HYDROPOWER DAM AND HYDROLOGICAL ALTERATION ON THE DA RIVER IN SON LA, VIETNAM

Chao Thi Yen[1], Lorenzo Picco[1], Bui Xuan Dung[2], Tran Quang Bao[2]
[1]*University of Padua, Padua, Italy*
[2]*Vietnam National University of Forestry*

SUMMARY

The Da River basin, the largest tributary of the Red River, has experienced a rapid development of hydropower dams, of which Son La hydropower plant is the biggest and the most complex dam project ever built in Vietnam. The study was aimed to examine the hydrological alterations after the construction of Son La hydropower dam in downstream of the Da in pre- and post-dam period. The flow regime information from 1961 to 2016 was obtained from the Vietnam Meteorological and Hydrological Administration. The hydrological alteration was quantified by using IHA (Indicators of Hydrologic Alteration). The Kruskal – Wallis test was applied to examine the changes of hydrological regime between pre- and post- dam period. The results showed that 4 groups of IHA had significant change and one group had no significant difference in pre- and post-dam period. Particularly, the flow in rainy season decreased between 5% and 43% and increased average 71.6% in dry season in the post-impact period. Minima and maxima of 1-, 3-, 7-, 30-, and 90-days flow had a broad fluctuation with a reduction of mean flow between 37% and 90%, except 30- and 90-day minimum having an upward trend of 6% and 129%, in the order. The low and high pulse count increased 40% and 100% in post-2010, respectively, whereas the low pulse duration decreased 60% in the post-dam period. Fall rate had greater fluctuation than rise rate with an increase of 123% compared to the change of +57%, in the order.

Keywords: Da river, hydrology, hydropower dam, water flow.

1. INTRODUCTION

The development of hydropower dams and the changing of climate have altered the river ecosystems (Khoi & Hue., 2012; Sadek, 2012; Ty, 2014; Marcinkowski & Grygoruk, 2017). Hydropower dam construction used to be considered a symbol of nation-building and national pride for the growth of many developed countries before 1975 (Ty, 2014). By the end of the 20th century, there were over 45000 large dams in the world, built across 140 countries (Nhung, 2017) as the hydropower dams provide human benefits in energy production, flood control and agricultural drainage (Ty, 2014; Nhung, 2017). According to Ty (2014) hydropower plants cause huge environmental and social costs that far outweigh any benefit dams provide to society. Marcinkowski& Grygoruk (2017) stated that dams influence all elements of the riverine ecosystems and the influence of dams was reportedly several times greater than the influence of climate change. The operation of dams or any water infrastructure disrupt the natural water movement and change significantly the hydrological indicators (e.g. rise and fall rates of water, flood extent and extreme water levels) (Dang et al., 2016). They modify hourly and daily discharge, adjust seasonal flow regimes, alter water temperature, water quality, magnitude, and change the rate of specific flow regimes, sediment transport and river channel sedimentation/erosion balance, riparian vegetation and active channel areas (Magilligana & Nislow, 2005; WeiHu et al., 2008; Dang et al., 2016; Marcinkowski& Grygoruk, 2017). Moreover, fish and macroinvertebrate communities are also affected by the changes in longitudinal connectivity, unstable flow regime, water temperature and the trophic structure of those species (Cooper et al., 2016).

As such, the impacts of water infrastructure on riverine ecosystems have been widely studied in the world (Dang et al., 2016). The effects of dams on hydrologic conditions in the main rivers in America were well-documented by Magilligana & Nislow (2005) and Graf (1999 & 2006). In China, a numerous of literatures early reported the dams impacts on hydrological processes and ecosystems. Yan et al., (2010) accessed the effects of dam operation on flow regimes in the lower Yellow River. Zuo & Liang (2015) using IHA/RVA to determine dam impacts on river flow in Shaying River. In Europe, a majority of studies on dam impacts has been carried out spaciously. For example: In Germany, Schmidt and Wilcock (2008) carried proposing three metrics (the shift in balance between sediment supply and transport capacity, the postdam stream competence and potential for channel incision, and the relative reduction in flood magnitude) for accessing the downstream effects of dams. All of the studies showed significant impacts of the dam construction to downstream hydrologic ecosystem.

In Vietnam, the river network is very dense and complex, with most of the large river system linked (Jakob & Khemka, 2017). The number of rivers and canals in the country was approximately 2,360 with total length of 220,000 km (Jakob & Khemka, 2017; World Bank, 2011). Thanks to the diverse river system, the hydropower construction has been developing rapidly especially after 1945 since independence (Ty, 2014). In 2014, the number of hydropower dams in Vietnam was 450, of which 268 dams have been operated for electricity (Nhung, 2017). This number of dams is projected to increase in the future (155 more available potential location for hydropower construction) to meet the predicted demand of electricity consumption (Ty, 2014), which is expected to increase 1.6 times by 2020 (contributing 23.1 percent of the country's electricity supplies), and 4.5 times by 2030 (Nhung, 2017). The hydropower dam development is not only a good solution for energy requirements but also helpful in regulating stream flows, and controlling floods and droughts in downstream areas (Nhung 2017; Yang & Chen, 2014). However, recently, hydropower has become an issue in political forums, mass media, academia, social and environmental movements, and daily conversation in Vietnam (Ty, 2014). People from different sectors of Vietnamese society have raised questions of whether hydropower is a clean and sustainable energy as it leads to adverse consequences on society and environment (Ty, 2014; Nhung, 2017). Hydropower is related to the loss of land area and valuable ecosystem (Ty, 2014). Over 620,000 ha of land has been lost, in which small hydropower dams accounting for 6% of this total. Hydropower also displaces and deteriorates the resettled people's living standards. The hydropower development is predicted to displace approximately 300,000 people (approximately 0.3% of the total population), of which 90% are poor ethnic minority groups who rely on forest and agriculture livelihoods (Ty, 2014). Hydropower is now not a pride, it is a fear, said Ty (2014).

The Da River (or black river) is one of the three tributaries of the Red River basin which has the second largest basin area (155,000 km^2) and total volume of water flow in Vietnam, after the Mekong River basin with the area of 795,000 km^2 (Hanh & Dong, 2008; Rossi, 2016). In terms of water flow, Da River is the largest tributary of Red River basin among Thao River and Lo River. Increasing the demand for water leading to an increase of the number of reservoirs. According to Rossi (2016), several reservoirs have been built and operated since the 70s, those reservoirs play an important role not only in hydropower production but also in flood control and water supply for irrigation, domestic use, and industries in the river delta. As the largest tributary with the highest total volume of water flow in the Red River basin, on the Da River, there two large multi-purpose reservoirs were constructed, Son La and Hoa Binh, one is under construction in Lai Chau. Son La hydropower dam, was built in 2005 and started operating in 2010, is the biggest in Vietnam in terms of power generation with a total design capacity of 2,400 MW (Rossi, 2016). Due to climate change and human interventions, the Da River has been disturbed by an increase in frequency and severity of floods, and the rapid expansion of reservoirs (Ha et al., 2013).

Water infrastructures have those negative and positive influences on the river, the surrounding ecosystems and water flow. Therefore, the main objective of the study is to understand the influence of Son La dam construction on downstream flow regime through the Indictors of Hydrologic Alteration analysis.

2. MATERIALS AND METHODS

2.1. Study site

The research was conducted on the Da River, the largest tributary of Red River basin, particularly in the reach crossing Muong La district, Son La, Vietnam. The river's total length is 910 km and the basin area is 52900 km^2. The Da River yields substantial hydroelectric power for the Vietnamese electricity industry. At this river, Son La hydropower plant, the largest hydropower dam in Vietnam was built in 2005 and started operating in 2010.

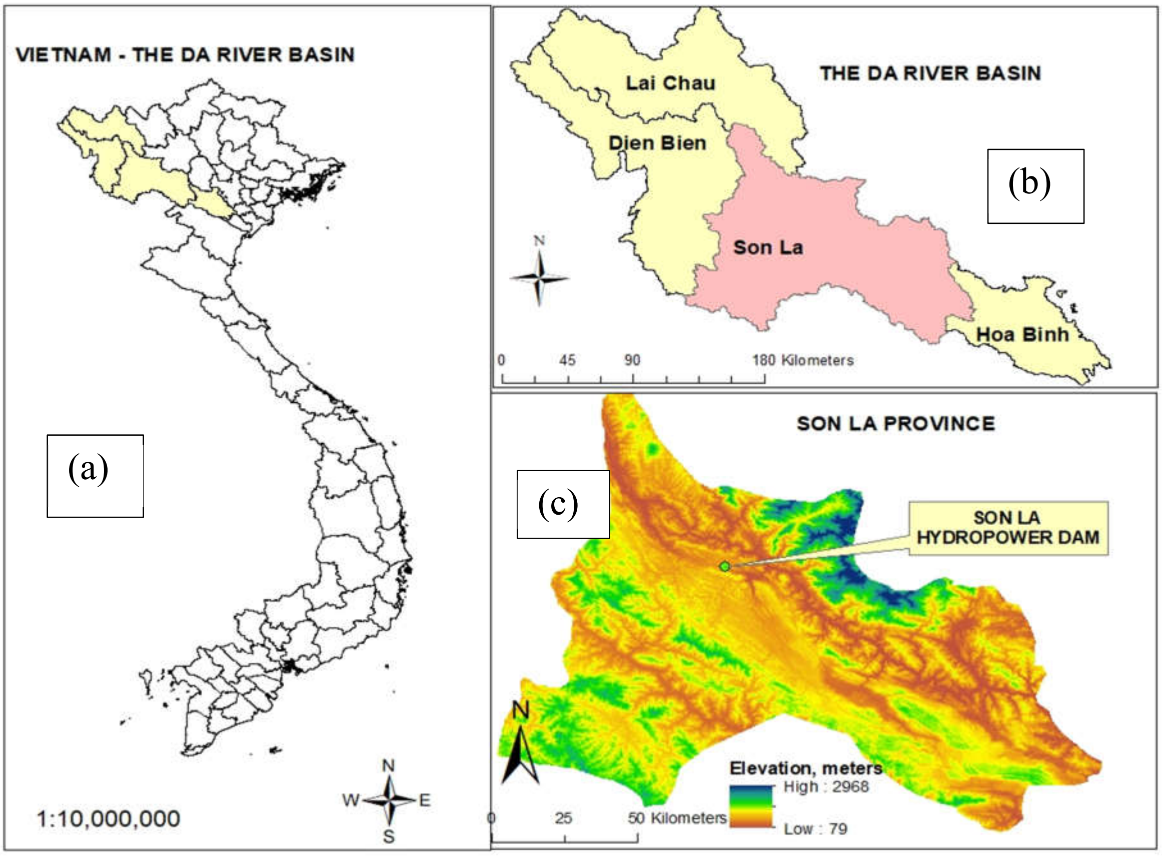

Figure 1. The study area map: (a) The Da River basin in Vietnam; (b) The Da River basin area and; (c) Son La Province topography map in which the hydropower dam located.

2.2. Methods

Because of the external factors, the data was collected by using 56-year hydrologic data from the Vietnam Meteorological and Hydrological Administration. The input data is the daily discharge (Q) observed at Ta Bu station, which is located in downstream of Son La hydropower dam. Flow discharge variation was evaluated by non-parametric analysis in two periods: Before dam construction and after dam construction (from 1961 to 2016). Each of the period was divided into dry season which is defined from November to April of next year and flooding season which lasts from May to October.

IHA, a software developed by scientists at the Natural Conservancy (NC), is common used to access the hydrologic alterations preand post-development of hydropower dams and/or any type of water infrastructure. It calculates total 67 statistical parameters including 34 Environmental Flow Component (EFC) parameters and 33 ecologically relevant hydrologic parameters and accesses the changes by using the parameter of magnitude, frequency, duration, timing and rate of change (WeiHu et al., 2008; Dang et al., 2016; Huong, 2016). The IHA is divided into five groups (Table 1) (NC, 2009).

Group 1: Monthly flow indices: The group, consists of 12 indices corresponding to the monthly average flow of water, provides a summary of the annual flow and reflects the monthly hydrological conditions as well as annual flow trend of variation.

Group 2: Extreme flow indices: The group includes 11 indices corresponding to the average of 1-, 3-, 7-, 30-, and 90-day minimums and maximums in the year. Moreover, the base flow of the year is determined by the ratio of 7-day minimums and the annual average flow.

Group 3: Timing indices: The group consists of two indices corresponding the extreme minimum and maximum of the year. If the water year with the same flow value is recorded in multiple days, the earliest date is reported.

Group 4: High-flow and low-flow indices: The groups comprises of 4 indices correlated to number of high pulses, number of low pulses, duration of high pulse and duration of low pulse. A day can be classified as a pulse if it is greater than or smaller than a specified threshold.

Group 5: Rising and falling indices: The group encompasses three indices correlated to rise rates, fall rates and reversals. Reversals are computed by dividing the hydrologic record into "rising" and "falling" periods corresponding to periods in which daily flow changes are respectively either positive or negative.

The parameter “Number of zero-flow days” was not used in this study, because no zero flow event occurred during 1961 to 2016 in the Da River. Hydrologic alteration parameters used in this study were, therefore, 32 as according to Table 1. They were calculated by using non-parameter statistics which give the median, percentile and are useful because of the skewed (non-normal) nature of hydrologic dataset in two period analysis.

The hydrological alteration is determined by IHA in four steps (WeiHu et al., 2008; NC, 2009; Huong, 2016).

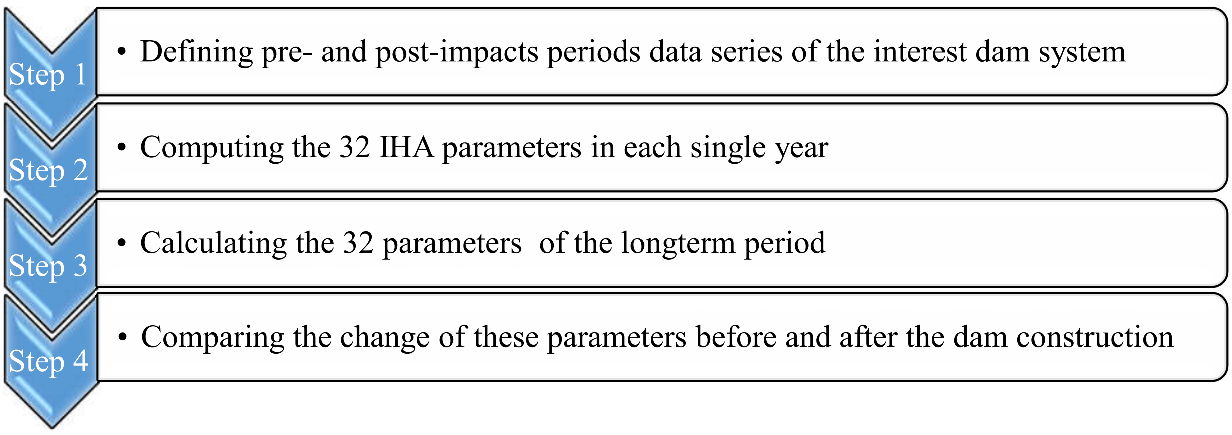

Figure 2. IHA calculation process

The statistical significance of changes between pre- and post-impact periods was tested by using non-parametric Kruskal – Wallis test that is commonly used to compare two or more independent samples with different sizes.

Table 1. Characteristics of the 33 IHA parameters (NC, 2009)

IHA Parameter Group	Features	Hydrological Parameter
1. Magnitude of monthly water conditions	Magnitude, timing	Mean or median value for each calendar month
2. Magnitude and duration of annual extreme water conditions	Magnitude, duration	Annual minima, 1-day mean Annual minima, 3-day means Annual minima, 7-day means Annual minima, 30-day means Annual minima, 90-day means Annual maxima, 1-day mean Annual maxima, 3-day means Annual maxima, 7-day means Annual maxima, 30-day means Annual maxima, 90-day means Number of zero-flow days Base flow index: 7-day minimum flow/mean flow for year
3. Timing of annual extreme water conditions	Date of the maximum and minimum flow	Julian date of each annual 1-day maximum Julian date of each annual 1-day minimum
4. Frequency and duration of high and low pulses	Number and duration of high pulses and low pulses	Number of low pulses within each water year Mean or median duration of low pulses (days) Number of high pulses within each water year Mean or median duration of high pulses (days)
5. Rate and frequency of water condition changes	Rise rate, Fall rate and Reversals	Rise rates: Mean or median of all positive differences between consecutive daily values Fall rates: Mean or median of all negative differences between consecutive daily values Number of hydrologic reversals
		Total 33 parameters

3. RESULTS AND DISCUSSION

By analyzing the variation of daily discharge from 1961 to 2016, the result showed that the most fluctuation was observed in the period of post-Son La dam construction (2010 to 2016) as flow was more increased in dry season and more decreased in rainy season (Figures 4 and 5).

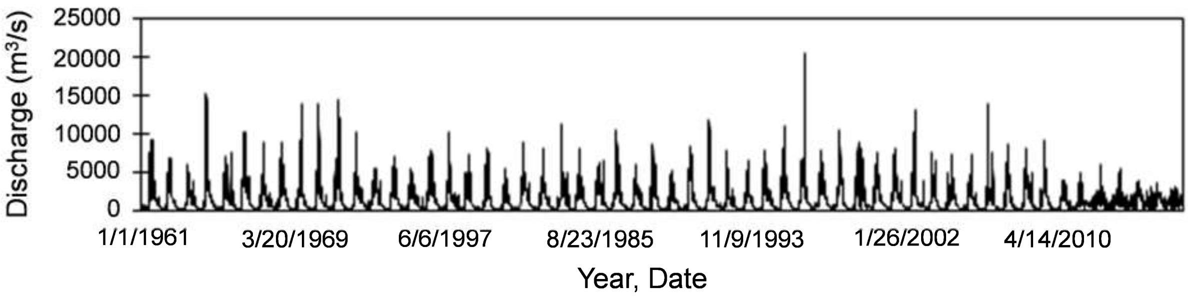

Figure 3. 56-year daily flow variation (1961 – 2016)

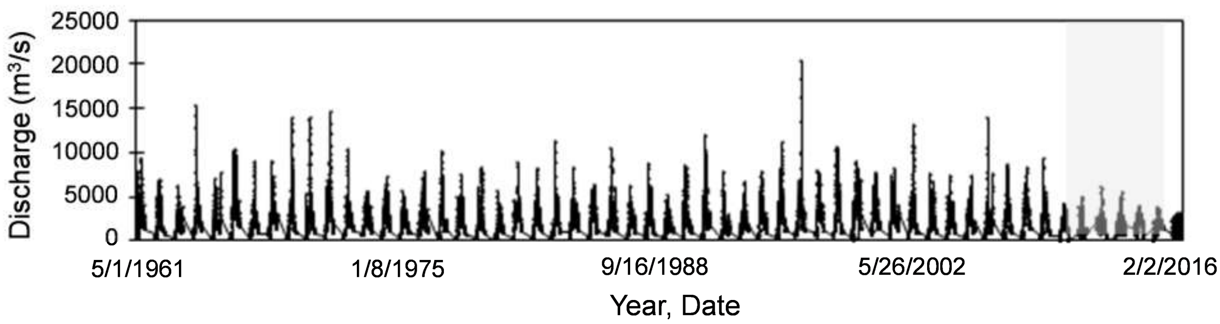

Figure 4. The variation of rainy season flow (1961 – 2016) - more fluctuated (decreased) after 2010 (shaded area)

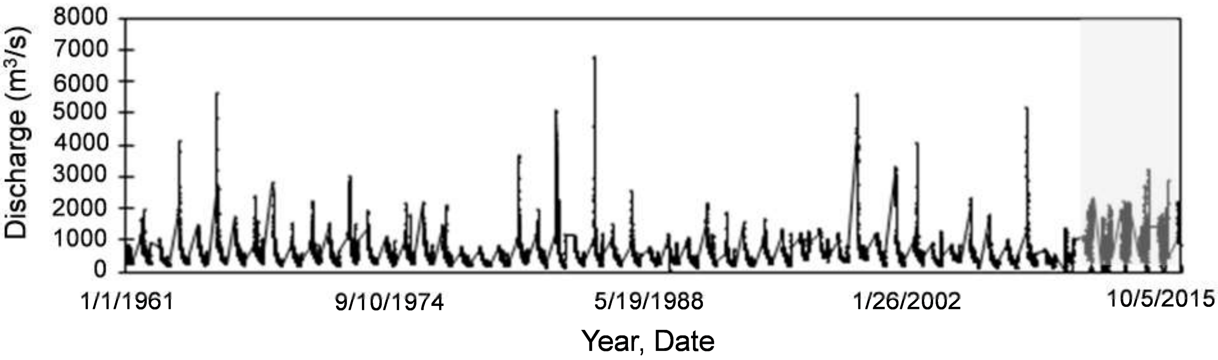

Figure 5. The variation of dry season flow (1961 – 2016) – more fluctuated (increased) after 2010 (Shaded area)

The Son La dam was officially operated in 2010, as such the fluctuations in the period of post-dam was greater than pre-dam period (Figure 3). Therefore, we analyzed the impact of the dam by using a 20-year daily flow data (from 1997 to 2016) from Ta Bu station which is located at the downstream of Son La dam. The mean daily flow data was divided into pre- and post-impact data series, of which the data from 1997 – 2009 was pre-impact and 2010 to 2016 was post-impact.

(1) Group 1: According to the IHA analysis (Table 2), the mean flow in all 12 months has altered in post-impact period, the change is apparently separated in two seasons, of which the mean flow in dry season (November to April of the following year) increased and the mean flow in rainy season (May to October) decreased. However, the difference between pre- and post-2010 was only significant in some months as indicted by Kruskal-Wallis test (Table 2). In dry season, the mean flow in April, March and February was the most altered with an increase of 171% (p>0.05), 98% ($p \leq 0.001$) and 55% (p>0.05), respectively. The monthly mean flow change in January, November and December also ranged between 24% and 46% with a p-value greater than 0.05 (no significant difference in statistics meaning). In rainy season, the most altered months were May, July, June and August with an increase of 61% ($p \leq 0.05$) in May and a decrease of 43% ($p \leq 0.001$), 25% ($p \leq 0.05$), and 24 %($p \leq 0.01$) in July, June and August, in the order. October was the least altered hydrological month as it decreased 5% (p> 0.05). In overall, in the post-2010 period, the mean flow in dry season (dry season months) increased and the mean monthly flow in rainy season decreased (Figure 6).

Table 2. Alteration of 32 IHA parameters and Kruskal-Wallis test

IHA parameter group	Mean		Mean (% percentage change)	Significance count[a]	Kruskal-Wallis test[b]
	Pre- impact (1997-2009)	Post-impact (2010-2016)			
1. Monthly magnitude					
January	490	713	223 (+46)	0.02503	ns
February	422.5	654.5	232 (+55)	0.02903	ns
March	360	712	352 (+98)	0.003003	***
April	407.5	1105	697.5 (+171)	0.004004	ns
May	744	1200	456 (+61)	0.03303	*
June	1940	1450	-490(-25)	0.2733	*
July	4330	2460	-1870 (-43)	0.02903	***
August	3810	2900	-910 (-24)	0.07207	**
September	2175	1665	-510 (-23)	0.2022	ns
October	1290	1220	-70 (-5)	0.7377	ns
November	844	1050	206 (+24)	0.2482	ns
December	590	805	215 (+36)	0.1572	ns

IHA parameter group	Mean		Mean (% percentage change)	Significance count[a]	Kruskal-Wallis test[b]
	Pre- impact (1997-2009)	Post-impact (2010-2016)			
2. Magnitude and duration of annua extreme					
1-day minimum	206	20.7	-185.3 (-90)	0.1181	***
3-day minimum	233	29.3	-203.7 (-87)	0.01201	***
7-day minimum	241.4	71.87	-169.53 (-70)	0.02402	***
30-day minimum	308.8	328.1	19.3 (+6)	0.7097	ns
90-day minimum	358.8	820.1	461.3 (+129)	0.003003	***
1-day maximum	8340	4140	-4200 (-50)	0	***
3-day maximum	7667	4013	-3654 (-48)	0	***
7-day maximum	6746	3927	-2819 (-42)	0.01201	***
30-day maximum	4978	3122	-1856 (-37)	0.005005	***
90-day maximum	4034	2497	-1537 (-38)	0.03904	***
Base flow index	0.1522	0.0467	-0.10549 (-69)	0.01301	**
3. Timing of annual extreme					
Date of minimum	113	104	-9 (-8)	0.2693	ns
Date of maximum	203	216	13 (+6)	0.07007	ns
4. Frequency and duration of high and low pulses					
Low pulse count	4	8	4 (+100)	0	***
Low pulse duration	12	3.5	-8.5 (-71)	0.1101	**
High pulse count	5	7	2 (+40)	0.004004	*
High pulse duration	7.5	3	-4.5 (-60)	0.1051	ns
5. Rate and frequency of change in conditions					
Rise rate	70	110	40 (+57)	0.1722	Ns
Fall rate	-40	-89	-49 (+123)	0.002002	**
Number of reversals	99	144	45 (+45)	0.003003	***

[a]Significant count: calculated by the IHA, it can be interpreted as a p-value in parametric statistics, however, in some infrequent situations, the significance counts are very small (can be zero) even no apparent difference between two values, that low significant counts are resulted from the low or zero deviation factor and the overall distribution contains a large number of values right at or very near the center of the distribution.

[b]Kruskal-Wallis test- significant code: ***: $p \leq 0.001$; **: $p \leq 0.01$; *: $p \leq 0.05$, ns: no significant difference

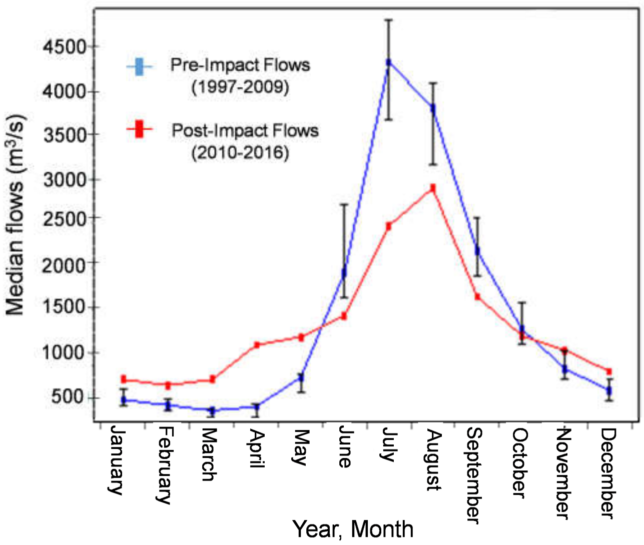

Figure 6. Monthly mean flow in pre- and post-2010 period

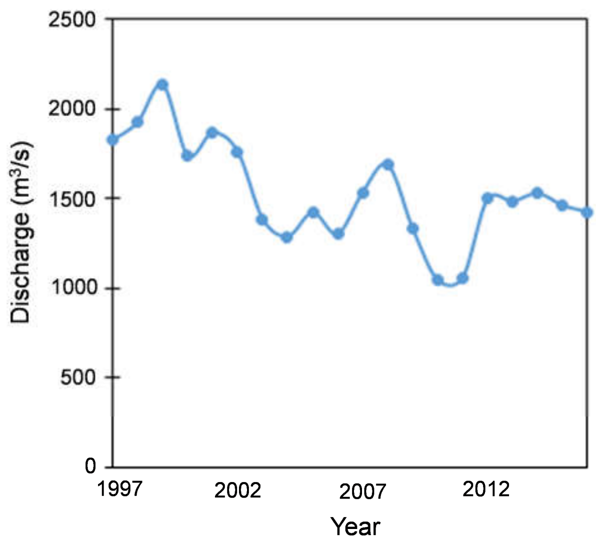

Figure 7. The flow variation during 1997 to 2016

The alteration was from the fact that, the Son La hydropower dam operates as an electricity and water supplier and flood controller. Nevertheless, the hydropower dam storages water at the end of rainy season and release water at higher volumes than natural flows in the dry season to extend the generation capacity of power. By release of a huge amount of water for electricity purpose gradually, the water flow downstream in dry season increased apparently compared to the case of river without anthropogenic interventions (Cochrane et al., 2014; Dang et al., 2016). A study carried out by Khoi & Hue (2012) on the impacts of hydropower dam development in China part of the Da also reported that the development of water reservoirs in 2006, 2007 and 2008 in China has altered the monthly magnitude downstream by increasing the mean monthly flow 2.3 times in dry season in the post-dam period (Khoi & Hue, 2012). In addition, the change of monthly mean can also be explained by the dramatical decrease of mean fow in 2010 - the first year of dam operation (Figure 7). Since the dam started operating, the flow of Da River was impounded leading to nearly a "no-flowing" river in downstream of the dam due to water storage requirement for operation of hydropower plant (Vietnamnet.vn, 2012).

(2) Group 2: Differences IHA parameters were the most significant among five groups. These parameters described the magnitude and duration of annual extreme water conditions. The HA values in this group decreased between 37% and 90% from the pre- to post-2010 period with significant level $p \leq 0.05$, ≤ 0.01 and ≤ 0.001. The only two indicators having an increasing trend were 30-day minimum and 90-day minimum with values of 6% ($p>0.05$) and 129% ($p \leq 0.001$), respectively. The most altered indicators were 90-, 1- and 3-day minimum with an increase of 129% ($p \leq 0.001$) in 90-day and a decline of 90% ($p \leq 0.001$) and 87% ($p \leq 0.001$) in 1-day and 3-day minimum, in the order (Table 2). The change was a result from the flood-control function of the dam. The Son La dam was designed with a flood-prevention capacity of 7 bn m^3, in flooding season, the dam storages the flood flow, slow down the high peak of flood and release gradually to protect downstream of the Da (MONRE, 2017).

(3) Group 3: Group 3 includes IHA parameters providing information about timing of annual extreme during 1997 to 2016 (Table 2). The Julian date, the order number of day of the hydrological year, was used to define the date of an occurred event. There was no significant difference in date of minimum and date of maximum between the two periods. It was noticed that, the date of minimum dropped from the day of 113 down to the day of 104, decreased 8% ($p>0.05$), and the date of maximum moved from 203 up to 216, increased 6% with no significant sign ($p>0.05$).

(4) Group 4: The parameters of Mean of low and high pulse count increased in post-2010 period, of which low pulse count increased from 4 to 8 representing for a positive change of 100% ($p \leq 0.001$) and the low pulse count increased 40% ($p \leq 0.05$) from 5 to 7. On the other hand, different results were obtained in the low and high flow pulse duration. Mean of these parameters were higher in the pre-dam period. The same as the case of Group 2, the variation might due to increasing of flood-control capacity of reservoir.

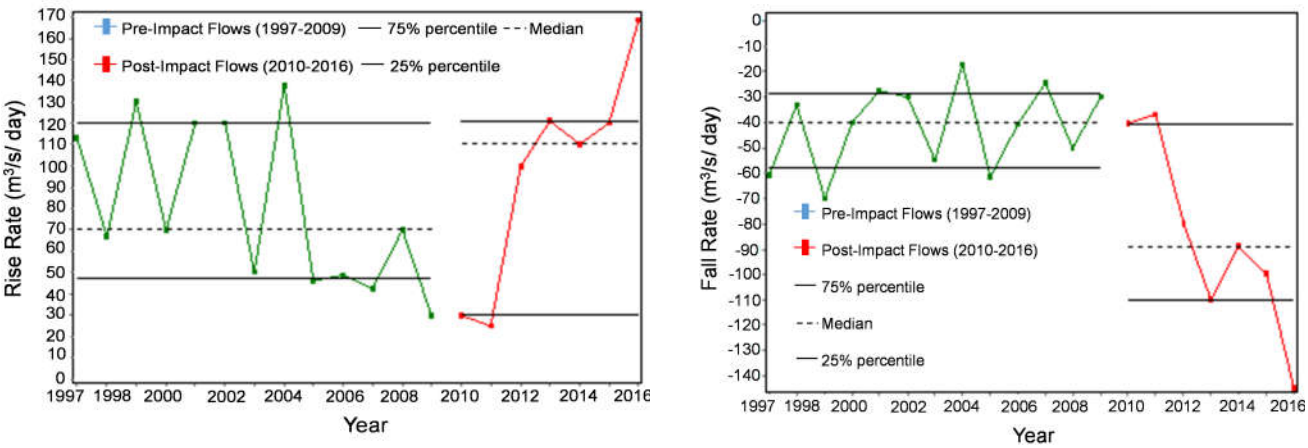

Figure 8. Rate and frequency of change in conditions

(5) Group 5: Both rising rate and falling rate had an increasing trend (Figure 8), of which the daily fall rate changed by +123% ($p \leq 0.01$) from 40 m^3/s/day to 89 m^3/s/day, and the rise rate altered by +57% from 70 m^3/s/day to 110 m^3/s/day, however, Kruskal test showed a no-significant change (*p>0.05)* between two periods. Number of reversals increased significantly with a mean increase of 99 fluctuations per year in pre- to 144 fluctuations per year in post-2010 period representing for 45% ($p \leq 0.001$) (Table 3).

Under the control of the dam during rainy season, the rising rate was expected to decrease in the post-dam period as the dam release water flow gradually (Cochran et al., 2014; Dang et al. 2016), however, the rise rate in the post-2010 period increased by 57%. The change might due to the rapid increase of flow during flood events leading to an over-storage capacity of the reservoir. The hydropower plant thus open the floodgate in order to protect the dam. According to Khoi & Hue (2012), the rapid development of water infrastructures in China disadvantaged the flood prediction downstream since those dams had no flood prevention function. The dams upstream of the Da storage water for electricity purpose from Mid-April to July. When heavy storms occur, these dams open the flood gates for the safety of the reservoirs, thus the huge unpredictable amount of water comes to downstream without any plan for flood control to protect the downstream of the river delta, downstream is also forced to release a large amount of water discharge (Khoi & Hue, 2012).

4. CONCLUSION

Son La dam notably affect hydrology in the Da River basin, originally through the change of 32 IHA parameters including the change in monthly magnitude, annual extreme magnitude and duration, timing of annual extreme, frequency and duration of high and low pulses, and rate and frequency of changing condition. The monthly mean flow increased between 24% and 171% in dry season, and decreased between 5% and 43%, of which April and July were the most altered months at 171% and 43% representing for dry season and flooding season, respectively. The minima and maxima of 1-, 3-, 7-, 30-, and 90-days flow had a broad fluctuation with a reduction of mean flow between 37% and 90%, except 30- and 90-day minimum having an upward trend of 6% and 129%, in the order. Low and high pulse count increased 40% and 100% in post-2010, respectively, whereas the low pulse duration decreased 60% in the post-dam period. Fall rate had greater fluctuation than rise rate with an increase of 123% compared to the change of +57%, respectively. There was no apparent difference in date of minimum and maximum between two periods.

After 2010, the number of hydropower reservoir upstream still increased (e.g. Lai Chau dam has been operated since 2016 and several dams have been built in China). The more dam construction could drive to the more environmental and economic problem downstream as changes of hydrological regime affect both river structure and species habitat and diversity downstream. Nevertheless, a strong collaboration among provinces and between Vietnam and China, and common management policy applied for the whole basin is urgently required. Besides, Son La hydropower dam should also improve its flood controlling and water supply functions for a healthier river in downstream.

REFERENCES

1. Cochrane, T. A., Arias, M. E. & Piman.T. (2014). Historical impact of water infrastructure on water levels of the Mekong River and the Tonle Sap system. *Hydrol. Earth Syst. Sci., 18, 4529–4541.*

2. Cooper, A.R., Infante, D.M., Wehrly, K.E., Wang, L. & Brenden, T.O. (2016). Identifying indicators and quantifying large-scale effects of dams on fishes. *Ecol. Indic. 61, 646–657.*

3. Dang, T. D., Cochrane, T. A., Arias, M.E., Van, P. D.T. & T de Vries. T. (2016). Hydrological alterations from water infrastructure developement in Mekong floodplains. *Hydrological Process*, 30, 3824-3838. DOI: 10. 1002/hyp.10894.

4. Graf, W. L. (1999). Dam nation: A geographic census of American dams and their large-scale hydrologic impacts. *WATER RESOURCES RESEARCH, VOL. 35, NO. 4*, PAGES 1305-1311.

5. Graf, W. L. (2006). Downstream hydrologic and geomorphic effects of large dams on American rivers. *Geomorphology, Volume 79, Issue 3-4*, p. 336-360.

6. Ha, N P N., Tu, D T.,Toan, N V., Mai, P T., Seng, S., Keartha, C. & Phyrom, S. (2013). River basin management in Vietnam: sectoral and cross-boundary issues.

7. Hanh, H D. & Dong, N T. (2008). The Current

State of River Basins in Vietnam Pollution and Solution. *The Third WEPA International Forum on Water Environmental Governance.* Malaysia.

8. Huong, N. T. (2016). Evaluating the impact of water infrastructure system on hydrological regime in the Ba River. *Undergaduate thesis, The University of Science, Hanoi, Vietnam*.

9. Jakob, C. & Khemka, R. (2017). Viet Nam: Hydro-Economic Framework for Assessing Water Sector Challenges. *2030 Water Resource Group*.

10. Khoi, H. V. & Hue, V.T.M. (2012). Research the effect of upstream reservoirs on china to flow regime of da river and thao river. *Hydrological and Environmental Science*, no.38 (9/2012).

11. Magliligan, F. J & Nislow, K.H. (2005). Change in hydrologic regime by dams. *Geomorphology 71*, 61 - 78.

12. Marcinkowski, P. & Grygoruk, M. (2017). Long-Term Downstream Effects of a Dam on a Lowland River Flow Regime: Case Study of the Upper Narew. *Water 2017, 9, 783* .

13. MONRE. (2017). Inspection of inter-reservoir operation in the Red River basin (in Vietnamese). *(http://dwrm.gov.vn/uploads/laws/file/2017/1884.pdf)*.

14. Natural Conservancy (2009). Indicators of Hydrologic Alteration Version 7.1 User's Manual. *The Natural Conservancy* .

15. Nhung, T. P. (2017). Impacts of Hydropower Development on Natural Resource Accessibility and the Livelihoods of Local People: The Case of Quang Nam Province in Vietnam. *ASEAN-Canada Research Partnership Working Paper Series Working Paper*, no.7.

16. Rossi, S. (2016). A vulnerability analysis of the red river basin, vietnam, under co-varying climate and socio-economic changes. *Master thesis*.

17. Sadek.N. (2013). Island development impacts on Nile River morphology. *Ain Shams Engineering Journal*, 25-41.

18. Schmidt, J C. & Wilcock, P R. (2008). Metrics for assessing the downstream effects of dams. *WATER RESOURCES RESEARCH, VOL. 44, W04404*, doi:10.1029/2006WR005092.

19. Ty, P. (2014). Dilemmas of hydropower development in Vietnam: between dam-induced displacement and sustainable development. Delft: Uitgeverij Eburon .

20. Vietnamnet.vn. (2012). The record of Son La Hydropower Dam. *(http://vietnamnet.vn/vn/thoi-su/nhung-ky-luc-o-thuy-dien-son-la-102008.html)*.

21. WeiHu, W., Wang., G., Deng, W. & Li, S. (2008). Influences of dams on ecohydrological conditions in the Huaihe River Basin, China . *Ecological Engineering 33*, 233 - 241.

22. WorldBank. (2011). *Vietnam Urbanization Review Technical Assistance Report.* Hanoi.

23. Yan, Y., Yang, Z., Liu, Q. & Sun, T. (2010). Assessing effects of dam operation on flow regimes in the lower Yellow River. *Procedia Environmental Sciences 2*, 507 - 516.

24. Yang, S. & Chen, B. (2014). Environmental Impact of Manwan Hydropower Plant on River Ecosystem Service. *The 6th International Conference on Applied Energy – ICAE2014.* Energy Procedia 61 (2014) 2721 – 2724 .

25. Zou, Q & Liang, S. (2015). Effects of dams on river flow regime based on IHA/RVA. *Remote Sensing and GIS for Hydrology and Water Resources*, (IAHS Publ. 368, 2015).

ĐẬP THỦY ĐIỆN VÀ SỰ BIẾN ĐỔI THỦY VĂN TRÊN SÔNG ĐÀ TẠI SƠN LA, VIỆT NAM

Chảo Thị Yến[1], Lorenzo Picco[1], Bùi Xuân Dũng[2], Trần Quang Bảo[2]

[1]*Đại học Padua, Padua, Italy*

[2]*Trường Đại học Lâm nghiệp*

TÓM TẮT

Lưu vực sông Đà - nhánh sông lớn nhất của lưu vực sông Hồng, đã trải qua sự phát triển nhanh chóng của các đập thủy điện, trong đó nhà máy thủy điện Sơn La là dự án đập lớn nhất và phức tạp nhất từng được xây dựng tại Việt Nam. Nghiên cứu nhằm mục đích đánh giá sự biến đổi thủy văn ở hạ lưu sông Đà trong giai đoạn trước và sau khi xây đập. Số liệu về chế độ dòng chảy từ năm 1961 đến năm 2016 được lấy từ Cục Khí tượng Thủy văn Trung ương. Sự biến đổi thủy văn đã được định lượng dựa trên các chỉ số thay đổi thủy văn IHA (Indicators of Hydrogic Alteration). Kiểm định Kruskal - Wallis được sử dụng để kiểm tra sự thay đổi của chế độ thủy văn giữa hai giai đoạn. Kết quả cho thấy sự thay đổi đáng kể của bốn nhóm thông số và một nhóm không có sự khác biệt đáng kể trong giai đoạn trước và sau khi xây đập. Cụ thể, dòng chảy giảm trong mùa mưa từ 5% đến 43% và tăng trung bình 71,6% vào mùa khô trong giai đoạn sau tác động. Giá trị dòng chảy cực tiểu và cực đại thời đoạn 1-, 3-, 7-, 30- và 90 ngày có dao động lớn với mức giảm lưu lượng trung bình từ 37% đến 90%, trừ dòng chảy cực tiểu thời đoạn dài 30 và 90 ngày có mức tăng lần lượt là 6% và 129%. Số lần xuất hiện xung thấp và xung cao cũng lần lượt tăng 40% và 100% trong năm 2010, trong khi đó khoảng thời gian xung thấp giảm 60% trong giai đoạn sau tác động. Cường độ giảm của dòng chảy tăng 123% và có biên độ giao động lớn hơn cường độ tăng của dòng chảy với mức tăng chỉ 57%.

Từ khoá: Dòng chảy, đập thuỷ điện, sông Đà, thuỷ văn.

Received	**: 20/3/2019**
Revised	**: 19/4/2019**
Accepted	**: 25/4/2019**