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APPLYING THE LEAST ACTIONS PRINCIPLE TO ASSESS THE TRENDS IN RAINFALL-RUNOFF RELATIONS IN A CONTEXT OF CLIMATE CHANGE AT UNGAUGED BASIN: CASE OF NANON BASIN IN THE NORTHERN REGION OF THE BENIN.

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ABSTRACT: *Water resource shortage is paradoxical in a context of increasing water need, under the combined effects of demographic growth and the impacts ofclimatic changes inducing water resources degradation. So there was an awakening of conscience about water resources management which presents a capital stake for all water actors around Okpara dam in Benin.The major concern in this study area always remains the lack of knowledge which requires the availability of quantity and quality of data for all water related sciences. In this context, Principle of least actions is used to determine the series ofstream flows to the dam fora best monitoring of water Supply system at Parakou.That makes it possible to have a long time series of flows that is enough to estimate water resource and its seasonal and inter-annual fluctuations. The results show that overall the model represents in a satisfactory way the form of observed hydrographs.The calculated output of peak is well located in time, even if they are sometimes underestimated or over-estimated. On the other hand,the low levels of water are perfectly reconstituted and there is a good superposition of initial hydrographs of flows and the calculated oneComparatively to the period of 1950 to 1969 it comes out that for the period of 1990 to 2010 precipitations is reduced in frequency and intensity: For an intensity of rain superior to 2 mm, 10 mm, 20 mm and 30 mm respectively, the decrease correspond to 7%, 8%, 18% and 41% respectively; whereas the annual average pluviometry is reduced at 10%. Indeed,flows depend on precipitations and are downward trend more amplified:over the four last decades compared to the wettest period of 1951 to 1970, the tendency is with the fall, as well for the minimal flows (17%) as for the maximum flows which are reduced by 22% for the period of 1971-1990, and of 18% for the period of 1971-1990. finally, the average of the flows has been reduced by 19% for the four last decades.Three rivers sections were now identified for further field hydrological measurements. They are accessible by the road at Binassi, Darnon and Douroube. Request are already introduced to equip those land markstations very soon.*

KEYWORDS: Ungauged Basin, The Least Actions Principle Of , IWRM, Nanon,Okpara Dam At Kpassa, Climatic Changes,

INTRODUCTION

It is well established that the existence of water resources often attracts people who settle for the services and benefits that proximity to water gives them (World Water Asseessment Programme 2003, Caî 2004). Indeed, in addition to drinking water, irrigation, cattle watering and fisheries are also being developed around the dam at Kpassa in the northern region of Benin. River basin system's knowledge is essential to Integrated Water Resources Management (IWRM)(Lasserre et Descroix 2003, Global Water Partnership 2009, Bérenère 2010). Nanon catchment that collects water to Okpara dam confirms that infrastructures are often built in ungauged basins with few data (Antoine 2003, Robert J., et al. 2006).

The major concern on the study area remains the need for better understanding of the links between the hydrological functions and all interactions with climate, topography, geology, soil type and land use. This requires the availability of data in all water related sciences (Hrachowitz, et al. 2013). Nowadays, due to population growth, climate hazards, and increase in the volume of sediments, water resource gets special attention from all stakeholders. In a context of stream flow data scarcity it would be compelling to simulate hydrological events (Bodian 2011, Sébastien 2013). In these cases, hydrologists use various methods including estimation procedures to transfer available spatial hydrologic data from another basin with similar hydrologic regime to the landmark where hydrological estimation is required. Due to deficient conditions, uncertainties on the results may be important (Claudia 2005, Randrianasolo 2012, Hrachowitz, et al. 2013) .In this report we focus on the quantitative aspects related to the management of the dam. Therefore, this study aims to develop a better knowledge of hydrology related to Okpara dam at Kpassa for a sustainable management of the associated water resources.

MATERIALS AND METHODS

Study Area

Okpara dam is built since 1969at twelve kilometers from Parakou. It is located in the village of Kpassa, at Tchaourou township in the region of Borgou, North Benin. Nanon is the related river; it is a tributary of the Okpara river in Oueme basin. The related basin is 2410 square kilometers extent between latitudes 9 ° and 00 ° 9 80 N and longitudes 2 ° and 3 ° 31 08 E (figure 1). This area is essentially agricultural for 80% of the land (The Beard L, and al. 1993). The hypsometric repair showed that 95% of the area of the basin is 310 m above sea level and 5% of the area located above 422 m. Since 1972, the prior purpose of the dam is drinking water supply. Yet, local residents gradually develop irrigation as an adaptation measure to climate changes impacts. However, due to demographic pressure, human activities inducing pressure from multiple water usages, siltation, climate changes, and water shortage can jeopardize basic usages in a very close future.

Figure 1: Nanon basin for Okpara dam, hydrological network (by the authors using MapInfo)

Data and Methods

The National Office of water management called *"Direction General de l'Eau, (DGEau)"*provided data base for basin characterization. Rainfall data (1950-2010), evapotranspiration and temperature data were collected from the National Directorate of Meteorology (DNM / ASECNA), and river flows data (1952-1967) measured at the station Nanon were reported in (Le Barbe L, et al. 1993). Physiographic, morphometric and hydrological parameters of the basin were assessed using FAO manual number 54 (FAO 1998). Data preprocessing was to characterize the climate regime based on statistical analysis of monthly and daily rainfall annually. Spatialisation was performed by the method of Thiessen polygon (Thiessen 1911, L.Galvàn, et al. 2014)(figure 2). The characterization of the climate regime was based on statistical analysis of daily, monthly and annual rainfall data. Average rainfall at the basin level is calculated with equation 1.

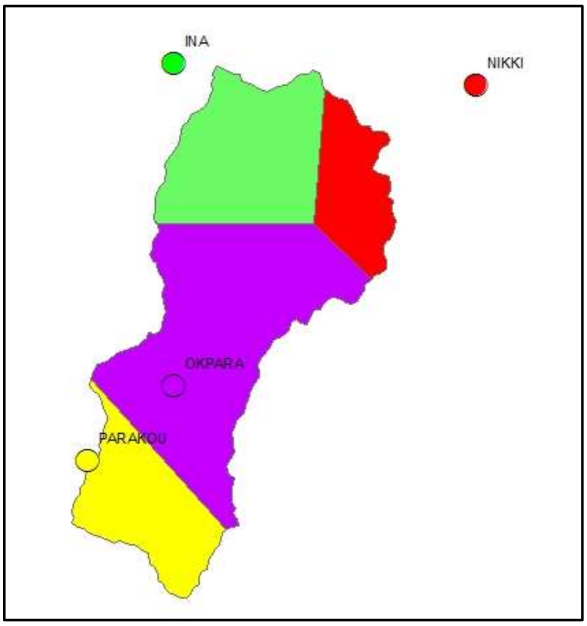

Figure 2: Zoning Nanon basin by ThiessenPolygone and proximate pluviometrical networkBy the author using ArcGIS 10.1

$$Pmoy = \frac{\sum_1^i Ai*Pi}{A} \quad (1)$$

Hydrological Model based on the Principle of Least Actions (ModHypMA) is built based on data from Oueme basin (Afouda et Alamou 2010). The model uses daily data. In this study, the calibration /validation of (ModHypMA) run from 1952 to 1967 allowed us to choose the settings that best translates the transformation of rainfall into runoff ; both decisive model parameters (λ and ν)(equation 2) were resolute by iteration using computer skills. Once the selected parameters were fixed then this version of the model was applied to the entire series to simulate river flows from 1968 to 2010.

For the application to the site of Okpara dam, the outlet of the basin is considered at the input of the reservoir. The current site is located at up stream of reference basin or « donor ». The corrections on the parameters of the model must take into account the reduction of basin surface.

Because of a nonlinear relation between the flows and surfaces of the basin, it was possible to make the required correction on the parameters of the model using the expression in equation2

$$\lambda_2 = \lambda_1 \frac{{S_1}^{\nu_1}}{{S_2}^{\nu_2}} \quad (2)$$

Thanks to the increasingly powerful data-processing tool, one succeeds easily and quickly to determine the suitable values for $\boldsymbol{\lambda}$ and ν for the new site.

At the end we evaluated the potential impacts of climate change on the development of water resources in the Nanon basin. Key equations are presented below from 3 to 8.

S is the area of the watershed. Q_t and Q_{t-1} designate the input flow to the dam at dates t and (t-1), respectively; X_t describes the way rain is on date (t-1) through runoff at the measurement point of the basin. It is noticed that the hydrological response of rainfall processing to runoff on day (t-1) at the outlet of the watershed occurs on day t (Afouda et Alamou 2010). Through a good linear adjustment between $\mathrm{Ln}(Q_{t-1} - Q_t)$ and $\ln Q_{t-1}$, the use of average daily flows observed at the watershed outlet for the calibration period of the model allows determination of A and B.

$$Q_t - Q_{t-1} = -\frac{\nu}{\lambda} Q_{t-1}^{2\nu-1} \quad (3)$$

$$A = (2\nu - 1) \quad (4)$$

$$B = \ln(\frac{\nu}{\lambda}) \quad (5)$$

$$\ln(Q_{t-1} - Q_t) = A ln Q_{t-1} + B \quad (6)$$

$$\text{then}\begin{cases} \nu = \frac{A+1}{2} \\ \lambda = \frac{\nu}{e^B} = \frac{A+1}{2e^B} \end{cases} \quad (7)$$

Equation 8was used for drying up simulation.

$$\ln(Q_{t-1} - Q_t) = \ln\left(\frac{\nu}{\lambda}\right) + (2\nu - 1) ln Q_{t-1} \quad (8)$$

To simulate the high water and the entire hydrograph, we calculate the values of X_t using equation 9 with the same values of λandν as after calibration.

$$X_t = \begin{cases} \frac{\lambda(Q_t - Q_{t-1} + e^B Q_{t-1}^A}{q_{t-1}} & si q_{t-1 \neq 0} \\ 0, si q_{t-1} = 0 \end{cases} \quad (9)$$

RESULTS AND INTERPRETATIONS

Characterization of the basin

Nanon basin hydrologic system responses according to the parameters defined on table 1

Table 1: Synthesis of hydrologic parameters determination for Nanon basin

Parameters	**Symbol**	**Value**	**Unit**	**Method/ Reference**
Hydrological parameters				
Height of decennial daily shower	P10)	120,0	mm	Bulletin FAO N°54 Page16 Fig.4
Annual Precipitation	Pan (1950 à 2010)	1044,0	mm	ASECNA (Ina, Nikki, Parakou et Okpara)
	Pan (1950 à 1970)	1143,0	mm	
	Pan (1971 à 2010)	992,0	mm	
Coefficient of Vuillaume (1974)	A1 (1950 à 2010)	0,60		Fig.4 Bulletin FAO N°54 Page17
	A2 (1950 à 1970)	0,62		
	A3 (1971 à 2010)	0,60		
	A moy. (A2;A3)	0,61		
Decennial average rainfall	Pm10	72,5	mm	Fig.4 Bulletin FAO N°54
Decennial of runoff index				-
By analytical method				-
Kr70 coefficients	a'=	112,0		-
	b'=	20,0		-
	c'=	12,8		-
	Kr70=	12,8	%	-
Kr100 coefficients	a'=	180,2		-
	b'=	30,0		-
	c'=	14,5		-
	Kr100=	14,6	%	-
Determination of Kr10	Kr10=	15,8	%	-
By graphic method	Kr70=	11,5	%	-
	Kr100=	14,3	%	-
Determination of Kr10	Kr10=	16,1	%	-
Average value from both calculation methods Kr10	Kr10moy.=	15,9	%	-
Base time (Tb)	Tb10=			-
for Ig=1	Ig=1	9641,5	mn	-
for Ig=1,02	Ig=1,02	9601,9	mn	-
or Ig=3	Ig=3	5678,4	mn	-

Parameters	Symbol	Value	Unit	Method/ Reference
Ascent time (Tm)	Tm10=	3168,6	mn	-
Decennial peak of runoff index (α10)	α10	2,5		-
Decennial Flood Flow	Qr10	121,5	m3/s	-

Changes in the frequency and intensity of rainfall

The different types of rainfall were analyzed: Considering the rainfall greater than 2 mm / day, they vary between 68 days and 147 days in 1983 recorded for 2003 with an irregular interannual fluctuation. The same observation is made for rainy days where the height is greater to 10 mm (with a minimum of 14 days in 1983 and noted the maximum 61 days in 1963) and about rainy days with a height greater than 20 mm (lower value of two days in 1982 and 28 days the maximum record was in 1963). These observations remain valid for the number of days with rainfall height greater than 30 mm with the difference that the numbers were very low and such even not observed in 1952, 1971, 1980, 1984, 1999 and 2002.It came out three major phases: - Period I of 1950 to 1969, is the most wet one, - Period II from 1970 to 1989, is the most contrasted one. It is drier than the previous one. The period III from 1990 to 2009: overall wetter than the period II, the trend is still down with a reduction of 10% compared to the average annual rainfall for the period I. For this period, the number of days greater than 30 mm of rain is reduced significantly by 41% compared with the initial period. As for above 2 mm, 10 mm and 20 mm rain is also reduced by 7%, 8% and 18%.

For the annual rainfall intensity the pattern is similar to changes in the frequency of rainy days, The average annual rainfall amounts are 10% reduced over the past 20 years compared to the period 1950-1969. For the period 1990-2009 the dry season become driest; up to 64% of water loss is recognized in November which is the beginning of the dry season, 22%, 18%, 36%, 40% and 21% rainfall reduction respectively from December to April. The rainy season starts in May with a week of lateness but the rainfall for the month is quickly reached with 7%more moisture compared to the reference period. the peak value for the year is now observed nowadays and it is 12% reduced compared to the first period so that the peak for the period 1990-2009 is rather observed in July (175 mm) when it was in September (196 mm) for the first period. October marks the end of the rainy season. During the last two decades the average monthly rainfall in October was 23.3% reduced compared to the period from 1950 to 1969. It is easy to deduce from that analysis that rainy season is precocious with reduced rainfall.

It is also noticed that the number of dry days between wet days has increased in full rainy season, leaving pockets of drought in the season and especially early in the season. Extreme rainfall often occurs in the basin: These are stormy and brief intense rains that cause violent floods. And we highlight seasonal contrasts with a shorter rainy season is drier overall, and a dry season becoming drier.

Evapotranspiration

The highest value of evapotranspiration is met in March and the lowest are noticed in August. The evaporating power of the atmosphere increases with high temperature especially during the dry season. We can infer from observations that contrary the rainfall with a tendency to decline, to evapotranspiration losses tend to rise as evapotranspiration is also depending on sunlight and temperature.

Output of ModHypMa applied to flow calculation on Nanon basin:

The best combination of parameters which optimizes the performance criteria of the model for Nanon basin is $\boldsymbol{\nu}$**= 1.24;** $\boldsymbol{\lambda}$**= 28.** An acceptable result is obtained (Figure 3) at 64% as NASH coefficient. From obtained results we can deduce a description of hydrological response of the basin per period as is presented on table 2, the trend of related evolution is apparent on figure4, 5and 6.It came out that for dry season ie. November December, January, February, March and April, which has minimum flows recognize increasingly very low values leading to dry some of the rivers early in the dry season. Those so called temporary rivers multiply because of combined effects of climate and siltation For rainy season results showed that two consecutive dry years intercepted every five years from 1950 to 2010.That irregularity is very clear in June when outflows from rainfall contribution is effective.

We also notice that values in April were inconsistent regarding the corresponding flows. This confirms the precocious starting rainy season appeared more intensely in 1980 and 1996. Results also are noted that the last six decades stand in pairs according to the values of flows. Analysis of results rather showed a trend to decrease in both minimum and maximum values; minimum flows (17%) over the last four decades with respect the period 1951-1970 for peak flows that are diminished of 22% for the period 1971-1990 and 18% for the period 1971-1990 compared to the so-called wet period. Definitely, the average flow is reduced by 19% over the past four decades.

Table 2: Evolution of hydrographs perpériod

Période	Q_{min}	Q_{max}	Q_{moy}
1951-1970	9.579	59.096	24.37
1971-1990	7.891	36.506	17.374
1991-2010	7.359	37.675	17.023

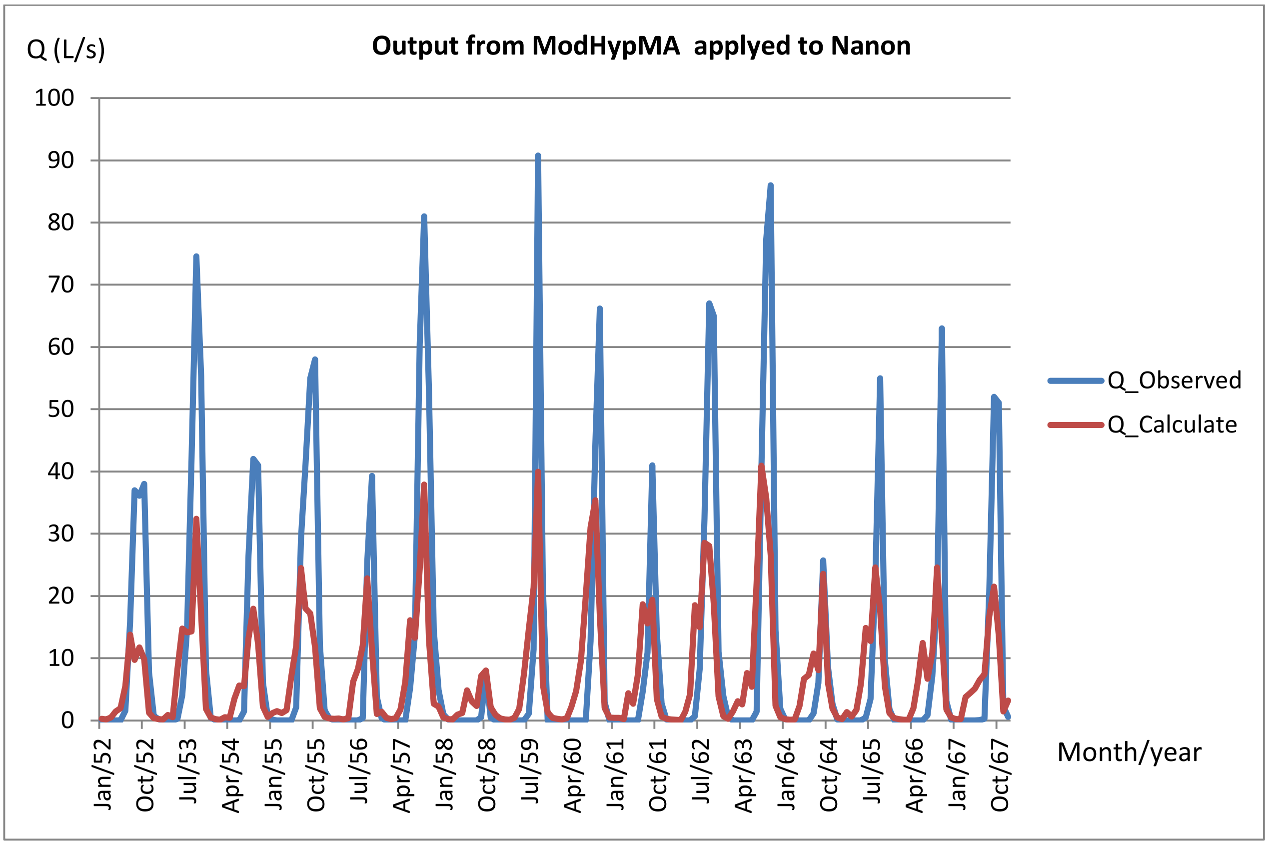

Figure 3: Output from ModHypMa applied to Nanon basin

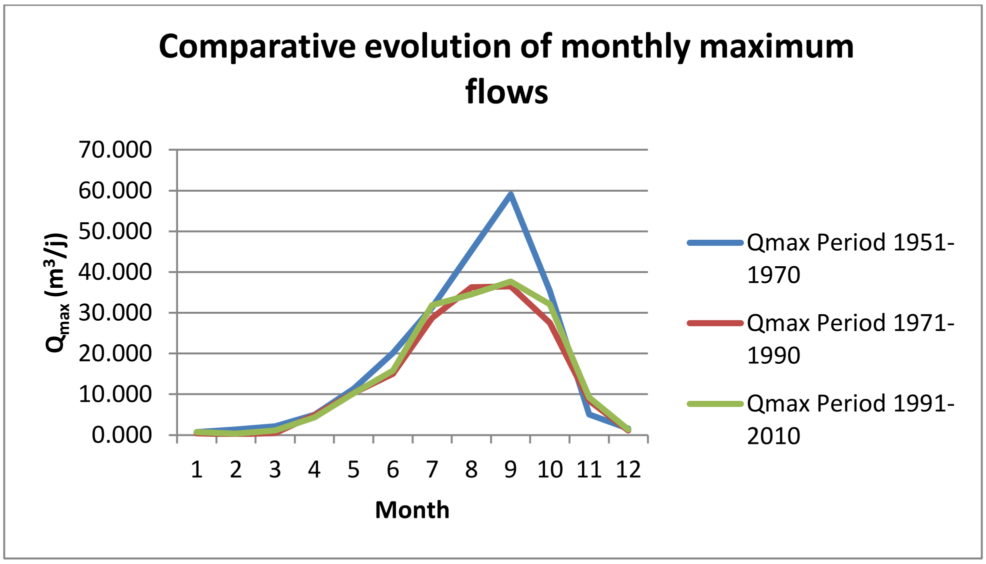

Figure 4 : Comparative evolution of minimum outflows

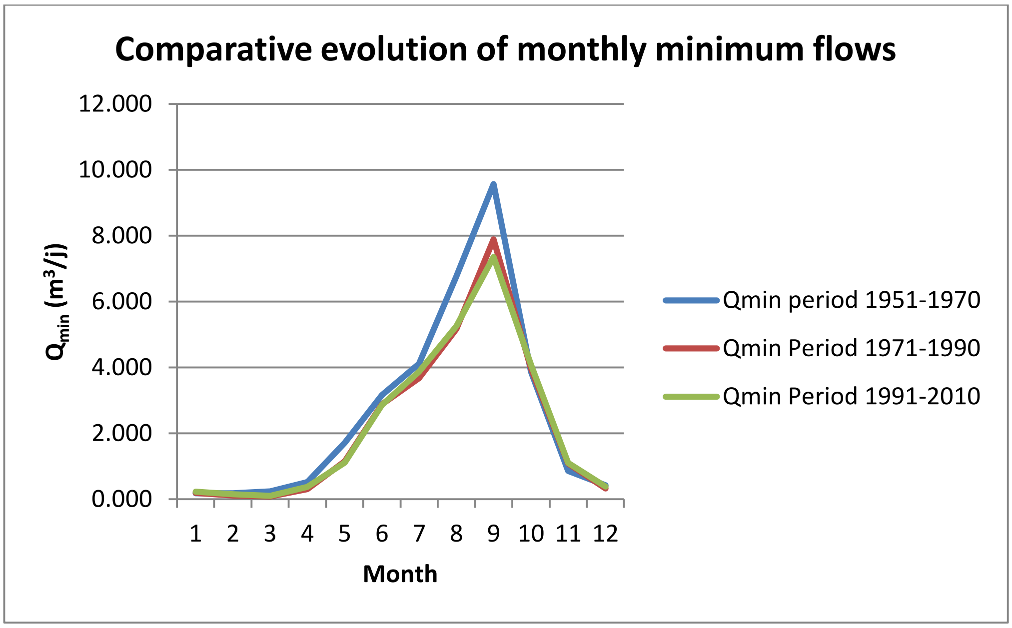

Figure 5 : Comparative evolution of maximum outflows

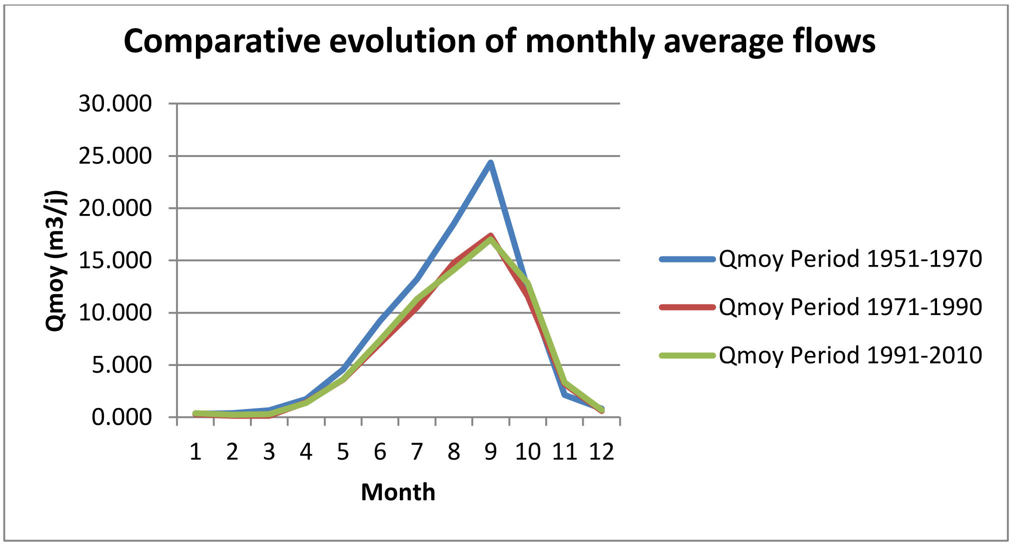

Figure **6** : Comparative evolution of average outflows

DISCUSSION

The present results are similar to those obtained in Oueme basin (Alamou Adéchina. 2011) which is the mother river basin. Previous studies in Benin and in oust Africa for similar geographical and climatic zones had already reported a decrease trend in precipitation (Mahè.

Gill 1995, Mahè, et al. 1998, Hôte, Mahe et Some 2003, Afouda et Alamou 2010, Bodian 2011, Ibrahim 2012) . This decrease in precipitation results in more naturally larger decrease runoff with the existence of an amplifying effect in throughput and the many integration features of watersheds; Runoff coefficients, infiltration, vegetation type, presence and importance of groundwater. (Vissin 1992, Bamba, Mahè et Bricquet 1996, Atchadé, Vissin et Totin 2013). However according to some of the research there was an increase in peak flows and flow coefficient despite the drop in rainfall; This is about the "Sahelian paradox" due to advanced land degradation (H, Mahe et Some 2003, Mahè et Paturel 2009, Benjamin 2013). Indeed the knowledge of the water resource and its seasonal variations at the catchment level has some weaknesses because of hydrological, lithological and geological data that are truncated or missing: The chronicles of flows was of very short duration. About the current basin rainfall data were missing at 37% of daily measures with consequence that they are not easily exploitable for a reliable hydrological analysis.

However, extrapolation of information or knowledge measured to gauge basins does not take place without uncertainty due to the large spatial and temporal heterogeneity of climate and landscape properties (Annie 2012). Indeed, we should continuous working to reduce those defects. It would be more successful to start measuring field data to develop in specific water related science. The precision of hydrology science is very important for infrastructure planning and the implementation of water management law.

CONCLUSION AND FUTURE PROSPECTS

Water management is a key area of development in the context of climate change. Indeed for the modernization of agriculture for self-sufficiency and food security, for the prevention of water hazards (floods and drought), and ultimately for the well-being of populations and ecosystems, Water managers need to get a good knowledge of hydrological and climatic phenomena integrating all interactions that exist between different components of the basin because water resources depend not only on rainfall events but also on the water-soil-vegetation dynamic.

After all description of the study area, it was evident that we could not expect more results in that work conditions. Whatever the model implemented, a satisfactory refund of the hydrograph is made as soon as a set of representative precipitation of the entire basin is available. However, a good restitution of flows does not garantee realistic simulation of intermediate process of hydrologic cycle. For the current state of ungauged basins as it is the case of Nanon basin, the simulated data can help to propose a model for water resources management on Okpara dam at Kpassa in our forthcoming paper.Yet, improving scientific bases through regular monitoring of land use, land occupation, and measurement of parameters is a first approach to integrate the impact of climate and environmental changes in hydrology. For flow measurement, three rivers sections were identified, their references are indicated on table

Table 3 : Référence of propose river section for hydrological measurement

N°d'ordre	village	Geographical coordinates		road
		Longitude	Latitude	
1	Binassi	0246374	0929009	From Alafiarou to Bougnakou
2	Darnon	0242586	0925363	
3	Douroube	0241011	0924354	

We are now dealing to install automatic recorder at each of these sections, we should also purchase kits for field works.

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