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Influences of Three Gorges Dam on Flow Regime of Yangtze River, China

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Abstract: The ecosystem of river is one of the most powerful forces of determination of hydrologic regime. The study emphasis and focuses that hydrological situation of river which has a significant impact on operation of sluices and dams. River Yangtze is chosen as a best specimen to analyze the power effects of the dams and sluices upstream on the hydrological regime. Hydrological station was set to examine the daily flows where periodical impacts of hydrological periods were distributed into two segments as pre and post-impacts. The variability rang of 33 flow coefficients were calculated on the basis of the IHA to compute the set task. The result of finding shows that dams have a powerful effect on hydrologic regime. The studies calculated the aggregate eco-hydrological targets of the river that give some support for ecosystem management and water resources of Yangtze River. Dams and sluices determined by hydrological alteration and to determine the effect of dams on the hydrological condition at the stream gauge site the hydrologic alteration was calculated.

Key words: Flow regime, hydrological alteration, ecosystem sluices and dam, management, flow coefficients, alteration

INTRODUCTION

The Three Gorges Dam (TGD) is the largest dam of the world located on the top of River Yangtze and possessing approximately 1 million km^2 drainage capacities (Gao *et al*., 2013). It is the world's largest hydropower generator. The Three Gorges Dam (TGD) has 50,000 reservoirs. Due to world's largest hydroelectricity plant, it is inviting the global interest while its upstream environmental origins play a leading role to attract the world's attention. The Yangtze is third longest and ninth largest river of the world. It is documented one of the most important rivers of the world (Changjiang). Various studies have been done on different features and facts of Yangtze but the impact of upper reached ecological flow of the Yangtze River on the hydrological regime has been ignored. Therefore, the impacts of upper reached flow of reservoirs need to be examined (Wang *et al*., 2018). Hydrological regime downstream is affecting Yangtze River directly. To examine hydrological variability the Range of Variability Approach (RVA) is a suitable technique that handles the critical role of hydrological variation. It is a helpful tool to enable river manager to define river management strategies likewise catchment restoration and reservoir operation rules (Richter *et al*., 1997). RVA is suitable method to river application that protect the biodiversity of natural ecosystem and conservation of native aquatic biodiversity. Yangtze River has a great potential to serve as the strategic navigation route between the East and West zone of the China. So, due to strategic routes it is marked top in all around the world. Hence, it's safe and resourceful transportation system got significant importance (Ding *et al*., 2017). Statistics shows that the constructed reservoirs on the Yangtze River are 45,694 with 1.59*1011 m^3 storage capacity that marked Yangtze's as the world's most

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extremely imputed river. Dams are main cause of the upstream and downstream of river hydrology and water ecology that require modification. The ecosystem of the river fundamentally depends on dynamic variations and can be determined predominantly by flow regimes with stable and integrate stream flow (Poff *et al*., 1997). Determining the fair ecological flow and examine the hydrologic regime are the significant subjects of water resources management. Natural flows of river transmuted and get disturbed by interruption of human activities in all around the world (Richter *et al*., 1997). Alterations in the flow regime of the Yangtze River is one existing example, of human interruptions. Energy source, biotic interaction, physical habitat and most important quality of water affected due to flow regimes variation as a result river's ecological integrity got destruction (Zuo and Liang, 2015). An important insight that thermal modification can be obtained by regional assessment and results of this assessment serves as a helpful device to monitor the biological efforts, dam operations, river regulation and management for Yangtze River. The dam's life time needed to be satisfied by the artificial and novel aquatic environment. The ground breading, quantity and quality of water affected by the interruption of dam's adjustments. The environmental, political, social and economic concerns of TGD raised. That's why projects like electricity power production plant and dirty Chinese coal burning power plants face conflict by opponent argument. The most consistent project argument of Yangtze River on its upstream and downstream is the vast scale of the social and environmental transformations of the watershed (Gleick, 2009). The general objective of the current study is to improve the understanding level regarding the effects of dam on river regime. The study having two more specific objectives that are: to analyze the temporal variability in hydrologic regime through hydrological parameters of Yangtze River and comparative analyze of two periods hydrologic regimes regarding to quantify the hydrologic alteration associated along with dam operation, respectively.

Literature review

River basin (Yangtze River): The Yangtze River starts from Tibetan Plateau and cross the sinuous route of West to East and scotch into East China Sea. The length and drainage area of Yangtze is around 6300 km to 1.8 million km^2, respectively. Due to its geographical features the basin has a huge amount of traded atmospheric moistures form East to South Sea of China. The basin due to its subtropical monsoon climatically characteristics infusing the spatial and temporal precipitation variation (Xu *et al*., 2008). The findings shows human's activities specially, the dams constructions on top are the main factor that determines the dynamic force of alteration in the flow and Hydrological regime of Yangtze over several decades of past it gets disturbed is just because of human activities. The top reach of Yangtze possessing two remarkable zones, the subtropical zone, frigid zone. Generally, zones cover to the monsoonal area in the Eastern China and the temperate area in Qinghai-Tibet plateau, respectively (Wang *et al*., 2018). The monsoon area and the climate are warm and humid with an average precipitation of 31-63 inches out of which 60-80% over runs during June to September in subtropical zone. From July to August wet season starts bringing excessive storm about 40% of the total rainfall of a year. There are two regular storm zones; Western sichuan zone; Bashan mountain zone. The average storm of Western Sichuan is around 6.9 days and the Bashan mountain zone has approximate 5.8-7.7 days average storm. The topographical storm intensity, local

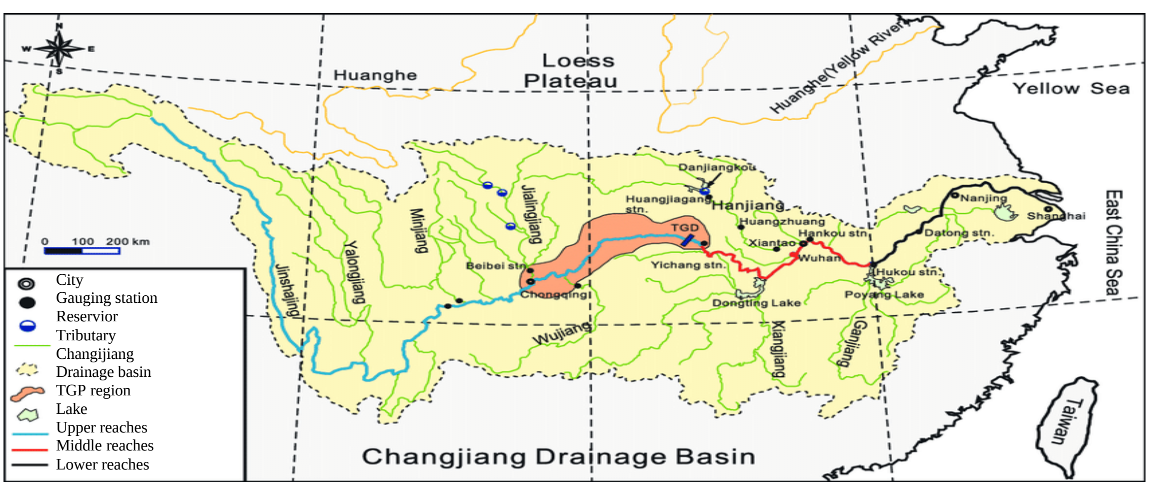

Fig. 1: Map of the Changjiang (Yangtze) River: TGD (Three Gorges Dam); TGP (Three Gorges Project)

and seasonal storm distribution has excessive effect on the sediment variation on the upper reaches of the Yangtze River shown in Fig. 1 (Yang *et al*., 2006).

Three Gorges Dam: The construction of TGD was consisted on three phase starts from 1993-1997, 1998-2003 and 2004-2011, respectively. The first phase contains the planning and preliminary constructions and major constructions of the dam and implementations of power generation have been covered in second phase, however,the third phase is persistent and comprises the completion of the supplementary facilities of its 19 years project conclusion. In 2003 the full fledge operation of TGD has been marked. During June 1st-10th 2003 upon conclusion of the second phase, TGD's early impoundment to improve the dam water level from 105-135 m. The middle reach of the Yangtze River situated 1118.4 miles upstream of the China which occupies 386102.1 square miles drainage regions and a total water storage volume of 39.3 billion m^3 and an adaptable storing capacity of 16.5 billion m^3 shown in (Fig. 1). TGD has lakes, basins and tributaries, it was constructed to produce hydropower, to minimize flooding and droughts in the middle and lower reaches of Yangtze River. Having gone through the TGD's theoretical seasonal process method (Suen, 2011; Yan *et al*., 2010), the reservoir sustains the lowest water level at 145 m for flood prevention from June-Sept. In declining flood season (October-December) the dam starts storing water at rising level up to 175 m. From (January to April) the reservoir water level decreases which is higher than 155 m in pre-April to ensure electricity generation and keep the needed navigable depth upstream. In May the water level declines to the partial water level at 145 m. during the flood recession TGD impoundment work as soldier because the large-scale water storing activities was inattentive during 2004-2005, however, water level of reservoir increased 135-156 m during 20 September to 27 October. Water level of reservoir increased 156,172.8, 170.9, 175 and 175 m from 2007-2011 (Yu *et al*., 2014).

While the technical achievements in building this monumental structure and making it function as designed are significant achievements, there are concerns about potential effects of the construction and operation of the dam and reservoir on the hydrological environment, aquatic and terrestrial ecosystems, regional climate and the lives of millions of people around the dam, in the lower reaches of Yangtze River and in Southeastern China. While most of these effects were estimated and their consequences assessed during the design stage for the dam, many of the dam's influences have just begun to be evaluated in recent years after the dam has been in operation. Most of these previous studies, e.g., predicting TGD's possible impacts on estuarine saline water intrusion (Chen and Haigeng, 1995; An *et al*., 2009) downstream nutrient and sediment transports (Duan *et al*., 2008; Wang *et al*., 2009) landslide deformation in the reservoir (Jiang *et al*., 2011) and downstream flood dynamics (Hayashi *et al*., 2008; Nakayama and Shankman, 2013) were based on TGD's theoretical operation mode. Since, 2003, there have been many studies attempting to analyze the actual impacts of TGD (vs. possible impacts of TGD estimated according to TGD's theoretical operation mode) on estuarine ecological anomalies (Jiao *et al*., 2007) and nutrient changes (Chai *et al*., 2009), downstream flow dynamics (Dai *et al*., 2008) landslide dynamics near the reservoir (Li *et al*., 2010) downstream water quality deterioration in Poyang lake (Wu *et al*., 2011) and sediment transports at the dam (Luo *et al*., 2012) in downstream (Yang *et al*., 2006, 2007) and along the whole river (Xu and Milliman, 2009; Li *et al*., 2011). Nevertheless, because of the long distance between TGD and the lower reach of Yangtze River and the complex impacts of multiple stochastic factors, except for the damming factor on river dynamics along the river, it is definitely hard to reject all stochastic factors and precisely evaluate the impact of river dynamics in upper stream on the downstream. Although, some efforts were made to reject the impact of stochastic climate change factor by comparing river dynamics downstream before and after TGD's impoundment in the ''analogous years'' with similar precipitation conditions (Guo *et al*., 2012).

Large dams could be a great way to modify the river flow regime and can create a series of consequences. Consequences are entitled, e.g., the absolute conversion of the flow system in the Nile River due to closeness of the Aswan Dam which led a sharp decline in life cycle of marine, added fuel to the coastal erosion by accelerating it and interruption of high water salinity (Stanley and Warne, 1993). At the downstream marine biology and flood regime get affected due to Itaipu Dam.

Agostinho*et al*. (2004) various schools of thoughts discussed that operation of the TGD initiative is another hazard a like Nile River met. The upper Yangtze River basin considered as one of the most advanced and developed regions in China by three hundred million local communities is just due to bio diversification. Flow regime modifications may considerably impact water supply and ecosystem health. Hence, it is very much crucial to understand the TGD influence on the downstream of flow regime. In order to define the features of flow regime variations a lot of clues have been put forward. The most standard technique the "Indicators of Hydrologic Alteration" (IHA) is widely used (Richter *et al*., 1996) In hydrologic condition the five critical mechanisms of river flow regime like frequency, intensity, derivation, timing and duration is shown by IHA metrics (Poff *et al*., 1997). The measurement of these matrices performed a vital role to know the hydrological modifications effects on

Table 1: Chronology of events: Three Gorges Dam Project (Gleick, 2009)

Years	Chronology of events
1919	"Plan to Develop Industry" is the first project of three Gorges held by Sun Yat-sen
1931	145,000 people were killed via. massive flooding of Yangtze River
1932	Construction of small dam at TGD was suggested by Nationalist Government
1935	142,000 people were killed by heavy flooding
1940s	One of reliable source US Bureau of reclamation that helps Chinese engineers to find a site
1947	Almost design work is terminated by Nationalist Government
1949	The revolution era of Chinese communist
1953	Mao Zedong developed the idea of dam construction on TG for flood control
1954	Flooding figured about 30,000 -10, 00000 dead and homeless individuals, respectively
1955	Soviet engineers performs a vital role in design and project planning
1958	Zhou Enlai is appointed by Mao for planning initiates
1959	Yangtze Valley Planning Office (YVPO) is an official site of dam identified by Sandouping
1966	Cultural revolution (1965-1975) is the factor of aggregate work termination
1976	Planning recommences
1984	Immediate origination of construction is recommended by Ministry of Water Resources and Electric Power
1985	Until 1987 resistance accrued in decision via. The National People's Congress. Due to economic complications
1986	The Canadian government finance a feasibility study on request of Chinese Ministry of Water Resources and Electric Power
1988	Water Control project of three Gorges feasibility is accomplished and early date construction is recommended by world bank and canadian government
1989	Democratic movement swings through China
1992	Politburo standing committee approved the project construction
1992	The "Resolution on building of the Yangtze River three Gorges project" was accepted by China's National People's Congress (NPC) where 177 delegates rejected the project, 644 gave up and 1767 accepted it
1992	In this period the Canadian Government stopped financial help for the development of project
1992	HRW 1995 Sichuan "the Democratic Youth Party along with 179 supporters protested against TG protest in Kai Country"
1993	An armed battle of three hundred persons happened in the surrounding of the dam (HRW 1995)
1993	Due to economic and environmental consequences the US Bureau of Reclamation lay off technical services agreements
1994	Migration program initiated
1994	Foundations of dams along with ongoing Excavation at Sandouping, the selected dam site
1994	The project under construction is formally confirmed by Premier Li Peng
1996	The US Ex-Im Bank on board voted against the project and highlighted the economic viability of dam along with social and environmental impacts
1997	an industrial consortium formed by General Electric Canada (VGS) with the collaboration of Germany's Voith and Siemens where 14 power generating units contract awarded by China to GEC Alsthom, ABB
1997	The China's State Development Bank signs $200 million commercial loan with Germany's Dresdner Bank, Kreditanstalt Fur\Wiederaufbau, and DG Bank to encompass exports credits
1997	The River Yangtze was dammed
1998-2002	Physical driving on left bank
2003-2006	Physical driving on right bank
2003	Completion data of water reservoir with its incremental record where 135 m increment of water is recorded in June
2003	Generation of first electricity
2006	Accomplishment of dam
2006	Operation of 14 700-MW turbine generators in north zone reach its full capacity in 2007
2008	Completion date of current measured
2009	Actual projected accomplishment period. 175 meters increase of reservoir estimated

Chronology of the internal political debates between 1955 and 1992

biodiversity of Yangtze River (Huang *et al*., 2011). Investigate the TGD influences on Yangtze River discharge and sediment erosion the researchers did their best till 2006 by applying the time series analyses (Dai *et al*., 2008).

In 2006 a study was done to highlight the influences of TGD and drought on the river discharge diminishes. Zhang *et al*. (2012) Concluded that initiative of the TGD has a great impact on sediment load rather than stream flow while observing monthly impacts of sediment and stream flow comparatively in the middle reach of the Yangtze River. A sharp sediment erosion declination is evaluated after operation of TDG initiative by Yang *et al*., (2007). Certain studies argued that hydrological processes may have significant effect on middle and lower stream of Yangtze River.

However, more investigation is required to understand the impacts of TGD on flow regime on its downstream to address the impact of flow regime at full capacity adequate knowledge need to be attempt (Gao *et al*., 2013) (Table 1).

IHA/RVA method: To meet economic and social development requirements for water resources and flood control, a huge number of water conservancy projects consisting of dams and sluices have been constructed along the rivers. Dams and sluices can bring a huge change by altering the downstream flow regime by affecting total flow quantity, water quality and the magnitude, seasonal timing, duration and change rate of specific flow events (Hu *et al*., 2008; Yan *et al*., 2010; Zuo *et al*., 2012). A number of ecologically important stream flow characteristics constitute the natural flow regime as well as the seasonal patterning of flows, timing of extreme flows, frequency, predictability and duration of floods, droughts and intermittent flows, daily, seasonal and annual flow variability and rates of change (Poff *et al*., 1997). Evaluation of these stream flow characteristics is vital for understanding and forecasting the biological influence of both natural and changed flow regimes on riverine biota. Accordingly, researchers have introduced and applied a number of hydrologic indices to describe several components of the flow regime. As one set of proposed hydrologic indices, the Indicators of Hydrologic Alteration (IHA) are extensively used which study a full range of natural flow variability, including magnitude, frequency, timing, duration and change rate, the 33 parameters of IHA were put into five categorized group of hydrologic features (Richter *et al*., 1996). In order to define the flow regime target with IHA, the Range of Variability Approach (RVA) was discovered to assess the hydrologic alteration caused by hydraulic control structures (Richter *et al*., 1997, 1998). The approach for assessing hydrologic alteration is grounded on the changes in the stream flow regime characteristics between two defined periods at a given stream gauge. The RVA approach offers a more and a better quantitative way to evaluate the degree of modification by giving a target range (e.g., the percent difference between the 25th and 75th percentile pre-impact indicator values) for each hydrologic indicator. Current RVA applications display high degrees of alteration at locations downstream of the hydraulic control structures (Shiau and Wu, 2004; Yang *et al*., 2008). Analyzing the hydrologic regime and defining the reasonable ecological flow are the key problems in water resources management. By studying the impact of dams on hydrologic regime alteration in the Yangtze River.

METHODS AND DATA

Analyze of flow regime variation at hydrologic section is based on the daily flow. The study attempted IHA/RVA method to investigate the continuous daily flow of more than 20 years of data. The data has been collected from hydrological data management department/station is one of the reliable source having annual hydrological reports. In this study the stream flow has been divided into segments pre and post period impacts in order to analyze the stream flow under natural conditions and changeable conditions, respectively. The consideration of the pre and post periods impacts to highlight the stream flow to address flow regime characteristics by applying the IHA/RVA method.

To measure hydrologic regime alteration the IHA method is significant. It includes 33 ecologically relevant

Table 2: Summary of hydrologic parameters used in the IHAs and their characteristics (Richter *et al*., 1997)

IHA statistic group regime	Hydrologic parameters	Characteristics
Group 1:		
Magnitude of monthly	Mean value for each calendar month	Magnitude
Water conditions		Timing
Group 2:		
Magnitude and duration	Annual minima 1-day means	Duration
Conditions of annual extreme water	Annual maxima 1-day means	Magnitude
	Annual minima 3-days means	
	Annual maxima 3-days means	
	Annual minima 7-days means	
	Annual maxima 7-days means	
	Annual minima 30-days means	
	Annual maxima 30-days means	
	Annual minima 90-days means	
	Annual maxima 90-days means	
Group 3:		
Timing of annual extreme water condition	Julian date of each annual 1 day maximum	Timing
	Julian date of each annual 1 day minimum	
Group 4:		
Frequency and duration of high/low pulse	No. of high pulses each year	Frequency
	No. of low pulses each year	
	Mean duration of high pulses within each year (day)	Duration
	Mean duration of low pulses within each year (day)	
Group 5:		
Rate /frequency of water condition change	Means of all positive differences between consecutive daily value	Rates of change frequency
	Means of all negative differences between consecutive daily values	
	No. of rises	
	No. of falls	

hydrologic parameters and five major categorical parameters in order to quantity hydrologic regime alteration (Richter *et al*., 1998). The IHA method has four stages. The first stage defines the data series for pre and post-periodical impact, second stage calculates the values of hydrologic attributes and third stage compute inter-annual statistics and last stage calculate the values of the IHA. The study evaluates the effects of dams operation upon river flow regime on the bases of the RVA and IHA method.

The RVA target range for each hydrologic parameter is usually based on the selected percentile levels or a simple multiple of the parameter standard deviations for the natural or pre-impact hydrologic regime. The management objectives are to accomplish the targeted range at the same frequency as occurred in the natural or pre-impact flow regime then evaluate the effects of dams and sluices on river flow regime and finally set management targets. For instance accomplishment of the RVA target range defined by the 25th and 75th percentile values of a particular parameter that would be expected 50% of years. To quantify the hydrologic alteration, Richter *et al*. (1998) divided the ranges of hydrologic alteration into three classes of equal range: 0-33% (L) represents little or no alteration, 34-67% (M) represents moderate alteration and 68-100% (H) represents a high degree of alteration (Table 2).

CONCLUSION

The aim of this study is to review thoroughly the operational and functional effects of TGD on flow regime. The study shows that hydrologic regime alteration has significant impact on natural flow regime as a result the undesirable ecological effects appears. The aim of the TGD construction and its operation is to control flood and generate electricity. It is predicted that significant cause of hydrological alterations can change the natural flow regime balance and consequent outcomes will appear in the nature of ecological effects. RVA Model applied to measure the hydrological regime alterations and spatial pattern of Yangtze River after consecutive operation. The study highlighting the influence of Three Gorges Dam on hydrologic regime alteration of Yangtze River .the daily record of flow has been taken from hydrological station along with deliberate time series pre and post periodical impact. The finding of the study confirmed that flow regime has substantial threats on wild species and consequently undesirable ecological effects resulted. Therefore, it is necessary to investigate the responses to hydrological regime alteration resulting from dam and sluice construction.

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