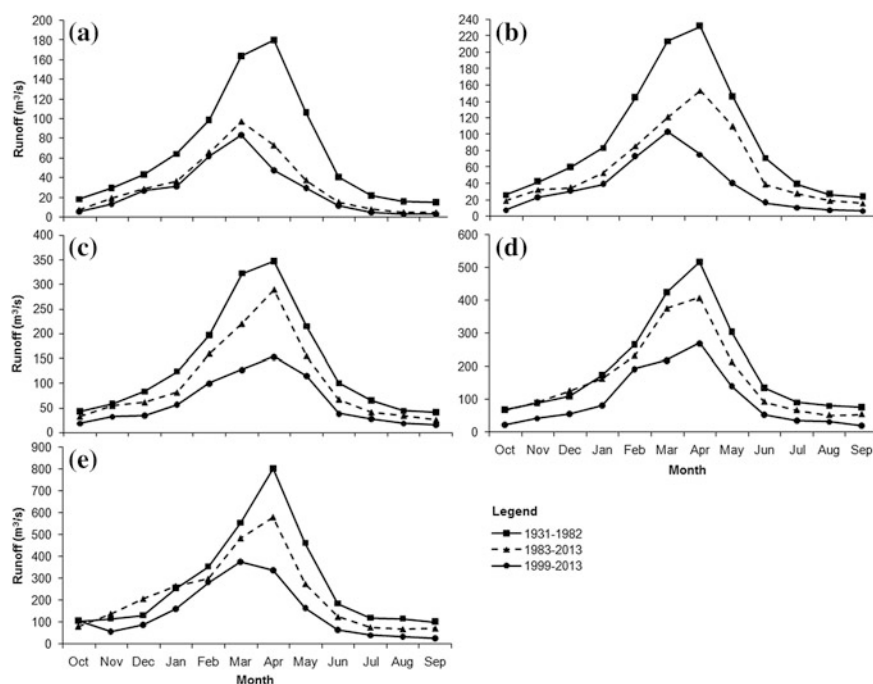


Fig. 3 Alterations in monthly flow percentiles relative to the reference natural monthly flow percentiles: **a** 10th percentiles; **b** 25th percentile; **c** median; **d** 75th percentile; and **e** 90th percentile

altered period of (1999–2013), while 3- to 90-day minima flows were incorporated with moderate deviation between -47.6 and -59.3% . Low alteration was associated with the parameters of 1- to 90-day maximum flows for the impaired period of (1983–2013), while moderate deviation was linked to the corresponding parameters for the altered period of (1999–2013).

The mean Julian date of annual 1-day minimum moved forward from the 275th day in the undisturbed time span to the 260th day of the disturbed period of (1983–2013) and to 251st day in the impaired period of 1999–2013. The mean Julian date of annual 1-day maximum impaired was later than that unimpaired, moving from 76th day in the undisturbed period to 78th day in the impaired period of 1983–2013 and to 86th day in the disturbed period of 1999–2013.

The number of the low pulse counts in the regulated periods was higher than in the unregulated period while the high pulse counts of the impaired period of 1983–2013 were equal to those in the pre-impact period while the impacted period of 1999–2013 was associated with lower counts. The duration of high and low pulses both decreased; e.g. the duration of low pulses dropped from 9.5 days in the pre-impact period to 3 and 4 days in the impaired period of 1983–2013 and 1999–2013, respectively. The duration of high pulses landed from 3.5 days in the

unimpaired period to 3, and 2.5 days for the 1st and 2nd impaired periods, respectively.

The number of reversals was increased from 2 in the undisturbed period to 8 in the impaired period of 1983–2013 and to 177 for the regulated period of 1999–2013.

3 Conclusions

The flow regime of the Diyala watershed has experienced immense alteration. The construction of a web of dams, water abstraction for irrigated agriculture and public water supply, and water conveyance networks within and outside the basin have notably shifted the natural flow regime of the river. Exploring the extent to which human interventions would support water managers to manage the water resources in an integrated mode. The rapid growth of public water supply and irrigation demands, particularly in transboundary watersheds coupled with the effect of climate change and variability have increasingly called for a further understanding of the joint impact of the river regulation arrangements upstream and multi-year droughts at the basin scale, on the hydrologic regime of the lower riparian country. River regulation activities associated with successive droughts substantially shifted the flow characteristics of the Diyala River. The rates of water abstraction and diverted flow in the upper riparian country are expected to escalate and the degree of vulnerability of the downstream riparian country is expected to develop. The drought spells of 1999–2001 and 2008–2009 coupled with watershed development upstream, have resulted in severe modifications in the hydrologic regime of the river and produced a remarkable adverse impact on water availability of the downstream riparian country. The descent in the long-term yearly average altered runoffs relative to the long-term mean annual undisturbed flow was about –25% for the disturbed period (1983–2013) and –55% for the impaired period (1999–2013). The deviations of the long-term mean monthly flows for the post-alteration time window (1983–2013) ranged between –7.2% observed in November to –36.1% perceived in September. Concerning the second altered period (1999–2013), the alterations ranged between –45.1% in November and –61.4% in September. Results reveal that the man-made changes upstream associated with consecutive severe droughts have resulted in a notable negative impact on flow characteristics of the downstream country Iraq. This has influenced the development of the middle and lower portions of the basin in Iraq.

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