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Abstract: In this study, daily streamflow data of 35 years records and water quality data were investigated to determine Lake Guiers hydrologic alteration within its ecosystem. The Range of Variability Approach (RVA) was used to quantify the modification of the Indicators of Hydrologic Alteration (IHA) and the trophic State Indices (TSIs) was calculated to characterize the eutrophication level. Results show that the flow pattern at Lake Guiers is reversed from the pre-impact with high alteration on most of indicators. These changes on flow have greater impacts on the lake ecological functioning and on water quality. The trophic State Indices (TSIs) of Nitrogen (N) and Phosphorus (P) indicate respectively a eutrophic and hypereutrophic state. Lake Guiers hydrological alteration endangers its ecological integrity. Its restoration requires more than ever reconciling economic needs and ecological requirement.

Key words: environmental flow, hydrologic alteration, indicator, Lake Guiers, Senegal, streamflow

1. Introduction

River flow regimes are considered to be the primary driving force of the river ecosystem [1]. The integrity and stability of river ecosystems is largely dependent on the natural dynamic change characteristics of the streamflow [1]. The development and management of water resources by humans has altered the natural flow of rivers around the world [2]. Taking the example of Senegal River Basin (SRB), the downstream flow regime has been widely affected when the Senegal River Development Organization (OMVS), a regional cooperative management body of the Senegal River built along the river: Diamadam in 1985 and Manatali dam in 1987 and structures (sluices, dikes, irrigation systems) in order to meet economic and social development needs for water resources.

In Lake Guiers, one component of the Senegalese River system, several studies have been carried out on first-order impacts in hydrology resulting from dams operation. Water quality and environmental hazards in general are among the focus of research in the last twenty years. M. Bouvy et al. (2006) [3] describes the phytoplankton/environment relationships and provides valuable information on algal strategies in a shallow tropical lake like Lake Guiers. Seasonal variations of zooplankton communities and their interactions with phytoplankton and environmental parameters has been investigated by S. Ka et al. (2011) [4]. They find out the existence of seasonality in zooplankton communities and confirm the importance of using biological indicators such as phyto- and zooplankton to monitor Lake Guiers water quality. S. Sané et al. (2013) and O. Varis and S. F. Jussila (2002) [5, 6] focused on Lake Guiers's eutrophication level and conclude that its management has to be revised because of changes in water quality and ecosystem and increasing pressure on its water resources. C. Berger et al. (2006) [7] point out seasonal dynamics that will constitute an increasing challenge in Lake Guiers.

The impact of dams and the multipurpose use and water quality challenge in Lake Guiers has been investigated by Cogels et al. (1997, 2001) [8, 9]. They

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describe the water quality effects on the management of the lake, with special emphasis on salinity and eutrophication. Recently by remote sensing tools [10]; E. C. Merem and Y. A. Twumasi (2008) [11] assess water quality. They compared the FUB-predicted image and study results with those from earlier studies and revealed good correlation.

As we can notice a large number of studies carried out have been focusing on water quality, hydro-biology, invasive aquatic plants, while limited research in view streamflow pattern (magnitude, duration, frequency, timing, and rate of change). Assessment of these streamflow characteristics is essential for understanding and predicting the biological impact of both natural and altered flow regimes on riverine biota [12].

In Lake Guiers this assessment is particularly important since 2013, the Lake Guiers authority has undertaken a wide project that aim to "restore the ecological and economic functions of the Lake". The main actions planned are: dredging channel, rehabilitating dyke, constructing water supply network and a crossing structure. How are the physical components expected to change after the re-planned development and what is the expected effect on ecological condition?

Accordingly, researchers have developed and applied methods to quantify indicators and to assess alteration in a flow regime through time. A great number of methods has been suggested for this purpose. The 33 Indicators of Hydrologic Alteration (IHA) [13] are intended to represent each of the major facets of the flow regime [14]. As one set of proposed hydrologic indices assessment, the Streamflow Analysis and Assessment Software (SAAS) 4.0 [15]was developed based on focusing on hydrology-based environmental flow methods. It calculates hydrological indicators through time with respect to a reference condition, and relate hydrological alteration to changes in ecological condition [16]. The Range of Variability Approach (RVA) was established to evaluate the hydrologic alteration caused by hydraulic control structures [2, 17].

In this study, we focus on changes in the hydrologic regime and its potentials impacts on ecosystem caused by dams operation. To assess this particular impact, time series of daily mean discharge for Ngnith station (water treatment plant) were evaluated using the Indicators of Hydrologic Alterations (IHA) [13] and RVA associated SAAS [15]. Comparison of pre and post-dams periods allows evaluation of their effects on hydrology and ecosystem.

The ability to assess the condition of lake and river ecosystems, evaluate sensitivity to alteration, and identify potential changes to the ecosystem resulting from different development and redevelopment options is important to inform decision making. In this perspective this study focuses on variables of a flow regime strongly associated with ecological condition and, therefore, most suited to serve as indicators of hydrologic alteration. It aims to quantify and assess Lake Guiers hydrologic alteration arising from in-stream development. This assessment will inform a decision-making process and the implementation of a post-alteration monitoring program; and build knowledge that can inform future policy and management directions by allowing the analysis of information collected in a standard way across sites consistent with an adaptive management approach.

2. Study Area

Lake Guiers is an important fresh water reserve for Senegal. Its water is use for irrigating crops and drinking water resource for urban centres, including Dakar, the capital city, as well as for continental fishing and livestock breeding. It is located in the north of Senegal on the right bank of the Senegal River, between latitudes 16'23 N and 15'55 N, and longitudes 16'12 W and 16'04 W. It lies on the downstream of the Ferlo hydrological Basin (Fig. 1).



Fig. 1 Study area: Lake Guiers within its hydrologic Basin and the main hydraulic infrastructures.

2.1 Hydrology

The lake is 53.5 km long and up to 7 km wide, with a surface area of 274 square kilometers (measured and calculated with Google earth Pro and GIS). Its maximum depth is 4m and average depth is 2 m. Like most of the sahelian lakes, it is classified as a "shallow lake".

Lake Guiers hydrological system is composed of the following hydrological units (Fig. 1):

- Taouey canal: It connects Lake Guiers to the Senegal River at Richard Toll city. Originally Taouey was a winding stream of 26 kilometers, rectified by a canal long to 17 kilometers. It supplies 88% of the total water into Lake Guiers from Senegal River [9].
- YettyYone: Situated on west of Lake Guiers, it is a 28 kilometers hydraulic axis which supplies the Ndiael depression.
- Ndiael: it is a depression designated as wetland area by the RANSAR convention in 1977. The great expanse that is the core of the Ndiael

covers 10,000 hectares. The site is listed on the Montreux record (endangered sites) since 1990.

 Lower Ferlo: Located in the southern part of the lake, it is complemented by the Ferlo valley. A dyke built in KeurMomarSarr regulates the outflow from the lake into the lower Ferlo region.

2.2 Climate

The climate in the basin of Lake Guiers is similar to much of the Sahel and characterized by two main seasons: a dry season that lasts nine months from October to June, and a rainy season of three months (July, August, September). Total annual rainfall is generally low, but highly variable among years. In the basin, the average of total annual rainfall from 1982-2012 is estimated to 225 mm. The mean annual temperature oscillates around 27.6°C and fluctuates between a maximum average of 30.6°C in the month of June and a minimum of 23°C in the month of January (Fig. 2).



(http://de.climate-data.org; average 1982-2012).

In Lake Guiers, the hydrology depended on these situations described above. During high water period the lake was filled once a year from the Senegal River and the damming up of the northern region and the closing of the southern and western outflows made it into the largest water reservoir which can be used extensively as a stable freshwater source throughout the dry season [8]. Under the combined effect of insufficient filling (during drought years in the whole basin), increased pumping for irrigation, and evaporation (2.2 meters per year), the level of the lake in certain years went below the threshold levels. Extreme conditions were reached during water year 1983-1984 when the lake was almost completely dried up [8].

In order to meet economic and social development needs for water resources, OMVS has undertaken the construction of Diama and Manantali Dams along the Senegal River. The Diama Dam is located 30 kilometers upstream of the city of Saint Louis. It was built in 1985 in order to stop the dry season intrusion of seawater along the river bed and to irrigate 375,000 hectares of former flood plain for production of two crops per year, especially for rice production [9].The second dam, the Manantali, was completed in 1987 and is located in Mali 1,200 kilometers upstream from the Senegal River outlet. Its storage capacity is 12.8 km³. It was built on the river, which supplies approximately 60% of the annual flow of the Senegal River in a reservoir.

Since 1986, the operation of the Diama Dam has prevented any seawater intrusion upstream and fresh water is available all the year at the Taouey-Lake Junction [8]. Since 1992, the steady and continuous operation of the Manantali Dam and the regulation of the river have changed the hydrological conditions in the lower valley and the delta region. There is now a constant supply of fresh water, sufficient to fill the lake several times a year. From 1986 to 1991, as before 1986, the lake was filled only once a year during the annual flood. However, water levels became clearly higher than before 1986 with an average levels of 0.8 m, compared with 0.4 m prior to 1986 [8]. Since 1992, the partial regulation of water flow by the Manantali Dam has further altered the hydrological regime of the Lake Guiers, which may now be filled several times a year. The annual average level has reached 1.5 m and its annual range is not greater than 0.96 m. Since 2002, the annual average level has reached 1.9 and the range of water level in the Lake is between 1.9 and 2.5 m.

3. Material and Method

The daily flow data were used to analyse the variation of the flow regime at Ngnith station (water treatment plant). We collected observed water level data from 1976 to 2011, a total of 35 years of hydrological data, provided by Lake Guiers Authority (OLAG). Discharge has been calculated from daily water level using Manning-Strickler equation

$$Q = K * R H * i$$
 (1)

Q: Discharge in m/s, K: Roughness coefficient, RH: Hydraulic flow radius, i: Flow slope in m/m

A literature review allowed us to determine the following variables in the flow calculation: hydraulic flow radius (RH) = 7 m; the flow slope in Ngnith station (i) m/m = 0.001; and the roughness coefficient (K) = 35.

The stream flow data from 1976 to 2011 was divided into pre-impact period (1976-1986) and post-impact period (1987-2011), representing the stream flow under natural conditions (before dams) and changeable

conditions (after dams), respectively. To address hydrologic regime alteration, we investigated stream flow through Stream flow Analysis and Assessment Software (SAAS) 4.0 developed by Metcalfe et al. (2013) [15].

SAAS is a tool based on focusing on hydrology-based environmental flow methods. Comparison of pre- and post-dams periods allows evaluation of the dam's effects on hydrology and ecosystem.

To determine the flow regime target, the Range of Variability Approach (RVA) [2] was used to evaluate the hydrological alterations. The RVA was formulated to quantify the modification of the Indicator of Hydrologic Alteration (IHA) by comparing the frequencies within three fixed intervals. The RVA is a milestone in the hydrologic alteration assessment and has been widely used (e.g.: [12], [18-20]). B. D. Richter et al. [17] used the degree of hydrologic alteration as a measure to quantify a deviation of the post impact flow regime from the pre-impact one. The degree of alteration D is defined as:

$$D = [(Post-Pre)/(Pre)]*100\%$$
 (2)

Where "Post" is the median flow of the post-impact period, "Pre" is the median flow of the pre-impact period. B. D. Richter et al. [17] further suggested that the value of D ranging between 0 and 33% represents little or no alteration (i.e., low alteration); 33-67% represents moderate alteration, and 67-100% represents high alteration.

In order to characterize water quality alteration, we use monthly water quality data from 2008 to 2010 provided by Direction de la Gestion et de la Planification des Ressourcesen Eau du Sénégal (DGPRE), a national management body of Senegalese water resources. These data were observed in 7 sites in Lake Guiers from nord to south (Richerd Toll, Mbane, Téméye, Syer, Gnith, KeurMomarSarr, and Lower Ferlo). However, in this study the focus in water quality analysis is primarily on salinity and eutrophication. To characterise the trophic state in Lake Guiers, we calculate the Trophic State Indices (TSIs) of SecchiDisque (SD), Nitrogen (N) and Phosphorus (P) by using Environmental Protection Agency (EPA)'s nutrient criteria technical guidance manual. The results were interpreted according to EPA's criteria. It suggested that the value of TSI < 40 represents oligotrophic state. The value of TSI ranging between 50 and 60 represents a eutrophic state and the value of TSI>60 represent a hypertrophic state.

4. Results

4.1 Indicator of Hydrologic Alteration

4.1.1 Streamflow

The operation of Diama and Manatali Dams has significantly modified the flow regime of Lake Guiers over the past 30 years. The annual flow increased by more than 269% at Ngnith station. Table 1 shows a summary record of stream flow statistics. The maximum flow during pre-impact $(15.6 \text{ m}^3/\text{s})$ is far less than in post impact $(30.7 \text{ m}^3/\text{s})$. It can be noticed that zero flow days, decreased drastically between the preand post-impact periods, from 1041 to 153 days and has been eliminated since 1991.

The flow pattern in Lake Guiers is reversed from the pre-dam. Significantly greater median flows occurred

Table 1Stream flow statistics in Lake Guiers before andafter dams construction.

Streamflow statistics	Before dams construction	After dams construction	Unit
Maximum	15.6	30.7	m ³ /s
Minimum	0	0	m ³ /s
Mean	4	15.1	m ³ /s
Standard Deviation	4.1	6.2	m ³ /s
Coefficient of variation(SD/Mean)	1	0.4	m ³ /s
Median	3	17.1	m ³ /s
Upper quartile	6.9	19.8	m ³ /s
Lower quartile	0.1	11.2	m ³ /s
Relative Dispersion (IQR/mean)	2.2	0.5	m ³ /s
Number of zero flow days	1041	153	

almost during all twelve months (increases of $14 \text{ m}^3/\text{s}$), which were the typical high flow that occurred in September-October during the pre-dam period (Fig. 3).

4.1.2 Flow Duration

A flow-duration curve (FDC) represents the relationship between the magnitude and frequency of daily, weekly, monthly (or some other time interval) of stream flow for a particular river basin, providing an estimate of the percentage of time a given stream flow was equaled or exceeded over a historical period [21]. Fig. 4 compares annual and seasonal median of FDCs

at Lake Guiers using two different periods of record (pre and post impact). The FDC for these two periods are significantly different. For instance, in pre impact period the highest Q = 11.4 m^3 /s and the percentage of exceedance equal to 0.01%; and the lowest Q= 0.00m^3 /s and the percentage of exceedance equal to 99.9%. For Post impact the highest Q = 21 m^3 /s and the percentage of exceedance equal to 0.01%; the lowest Q = 13.7 m^3 /s and the percent exceedance equal to 99.9%. Comparable changes are also observed on seasonal median FDCs.

Lac de Guiers Post Diama Dam (1) Lac de Guiers Pre-Diama Dam (19)



Fig. 3 Monthly alteration with RVA in Lake Guiers 1976-2011.



Fig. 4 Annual (a) and (b) and seasonal median (c) and (d) FDCs at Lake Guiers before impact (a, c) and after impact (b, d).

4.1.3 Base Flow Index (BFI)

Base flow is defined as the stream flow portion generated by persistent slowly varying sources (i.e., groundwater, lakes, and wetlands) between precipitation events [22]. SAAS separates base flow from stream flow using a recursive digital filtering as described by Nathan & McMahon (1990) [23]. The filter parameter recommended by Nathan and McMahon of 0.9 is used in the SAAS daily stream flow and base flow separation analysis with three filter passes. Base flow separation technique was used to estimate Base flow Index (BFI).

Base flow index (BFI) is the ratio of the base flow to the total stream flow. The value ranges from 0 to 1. Therefore a BFI of 0.5 indicates that 50% of total stream flow can be attributed to base flow for the respective time period (i.e., period of record, month or season).

In Lake Guiers, before the dam's operation BFI for the entire period of record was 0.73 which is less than after dam operation (BFI= 0.92). This implies that 73.9% of total stream flow can be attributed to base flow for the respective time period. In the post impact period it's 92.6% that can be attributed to base flow.

Before and after impact periods, base flow constitutes the highest part on total stream flow.

Fig. 5 shows extreme hydrologic event (high and low flow). The extreme low flow during 1976-1986 was more than twice the average number during 1987-2011 at Ngnith station. By using the high flow events, we explore the frequency and duration of those events on seasonal basis Figs. 5 and 6. The frequency refers to how often a flow above a given magnitude recurs over some specified time interval. The duration is the period of time associated with a specific flow condition. Duration can be defined relative to a particular flow event or a composite expressed over a specified time period [13].

While seasonal high flow frequency has increased by 109% during season 1 and 130% during season 2, high flow duration has decreased to (-53%) during season 1 and, (-69%) during season 2 in Lake Guiers (Table 2).

4.1.4 Rate of Change (ROC)

Rate of change represents the change between stream flow data points. Figs. 7 and 8 show POR and



Fig. 5 Seasonal high flow frequency. This figure shows the seasonal High flow frequency on pre-impact (a) and post impact (b). For pre-impact, the total events equal to 133 and the number of year = 12. During season 1, the 25 % ile = 3; Median = 5.5 and 75% ile = 7; during season 2, the 25 % ile = 3; Median = 4.5 and 75% ile = 8. For post-impact period, the total events equal to 655 and the number of year = 26. During the season 1, the 25 % ile = 6; Median = 11.5 and 75% ile = 17 and during season 2, the 25% ile = 6; Median = 11.5 and 75% ile = 15.



Fig. 6 Seasonal high flow duration. This figure show the seasonal High flow duration on pre-impact (a) and post impact (bt).

seasonal raw rate of change. Its duration curves was created using the unfiltered rates of change (i.e., all rates including low flows)[16]. For daily input data these hourly rates are calculated by dividing the daily rates of change by 24, assuming a linear rate of change throughout each day. Raw ROC curves terminate at less than 100 percentage of exceedance because the percent exceedance is calculated using all rates (i.e., positive, negative and zero)[16].

In Lake Guiers, for pre impact the POR ROC duration curves show that 21% of the time the rates are



Fig. 7 POR and seasonal raw rate of change on pre-impact period. It shows the positive POR and seasonal raw rate of change (a) and negative POR and seasonal raw rate of change (b) on pre-impact period.

positive and 49% of the time they are negative, implying that 2% of POR rates are zero. Compared to post impact period ROC duration curves show that 27% of the time the rates are positive and 36% of the time they are negative, implying that 1% of POR rates are zero.

4.1.5 Trends in hydrologic indicator

The Mann-Kendall non-parametric trend test is used to statistically assess whether there is an upward or downward monotonic trend in a variable. The temporal variability (summarized annually) of a variety of hydrologic metrics (annual median stream flow, annual median base flow, and annual number of high flow

events) were tested (Fig. 9). The Mann-Kendall τb co (tau-b) test statistic, similar to the correlation p-

coefficient in regression analysis, and the associated p-value used to test the zero-slope hypothesis (at 95%



Fig. 8 POR and seasonal raw rate of change on pre-impact period. It shows the positive POR and seasonal raw rate of change (a) and negative POR and seasonal raw rate of change (b) during post-impact period.



Fig. 9 Temporal variability of hydrologic metric. It shows trends in stream flow (a), base flow (b) rate of change (c) and number of high flow events (d) during post impact period in Lake Guiers. Trend lines are shown in red if the slope of the line is significantly different from a slope of zero (i.e., temporal trend detected) with 95% confidence.

Indicator of Hydrologic Alteration	Pre-Impact	Post-Impact	RVA (target) Lower Upper		Deviation %(Magnitude)	Class
Stream flow						
Mean	04.0	15.1			269	Н
Maximum	15.6	30.7			96.3	Н
Zero Flow Days	1041	153			-85.3	Н
POR BFI	0.7	0.9			25.5	L
Seasonal BFI		-				
Season 1	0.8	0.9			18.9	L
Season 2	0.7	0.9			27.5	L
Monthly High flow frequency (median)						
January	2	2	0.5	3	0	L
February	1	2	0	3	100	Н
March	1	1.5	0	4	50	М
April	0	2	0	4	-	-
May	0.5	1	0	3	100	Н
June	0	2	0	3	-	-
July	0	2	0	4	-	-
August	1	2	1	3	100	Н
September	1	1.5	0	2	50	М
October	1.5	2	1	2	33.3	М
November	1	1	0	3	0	L
December	0.5	2	0	3	300	Н
POR High Flow Frequency(median)	10.5	23	7.5	31	119	Н
Seasonal High Flow Frequency (median)						
Season 1	5.5	11.5	3	17	109	Н
Season 2	5	11.5	3	15	130	Н
POR High Flow Duration(median)	20	9	4	43	-55	М
Seasonal High Flow duration (median)						
Season 1	17	8	4	24.7	-52.9	М
Season 2	29	9	5	56.7	-68.9	Н

Table 2Hydrologic alteration, Lake Guiers, 1976-2011.

confidence a p-value of 0.05 or less allows the zero-slope hypothesis to be rejected). During post impact period the stream flow show an increased trend of 93% with 95% confidence. In addition, base flow and number of high flow events show respectively trends 91% and 42%. They are statistically significant. However, temporal trend were not detected in the annual median rate of change.

The median flow was used to quantify a deviation of the post impact flow regime from the pre-impact ones for Lake Guiers. The results show that the reservoir was strongly affected by the construction and operation of Diama and Mananatli Dams (Table 2).

The hydrologic regime of Lake Guiers has been altered over the past 30 years. Annual flow increased more than 100% at Ngnith station.

4.1.6 Hydrologic Alteration Magnitude

Monthly flows for May in dry season and monthly flows for October in flood season were selected to analyse monthly water condition alterations, which indicated magnitude alteration in Lake Guiers reservoir. Median monthly flows for May, the driest month, at Lake Guiers increased up to 100% (Table 2).

Median monthly flows for October, the month in which, the flood pick occurs, account for 33.3% of the total annual flows. The increasing trend of flow is obvious. During all months flow increased and the largest monthly alterations occurred during the dry season.

4.2 Water Quality Alteration Indicator

4.2.1 SecchiDisque (Water Transparency)

Variation in Secchidisque (water transparency) are quite low between 54 cm to 86 cm (coefficient of variation = 24%) with an average of 66 cm (Fig. 10). Throughout the study period, Secchi values remained less than 100 cm. However, they seem to draw a slight difference from year to year and show a seasonal trend. In addition, the fluctuations in water transparency seem to follow water volume variation in the lake. The increase in lake's water volume resulted in a decrease of transparency and vice versa.

4.2.2 Salinity

The results of surveys between 2008 and 2010 indicates an average salinity in Lake Guiers of 199 ppt (392 μ S/cm) with a maximum of 257 ppt (506 μ S/cm) and a minimum of 124 ppt (244 μ S/cm).

Fig. 11 shows the evolution of the salinity during this period, superimposed with water volume in the lake. We can notice that the salinity increases when lake's water volume is low and decrease when lake's water volume is high.

In addition, there is a spatial and temporal distribution of salinity into the lake. The results show a north-south gradient of salinity. The measurements observed from Richard Toll increase significantly as we move towards KeurMomarSarr. They are even more (10 times higher) towards lower Ferlo.



Fig. 10 Water transparency with water volume in Lake Guiers, 2008-2010.



Fig. 11 Evolution of salinity in Lake Guiers with water volume 2008-2010.

They also indicate seasonal trends of salinity. Higher concentrations were noticed in August 2009.

The main source of salt concentration into the Lake is an inappropriate discharge outlet in lower Ferlo and a high evaporation rate. The irrigated crop drainage water discharged into the northern part of the lake is the second main source of salts accumulation. It accounts for 56% of the salt influx [24]

4.2.3 Nutrients concentration

Results of nutrient surveys between 2008 and 2010 show stabilized concentrations not exceeding 1 mg/L.

Total Nitrogen (N) during the study period ranged from 0.74 to 0.90 mg/L with an average of 0.75 mg/L. Total Phosphorus (P) ranged from 0.15 to 0.27 Mg/L with an average of 0.19 mg/L (Fig. 12).

In addition, Fig. 13 show during the study period, Total Ammonia (NH3 & NH4+(mg/L)) varying between 0.1 mg/L and 0.09 mg/L with an average of 0.1 mg/L. Nitrates (NO₃ (mg/L)) range from 0.7 mg/L to 0.5 mg/L. Concerning pH, it varies between 8.5 and 6.3. However, no correlation was found between NH3 and pH.



Fig. 12 Evolution of Nitrogen (N) and Phosphorus (P) in Lake Guiers, 2008-2010.



Fig. 13 Evolution of ammonia with pH in Lake Guiers, 2008-2010.

These results did not reflect the spatial tendency of the nutrients which change from the Taouey canal, the northern part of the lake towards the south and Ferlo.

4.2.4 Trophic State Indices (TSIs)

Throughout the study period, the low measured water transparencies reveal a TSI of Secchidisque of 65.91, which would indicate a hypertrophic state. Total N measured show a TSI of 50.22 indicating a eutrophic

state. Finally, total P measured indicate a TSI of 79.57 which would indicate a hypertrophic state.

5. Discussions

5.1 Lake Guiers Hydrologic Alteration

Key ecosystem components that have important functions in determining the integrity of river ecosystems include hydrologic regime, sediment regime, water quality, thermal regime, and biologic components. However this study focuses on hydrologic regime and water quality factors that most strongly shape the ecological condition of river systems and that are often of greatest importance to the health of valued ecosystem components.

In Lake Guiers, flow regimes pattern considered important for maintaining the ecological condition of riverine ecosystems have been investigated. Results show that hydrology in Lake Guiers depend in natural conditions on the filling and discharge phases following the rhythm of floods and low flows of the Senegal River. These hydrologic events played an important role in regulating the structure and function of the lake and flood plains. Low flows are necessary for many processes in riverine ecosystem functioning. If the low flow situation reaches extremely low levels, however, ecological communities are impaired.

Low frequency but high intensity events, such as severe floods or droughts that used to occur in Lake Guiers had long lasting effects on the structure and function of lotic ecosystems.

Extreme low flows may be necessary to dry out floodplain areas and enable certain species of plants to regenerate. On the other hand, water chemistry and dissolved oxygen availability can become highly stressful to many organisms during extreme low flow [25].

Since 1986, in-stream developments along Senegal River and Lake Guiers have changed the distribution of flow magnitude, duration, frequency, seasonality, and rates of flow increase and recession. The steady and continuous operation of dams and its regulation have changed the hydrological conditions. These new conditions have favored a few years after the proliferation of invasive aquatic plants.

V. M. Faye, C. Mbow, and A. Thiam (2016) show that aquatic plants has settled on a surface area of 7,458ha in Lake Guiers from 1988-2010 [26]. This has led to a decrease of 2,339 ha on open water and 4,021 ha on flood plains area.

5.2 Lake Guiers' Water Salinity

During the study period, results indicate an average salinity in Lake Guiers of 199ppt (392 μ S/cm) with north/south gradient. This result is supported by studies carried out in September 2004 by DHI water and environment and TROPIS under the Long Term Water Project (Projet Eau Long Terme). They showed a salinity gradient of about 30 μ S/cm in Taouey channel entry until about 550 μ S/cm to KeurMomarSarr dyke and a strong rise about 992 μ S/cm in lower Ferlo.

Studies carried out before Diama dams showed large variations in salinity in Lake Guiers. Indeed, the salts concentration from the Senegal River was relatively low with a salinity of 20-50 μ S/m. (Carl Bro International c/o in Ref. [5]. However, it gradually increased in the Taouey before becoming constant in northern part of the lake. Then it increased again in lower Ferlo due to high evaporation rate and increase of dissolved salts in water.

The large variations in salinity (from 1972 until 1985) were therefore due to the intrusion of seawater. After Diama dam, the oscillations were due to the opening and closing of the valves at Richard Toll .The Lake was still subject to relatively large salinity oscillations until 1992.

These continuous variations were probably due to salt discharges stored in Lake Guiers's sediments. Since 1992 with Lake Guiers water level regulation (between 1.90 m and 2.50 m), annual variations in salinity are limited to minor seasonal variations

However, S. Sanéet al. (2013) noted that the water salinity in Lake Guiers did not show a significant

difference between 2002 and 2003 with respectively average value of 180.5 and 178.4 μ S/cm [5]. However, a significant increase occurred in 2004 and 2005 with respectively an average of salinity of 220.6 and 207.0 μ S/cm. This is probably due to water level elevation and a low water renewal.

5.3 Eutrophication Level in Lake Guiers

Nutrient surveys during the study period show stabilized concentrations not exceeding 1 mg /. These results do not reflect those obtained previously. According to F. X. Cogels, S. Fraboulet-Jussila, and O. Varis (2001) [9], eutrophication is already a serious problem in Lake Guiers. Total N and nitrates are quite higher into the lake. They are even higher in the Taouey canal. However, they tend to decrease and stabilize in the central and southern parts of Lake Guiers. Mean concentrations of nitrogen (N) range from 1 to 2.5 mg/L in the lake and Ferlo, whereas in the Taoueythey are estimated to be 6.5 mg/L [24]. The Taouey channel provides significant amount of phosphorus (24%) and nitrogen (25%) into the lake, especially during the rainy season [24]. This could probably be attributed to agricultural activities around the lake. V. M. Faye, C. Mbow, and A. Thiam (2016) indicates that irrigated agriculture is currently the most common activities in the area [26]. The irrigated areas comprise a large scale irrigation field and peri-urban irrigated horticulture. About 20,063 hectares of land are now cultivated around Lake Guiers.

In this study, the TSIs of N (50.22) and P (79.57) would indicate an eutrophic and hypertrophic state, respectively. These results are likely due to over-use of nutrients by algae and plants. S. Sané, N. Bâ, P. I. Samb, and R. Arfi (2013) [5], also describe an eutrophic state from 2002 to 2004 and hypertrophic since 2005, based on chlorophyll estimation. According to them, their production has tripled in 2005.

6. Conclusion

Daily streamflow data of 35 years records and water

quality data were investigated to determine Lake Guiers hydrologic alteration within its ecosystem. Comparison of pre and post-dams periods allows evaluation of their effects on hydrology and ecosystem. The results show that dams and sluices profoundly affect the hydrologic conditions in the Lake Guiers. They reduced high monthly variability of discharges, increased the range of daily discharges, altered the timing of high and low flows, and changed the timing of the yearly maximum and minimum flows.

Hydrologic features demonstrated obvious changes during the post-impact period. The flow magnitude was smaller and the frequency of low flow events decreased during all the year; and the maximum flows and minimum flows increased. The number of high flow events presented increasing trend. Annual median rate of change appeared as a decreasing trend. Base flow remains low both in pre and post impact.

The trophic State Indices (TSIs) of Nitrogen (N) and Phosphorus (P) indicated respectively a eutrophic and hypereutrophic state.

These new features in hydrology regime resulting to in stream development lead to changes to the ecosystem. The flood plain ecosystems have been mostly affected. After 1986, Diama dam blocked seawater intrusion. The water into the Lake is now fresh year-round, creating ecological conditions favoring the proliferation of freshwater plants (Typhasaustralis, Pistiastartioles, Salviniamolesta and various alga species). Recent studies show that invasive plants currently occupy 7,458 hectares in Lake Guiers. These are very invasive and eutrophication has begun at some places in the Lake. Downstream of the Diama dam, perturbations in the functioning of ecosystems takes the form of an increase in salinity and/or a drying-up during part of the year (Ndiael wetlands) due to the reduction of flooding or the destruction of water inflow channels during construction of hydrologic infrastructures (dikes, irrigated areas).

With the permanent standing freshwater, aquatic plants developed to excess and now prevent access to the water at some places. The Typhaaustralis constitutes a refuge and a spawning area for fish. However, the abundance of vegetation also constitutes an obstacle for fishing. In addition, infrastructure installations represent obstacles for fish migration to spawning areas.

Lake Guiers's hydrological alteration endangers its ecological integrity. Each aquatic ecosystem requires a certain amount of water to maintain its ecological integrity. These environmental water requirements can be defined as the quantity and quality of water required to protect the structure, function, and species composition of that ecosystem. Therefore to ensure ecologically sustainable development, we propose the following recommendation: After an alteration in the flow regime, a hydrometric monitoring program should be implemented to provide a thorough assessment of the degree of alteration. This would include measurement of continuous discharge using a data recording frequency that adequately captures the pattern of flow in the altered flow regime.

Continuous discharge measurements of inflows to the structure should also be estimated using back-calculations or measured directly. This will be particularly important where there are no upstream alterations, providing an indication of the natural variability in streamflow during the assessment period of interest.

We also encourage the implementation of best management practices on water resources and landscapes to reduce non-point sources of phosphorus transport in the Lake. Also we recommend that water resources manager work with municipalities to protect the lake shorelines and floodplains in order to better accommodate their natural processes as well as to improve resilience to flooding and to improve water quality. Finally water resources managers should increase public education and provide resources for local residents regarding impacts of fertilizer use on water quality and the benefits of vegetated buffers.

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