



# **Water Flow Analysis of the Kayanga-Anambé-Lake Waïma Hydrological Complex by Flow-flow Correlation and Rainfall-flow Modeling Approaches**

**Ibrahima Thiaw <sup>a\*</sup>**

<sup>a</sup> *Hydrology and Morphology Laboratory, Department of Geography, Cheikh Anta Diop University of Dakar, Senegal.*

## **Author's contribution**

*The sole author designed, analyzed, interpreted and prepared the manuscript.*

## **Article Information**

DOI: 10.9734/JSRR/2023/v29i101792

## **Open Peer Review History:**

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/106972>

**Original Research Article**

**Received: 21/07/2023**

**Accepted: 26/09/2023**

**Published: 30/09/2023**

## **ABSTRACT**

This article presents an assessment of the surface water resources of the Kayanga-Anambé hydrological complex, located in West Africa. This hydrological complex, one of the main characteristics of which is exclusively agricultural and pastoral, is subject to a changing climate and strong anthropogenic pressures leading to resource use conflicts. Therefore, a better knowledge of water availability is essential to guide policies for the management and adaptation of this geosystem. Two approaches are used to estimate the contributions from the different sub-watersheds of the Kayanga: (i) a correlation between the flow rates of Wassadou and those of the other hydrometric stations of the Management and Planning Unit (UGP) of Casamance and eastern Senegal – in particular for filling the gaps observed in the data series from the Wassadou, Niandouba and Vélingara Pakane stations – and (ii) the implementation of a rainfall-runoff modeling approach at monthly time intervals, with the GR2M model, to reconstruct seasonal flows and contributions from the Kayanga-Anambé-Lake Waïma complex. The results show correlation

\*Corresponding author: E-mail: [ibrahima4.thiaw@ucad.edu.sn](mailto:ibrahima4.thiaw@ucad.edu.sn), [biwaith@hotmail.fr](mailto:biwaith@hotmail.fr);

coefficients which vary from 0.24 to 0.96 depending on the stations, showing a strong relationship between the flow rates of the Kayanga at Wassadou and those of the other stations. The maximum correlation coefficient is noted at the Mako station (0.96), on the Gambia river. Furthermore, a Nash of 0.86 was obtained with the GR2M model. Thus, the parameters X1 and X2 of the model were used to reconstruct the seasonal flows and contributions from the Kayanga-Anambé-Lac Waïma complex. This made it possible to have long enough time series of flow rates for a better estimation of water resources and their temporal fluctuation.

*Keywords: Kayanga-Anambé-Lake Waïma; flows; GR2M; flow-flow correlation.*

## 1. INTRODUCTION

The Kayanga-Anambé-Lake Waïma hydrological complex is located in upper Casamance, in the Kolda region, in the south of Senegal, the central part of which is a vast flood basin of around 16 000 ha, lake Waïma. The desire to control the water resources of the Kayanga River to fight against food and nutritional insecurity which threatens the populations, the State of Senegal, through the Agricultural Development Company (SODAGRI), has built hydro- agricultural areas on the main tributaries of the Kayanga. These are the Niandouba, Confluent (Kayanga-Anambé confluence dam), and Kounkané dams. The hydrological functioning of this Anambé-Kayanga system is relatively simple and purely gravity-based: the confluence reservoir (Confluent dam), which receives water from the Niandouba dam, fills by gravity Lake Waïma which also receives water from runoff from slopes. During low water, part of the water is trapped in Lake Waïma by the threshold of the Kounkané bridge which prevents the exit of water towards the Kayanga. This reservoir is then used for hydro-agricultural activities in the Anambé plain.

However, the hydrological regime of the Kayanga River, like that of tropical rivers, is marked by an alternation of wet periods and dry periods. Wet decades of 1950 and 1960, followed by dry periods of the 1970s and 1980s, which have been highlighted by several authors [1,2,3,4,5,6]. Today we are witnessing a slight return of humid conditions, in general, in the Sahel and, in particular, in the Kayanga basin, demonstrated by certain authors including Sambou, [3]. But, this return of humid conditions in the basin will only be effective from 2060 [7]. However, very few studies have focused on the effect of climate variability and anthropogenic action (hydro-agricultural dams) on the hydrological regime of the Kayanga. This situation is justified by the lack of hydrological

information on the river, the flow chronicles being incomplete, discontinuous, of short duration, and therefore difficult to exploit for a reliable hydrological analysis. A reliable response to this problem will make it possible to define the distribution of the characteristic hydrological series which are the basis for the sizing and calculation of profitability of the hydraulic structures in place. Thus, modifying a distribution assumed to be constant over time would have disproportionate socio-economic impacts. The objective of this work is therefore to simulate and then extend, as far as possible, the hydrological series using a linear regression method, flow-flow correlation, and a rainfall-flow model, at monthly time steps, GR2M.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The Anambé watershed is a tributary of the Kayanga, in upper Casamance in southern Senegal, the central part of which is a vast flood-prone basin of around 16 000 ha, lake Waïma (Fig. 1). It is located, in its entirety, in the Kolda region which is limited to the South by Guinea Conakry and Guinea Bissau, to the North by Gambia, to the East by the Tambacounda region and to the West by the Sédhiou region. It extends between latitudes 12°40' and 13°10' North and longitudes 13°40' and 14°20' West and covers an area of 1 077 km<sup>2</sup> at the Kounkané bridge, while at the Confluent dam its area is 1 157 km<sup>2</sup> (Fig. 1).

The Kayanga basin straddles Guinea, Senegal, and Guinea Bissau. The Kayanga has its source in a marshy area at the foot of Fouta Djallon in Guinea. It flows in a northwest direction until it enters Senegalese territory where it makes a loop taking a southwest direction to enter Guinea Bissau where it takes the name of Rio Gêba. At the Wassadou bridge, the Kayanga drains a watershed of 3 107 km<sup>2</sup> with a length of 280 km. In Senegalese territory,

its main tributary is the Anambé river whose flow is oriented north-south until its confluence with the Kayanga, 10 km south of Kounkané (Fig. 1).

The Anambé basin has an almost circular shape with a peduncle that connects it to the Kayanga (Fig.1). The Anambé and its tributaries have a complex layout. Indeed, if its main axis has a simple layout, the shape of the basin creates a significant branching of the third-order tributaries on the right bank, with a convergence of the secondary network towards the center of the basin (Fig. 1). The left bank, for its part, receives a few tributaries with temporary flow.

Three dams were built on the Kayanga, at Niandouba (upstream) and at the confluence with the Anambé, and a threshold was built at the Kounkané bridge (Fig. 1):

- The Confluent Dam was built in 1983 for a reservoir capacity of 60 million m<sup>3</sup> (with an endowment flow of 2 m<sup>3</sup> s<sup>-1</sup>).
- The Niandouba dam was necessary to improve the system which was not operational; it was conducted in 1994 for

a reservoir of 90 million m<sup>3</sup> and an endowment flow of 4.2 m<sup>3</sup> s<sup>-1</sup>. [8].

- The Kounkané threshold (or Kounkané bridge) blocks the outlet of lake Waïma to increase storage possibilities upstream of the Kounkané bridge during low water and thus allows a retention of 25 million m<sup>3</sup> within the Anambé floodplain for the realization of hydro-agricultural projects [8].

The Kayanga-Anambé system is finally presented as a series of reservoirs and hydraulic axes: upstream, the Niandouba reservoir with 90 million m<sup>3</sup>, the Niandouba-Confluent dam hydraulic axis, then the Confluent dam reservoir of 60 million m<sup>3</sup>, and finally the reservoir of lake Waïma at the threshold of the Kounkané bridge with 25 million m<sup>3</sup> [8]. However, most of these structures were built during the drought that hit the Sahel hard from the early 1970s to the mid-1990s and the return of rainfall conditions to normal since 1993 [9,2,10,3,5], which then requires the resizing of all the discharge and overflow structures built during the drought period.

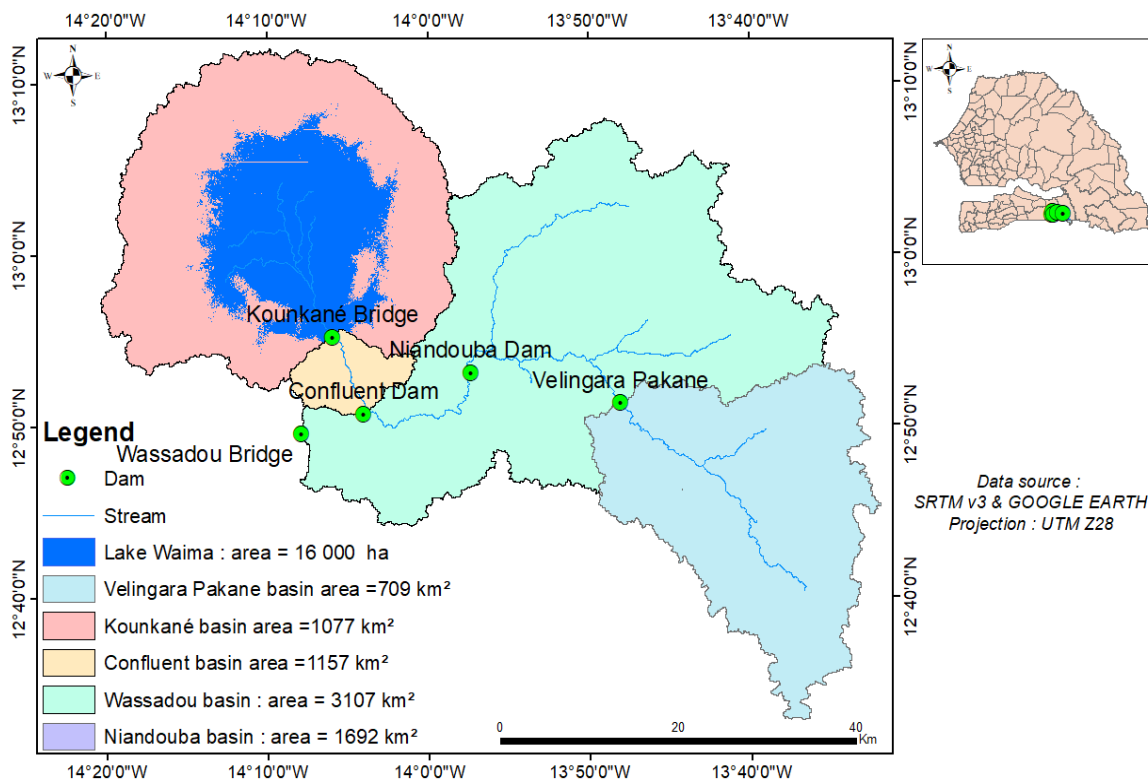


Fig. 1. The Kayanga and Anambé watersheds

## 2.2 Observed Data

### 2.2.1 Climatic data

The Kayanga basin is part of what is called the region of hot and humid low latitudes. In this region, the rivers are fed exclusively by rain, and this gives precipitation a decisive role in explaining the modalities of river flow. The characterization of the rainfall regime and its variability is done using rainfall chronicles (annual and monthly) from the measurement networks. At the level of the Kayanga basin, the monitoring and collection of rainfall data is the responsibility of the meteorological departments of the various countries making up the region studied. These are the National Meteorological Directorates (DMN) of Guinea, Senegal, and that of Guinea Bissau. Table 1 gives the geographical coordinates of the rainfall stations whose data were collected. The selection criteria for rainfall stations are based on three fundamental factors:

- the importance of the sample size,
- their proximity to the study area (i.e., their geographical position),
- the quality of the data (small gaps in the different series observed),

Based on these criteria, thirteen rainfall stations were selected as reference stations for the rainfall study (Table 1). Given the low density of rainfall stations, especially in the southern part of the basin, and the fact that Guinean climatic data (Guinea Conakry) could not be collected,

two fictitious stations (SF5 and SF6) were added to complete the data. data observed with those of the CRU [11]. Before using the CRU data, they were validated using data from the Kolda station which is the reference station in the area.

Regarding potential evapotranspiration (ETP), given the fact that only the station of Kolda which has climatic data for the calculation of the ETP, the data of the CRU are used for the calculation of the average ETP of the Kayanga sub-watersheds. The coordinates of Rainfall data were used for the extraction of ETP data from the CRU. As reminded above prior to use CRU data has been validated using station of Kolda as reference.

### 2.2.2 Validation of CRU and ETP data

As reminded above prior to use CRU data has been validated using station data Kolda reference. Fig. 2 provides a summary of CRU data validation and Fig. 3 gives the seasonal cycle of the ETP at the level of some stations.

In the approach of a global modeling, the average rains were calculated by the method of the inverse squared distance [11,5] at the sub-catchment scale using the point data. The results obtained are shown in Fig. 10. The average rainfall and ETP in Fig. 10 are used for the calibration of the GR2M model then for the simulation of the monthly flows of the different sub-watersheds.

**Table 1. List of rainfall stations selected for the study area**

Name of the Station	Latitude	Longitude	Obs. Variable	Period observed
Kounkane	12.93	14.08		1963-2012
Dabo	12.88	14.48	Rain	1975-2012
Fafacourou	13.07	14.57		1962-1998
Kolda	12.88	14.97	Rain, Temperatures	1940-2020
Médina Yoro	13.3	14.72	Rain	1973-2004
Vélingara	13.15	14.1		1940-2018
Basse	13.32	14.22		1942-2014
SF6	12.92	13.45	Rain, Temperatures	1940-2020
SF5	12.39	13.48	Rain, Temperatures	1940-2020
Pirada	12.67	14.17	Rain	1950-1989
Pakour	12.72	14		1997-2012
Linkering	12.97	13.73		1944-2004
Bonconto	13.02	13.93		1975-2004

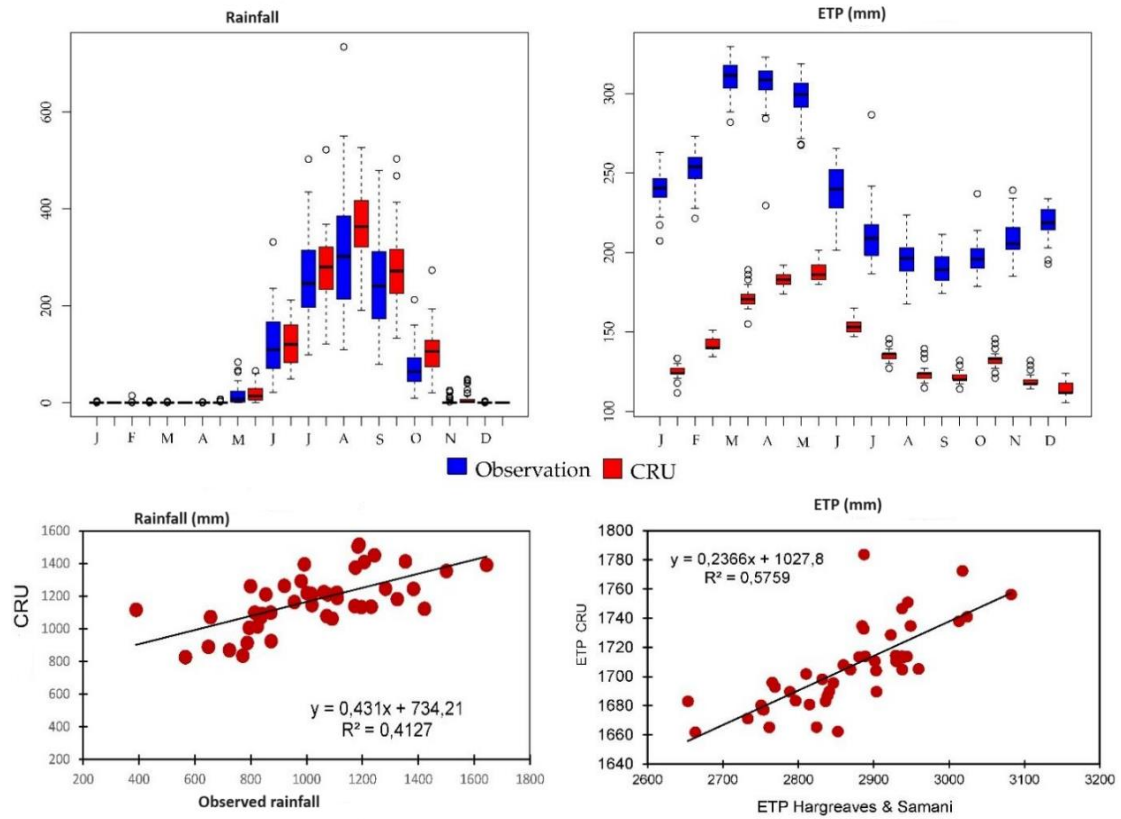


Fig. 2. Validation of CRU rainfall and ETP data with station data Kolda reference

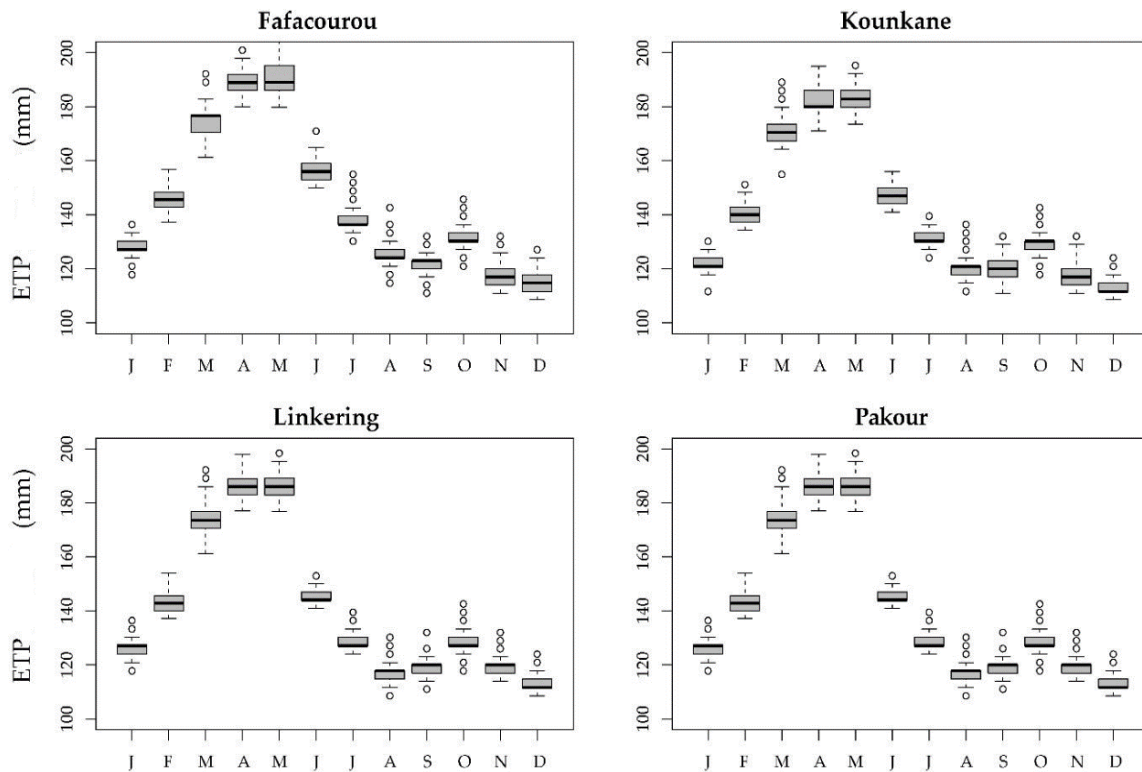
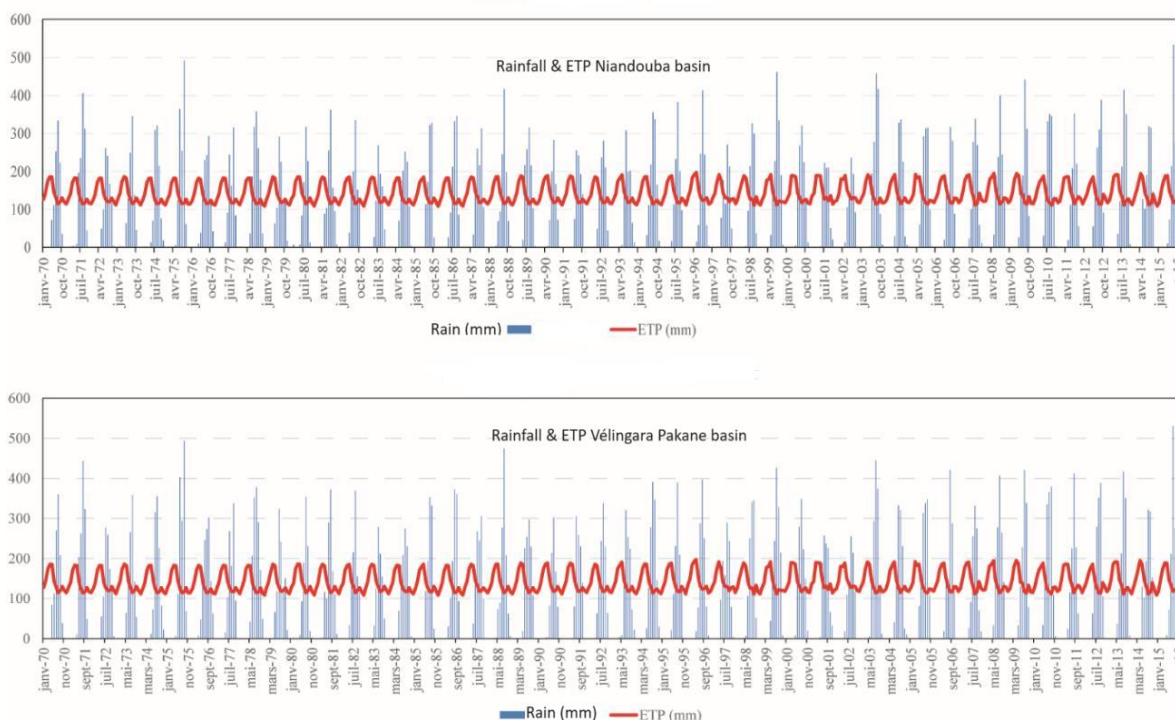


Fig. 3. Seasonal cycle of the ETP of some stations of the Kayanga basin



**Fig. 4. Average rainfall and ETP used for calibration-validation and flow simulation sub-watershed monthly**

### 2.2.3 Hydrometric data

The Kayanga watershed is equipped with nine hydrometric stations which are: the stations of Mayel Maréwé, Sansankoto, Kouthidy, Koundiama, Sector 5, the Kounkané bridge, the Wassadou bridge, the Confluence dam and the Niandouba (Table 2).

The spatial distribution of these stations is illustrated in Fig. 5 below. All the stations were equipped with thalimede (configurable electronic encoders) attached to limnometric

scales installed between 1999 and 2000. Each thalimede is attached to an IGN rating and instantly records water heights. At the two dams (Confluence and Niandouba), the thalimede records variations in the coasts of the body of water in the reservoir. Downstream of the two dams other thalimedes are installed. These make it possible to determine the leaks of water, which also makes it possible to monitor hydraulic structures because significant leaks indicate a malfunction or failure in the structure of the work which may constitute a danger potential for the safety of the latter.

**Table 2. Characteristics of the hydrometric stations in the Kayanga watershed**

Stations	Latitude	Longitude	Altitude m IGN	Date of activation
Mayel Maréwé	12° 57 N	13° 55 W	75	2005
Sansahkoto	12° 54 N	13° 46 W	90	2005
Kouthidy	12° 51 N	13° 47 W	75	2005
Koundiama	12° 41 N	13° 45 W	-	2005
Sector 5	13° 02 N	14° 10 W	60	2005
Kounkané bridge	12° 55 N	14° 05 W	17.2	1977
Wassadou bridge	12° 49 N	14° 07 W	13.9	1976
Confluence dam	12° 50 N	14° 04 W	22.3	-
Niandouba dam	12° 53' N	13° 57' W	30.9	1997

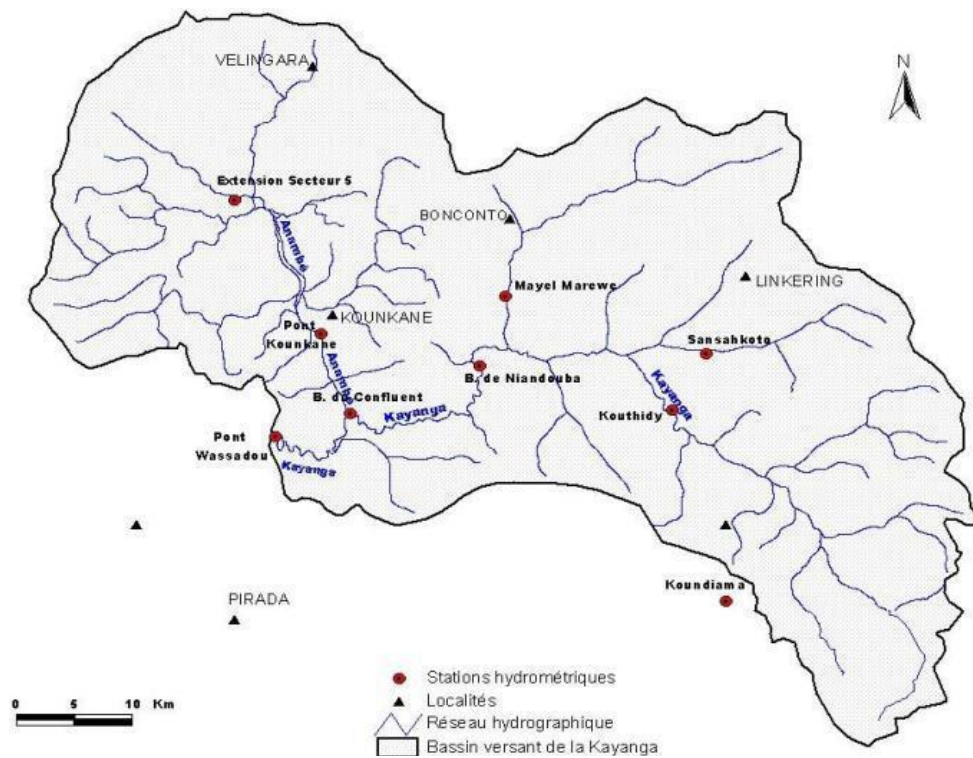


Fig. 5. Hydrometric network of the Kayanga basin

### 2.3 Status of Hydrometric Data

Table 3 gives the inventory of the hydrological data of the Kolda brigade which follows the basin of Kayanga. It should be mentioned that the hydrological monitoring of the Kayanga-Anambé complex is too incomplete. Only the

Wassadou station at the bridge has a rating curve (Fig. 6) by consequent amount of usable flow data. Indeed, most of the installed hydrometric stations only measure water levels. This situation constitutes a limit for the conduct of hydrological studies but also the assessment of water availability.

Table 3. Inventory of hydrological data of the Kolda brigade

Name	Longitude	Latitude	Start date	End date	% Gaps	Duration	Rivers
Alexandrie	-14.69	12.78	19/07/1988	09/12/1999	82	2	Tiangol
Confluence bridge	-14.07	12.85	11/08/1998	12/12/1999	0	1	Kayanga
Fafacourou	-14.55	13.05	02/01/1968	01/11/2000	85	5	Casamance
Kolda	-14.94	12.89	01/12/1963	19/10/2020	27	41	Casamance
Medina Abdoul	-14.58	12.85	30/10/1968	27/09/1993	40	15	Khorine
Medina Omar	-14.73	12.85	02/06/1967	02/08/2005	38	24	Khorine
Niapo	-14.07	12.85	22/05/1976	04/11/1982	25	5	Kayanga
Sare Fode	-15.35	13.08	11/05/1978	20/06/2001	78	5	Sougroungrou
Sare Keita	-14.94	12.83	02/01/1968	20/06/2001	65	12	Dioulakolon
Sare Koutayel	-14.88	12.93	19/10/1968	01/05/1990	31	15	Niampampo
Sare Sara	-14.75	12.84	02/06/1967	02/08/2005	38	24	Tiangol
Wassadou bridge	-14.13	12.83	01/05/1976	09/08/2005	27	21	Kayanga

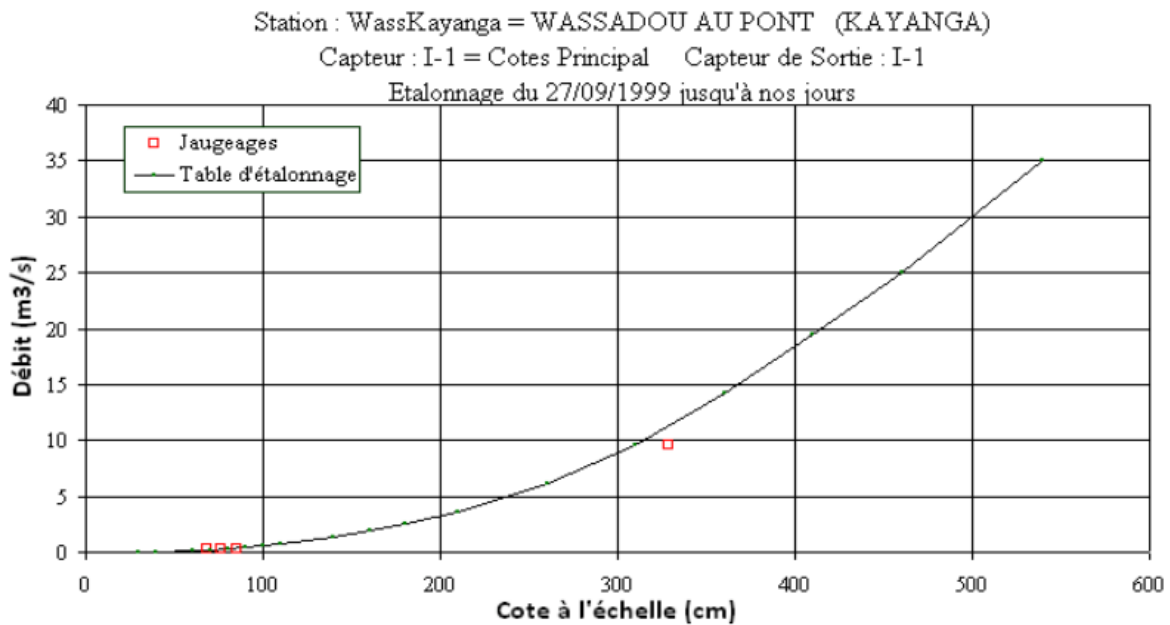


Fig. 6. Calibration curve of the Kayanga at the Wassadou bridge

#### 2.4 Critique of Hydrological Data and Extension of Series

The hydrological data from the Kayanga hydrometric stations do not make it possible to estimate the average contributions at the level of the various dams but also of the upstream basin of Vélingara Pakane. Indeed, the Wassadou station which has a few series controls all the flows Kayanga, including contributions from Anambé. But given the gradual implementation control structures on the watercourse, only the modules from 1976/77 to 1984/85 (commissioning of the Confluence dam) of this station will be taken into consideration, i.e., 9 years.

Indeed, after 1985 the Wassadou modules no longer correspond to the real contributions from the upstream basin: (i) the Koukané threshold created the Lake Waïma reservoir (twenty-five million m<sup>3</sup>) constituted by the contributions of the Anambé; (ii) the Confluence Dam created the transitional reservoir allowing the elevation of the plan in the Anambé basin. The volume of its reservoir is estimated at thirty-four million m<sup>3</sup>; (iii) the Niandouba reservoir, in 1997, whose useful volume is of eighty-five million m<sup>3</sup>. So only part of the basin's contributions upstream (ecological flow of SODAGRI) transits downstream and is measured at the Wassadou

station currently. This situation requires only taking the data from Wassadou before the construction of the various dams to estimate the contributions of different sub-basins. Within the framework of this study, a correlation between the flows of Wassadou and those of the other hydrometric stations of the UGP (Management and Planning Units) of Casamance and eastern Senegal was used to estimate the contributions of the different sub-watersheds of the Kayanga.

#### 2.5 GR2M Model

GR2M is a global conceptual hydrological model that operates on a monthly time step. It contains two free parameters to calibrate X1 and X2: X1 intervenes in the "production function" part then that X2 intervenes in the "transfer function" part. The production function reflects the actual transformation of rain into a layer of water available for runoff; the function of transfer translates the movement of this layer of water, accumulated on the ground during precipitation, towards the outlet of the watershed. These two parameters are determined for the entire catchment area. Fig. 7 presents the conceptual diagram of the model. We refer to Makhlof and Michel [12] and to Paturol et al. [13] for the detailed description of the model.



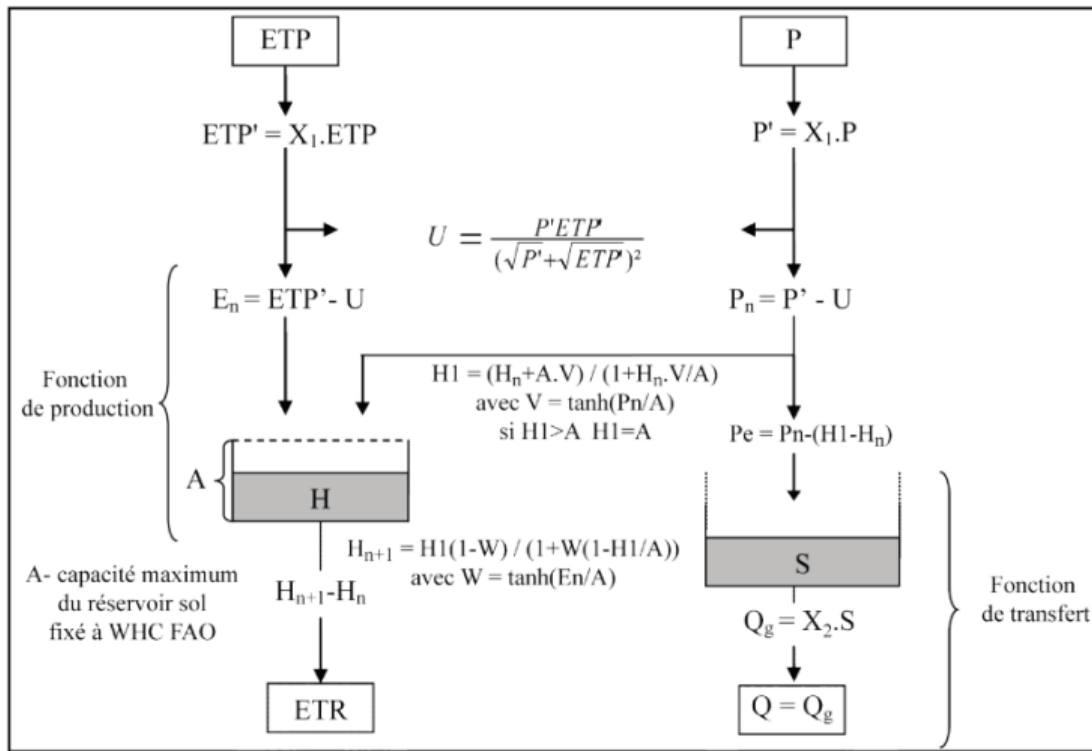


Fig. 7. Conceptual diagram of the GR2M model [14]

The robustness of this model to simulating flows in an African context has been shown in several studies [13,14,11] and it is not very data-intensive; it requires rain and ETP data as input.

### 2.5.1 Calibration and validation of the GR2M model

Calibration of a model consists of bringing the behavior of the model as closely as possible to that of the modeled basin reproduce as best as possible the hydrological behavior of the basin. In general, the method of bringing together these behaviors consists of perfecting the model parameters. In practice, there are two types of techniques for calibrating a model: manual techniques and automatic techniques. In this work a wedging automatic via one iteration was chosen.

Generally, it is cross-validation that is used in the literature to evaluate the performance of a hydrological model. This method consists of calibrating the model in a first time over a period then in a second time to conduct a critical examination of the latter by validating over another period [14,11,5,6]. Which allows to appreciate the quality of the model on data which was not used for calibration. However, given the nature of data available from Kayanga

to Wassadou (a very short series) so we calibrated the model GR2M over the entire period of available data (period 1977-1984); the parameters as well determined were used to simulate the flows.

### 2.5.2 Evaluation of model performance

Optimization (or calibration) of model parameters requires the definition of an objective function quantifying the model error, the difference between the observed flow rates and the simulated flow rates. We can distinguish two types of criteria for evaluating model performance [15]: quantitative criteria which use numerical evaluations. The qualitative criteria, for their part, are based on graphical observations (hydrographs comparing flow rates observed and simulated). These graphical observations make it possible to compare, through illustrations, the simulations with reality observed and detect certain anomalies that are poorly detectable by traditional numerical criteria [15]. The evaluation of the GR2M model was conducted using the Nash criterion and the coefficient correlation. The Nash criterion [16] calculated on flow rates is commonly used in hydrology. This criterion is based on the sum of squared errors and its formulation is as follows:

$$Nash(Q) = 1 - \frac{\sum_{i=1}^n (Q_{obs,i} - Q_{calc,i})^2}{\sum_{i=1}^n (Q_{obs,i} - \underline{Q}_{obs})^2} \quad (1)$$

where:

**Q<sub>obs, i</sub>**, **i** is the observed flow at time step **i**;  
**Q<sub>calc, i</sub>**, **i** is the simulated flow at time step **i**; **Q<sub>obs</sub>**  
 is the average observed flow; **i** is the time step;  
**n** is the total number of time steps of the simulation period.

The fitted model is all the better when the objective function is close to 1 (or 100% when we raise the values in percentage) and a criterion of less than 0.6 (or 60%) does not give a satisfactory agreement between the hydrographs observed and simulated by the model [17].

### 3. RESULTS

#### 3.1 Flow-flow Correlation

From the data in Fig. 8 below, a correlation was sought between the annual modules of the Kayanga in Wassadou and those of other hydrometric stations. Table 4 gives the coefficients correlation and determination of the flow rates of Wassadou-Kayanga and those of the stations of Bakel, Kedougou, Koussanar, Mako, Koulountou, Simenti, Wassadou upstream and Wassadou downstream of the Gambia. These eight stations are those which have a common data period with the Wassadou-Kayanga station (Fig. 8). Thus, the correlation coefficients vary from 0.24 to 0.96

depending on the stations showing overall a strong relationship between the flow rates of Wassadou-Kayanga and those of the other stations. The Maximum correlation coefficient is noted at mako station (0.96). The determination coefficients vary in the same proportion with values ranging from 0.06 to 0.92 (Table 4).

The linear relationship in Figs. 9-11, between the flow rates of Wassadou Kayanga and the flow rates of Mako (river Gambia) was used to reconstruct the annual modules of Kayanga-Wassadou over the period 1971-2000 (Table 5). The reconstructed flows of the Kayanga-Wassadou were then used to reconstruct the flows from the Vélingara Pakane basin and the inflows from the Niandouba dam. Indeed, the APD of the Vélingara Pakane dam considers that, the Vélingara Pakane sub-basin represents 40% of the flow of the Kayanga-Wassadou. Subsequently, the surface ratio between the basin of Wassadou and Vélingara Pakane was used to calculate the contributions from the Niandouba basin. The results obtained from these different flow-flow correlations are presented in the Table 5. The flow-flow correlation even if it made it possible to reconstituting the annual modules does not consider the monthly scale. Furthermore, because of the Kayanga exchanges and the Anambé-Lac Waïma complex, the flow-flow correlation will not be used to restore the flows of the basin controlled by the confluence dam. For the reconstitution of seasonal flows and contributions to the confluence dam the rainfall-flow modeling is privileged.

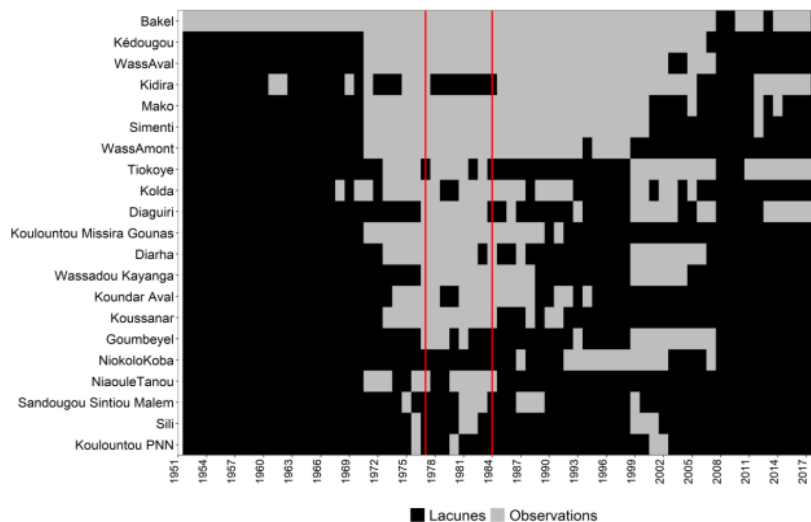
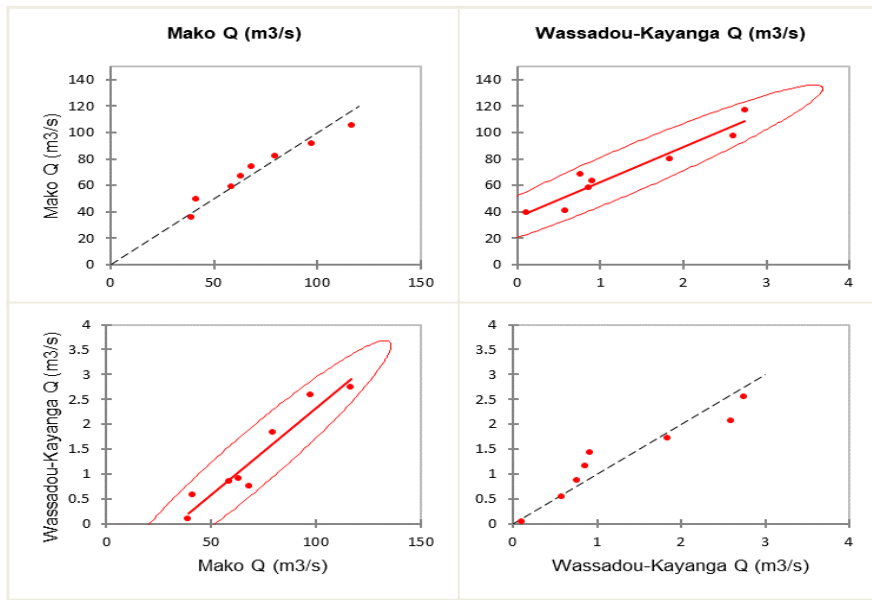


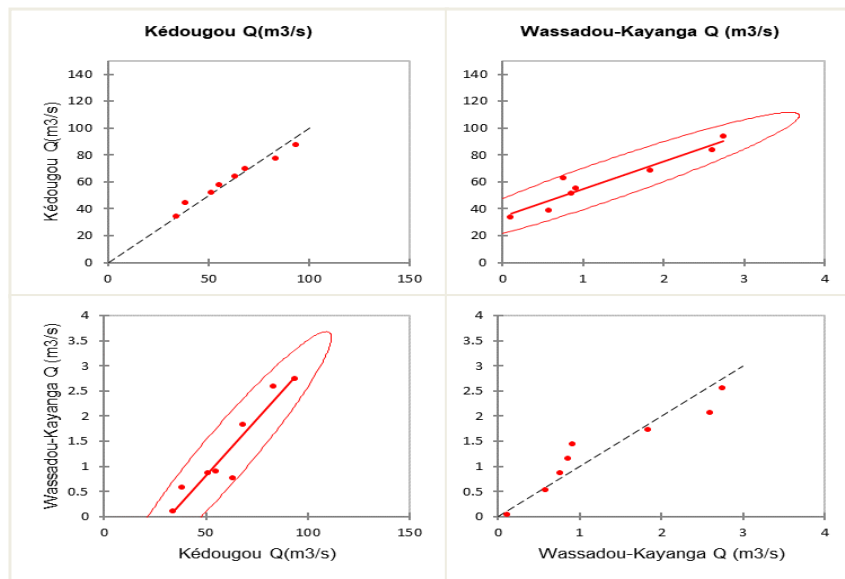
Fig. 8. Inventory of annual modules of the different hydrometric stations of the UGP of the Casamance and Eastern Senegal

**Table 4. Correlation and determination coefficients of the flows of Wassadou and the others hydrometric stations**

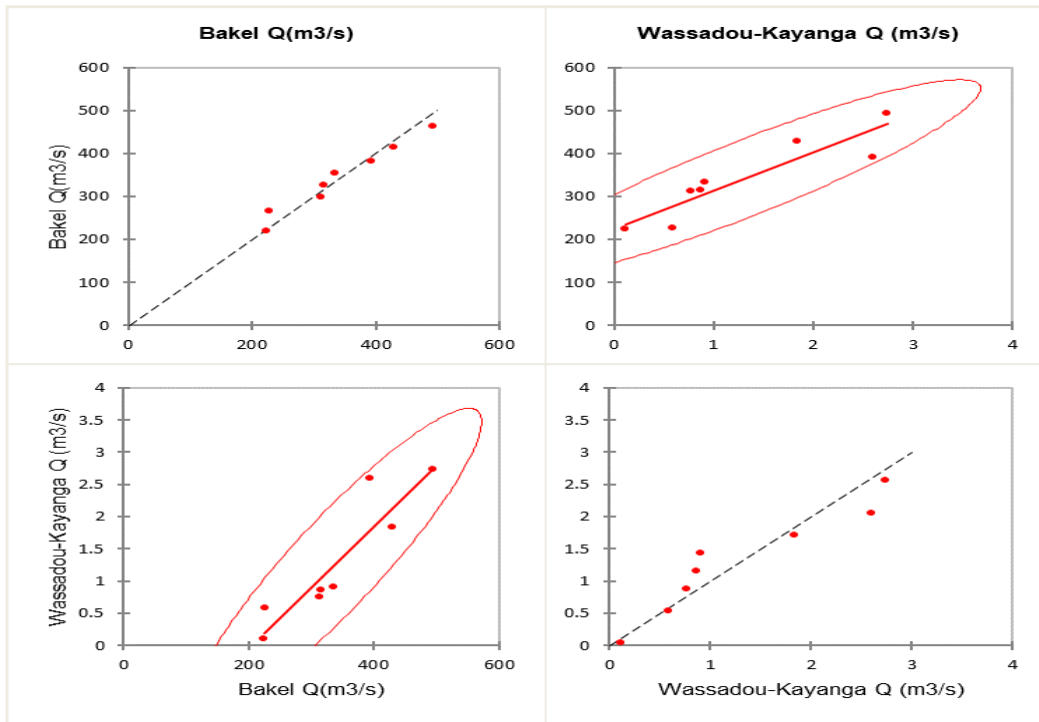
Station	Correlation coefficient (r)	Coefficient of determination (r <sup>2</sup> )
Bakel	0,91	0,84
Kedougou	0,95	0,91
Koussanar	0,24	0,06
Mako	0,96	0,92
Koulountou	0,72	0,52
Simenti	0,88	0,77
Wassadou upstream	0,89	0,79
Wassadou downstream	0,89	0,79



**Fig. 9. Linear relationship between Wassadou-Kayanga and Gambia discharges at Mako (River Gambia)**



**Fig. 10. Linear relationship between Wassadou-Kayanga and Gambia discharges at Kedougou**



**Fig. 11. Linear relationship between Wassadou-Kayanga discharges and Bakel discharges**

### 3.2 Flow Simulation with GR2M Model

The results of the flow simulation with the GR2M model are presented in Fig. 12, which gives the comparative evolution between the flow rates observed and calculated. There value of the Nash criterion obtained is 0.86, therefore greater than 0.60. However, the analysis of observed and simulated hydrographs (Fig.12) shows that the model has difficulty simulating flow rates extremes. This situation is inherent to the modeling approach used which is only a simplified vision of the complexity of the functioning of the watershed [18]. Moreover, Kingumbi [19] identifies four sources of uncertainty in the differences between data measured in the field and outputs simulated by a model: (i) the random or systematic errors arising from the data (precipitation, evapotranspiration) used to represent the variation in space and time of system inputs as well as its boundary conditions; (ii) random or systematic errors in the model output data (water levels in a river, piezometric levels, flow rates of a river, etc.); (iii) errors due to an incomplete or biased structure of the model, which may not be suitable for representing the phenomena involved in the system; (iv) errors

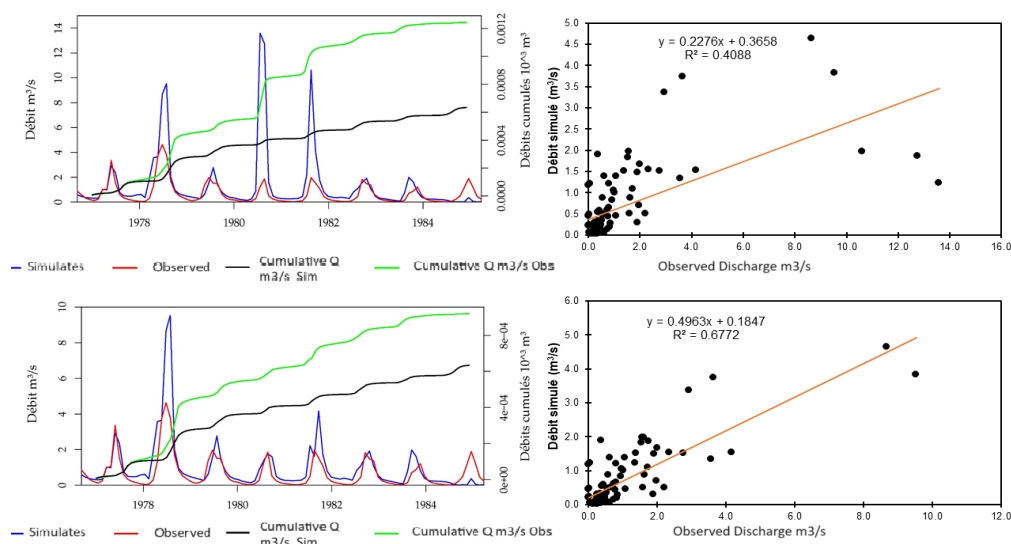
due to model parameter values that may not be optimal.

Despite this limitation of the GR2M model of which we are aware, and which may be due to the nature data used and the length of the series used, the parameters (X1 and X2) thus obtained are used for the simulation of flows from the Vélingara Pakane basin, Niandouba and the Kayanga before the Confluence over the period 1971-2000. The results of this simulation are used to evaluate water supplies to the Kayanga-Anambé-Lac Waïma complex on a monthly scale to complete the annual time step.

The analysis of Tables 6 and 7 allows us to see that the differences between the modules calculated from Mako and those simulated with GR2M are significant. Thus, the ratio between the volumes calculated from Mako data and those simulated with GR2M is 2.4 for the Velingara Pakane basin and three for the Kayanga basin in Niandouba and before the Confluence. Which makes an average value of 2.8. This value is used to correct monthly volumes of different sub-watersheds.

**Table 5. Reconstituted annual flows (m3/s) of the Kayanga and the corresponding volumes in m<sup>3</sup>**

Year	Mako	Obs. Q (m3/s) Wassadou	Calc. Q (m3/s) Wassadou	Calc. Q(m3/s) Vélingara Pakane	Calc. Q(m3/s) Niandouba	Vol. (m3) Wassadou	Vol. (m3) Vélingara P.	Vol. (m3) Niandouba
1971	79.95		1.62	0.65	1.56	51 182 455	20 472 982	49 135 157
1972	72.11		1.46	0.59	1.41	46 163 437	18 465 375	44 316 900
1973	95.18		1.93	0.77	1.85	60 932 409	24 372 963	58 495 112
1974	128.4		2.61	1.04	2.5	82 199 215	32 879 686	78 911 246
1975	107.2		2.18	0.87	2.09	68 627 382	27 450 953	65 882 286
1976	84.07		1.71	0.68	1.64	53 820 000	21 528 000	51 667 200
1977	63.19	0.9	1.28	0.51	1.23	40 453 025	16 181 210	38 834 904
1978	116.8	2.7	2.37	0.95	2.28	74 773 117	29 909 247	71 782 193
1979	58.44	0.9	1.19	0.47	1.14	37 412 166	14 964 866	35 915 679
1980	97.27	2.6	1.97	0.79	1.9	62 270 386	24 908 155	59 779 571
1981	79.69	1.8	1.62	0.65	1.55	51 016 008	20 406 403	48 975 368
1982	68.22	0.8	1.38	0.55	1.33	43 673 134	17 469 254	41 926 209
1983	41.1	0.6	0.83	0.33	0.8	26 311 431	10 524 572	25 258 974
1984	39.13	0.1	0.79	0.32	0.76	25 050 275	10 020 110	24 048 264
1985	96.26		1.95	0.78	1.88	61 623 804	24 649 522	59 158 852
1986	55.03		1.12	0.45	1.07	35 229 149	14 091 660	33 819 983
1987	62.68		1.27	0.51	1.22	40 126 533	16 050 613	38 521 471
1988	76.17		1.55	0.62	1.48	48 762 572	19 505 029	46 812 069
1989	94.93		1.93	0.77	1.85	60 772 363	24 308 945	58 341 469
1990	69.76		1.42	0.57	1.36	44 659 013	17 863 605	42 872 652
1991	79.06		1.6	0.64	1.54	50 612 694	20 245 078	48 588 186
1992	56.12		1.14	0.46	1.09	35 926 946	14 370 779	34 489 869
1993	62.93		1.28	0.51	1.23	40 286 578	16 114 631	38 675 115
1994	147		2.98	1.19	2.86	94 106 578	37 642 631	90 342 314
1995	122.1		2.48	0.99	2.38	78 166 076	31 266 430	75 039 433
1996	100.7		2.04	0.82	1.96	64 466 207	25 786 483	61 887 558
1997	127.1		2.58	1.03	2.48	81 366 980	32 546 792	78 112 300
1998	112.8		2.29	0.92	2.2	72 212 394	28 884 958	69 323 898
1999	112.7		2.29	0.92	2.2	72 148 376	28 859 350	69 262 441
2000	85.12		1.73	0.69	1.66	54 492 190	21 796 876	52 312 502
<b>Mean</b>	<b>86.4</b>	<b>1.3</b>	<b>1.8</b>	<b>0.7</b>	<b>1.7</b>	<b>55 294 763</b>	<b>22 117 905</b>	<b>53 082 973</b>



**Fig. 12. Calibration of the GR2M model at the Wassadou-Kayanga station over the period 1976-1984**

**Table 6. Average annual flows of the Kayanga sub-watersheds**

Year	Pakane Cal Mako*	Pakane Cal GR2M*	Niandouba Cal Mako*	Niandouba Cal GR2M*	Confluent Cal Niandouba*	Confluent Cal GR2M*
1971	0.65	0.577	1.56	1.145	1.656	1.217135
1972	0.59	0.244	1.41	0.475	1.494	0.504925
1973	0.77	0.213	1.85	0.426	1.972	0.452838
1974	1.04	0.227	2.5	0.434	2.66	0.461342
1975	0.87	0.53	2.09	1.02	2.221	1.08426
1976	0.68	0.398	1.64	0.692	1.742	0.735596
1977	0.51	0.247	1.23	0.406	1.309	0.431578
1978	0.95	0.592	2.28	1.019	2.42	1.083197
1979	0.47	0.297	1.14	0.515	1.211	0.547445
1980	0.79	0.169	1.9	0.287	2.015	0.305081
1981	0.65	0.254	1.55	0.425	1.651	0.451775
1982	0.55	0.216	1.33	0.404	1.413	0.429452
1983	0.33	0.119	0.8	0.234	0.851	0.248742
1984	0.32	0.178	0.76	0.342	0.811	0.363546
1985	0.78	0.207	1.88	0.386	1.994	0.410318
1986	0.45	0.28	1.07	0.541	1.14	0.575083
1987	0.51	0.28	1.22	0.562	1.298	0.597406
1988	0.62	0.358	1.48	0.639	1.578	0.679257
1989	0.77	0.298	1.85	0.665	1.967	0.706895
1990	0.57	0.131	1.36	0.26	1.445	0.27638
1991	0.64	0.151	1.54	0.235	1.638	0.249805
1992	0.46	0.216	1.09	0.33	1.163	0.35079
1993	0.51	0.191	1.23	0.287	1.304	0.305081
1994	1.19	0.414	2.86	0.668	3.045	0.710084
1995	0.99	0.3	2.38	0.584	2.529	0.620792
1996	0.82	0.275	1.96	0.514	2.086	0.546382
1997	1.03	0.223	2.48	0.312	2.633	0.331656
1998	0.92	0.251	2.2	0.353	2.337	0.375239
1999	0.92	0.499	2.2	1.042	2.335	1.107646
2000	0.69	0.367	1.66	0.726	1.763	0.771738
<b>Mean</b>	<b>0.7</b>	<b>0.29</b>	<b>1.68</b>	<b>0.53</b>	<b>1.79</b>	<b>0.56</b>

With:

- **Pakane Cal Mako\***: data from the Kayanga watershed at Vélingara Pakane calculated from discharge data from the Mako station in the Gambia.
- **Pakane Cal GR2M\***: Data from the Kayanga watershed at Vélingara Pakane calculated with the GR2M model.
- **Niandouba Cal Mako\***: Data from the Kayanga watershed in Niandouba calculated at from flow data from the Mako station in the Gambia.
- **Niandouba Cal GR2M\***: Data from the Kayanga watershed in Niandouba calculated with the GR2M model.
- **Confluent Cal Niandouba\***: Data from the Kayanga watershed upstream of the confluence calculated from flow data from the Niandouba station compared to

surface area between the Kayanga at Niandouba and the Kayanga upstream of the Confluence.

- **Confluent Cal GR2M\***: Data from the Kayanga watershed upstream of the confluence calculated with the GR2M model by transposition of simulations conducted in Niandouba.

### 3.3 Analysis of Annual and Monthly Flows

The different methods used made it possible to reconstruct the annual modules of the different sub-sections basins and calculate the corresponding water volumes. Fig. 13 below shows the variation in the reconstituted flows of Wassadou- Kayanga. We can notice, a variability of the flows modeled on the evolution of the rainfall, with:

**Table 7. Availability of surface water in the Kayanga sub-watersheds**

Year	Pakane Cal Mako	Pakane Cal GR2M	Niandouba Cal Mako	Niandouba Cal GR2M	Confluent Cal Niandouba	Confluent Cal GR2M
1971	20 472 982	18 196 272	49 135 157	36 108 720	52 230 672	38 383 569
1972	18 465 375	7 694 784	44 316 900	14 979 600	47 108 865	15 923 315
1973	24 372 963	6 717 168	58 495 112	13 434 336	62 180 304	14 280 699
1974	32 879 686	7 158 672	78 911 246	13 686 624	83 882 655	14 548 881
1975	27 450 953	16 714 080	65 882 286	32 166 720	70 032 871	34 193 223
1976	21 528 000	12 551 328	51 667 200	21 822 912	54 922 233	23 197 755
1977	16 181 210	7 789 392	38 834 904	12 803 616	41 281 503	13 610 244
1978	29 909 247	18 669 312	71 782 193	32 135 184	76 304 471	34 159 701
1979	14 964 866	9 366 192	35 915 679	16 241 040	38 178 367	17 264 226
1980	24 908 155	5 329 584	59 779 571	9 050 832	63 545 684	9 621 034
1981	20 406 403	8 010 144	48 975 368	13 402 800	52 060 816	14 247 176
1982	17 469 254	6 811 776	41 926 209	12 740 544	44 567 560	13 543 198
1983	10 524 572	3 752 784	25 258 974	7 379 424	26 850 289	7 844 328
1984	10 020 110	5 613 408	24 048 264	10 785 312	25 563 304	11 464 787
1985	24 649 522	6 527 952	59 158 852	12 172 896	62 885 859	12 939 788
1986	14 091 660	8 830 080	33 819 983	17 060 976	35 950 642	18 135 817
1987	16 050 613	8 830 080	38 521 471	17 723 232	40 948 324	18 839 796
1988	19 505 029	11 289 888	46 812 069	20 151 504	49 761 229	21 421 049
1989	24 308 945	9 397 728	58 341 469	20 971 440	62 016 981	22 292 641
1990	17 863 605	4 131 216	42 872 652	8 199 360	45 573 629	8 715 920
1991	20 245 078	4 761 936	48 588 186	7 410 960	51 649 242	7 877 850
1992	14 370 779	6 811 776	34 489 869	10 406 880	36 662 730	11 062 513
1993	16 114 631	6 023 376	38 675 115	9 050 832	41 111 647	9 621 034
1994	37 642 631	13 055 904	90 342 314	21 066 048	96 033 880	22 393 209
1995	31 266 430	9 460 800	75 039 433	18 417 024	79 766 917	19 577 297
1996	25 786 483	8 672 400	61 887 558	16 209 504	65 786 474	17 230 703
1997	32 546 792	7 032 528	78 112 300	9 839 232	83 033 375	10 459 104
1998	28 884 958	7 915 536	69 323 898	11 132 208	73 691 304	11 833 537
1999	28 859 350	15 736 464	69 262 441	32 860 512	73 625 975	34 930 724
2000	21 796 876	11 573 712	52 312 502	22 895 136	55 608 190	24 337 530
<b>Mean</b>	<b>22 117 905</b>	<b>9 147 542</b>	<b>53 082 973</b>	<b>16 743 514</b>	<b>56 427 200</b>	<b>17 798 355</b>

- a period of water deficit between 1971 and 1992 during which the modules decreased by 11% compared to the interannual module of Wassadou-Kayanga, 1.8 m<sup>3</sup>/s; This period is also the most deficient in terms of rainfall in the entire Kayanga basin [3,7] and,
- a period of excess water between 1993 and 2000 during which the modules exceed the interannual module of Wassadou by 22%. This increase in modules is a result of the improvement in the rainfall which however remains fluctuating from one year to another and particularly in years consecutive dry and wet periods, so that the tendency towards a replenishment of resources remains uncertain in the future and does not allow easy or robust prediction of the availability of water resources in the coming years. Moreover, this return of flows has as a corollary the more frequent waterlogging and silting of rice plots, thus severely compromising the resilience of producers to climate and food insecurity.

Tables 8 and 9 give the statistics of the modules and monthly average flow rates from the simulations with GR2M. The analysis of monthly average flow rates makes it possible to highlight the price regimes water and their inter-seasonal variations. The coefficient of variation shows that for all stations, the variation in flow rates is significant. This irregularity is stronger during periods of low water and especially at the start of the rainy season. Examination of monthly flow rates also shows a variation seasonal

characteristic of the uni-modal regime with a dry season and a wet season. The flow lowest monthly flow is between April and May and the maximum flow between August and of September. The statistical characteristics are supplemented by the monthly flow coefficient (CMD) allowing the periods of high water and low water to be determined. CMDs less than unity correspond to the months of low water and the CMD greater than unity represent the months of high waters (Tables 8 and 9). For the Kayanga basin at Vélingara Pakane and Niandouba, the high waters last 3 months from August to October (Tables 8 & 9).

### 3.4 Water Availability in the Anambé-lake Waima Complex

Previously we showed that the ratio between the annual volumes calculated from data from Mako and those simulated with GR2M is 2.4 for the Velingara Pakane basin and 3 for the Kayanga at Niandouba and before the Confluence. Which makes an average value of 2.8. Thus, the data flow rates in Tables 10 and 11 are multiplied by 2.8 to correct them. From the corrected flow rates, the volumes were calculated by taking the product of flow rate and time. This operation made it possible to calculate the monthly water volumes of the Kayanga at Vélingara Pakane, Niandouba and before the confluence on the period 1971-2000. The monthly and annual contributions from the Niandouba watershed are transposed to estimate the water resources of the Anambé-lac Waima complex. This transposition is carried out using the following equation:

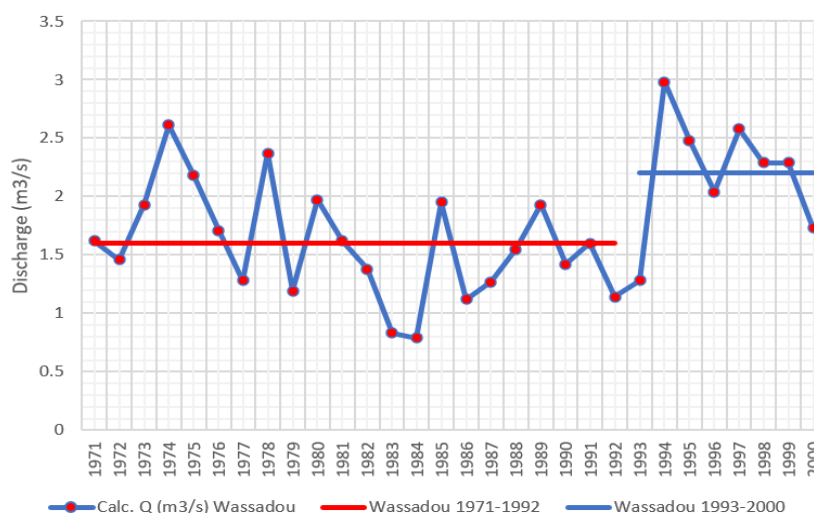


Fig. 13. Annual variation of the flows of Wassadou-Kayanga (reconstituted with Mako flows) over the period 1971-2000



**Table 8. Statistical characteristics of monthly flows (m3/s) at Niandouba**

Parameter	May	June	July	Aug	Sept	oct	nov	dec	jan	fev	March	April	year
Moyenne	0.04	0.14	0.52	1.56	2.43	1.29	0.52	0.28	0.17	0.12	0.06	0.04	0.6
Médiane	0.03	0.14	0.48	1.41	2.21	1.1	0.45	0.24	0.15	0.1	0.06	0.03	0.54
Maximum	0.22	0.41	1.14	3.5	6.01	3.2	1.27	0.6	0.38	0.25	0.14	0.08	1.24
Minimum	0	0.03	0.11	0.38	0.59	0.37	0.13	0.06	0.04	0.03	0.01	0.01	0.15
Ecart Type	0.04	0.08	0.26	0.72	1.36	0.73	0.29	0.15	0.09	0.06	0.03	0.02	0.28
Coef. Variation	0.84	0.55	0.5	0.46	0.56	0.57	0.55	0.53	0.52	0.51	0.51	0.52	0.47
Coef. Variability	44	14.64	10.66	9.08	10.21	8.65	9.91	9.28	9.64	9.54	9.64	9.87	8.17
Coef. Dispersion	1.32	1	1.07	1.11	1.1	1.17	1.16	1.16	1.17	1.15	1.14	1.14	1.11
CMD	0.07	0.24	0.86	<b>2.6</b>	<b>4.06</b>	<b>2.15</b>	0.87	0.46	0.29	0.19	0.11	0.06	

**Table 9. Statistical characteristics of monthly flow rates (m<sup>3</sup>/s) at Velingara Pakane**

Parameter	May	June	July	Aug	Sept	oct	nov	dec	jan	fev	March	April	year
Moyenne	0.02	0.08	0.28	0.84	1.25	0.68	0.28	0.15	0.09	0.06	0.03	0.02	0.32
Médiane	0.02	0.07	0.25	0.81	1.14	0.57	0.24	0.13	0.08	0.06	0.03	0.02	0.29
Maximum	0.1	0.18	0.62	1.84	3	1.61	0.75	0.35	0.21	0.14	0.08	0.05	0.59
Minimum	0	0.01	0.07	0.24	0.38	0.19	0.08	0.05	0.03	0.02	0.01	0.01	0.1
Ecart Type	0.02	0.04	0.13	0.34	0.63	0.34	0.14	0.07	0.04	0.03	0.02	0.01	0.13
Coef. Variation	0.73	0.52	0.46	0.4	0.5	0.5	0.51	0.47	0.46	0.46	0.46	0.46	0.41
Coef. Variability	24.5	13.14	9.18	7.55	7.88	8.68	9.51	7.73	7.21	7.26	7.7	7.5	5.82
Coef. Dispersion	1.2	1.06	1.15	1.04	1.1	1.19	1.19	1.14	1.12	1.11	1.12	1.11	1.1
CMD	0.08	0.24	0.89	<b>2.64</b>	<b>3.95</b>	<b>2.14</b>	0.89	0.47	0.29	0.2	0.11	0.06	

$$A_i = A_k \times \frac{P_i}{P_k} \times \frac{S_i}{S_k} \quad (2)$$

- SK: Area of the watershed “xxx” at the gauging station (km<sup>2</sup>).

With:

- Ai: Calculated water intake of subbasin “i” (m<sup>3</sup>/year),
- Ak: Observed water intake of subbasin “xxx” (m<sup>3</sup>/year),
- Pi: Average precipitated layer observed for subbasin “i” (mm/year),
- PK: Average precipitated blade observed for subbasin “xxx” (mm/year),
- Si: Area of watershed “i” (km<sup>2</sup>),

Analysis of the tables below shows that the average contributions from the Kayanga sub-basins vary between 28 million m<sup>3</sup> (Vélingara Pakane) and 56 million m<sup>3</sup> at the Confluent dam (Tables 10-12). In the Anambé-lake Waïma hydrological complex, the contributions are estimated at 12 million m<sup>3</sup> in a dry five-year recurrence and 36.8 million m<sup>3</sup> in a wet five-year recurrence (Table 13).

**Table 10. Annual and seasonal water availability in the Kayanga watershed at the water station Vélingara Pakane**

Month	Quantile 95% T = 5 years DR	Quantile 80% T = 20 years DR	Average Intake	Quantile 80% T= 5 years WR	Quantile 95% T = 20 years WR
May	45 947	82 222	179 307	253 558	425 297
June	162 097	284 746	515 883	716 471	1 052 363
July	846 782	1 303 095	2 119 978	2 833 283	3 973 319
August	2 587 190	4 012 581	6 094 570	8 013 683	10 546 410
September	3 531 075	5 419 310	9 411 045	12 772 914	19 025 947
October	1 873 048	2 856 732	4 930 220	6 677 545	9 919 083
November	815 755	1 238 193	2 130 716	2 877 859	4 268 076
December	443 276	676 017	1 123 224	1 508 546	2 165 581
January	269 969	410 599	676 111	906 007	1 291 715
February	187 044	286 037	466 675	624 362	880 753
March	63 651	153 148	246 923	340 699	430 199
April	38 311	92 895	149 820	207 282	261 868
<b>Year</b>	<b>12 175 857</b>	<b>18 244 084</b>	<b>28 043 531</b>	<b>36 865 004</b>	<b>49 665 092</b>

*DR: Dry recurrences; WR: Wet recurrences*

**Table 11. Annual and seasonal water availability in the Kayanga watershed at Niandouba**

Month	Quantile 95% T = 5 years DR	Quantile 80% T = 20 years DR	Average Intake	Quantile 80% T=5 years WR	Quantile 95% T = 20 years WR
May	74 987	140 190	325 718	461 545	795 256
June	286 228	519 249	966 338	1 352 061	2 008 819
July	1 393 820	2 256 641	3 873 843	5 273 361	7 606 405
August	4 145 825	6 810 341	11 317 402	15 333 327	21 418 153
September	6 196 265	9 675 597	18 233 719	25 171 721	39 955 683
October	3 148 856	4 805 902	9 340 531	12 956 883	21 407 551
November	1 327 158	2 089 961	3 912 193	5 407 124	8 508 415
December	712 535	1 135 684	2 079 753	2 867 728	4 405 368
January	430 257	691 834	1 257 544	1 732 973	2 635 193
February	299 740	487 272	873 524	1 201 949	1 798 293
March	159 630	260 151	463 992	637 849	949 130
April	44 859	161 283	283 277	405 270	521 705
<b>Year</b>	<b>20 271 701</b>	<b>31 629 761</b>	<b>52 902 213</b>	<b>71 396 067</b>	<b>102 187 840</b>

**Table 12. Annual and seasonal water availability in the Kayanga watershed before the confluence with the Anambé**

Month	Quantile 95%	Quantile 80%	Average	Quantile 80%	Quantile 95%
	T = 5 years DR	T = 20 years DR	Intake	T=5 years WR	T = 20 years WR
May	79 760	149 112	346 449	490 921	845 871
June	304 446	552 298	1 027 843	1 438 116	2 136 675
July	1 482 532	2 400 270	4 120 402	5 608 995	8 090 530
August	4 409 694	7 243 799	12 037 722	16 309 249	22 781 356
September	6 590 639	10 291 420	19 394 242	26 773 828	42 498 745
October	3 349 271	5 111 784	9 935 029	13 781 551	22 770 079
November	1 411 628	2 222 981	4 161 192	5 751 272	9 049 951
December	757 886	1 207 967	2 212 123	3 050 251	4 685 757
January	457 642	735 867	1 337 583	1 843 272	2 802 915
February	318 818	518 286	929 121	1 278 449	1 912 749
March	169 790	276 709	493 523	678 447	1 009 539
April	47 715	171 548	301 307	431 064	554 910
<b>Year</b>	<b>21 561 935</b>	<b>33 642 902</b>	<b>56 269 284</b>	<b>75 940 217</b>	<b>108 691 796</b>

**Table 13. Annual and seasonal water availability of the Anambé-lake Waima complex**

Month	Quantile 95%	Quantile 80%	Average	Quantile 80%	Quantile 95%
	T = 5 years DR	T = 20 years DR	Intake	T=5 years WR	T = 20 years WR
May	35 586	68 247	154 571	219 028	377 392
June	162 993	296 310	550 281	769 931	1 143 922
July	817 573	1 323 679	2 272 281	793 079	4 461 691
August	2 493 068	4 095 360	6 805 656	9 220 610	12 879 685
September	3 815 714	5 958 317	11 228 483	15 500 965	24 605 056
October	1 767 093	2 697 003	5 241 772	7 271 217	12 013 611
November	488 585	769 407	1 440 250	1 990 601	3 132 322
December	482 611	769 216	1 349 954	1 861 423	2 859 495
January	90 629	145 727	264 888	365 033	555 076
February	175 307	284 987	510 891	702 975	1 051 754
March	88 991	145 030	258 667	355 590	529 123
April	27 186	97 740	171 671	245 601	316 163
<b>Year</b>	<b>11 989 658</b>	<b>18 707 361</b>	<b>31 288 913</b>	<b>42 227 067</b>	<b>60 438 802</b>

**4. DISCUSSION AND CONCLUSION**

The aim of this article was to estimate and then extend, as much as possible, the hydrological series of the Kayanga using a linear regression method, flow-flow correlation, and rainfall-flow modeling, at monthly time steps, GR2M. The results showed a very good relationship between the flow rates observed at Mako, on the Gambia River, and those observed at Kayanga-Wassadou. The correlation coefficient is 96%, thus showing a good relationship between the flow rates of the two rivers. This is justified by the fact that these watersheds are subject to the same climatic environments, and similar physical and morphometric characteristics; this is why they react in much the same way to rainfall impulses.

Furthermore, for the simulation of monthly inflows, the GR2M model showed a good match between the observed and simulated flows from the Kayanga to Wassadou, illustrated by a Nash coefficient of 86%. However, this model encounters difficulties in simulating extreme flows and low flows. This situation is inherent to the modeling approach used which is only a simplified vision of the complexity of the functioning of the watershed [18,14,6]. Moreover, Kingumbi [19] identifies four sources of uncertainty in the differences between data measured in the field and outputs simulated by a model: (i) the random or systematic errors arising from the data (precipitation, evapotranspiration) used to represent the variation in space and time of system inputs as well as its boundary conditions; (ii) random

or systematic errors in the model output data (water levels in a river, piezometric levels, flow rates of a river, etc.); (iii) errors due to an incomplete or biased structure of the model, which may not be suitable for representing the phenomena involved in the system; (iv) errors due to model parameter values that may not be optimal. Thus, to take this limit into account, we consider the ratio between the flow rates calculated from Mako data and those simulated with GR2M, to correct the annual and monthly contributions from the Kayanga sub-basins. This made it possible to reconstruct and extend the Kayanga series over the same observation period as the Mako, 1971-2000.

The analysis of the flows of the Kayanga revealed a variability of flows modeled on the rainfall evolution, with:

- a period of water deficit between 1971 and 1992 during which the modules decreased by 11% compared to the interannual module of Wassadou-Kayanga, 1.8 m<sup>3</sup>/s; This period is also the most deficient in terms of rainfall in the entire Kayanga basin [3,7] and,
- a period of excess water between 1993 and 2000 during which the modules exceed the interannual module of Wassadou by 22%. This result is consistent with those of Amogu et al. [20] who noted an increase in the flow index during the period 1994 to 2006 on the tributaries of the Senegal river. Note, however, that the signals of this new climatic phase are only perceptible at the level of the average flow. Such a thesis is supported by Nouaceur [21] with the same method of analysis, supplemented by that of moving averages, through a study of rainfall in Mauritania.

In the Kayanga watershed, the increase in flows is a result of the improvement in the rainfall which however remains fluctuating from one year to another and particularly in years consecutive dry and wet periods, so that the tendency towards a replenishment of resources remains uncertain in the future and does not allow easy or robust prediction of the availability of water resources in the coming years. Moreover, this return of flows has as a corollary the more frequent waterlogging and silting of rice plots, thus severely compromising the

resilience of producers to climate and food insecurity.

Moreover, the reconstituted series of flow rates made it possible to identify the following annual contributions:

- a contribution of 53 million m<sup>3</sup> from Kayanga to Niandouba dam for an average year, and 20 million m<sup>3</sup> for a dry five-year year,
- a contribution of 56 million m<sup>3</sup> from the Kayanga before the confluence for an average year, and 22 million m<sup>3</sup> for a dry five-year year,
- a contribution of 31 million m<sup>3</sup> from Anambé to lake Waïma for an average year, and 12 million m<sup>3</sup> for a dry five-year year.

Under normal rainfall conditions, the water resources available in the Kayanga-Anambé-Lake Waïma complex should be sufficient to ensure a double crop of rice on 2,500 and 1,500 ha, respectively in the rainy season and in the off-season. The initial objectives of SODAGRI are not achievable today due to the mismatch between water supply and demand due to the anticipation of farmers in the development of land in relation to the pace of development, causing use uncontrolled water resources, due to unsuitable and poorly operational management of dams (particularly for the Confluent dam at which leaks are equivalent to more than 60%) [22], and because of water waste linked to compliance with irrigation rules (due to a lack of training for farmers) and lack of maintenance of canals [23].

## COMPETING INTERESTS

Author has declared that no competing interests exist.

## REFERENCES

1. Dacosta H. Precipitation and runoff in the Casamance Basin [postgraduate thesis]. Faculty of Letters and Human Sciences, Cheikh Anta Diop University of Dakar. 1989;278.
2. Descroix L, Diongue Niang A, Panthou G, Bodian A, Sané Y, Dacosta H, et al. Recent changes in rainfall in Africa of the West through two regions: Senegambia and the

- Middle Niger Basin. *Climatology*. 2015;12:25-43.  
DOI: 10.4267/climatology.1105
3. Sambou S, Dacosta H, Paturel JE. Spatiotemporal variability of rainfall from 1932 to 2014 in the watershed of the Kayanga/Géba river (Republic of Guinea, Senegal, Guinea-Bissau). *Physio Géol*. 2019;12 |, Online since 10 June 2018.  
DOI: 10.4000/physio-geo.5798.
  4. Thiaw I. Rainfall variability and water supplies in the Diarha watershed (tributary of Gambia river). *Hydrology*. 2017;5(4):41.  
DOI: 10.11648/j.hyd.20170504.11
  5. Thiaw I. Characterization and valorization of water resources in the lowlands of the Diarha watershed. [diss]. Cheikh Anta Diop University of Dakar; 2020.
  6. Thiaw Ibrahim, FATY Bakary, DACOSTA Honoré et al. Assessment of Hydrological Impacts of Climate Change on the Diarha Watershed. *Climate Change and Water Resources in Africa*. THIAW. 2021; 277.
  7. Thiaw I. Analysis of spatial and temporal variability of rainfall in the Kayanga-Anambé hydrological complex (Republic of Guinea and Senegal). *Int J Prog Sci Technol (IJPSAT)* ISSN: 2509-0119. 2023;40:122-38.
  8. Hathié I. Ex-post economic evaluation of the Niandouba and Confluent dams in Senegal. 2015;66.
  9. Bodian A, Ndiaye O, Dacosta H. Evolution of the characteristics of daily rainfall in the Senegal River watershed: before and after rupture. *Hydrol Sci J*. 2016;61(5): 905-13.  
DOI: 10.1080/02626667.2014.950584
  10. Faye C. Climatic variability and hydrological impacts in West Africa: Case of the Gambia watershed (Senegal). *Environ Water Sci Public Health Territ Intell J*. 2018;2(1):54-66.
  11. Bodian A, Dezetter A, Dacosta H. Rainfall-runoff modeling of water resources in the upper Senegal River Basin. *Int J Water Resour Dev*. 2016;32(1):89-101.  
DOI: 10.1080/07900627.2015.1026435
  12. Makhlof Z, Michel C. A two parameters monthly model for French watersheds. *J Hydrol*. 1994;162(3-4):299-318.  
DOI: 10.1016/0022-1694(94)90233-X
  13. Paturel JE, Servat E, Kouamé B, Boyer JF, Lubès H, Masson JM. Manifestations of drought in non-Sahelian West Africa. Case of Ivory Coast, Togo and Benin. *Drought*. 1995;6(1, March).
  14. Bodian A. Rainfall-flow modeling approach to regional knowledge of water resources: Application to the upper basin of the Senegal River. *Physio Géol* | 2012;6:3-5.  
DOI: 10.4000/physio-geo.2561
  15. Perrin C, Littlewood IG. A comparative assessment of two rainfall-runoff modeling approaches: GR4J and IHACRES. In: *Proceedings of the Prague conference (22-24 September 1998), IHP-V, Technical Documents in Hydrology*. Paris: UNESCO; 2000.
  16. Nash JE, Sutcliffe JV. River flow forecasting through conceptual model. Part 1—A discussion of principles. *J Hydrol*. 1970;10(3):282-90.  
DOI: 10.1016/0022-1694(70)90255-6
  17. Ardoin-Bardin S. Hydroclimatic variability and impacts on water resources in large hydrographic basins in the Sudano-Sahelian zone [doctoral thesis]. In: *Water Sciences*. France: Montpellier II University; 2004.
  18. Le Lay M. Hydrological modeling in a context of hydro-climatic variability. A comparative approach for the study of the mesoscale hydrological cycle in Benin [doctoral thesis]. France: Institut National Polytechnique de Grenoble-INPG. 2006; 67.
  19. Ahmadi K. Tunis: University of Tunis; 2006. Hydrological modeling of a basin affected by changes in occupation: Case of Merguellil in central Tunisia. *Tunis (TUN); Tunis (TUN) El Manar*. ENIT IRD. 218 p. multigr. Th: hydraulic engineering. El Manar: University of Tunis. Tunis; 2006/06/26.
  20. Amogu O, Descroix L, Yéro KS, Le Breton E, Mamadou I, Ali A, et al. Increasing river flows in the Sahel? *Water*. 2010;2(2):170-99.  
DOI: 10.3390/w2020170
  21. Nouaceur Z. Evolution of precipitation over more than half a century in Mauritania. *Geographia Technica, Special issue*. 2009;361-6.
  22. Dacosta H, Coly A, Soumaré Pope O. Adequacy of water supply and demand: Hydrological dynamics of Anambé

(Senegal). In: Integrated management of natural resources in tropical flood zones. Marseille: Institut de Recherche pour le Développement Éditions.  
DOI: 10.4000/books.irdeditions.8571

23. Harris I, Osborn TJ, Jones P et al. Version 4. of the CRU TS monthly high-resolution gridded multivariate climate dataset. Sci Data. 2020;7:109.  
DOI: 10.1038/s41597-020-0453-3

© 2023 Thiaw; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*

*The peer review history for this paper can be accessed here:*  
<https://www.sdiarticle5.com/review-history/106972>