Assessment of hydrologic alternation of flow due to dam construction in an arid basin (the case of the gadar river in Urmia basin)

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Abstract

Gadar River located at the south part of the Urmia Basin is one of the imperative source of water for Urmia Lake and its satellite wetlands. It has been regulated since 2000 by diversion of its flow to the Hasanlu dam for supplying irrigation water. This study was aimed at investigating hydrologic alternation of the river flow during the post-dam period compared to the natural reference condition using the RVA and Eco-deficit methods. Results show that simultaneous with decreased base flow index, occurrence of zero flows has been increased as well as the duration of low flow events. Furthermore, considerable decreases in the frequency and duration of the high flows were detected. Analysis of eco-deficit/surplus curve also indicated that not only the reservoir operation has created no eco-surplus but also it has produced an average eco-deficit of 218 MCM/y. To improve the hydrologic condition of the river through conserving low flow and peak flow components of its natural regime, the acceptable range for the regulated flow was calculated using the RVA method and recommended to be considered by implementing active and restrictive management policies in the reservoir and river, respectively.

Keywords: Hydrologic alteration, Eco-deficit, Range of Variability Approach (RVA), Environmental Flows.

1. INTRODUCTION

The World Resources Institute (WRI) found that at least one large dam modifies 46% of the world's 106 primary watersheds. In addition, more than 60% of the rivers worldwide have been regulated by dam construction. Among the many factors leading to the degradation of watershed ecosystems, dams are the main physical threat, fragmenting and transforming aquatic and terrestrial ecosystems with a range of effects that vary in duration, scale and degree of reversibility. Allocation and supplying environmental flows (EFs) of rivers are the most effective strategies to move toward the sustainable management of the river ecosystems (WCD, 2000). The foremost step to determine EFs is to assess the changes in the flow regime after regulation and then try to redesign modified flow pattern so that to preserve the main components of the flow which have critical ecological functions.

A number of hydrological methods have been developed to assess the variation in the regulated flow of the dammed river and to determine ecologically-sound environmental flow strategies (see review by Poff and Zimmerman, 2010). The Range of Variability Approach (RVA), developed by Richter et al. (1996), is among the most comprehensive techniques which employs a subset of 33 ecologically-important hydrological variables, called Indicators of Hydrologic Alteration (IHA) , to evaluate variability of the annual flow regime in terms of magnitude (size), frequency, timing, duration, and rate of change/ the IHA variables can be used for long-term trend analysis or for comparative statistical analysis to quantify change pre- versus post-activity, e.g. dam construction or water abstraction flashiness (Olden and Poff, 2003). The RVA identifies flow targets as ranges for each of the IHA variables (Richter et al. 1997).

In an effort to develop an overall measure of habitat alteration based on streamflow data, the concept of "eco-deficit" and "eco-surplus" were first introduced by Homa et al. (2005) and Vogel et al. (2007). These two eco-flow metrics provide an overall numerical and graphical representation of the tradeoff between human and ecological needs for available water. Later, Gao et al. (2009) found that the eco-deficit and the eco-surplus statistics can provide good overall measures of hydrologic alteration in a river. The annual eco-deficit appears to be the best generalized index among all the indices in the simulated data set.

GadarChay is one of the main rivers of the Urmia Basin, located at the south part of Urmia Lake (Fig.1). Based on the hydrometric records at the most downstream station of the river, Bahramlu Station, the river provides about 9 percent of Urmia Lake inflows between 1980-2013 water years (Fig.2).

The Hasanlu dam was constructed on the Shore of Gadar River near the Naghadeh city. It has been operated since 2000, for the aim of providing irrigation water for more than 12000 ha of downstream agricultural lands, which currently about 5000 ha are irrigated. It has a volume about 93 MCM and is fed through a diversion canal from Gadar River with a capacity of 15 m^3/s. Before construction of the dam, there was a seasonal brackish wetland at the site of reservoir having an area of 1100 ha, called Shurgol. There are also several wetlands near the reservoir including Dorgehsangi, GordehGhit and Solduz which are fed by the Gadar River, groundwater discharge as well as the flows from agricultural drainages. Therefore, the river not only plays an important role in supplying part of Urmia Lake environmental water requirements, but also it is of high importance for delivering water requirements of its downstream wetlands. Figure 3 shows the variation in the river's inflow into Urmia Lake. It is obvious that between 1998 and 2002, both the volume of inflow and the share of river compared to other surface runoffs to Urmia Lake were dramatically decreased due to impoundment of the Hasanlu dam.

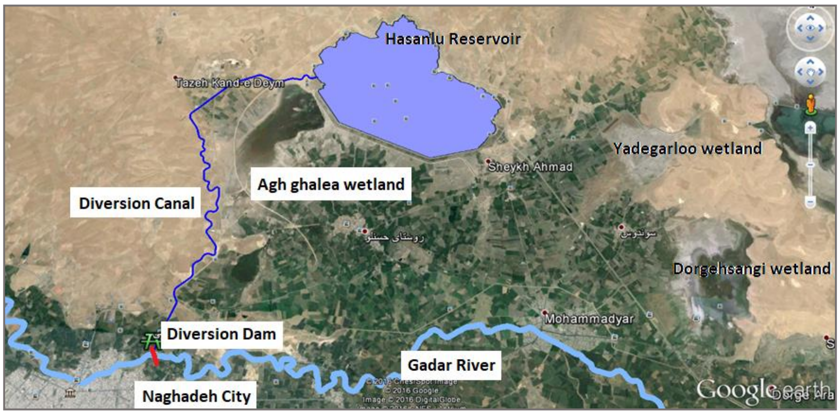

Figure 1. Study Area

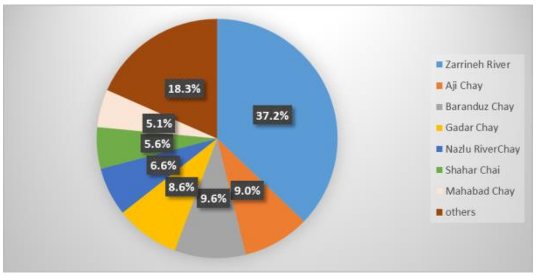

Figure 2. Portions of main rivers inflows into Urmia Lake based on the mean annual runoff from 1982 to 2012.

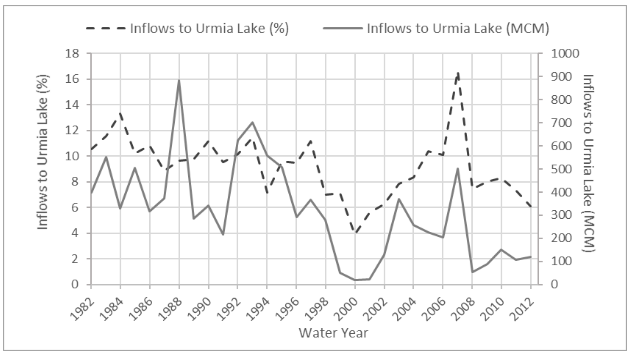

Figure 3. Variation in the volume and share of inflow from the Gadar River to Urmia Lake.

This study focuses on assessing the hydrologic alternation of the Gadar River after operation of the Hasanlu dam. To do this task first, the RVA and Eco-deficit methods were used to quantitatively describe changes in the frequency, duration, timing and magnitude of post-dammed period. Second, an appropriate range is determined for regulated flow to conserve the key component of flow regime within an ecologically acceptable range. Finally, several recommendations are provided to be taken into account as management strategies to improve hydrologic condition the river which in turn highly affects its ecological sustainability.

2. METHODOLOGY

To assess the variation of the flow regime of the Gadar River, a 20-year period before diversion of the river flow to the Hasanlu dam and 12 years after the dam operation were considered. Daily hydrometric data of the river at Bahramlu station, the most downstream station on the river, from 1981 to 2012 was acquired from Iran Water Resources Management Company (IWRMC). Then, the hydrological methods of RVA and Eco-deficit which are commonly used to determine EFs of rivers were used. However, the primary objective here, was not to determine the river's EF, rather was to investigate the hydrologic changes between pre and post-dam periods. To conduct the RVA method, the IHA software was used. This program was developed by researchers at The Nature Conservancy to facilitate hydrologic analysis in an ecologically-meaningful manner.

IHA parameters can be calculated using parametric (mean/standard deviation) or nonparametric (percentile) statistics. As recommended in the manual of the software for most situations, since the skewed (non-normal) nature of many hydrologic datasets violates the normality assumption required for non-parametric statistics, the former method is preferred in most cases. Then, the variation in the IHA parameters from the pre-impact period (reference scenario) to the variation in the post-impact period is compared to determine the extent of the changes. Each IHA parameter is analyzed to determine the frequency with which it falls into one of three RVA categories (Low, Middle, High), as defined by the RVA Category Boundaries. Hydrologic Alteration (HA) for each parameter is defined as the change in frequency from pre-impact to post-impact of that parameter in each of the three RVA categories (Eq.1).

HA= (observed frequency – expected frequency) / expected frequency (1)

Where "expected frequency" is the frequency expected in the post-impact period if it followed the same pattern as the pre-impact period, and "observed frequency" is the frequency actually observed in the post-impact period. A positive HA indicates increased frequency (from pre- to post-dam period), whereas a negative HA factor corresponds to decreased frequency.

As described in the previous section, the concepts of eco-deficit and eco-surplus, are metrics to evaluate the volumetric environmental flows of a river based on flow duration curves (FDCs) (Vogel et al. (2007)). Flow duration curves provide a graphical illustration of the overall hydrologic state of a river system and is commonly used in a variety of hydrological studies (Vogel and Fennessey, 1995; Acreman, 2004). FDCs are constructed from daily streamflow data over a time interval of interest and provide a measure of the percentage of time duration that streamflow equals or exceeds a given value (Gao et al. 2009). Two different types of FDCs are possible: (1) period-of-record FDCs and (2) a median annual or seasonal FDC (see Vogel and Fennessey, 1994). Based on FDCs, the eco-deficit and eco-surplus can be computed over any time period of interest (month, season, or year) and reflect the overall loss or gain, respectively, in streamflow during that period that results from flow regulation (Fig.4). In this study we employed median annual FDCs for the purpose of eco-deficit/Eco surplus calculation.

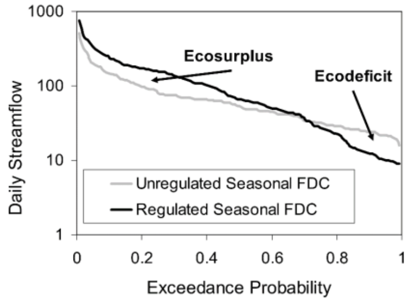

Figure 4. Schematic graph showing the eco-deficit and eco-surplus concepts corresponding to areas between regulated and unregulated (FDCs) of a river.

3. Results & Discussion

When the RVA and Eco-deficit techniques were applied the main outcomes including graphs and statistics were used for interpretation. In applying RVA, first the three categories of high, middle and low boundaries of HA, were determined to be more than 68%, 34-68% and less than 33%. Those parameters which showed high HA are base flows, mean monthly flows from June to September and from December to February and low flows with the duration of 1, 3 and 7 days as well (Fig.5). Other words, the highest impact of the river flow diversion has been on the low flow components of the hydrograph.

Fig.6 compares the mean monthly flow alternation in the regulated period versus natural reference condition of the river flow. The maximum reduction in the river flow has been occurred in April and May, while the expected variation from July to October is minimal. Moreover, ranges of the flow variation both in pre and post dam periods are wider in flood seasons (April, May, June), compared to other months. The amount of 7-days minimum flow has been also declined from 0.2 m3/s in natural condition to about zero after the Hasanlu Dam operation. This condition has been repeated in almost all years from 2001 to 2012, except the year of 2008 (see Fig.7).

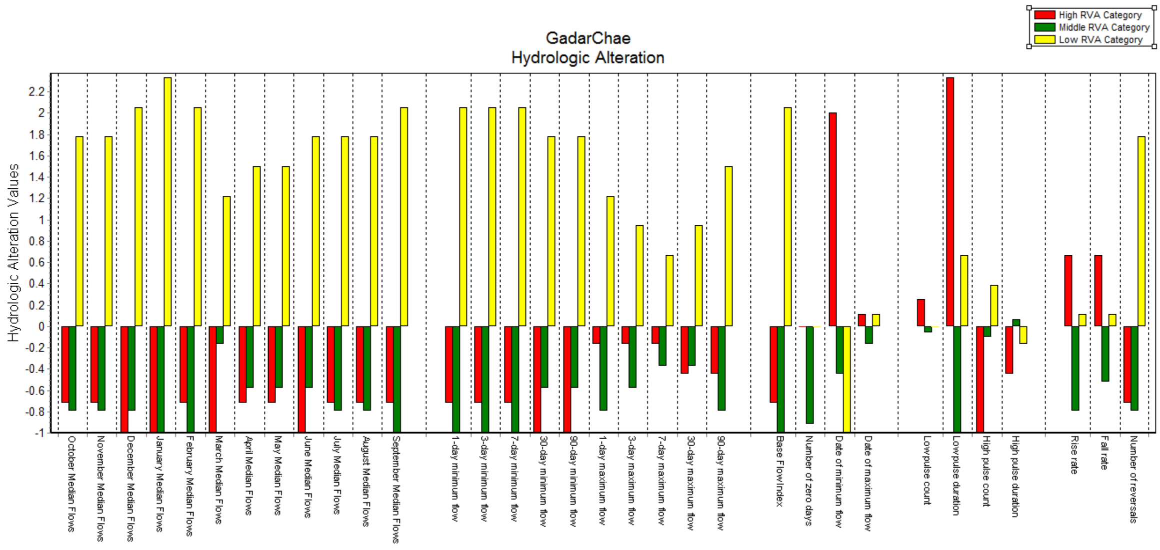

Figure 5. Hydrologic Alternation of various Hydrologic parameters in the Gadar River.

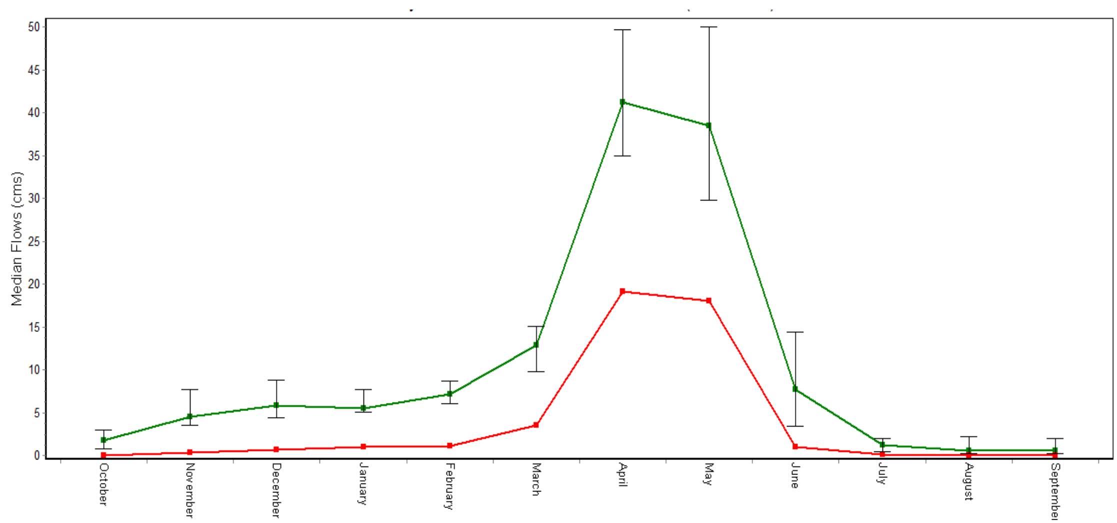

Figure 6. Mean Monthly Flow of the Gadar River during pre (green) and post-dam period (red line).

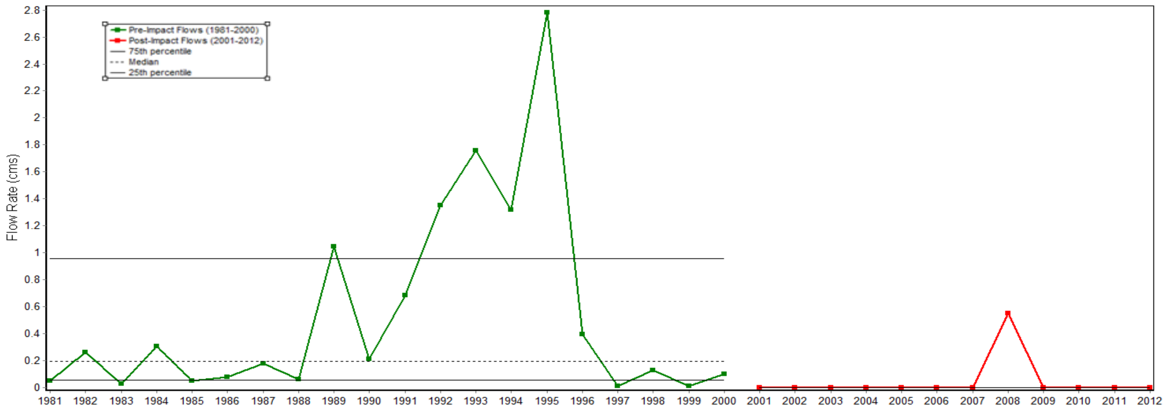

Figure 7. Comparison of the 7-days Minimum flows before (green line) and after (red line) the dam operation.

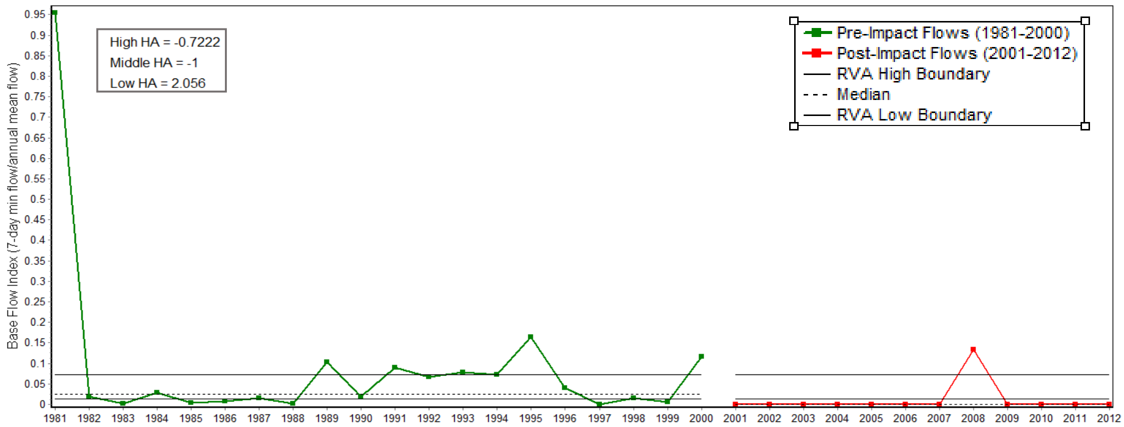

Figure 8. Comparison of the base-flow Index before (green line) and after (red line) the dam operation.

Base flow which is an important component of the streamflow especially in arid basins. Base flow Index (BFI), is defined as the ratio of annual base flow to the total annual run-off that and can be interpreted as contribution of ground-water discharge into a river. In general, the low BFI of the Gadar River shows the little dependency of the river flow to groundwater compared to the high runoffs, which usually occurs in early spring as a result of snow melt.

Decrease in BFI of the Gadar River from 2001 to 2012 as a result of water diversion to the Hasanlu Dam, reveals the fact that not only the mean annual runoff of the river has been declined after flow diversion (as displayed in fig.3), but also the minor inflows from ground water into the river has been approached zero in the last decade. The zero base flow of the Gadar River was reported in more than 90 percent of the post-dam period, whereas in the natural flow condition only in 3 out of 20 years such a situation had been observed (Fig.8).

As depicted in Fig. 9, before operation of the Hasanlu dam extreme low flows lasted typically less than 120 days, but since then it has been increased to more than 180 days a year. Obviously, extended period of extreme low flows can significantly change biodiversity of the rivers flora and fauna in an unpredictable way. The amount of extreme low flows has been also decreased by almost 90 percent (from 2.25 m3/s to 0.25 m3/s) after operation of the Hasanlu dam (Fig. 9). However, the average frequency of extreme low flows has been remained quite unchanged after regulation of the river.

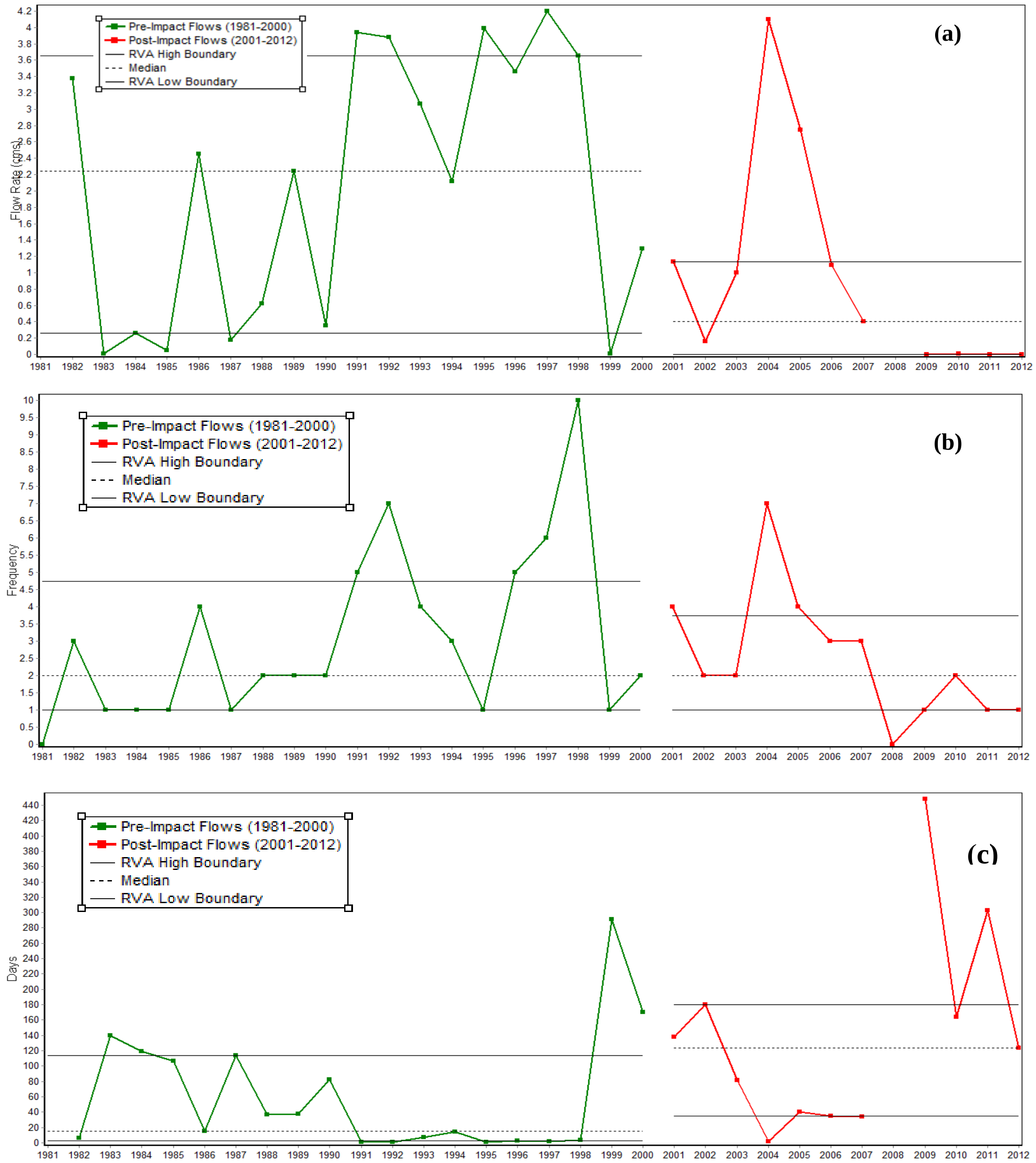

Figure 9 . Comparison of the (a) Mmagnitude, (b) Frequency, and (c) Duration of extreme low flows before (green line) and after (red line) operation of the Hasanlu reservoir.

When analyzing changes in the amount of high flow pulses, a slight decrease can be detected (Fig 10.a). However, both the frequency and the duration of high flows has been considerably influenced by the dam operation in 2000 and have been reduced in the post-dam period (Figs 10.b, c). Flood flows was occurred with the frequency of occurrence between 1 to 5 times per year (with an average of 3 times per year), whereas in the regulated flow period it has limited to 2 times per year in average. Furthermore, while peak flows lasted between 3 to 75 days before operation of the dam, their duration has been never exceeded more than 10 days, in the past decade. Peak flows provide variety of ecological functions which are vital for river, floodplain, riparian ecosystems including protection of plant habitats in the riparian zone and floodplain, improve connectivity between upstream and downstream habitats, providing suitable habitats for spawning and rearing of fish species, refreshing water quality conditions and helping transfer nutrients (e.g. Poff et al., 1997, Mathews and Richter, 2007). Reduction of flood flows, whether in their amount, frequency or duration, degrades or eliminates many of these functions. Moreover, such modifications in river systems can alter ecological communities and facilitate invasion of non-native species (Poff et al.,1997), and lead to a variety of negative geomorphological consequences (Magilligan et al., 2003). Flood flows are particularly important for the downstream wetlands which are highly dependent on such flows for flushing.

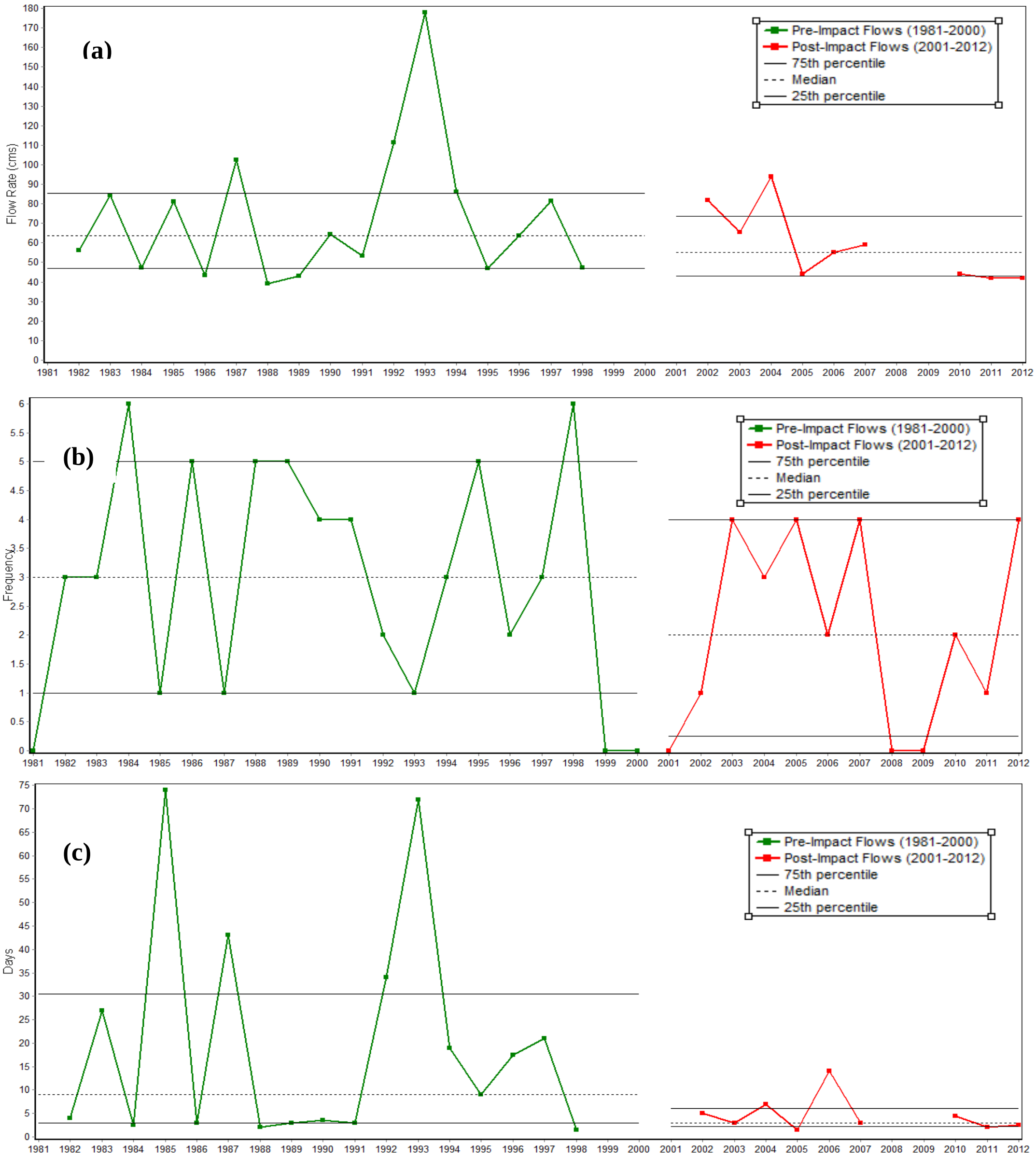

Figure 10. Comparison of the (a) magnitude, (b) Frequency, and (c) Duration of high flow pulses before (green line) and after (red line) operation of the Hasanlu reservoir.

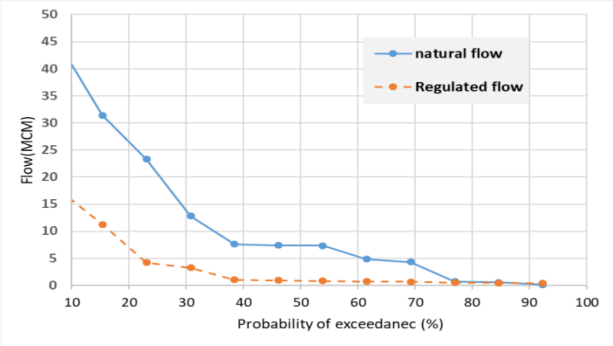

Figure 1. Comparison of Natural (Solid line) and Regulated (dash line) Mean Annual Flow Duration Curve (FDC) of the Gadar River.

As illustrated in Fig.11, The FDCs of the pre and post-regulation period are cross each other at about 85% exceedance probability, which causes near-zero eco-surplus volume. This means that after operation of the Hasanlu reservoirs, the volume of the river has been significantly decreased. It is usually expected that reservoir construction lead to an increase in the low flows (having high exceedance probability) of a river. However, in the case of the Gadar River, because of the concurrent development of the irrigated agriculture and the Hasanlu drain, dramatic diversion of water from the river channel has been occurred. This overexploitation of the water makes the river totally dried up in dry seasons. The amount of eco-deficit is about 218 MCM which can be interpreted as the total deficit in the volume of river compared to its natural ecological regime during the 11 years.

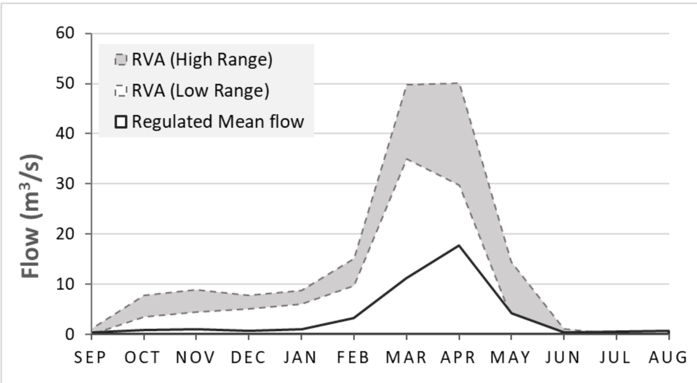

Figure 2. Comparison of the mean flow of Gadar River after operation of the Hasanlu Dam to the flow range proposed by the RVA method as environmental flows of the river.

When analysis of the hydrologic alternation was completed trough the RVA method, there is possibility to calculate the proper flow range for the sake of preserving the sustainability of the river environment. The recommended range for the river flow is depicted by a gray bound in Fig.12 and are supposed to be considered in the reservoir operation or flow diversion. Although keeping flow in this range does not guarantee the entire ecological health of the river and its relevant ecosystems, it can improve at least hydrologic condition of the river through the fulfilment of RVA criteria. The hydrograph of the average flow of the Gadar River during the post-dam period indicates that it is far beyond the proposed range. Therefore, there is an urgent need to revise the operation rules of the dam and adapt the flow diversion from the river so that the ultimate flow of the river after abstractions remain within the RVA suggested range.

4. CONCLUSIONS

Like many watersheds in the world, water resources of the Urmia Basin has been under extreme pressure during the past decades by the compound effect of increased water demands and arid climate. Almost all permanent rivers in the basin have been regulated by dams to supply water for agriculture. the Gadar River in the south part of Urmia Lake supplies about 9% of the lake and is an important source of water for the satellite wetlands at the region. Dramatic changes has been occurred in the natural flow regime of the river, since the operation of the Hasanlu dam in 2000. In this study the hydrologic alternation of the river flow in the post-dam period were investigated using the RVA and Eco-deficit methods. Main changes observed in the flow pattern include occurrence of more frequent zero flows, increase in the duration of low flows, considerable decrease in the frequency and duration of the high flows, and the decreased base flow index. Moreover, results of eco-deficit/surplus curve indicated that not only the reservoir operation has been no eco-surplus but also it causes an average eco-deficit of 218 MCM/y.

To modify some of these changes it is required to revise both the flow diversion volume from the Gadar River and the rule curve of the reservoir for the sake of the river ecosystem sustainability through considering environmental flows of the river and its relevant ecosystem. Beside active management action, implementing environmental flows also required restrictive flow management strategies for example through reducing the abstractions for irrigation. Application of active management will help to preserve the key components of flow regime, including low flows and floods. On the other hand, restrictive flow management policies can ensure that enough water is left in the river, particularly during dry periods, by controlling abstractions and diversions. Both types of interventions depend on people changing their behavior, and should be based on an informed decision that has broad societal support.

5. REFERENCES

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