Mini Review
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Characterization of the effects of manantali dam on the hydrological regime of the Senegal river by the IHA/RVA method

Volume 2 Issue 6 - 2018

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Received: November 12, 2018 | **Published:** November 29, 2018

Introduction

Stream flow regimes are considered the main driving force of their ecosystem.[1] The stability of river ecosystems is largely dependent on the natural dynamic change characteristics of river flow.[2] The water resources management has led to a change in the natural flow of rivers around the world[3] that affects water quality, energy sources, physical habitat, and biotic interactions.[4] To conserve water, many dams have been built along waterways and regulate the flow of a river. This regulation by dams modifies the natural flow mode of the rivers. This characterization of natural regime can be done by a number of hydrological indices and methods taking into account not only hydrological parameters but also ecological parameters. A range of Variability Approaches (RVA) is widely used to characterize the variability of a stream's natural flow.[4] With a number of 33 hydrological parameters, the IHA/RVA method evaluates the degree of alteration and allows recording the effects of river management on its ecology. It has been applied to study the influence of the Manantali dam on the hydrological alteration of the Senegal River regime.

Material and methods

In this article, the fluvial flow of period 1951-2014 was divided into three series of which two on the pre-impact period of dam (1951-1970 and 1970-1988 respectively representing the flow in wet and dry natural conditions) and one on the post-impact period of dam (1988-2014) under controlled conditions. Over these two pre-impact and post-impact periods, the characteristics of the hydrological regime were examined using the IHA/RVA method. The IHA (Indicators of Hydrologic Alteration) method developed by The Nature Conservancy[3] has been used to assess hydrological features primarily associated with downstream dams[5] and alteration of the hydrological regime of rivers. This model calculates 33 ecologically relevant hydrological parameters that describe the hydrological regime and are grouped into 5 categories.[3] (i) amplitude, (ii) amplitude and duration of annual extreme conditions, (iii) periodicity of these extreme annual conditions, (iv) frequency and duration of high and low pulsations, (v) rate and frequency of flow variations.

Results and discussion

Influence on the hydrological regime

For the parameters of different groups, situation 1 (post-impact period relationship: 1988-2014 and pre-impact wet period: 1951-1970) is more or less opposed to situation 2 (post-impact period relationship: 1988 -2014 and pre-impact dry period: 1970-1988).

Group 1 settings

In situation 1 (post-impact period to pre-impact wet period), hydrologic alteration favors a decline in flows in all months except May. In fact, 50% of the months (August to December, March) recorded a high degree of hydrological alteration. March records the maximum degree of weathering at 100% and in September, the month of maximum flow on the series has an alteration of 80.8%. The positive hydrological alteration for the month of May and negative for the months of June, July and January is moderate. Only the months of February and April experienced a slight to no deterioration. Average monthly flows during the post-impact period indicate a downward trend from July to January. The rate of decline during post-impact period ranges from 38% to 151%. On other hand, from February to June, the differences are positive. The positive deviations in low water months and negative ones in the high water months result from the management of Manantali dam, in particular with the flood rolling action and low flow support. Nevertheless, positive deviations noted during high water months resulted from climate change and its consequent hydrological deficit.[6]

In situation 2 (ratio between post-impact period and pre-impact dry period), the degree of hydrological alteration is more variable compared to situation 1. Indeed, the alteration is positive from May to August and negative from September to April. In addition, it is generally low to nil (May to October), moderate in January and February, and high over the rest of the year. Maximum weathering is noted in November and March with 79.1%. Beyond August, the differences are positive over the 11 months and indicate an upward trend in runoff compared to that in the pre-impact period. This is explained by the releases of dam which support, in a context of drought and hydrological deficit, the low flows of river. In general, monthly flow fluctuations in both situations are less important in the post-impact period due to flood rolling and low-flow support.

Group 2, 3 and 4 settings

Extreme events were characterized by minimums and maximum flows, zero-flow days, base flow index, Julian date of maximum and annual minimum, number and duration of strong and weak impulses, rate of rise and descent. These parameters are given in groups 2, 3 and 4 of Table 1 and indicate a more or less homogeneous character between the 2 situations, contrary to group 1. The average annual minimum flow rates of 1, 3, 7, 30 and 90 days show a significant maximum decrease between the two periods in situation 1 and an increase in period 2. In situation 1, the values of maximum flow rates of post-impact period (1988-2014) were smaller than that of pre-impact period (1951-1970), in contrast to the minimum flow rates. On

situation 2, only maximum flow 90 days has a higher pre-impact value than post-impact. With respect to the hydrologic alteration in situation 1, minimum and maximum annual flows have high IHA categories (between 99.4% and 100%). Only maximum annual flow of 90 days has an average degree (-51.9%). On the other hand, in situation 2, only minimum flow rates register high degrees, while on maximum flow rates, alterations can be low to zero. The average number of strong and weak impulses over the pre-impact period is the same over the wet period (1951-1970) and the dry period (1970-1988). The same is true for the average number of weak impulses in the post-impact period (1988-2014), value being equal to 1. On the other hand, the average number of strong impulses in post-impact period (with a value of 1.5) was higher than pre-impact period. For strong and weak impulses, a significant decrease in duration is noted between post-impact period and the pre-impact wet or dry period (Figure 1). For situation 1, for example, the duration of strong impulses is 86 days in pre-impact period and 28 days in post-impact period. In situation 2, the duration of weak impulses is 126 days in the pre-impact period and 55 days in post-impact period. Finally, average rates of climb and descent are generally lower in the post-impact period (1988-2014) than in the wet pre-impact period (1951-1970) as well as in the dry period (1970-1988), in contrast to the number of occasions whose value increases. The rate of decrease of the average rates of rise and fall is respectively 48% and 1.6% between wet pre-impact and post-impact periods. On the other hand, between pre-impact and post-impact periods, the rate average descent knows an increase of 57%. This same increase is the number of recoveries whatever the situation considered, the rate of increase being 19.4% and 30% respectively on situation 1 and on the situation.

Table 1 Impairment level of the 33 hydrological parameters between the wet (1951 -1970) and dry (1970-1988) periods compared to the post-dam period (1988-2014)

	Situation 1 (between 1951-1970 and 1988-2014)					Situation 2 (between 1970-1988 and 1988-2014)				
Parameters	**Average values**				**Hydrologic Alteration (%)**	**Average values**				**Hydrologic Alteration (%)**
	1951-1970	**1988-2014**	**Average difference**	**Difference in%**		**1970-1988**	**1988-2014**	**Average difference**	**Difference in%**	
Group 1 IHA										
May	134,8	161,7	26,9	17	34,6	8,434	161,7	153,3	95	4,4
June	223,8	224	0,2	0,08	-51,9	123,1	224	100,9	45	14,8
July	614,9	419,3	-195,6	-47	-51,9	378,3	419,3	41	10	25,3
August	2083	1031	-1052	-102	-71,2	1455	1031	-424,0	-41	14,8
September	3385	1828	-1557	-85	-80,8	1649	1828	179,0	10	-26,9
October	1714	683,9	-1030	-151	-90,4	673,3	683,9	10,6	2	-16,5
November	620	307,8	-312	-101	-90,4	284,9	307,8	22,9	7	-79,1
December	325,2	182,6	-142	-78	-80,8	128,9	182,6	53,7	29	-68,7
January	205,9	149,1	-56,8	-38	-51,9	95,78	149,1	53,3	36	-47,8
February	133,2	159,2	26,0	16	-23,1	72,75	159,2	86,5	54	-58,2
March	95,22	176,6	81,4	46	-100	47,65	176,6	129	73	-79,1
April	83,23	173,5	90,3	52	-13,5	29,87	173,5	143,6	83	-68,7
Group 2 IHA										
1-day minimum	31,45	116,5	85,1	73	-100	0	116,5	116,5	100	-100
3-day minimum	5474	2887	-2587	-90	-90,4	2578	2887	309	11	-6,0
7-day minimum	32,17	117,9	85,7	73	-100	0	117,9	117,9	100	-100
30-day minimum	5427	2858	-2569	-90	-90,4	2515	2858	343	12	-26,9
90-day minimum	33,6	120	86,4	72	-100	0	120	120	100	-100
1-day maximum	5208	2729	-2479	-91	-90,4	2279	2729	450	16	-37,4
3-day maximum	52,82	123,8	71,0	57	-90,4	1,827	123,8	122	99	-100
7-day maximum	4160	2020	-2140	-106	-100	1839	2020	181	9	-37,4
30-day maximum	106,2	143,4	37,2	26	-51,9	46,6	143,4	96,8	68	-89,6
90-day maximum	2668	1232	-1436	-117	-90,4	1304	1232	-72,0	-6	-6,0
Base flow index	0,04	0,24	0,2	534	-100	0	0,24	0,24	100	-100
Number of zero days	0	0	0,0		5,26	13	0	-13,0		46,2
Group 3 IHA										
Date of minimum	257er	248 er	-9	-3,31	-32,7	250 er	248 er	-5	-1	67

Table Continued...

Parameters	Situation 1 (between 1951-1970 and 1988-2014)					Situation 2 (between 1970-1988 and 1988-2014)				
	Average values			Hydrologic Alteration (%)		Average values			Hydrologic Alteration (%)	
	1951-1970	1988-2014	Average difference	Difference in%		1970-1988	1988-2014	Average difference	Difference in%	
Date of maximum	121 er	117 er	-4	-2,89	-65,8	131 er	117 er	-14	-11	-78,1
Group 4 IHA										
Low pulse count	1	1,5	0,5	50	-47,4	1	1,5	0,50	33	-31,0
Low pulse duration	1	1	0	0	-15,0	1	1	0	0	-88,8
High pulse count	86	28	-58	-67,1	-51,9	81	28	-53	-184	-26,9
High pulse duration	101	55	-46,0	-45,5	-80,8	126	55	-71	-129	-85,4
Group 5 IHA										
Rise rate	5,43	2,82	-2,6	-48,0	-42,3	6,11	2,82	-3,29	-116	100
Fall rate	-4,06	-4,12	-0,1	1,6	-32,7	-1,78	-4,12	-2,34	57	-47,8
Number of reversals	18	21,5	3,5	19,4	-35,9	15	21,5	6,50	30	-16,5

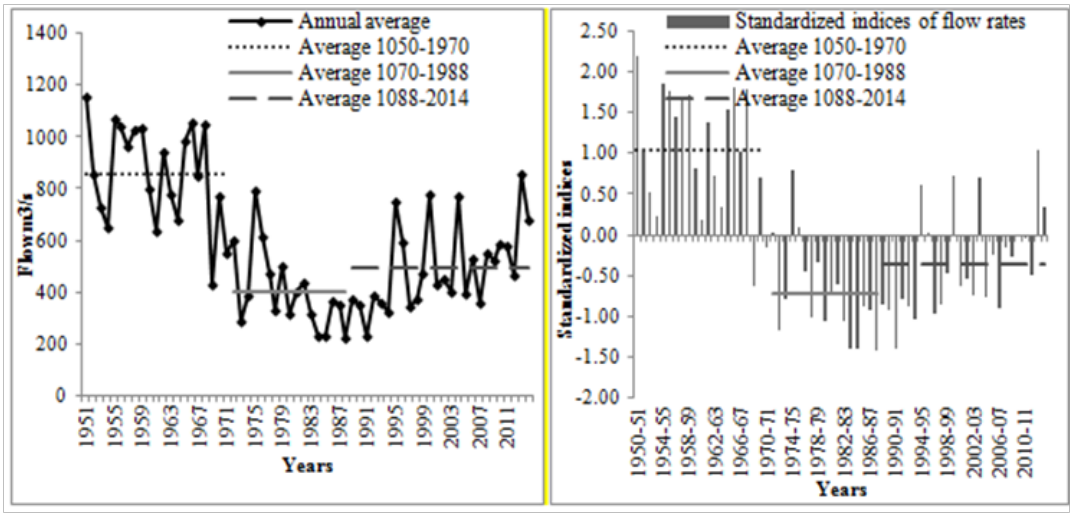

Figure 1 Variation of flow rates and standardized flow indices at Bakel from 1951 to 2014.

Degree of hydrological alteration

The 33rd and 67th percentiles were calculated for the 33 hydrologic alteration indicators and considered the lower and upper bounds of the RVA target variability range for the Bakel station. Between post-impact period (1988-2014) and wet pre-impact period (1951-1970), results show that the fall rate ranked first of all hydrological weathering values is maximal (100%) in the month from November, at least 1, 3 and 7 days, at most 30 days and at basic rate. They are followed very closely by the months of June and July, the maximum of 1, 3, 7 and 90 days and the minimum of 30 days whose degree of alterations are greater than 90%. Other parameters such as the months of September and December, and the duration of weak pulses record degrees of difference exceeding 67%, so high. The remaining parameters, although supposed to be strongly affected by the construction and operation of upstream dam, are less altered, the values being either moderate (as for May, June, July and January, the Julian date of annual minimum, the number and duration of strong impulses, the minimum 90 days, the rate of climb and the number of times), be low to zero (for the remaining parameters like the rate of descent, the Julian date of the annual maximum, the months of February and April). In the practical regulation, the objectives must be kept from 514 to 3777 m^3/s for the magnitude of monthly flow of high-water period (July to November) and with ranges of similar targets from 53 to 355 m3/s for remaining seven months (December to June).[7] Between the post-impact period (1988-2014) and the dry pre-impact period (1970-1988), the results show only the mean annual minimum flow rates of 1, 3, 7 and 30 days, the base flow and the The climb has a maximum of 100% weathering, followed by a minimum of 90 days, the number and duration of weak impulses, and November, December, and April, all of which continue to be tampered with.

Conclusion

The main conclusions can be given as follows:

I. The annual water discharge distribution model has been changing over the period from 1951 to 2014. The dam has a profound effect on the hydrological conditions of the Senegal River. Its management has led to a reduction in annual peak flows, a reduction in the range of maximum daily flows, an increase in the range of minimum daily flows, the modification of the calendar of periods of high and low water.

II. By comparing post-impact period with that of pre-impact period (both wet and dry), hydrological characteristics indicated obvious changes. The flow magnitude was lower during floods (with the

capping of dam floods) and higher during low water periods (low flow support).

III. The alteration is particularly important for monthly flows as well as for low minimum flows. Flows are much lower in the rainy season and much higher in the dry season than flows that normally would be observed without alteration. In fact, the presence of a dam upstream of the watercourse leads to a general decrease in flows during floods (flood capping) and an increase in flows during low water periods (support for low flows).

IV. Changing flow regime can pose serious threats to wildlife and therefore have adverse ecological effects. Therefore, it is necessary to deepen the responses of hydrological alteration study of the regime resulting from Manatali dam.

Acknowledgments

None.

Conflicts of interest

The auhtor declares there is no conflict of interest.

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