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Analysis Of The Spatial And Temporal Variability Of Rainfall In The Kayanga-Anambé Hydrological Complex (Republic Of Guinea And Senegal)

Analyse De La Variabilité Spatiale Et Temporelle Des Pluies Dans Le Complexe Hydrologique Kayanga-Anambé (République De La Guinée Et Du Sénégal)

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Résumé – La forte variabilité pluviométrique observée surtout à partir des années 1970 a intensifié la vulnérabilité des ressources en eau dans les bassins versants tropicaux. Elle s'est traduite par la récurrence des évènements hydrologiques extrêmes – conjuguée à l'augmentation de la température qui renforce l'évapotranspiration occasionnant des pertes considérables d'eau – mais aussi par la "Sahélisation" des zones soudaniennes se traduisant par la migration des isohyètes vers le sud.

Cet article étudie les évolutions spatio-temporelles récentes de la pluviométrie dans le complexe Kayanga-Anambé, ainsi que leurs potentiels implications hydrologiques. L'approche méthodologique est basée sur (i) la vérification de la qualité des données et le comblement des lacunes par la méthode des indices pluviométriques avec la Méthode du Vecteur Régional (MVR) ; et sur (ii) l'analyse de variabilité spatio-temporelle de la pluviosité à l'aide du test de stationnarité de PETITT et des indices pluviométriques standardisés (indice SPI).

L'évolution de la pluviométrie dans le bassin se traduit par un fait propre à la zone intertropicale en l'occurrence la variabilité des précipitations. Celle-ci est marquée par plusieurs séquences : une période humide entre 1940 et 1967, suivi d'une longue séquence sèche qui s'étend entre le début des années 70 jusqu'à la fin des années 90, et enfin une légère reprise de la pluviosité sur la période 1993-2020. Cependant, d'après les sorties des modèles climatiques globaux ("Multi-model Ensemble"), la reprise des pluies dans le bassin de la Kayanga ne sera effective qu'à partir de 2060. Cette variabilité notée sur les pluies induira une variabilité similaire sur les écoulements et les productions agricoles puis qu'ils en sont largement tributaires.

Mots clés – Kayanga-Anambé ; Retour des pluies ; Sécheresse ; Tendance ; Variabilité pluviométrique.

Abstract – The high rainfall variability observed especially from the 1970s has intensified the vulnerability of water resources in tropical watersheds. It resulted in the recurrence of extreme hydrological events – combined with the increase in temperature which increases evapotranspiration causing considerable water losses – but also in the "Sahelization" of Sudanian areas resulting in the migration of isohyets towards the south.

This article studies recent spatial and temporal changes in rainfall in the Kayanga-Anambé complex, as well as their potential hydrological implications. The methodological approach is based on (i) checking the quality of data and filling gaps using the method of rainfall indices with the Regional Vector Method (RVM); and on (ii) the analysis of spatial and temporal variability of rainfall using PETITT stationarity test and Standardized Precipitation Index (SPI).

The evolution of rainfall in the basin is reflected in a fact specific to the intertropical zone, namely the variability of rainfall. This is marked by several sequences: a wet period between 1940 and 1967, followed by a long dry sequence which extends between the beginning of the 70s until the end of the 90s, and finally a slight resumption of the rainfall over the period 1993-2020. However, according to the outputs of global climate models ("Multi-model Ensemble"), the resumption of rainfall in the Kayanga basin will only be effective from 2060. This variability noted in the rains will induce a similar variability in the flows and agricultural production since they are largely dependent on it.

Keywords – Kayanga-Anambé; Return of the rains; Drought; Trend; Rainfall variability.

I. INTRODUCTION

The Kayanga-Anambé complex is in upper Casamance in the Kolda region, south of the capital of the Vélingara department (fig.1). This area, the central part of which is a vast flood basin of around 16,000 ha, lake Waïma, despite its potential and natural wealth, is faced with constraints hampering its development:

- Natural, such as the degradation of arable land and irregular rainfall.
- Socio-economic, such as the low level of irrigation equipment, the poor mastery of new production techniques, the isolation of certain production areas, and the poor access of vulnerable groups to agricultural, post-harvest and transformation.

This vulnerability is due, among other things, to the frequency of droughts, the weakness of resilience to the effects of climate change, the strong dependence of populations on agriculture and the increasing degradation of natural resources. Thus, to contribute to the food security of the country which was hit by the rainfall deficits observed over the period 1970-92 [1] [2] [3] and the development of the area, the Agricultural and Industrial Development Company of Senegal (SODAGRI) was created for hydro-agricultural development and the organization of the rural area of the Kayanga watershed. This company, placed under the supervision of the Ministry of Agriculture and Water Resources, has the following main activities:

- steering rural development in Anambé;
- Project management of infrastructure and hydro-agricultural developments;
- Advisory support and training for producers;
- Upkeep and maintenance of the developments carried out;
- Water management ;
- Monitoring and evaluation ;

However, carrying out these activities first requires better knowledge of the climate and its structure, which in turn conditions the availability of water at the watershed scale. Several climate studies including those of [4] [5] [2] [6] confirmed the episodes of drought which hit the Sudanian zone hard from the 1970s. But the potential resumption of rains in this zone is the subject of numerous controversies. Moreover, very few studies mention the possibility of a resumption of rainfall conditions in the area. In this study, to remove any ambiguity, the variability of rainfall was studied on a temporal and spatial scale over a period of 80 years (1940-2020) with the consideration of rainfall data from the main stations in the watershed of the study.

II. 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 Waima (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 is crossed by the thirteenth parallel of the northern altitude and covers an area of approximately 1,100 km².

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 Niapo bridge, the Kayanga drains a watershed of 1,775 km² with a length of 95 km. In Senegalese territory, its main tributary is the Anambé whose flow is oriented north-south until its confluence with the Kayanga, 10 km south of Kounkané.

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.

Two 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 Confluence Dam was built in 1983 for a reservoir capacity of 60 million m3 (with an endowment flow of 2 m3 s-1). The Niandouba dam was necessary to improve the system which was not operational; it was carried out in 1994 for a reservoir of 90 million m3 and an endowment flow of 4.2 m^3 s-1 [7].

The Kounkané threshold 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 m3 within the Anambé floodplain for the realization of hydro-agricultural projects (fig. 2).

The Kayanga-Anambé system is finally presented as a series of reservoirs and hydraulic axes: upstream, the Niandouba reservoir with 90 million m3, the Niandouba-Confluent dam hydraulic axis, then the Confluent dam reservoir of 60 million m3 and finally the reservoir of Lake Waïma at the threshold of the Kounkané bridge with 25 million m^3 [7].

The hydrological functioning of this Anambé-Kayanga system is relatively simple and purely gravity: the confluence reservoir, which receives water from the Niandouba dam, fills Lake Waïma by gravity, which also receives runoff water from the slopes. In low water, part of the water is trapped in Lake Waïma by the threshold of the Kounkané bridge which prevents the water from exiting towards the Kayanga. This reservoir is then used for hydro-agricultural activities in the Anambé plain.

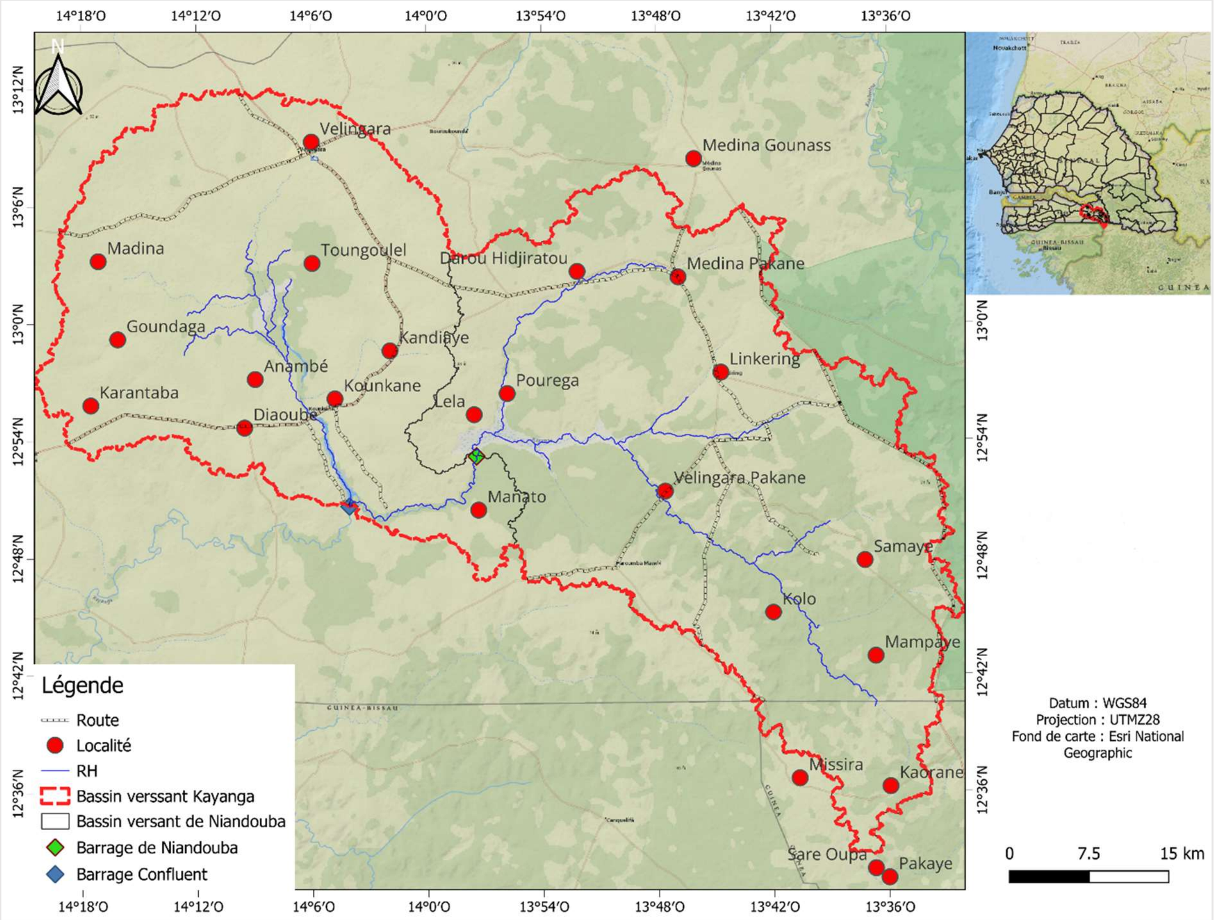

Figure 1. The Kayanga and Anambé watersheds

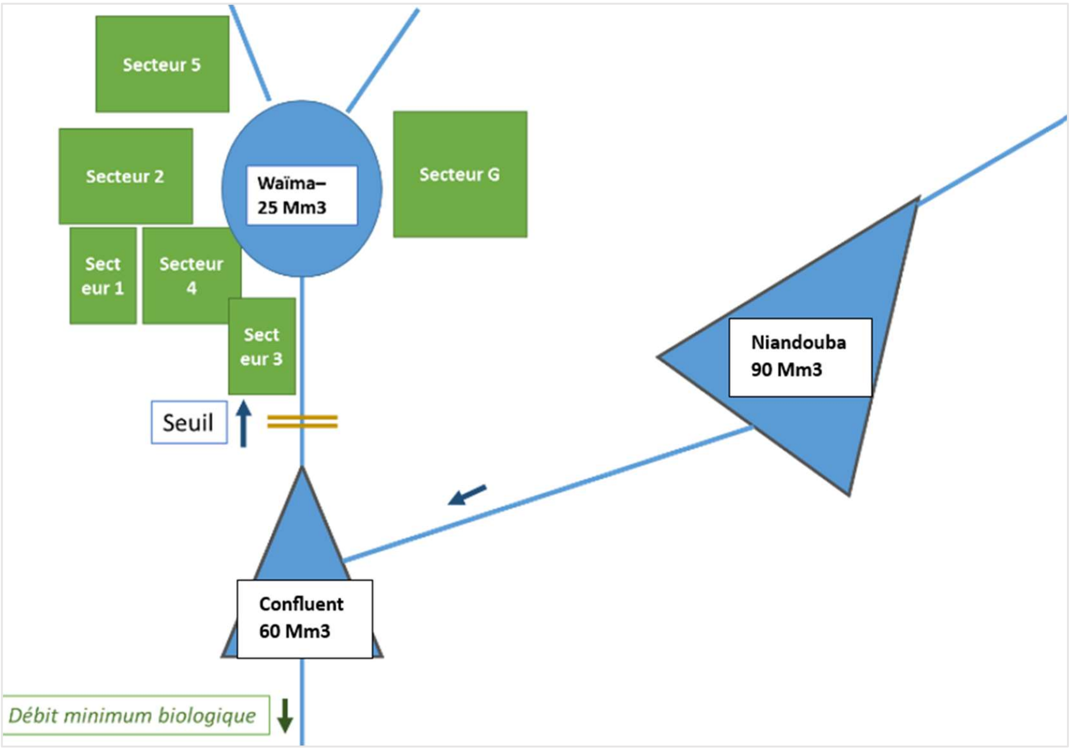

Figure 2. Diagram of the general arrangement of the Kayanga – Anambé – Lac Waïma system

The hydrographic network of the study area is mainly made up of the Kayanga and its tributary the Anambé. The Anambé flows in a north-south direction, with a slope of approximately 0.2 to 0.3%. It drains a watershed of 1,150 km² at Lake Waïma, it flows into the Kayanga about 9 km south of the N6 bridge. At the Confluent dam, its catchment area is 2,960 km².

The Kayanga has its source in the west of Fouta Djallon, the area of its watershed at the Niandouba dam is 1,700 km². At the confluence with the Anambé, its watershed is 1,755 km² with a length of 95 km. The slope is small, around 0.02%. The Kayanga enters Guinea Bissau where it takes the name of Rio Geba.

In addition to these two main axes, there is an important secondary network of backwaters, the most important of which are the Goundaga and the Hegal, tributaries of the Kayanga, and the Waïma, a tributary of the Anambé.

With a view to optimizing the availability of surface water resources in Kayanga to reduce the cereal deficit in Senegal and increase the income of producers, through the development of irrigated agriculture – the State of Senegal, through the Agricultural and Industrial Development Company of Senegal (SODAGRI) – has built several hydro-agricultural works on the Kayanga including those of Niandouba, Confluent, and the Kounkané and Wassadou bridges. 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 [8] [1] [9] [5] [2] [6], which then requires the resizing of all the discharge and overflow structures built during the drought period.

III. MATERIALS AND METHOD

1. Rainfall 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. Figure 3 gives the location 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, 13 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 [10]. Before using the CRU data, they were validated using data from the Kolda station which is the reference station in the area.

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

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

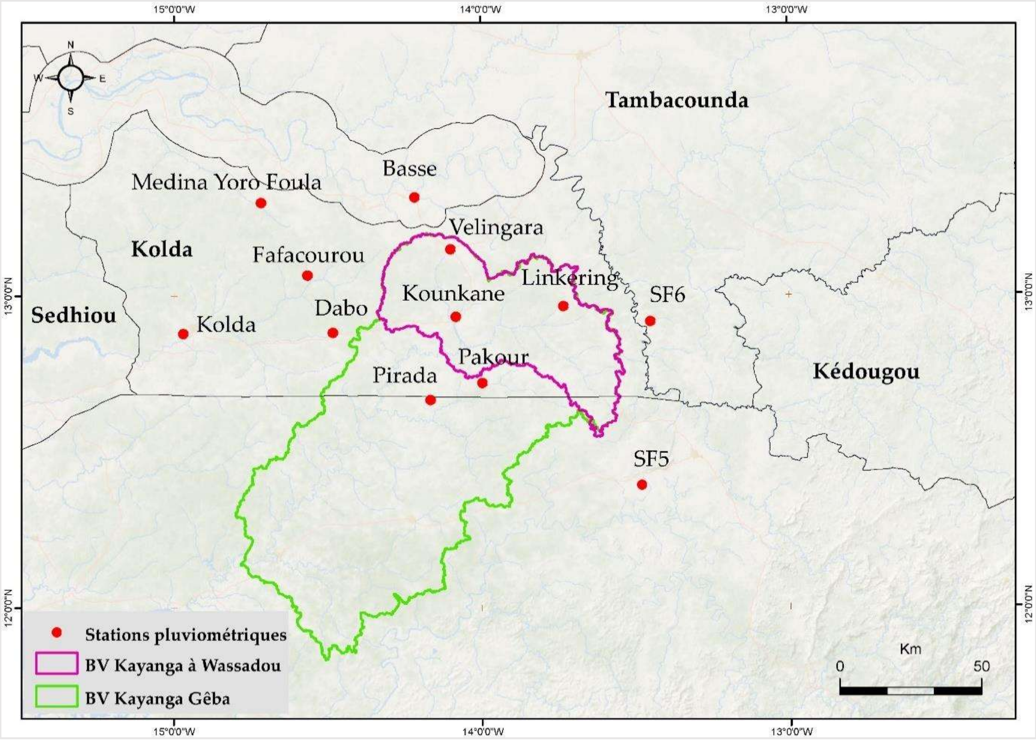

Figure 3: Location of rainfall stations across the Kayanga watershed

1.1. Critique and homogenization of data

Criticism of rainfall data is necessary, because the series collected are of size and uneven quality, difficult to use as is, given the various sources of error possible ranging from handling errors, forgetting, transcription [9] [6].

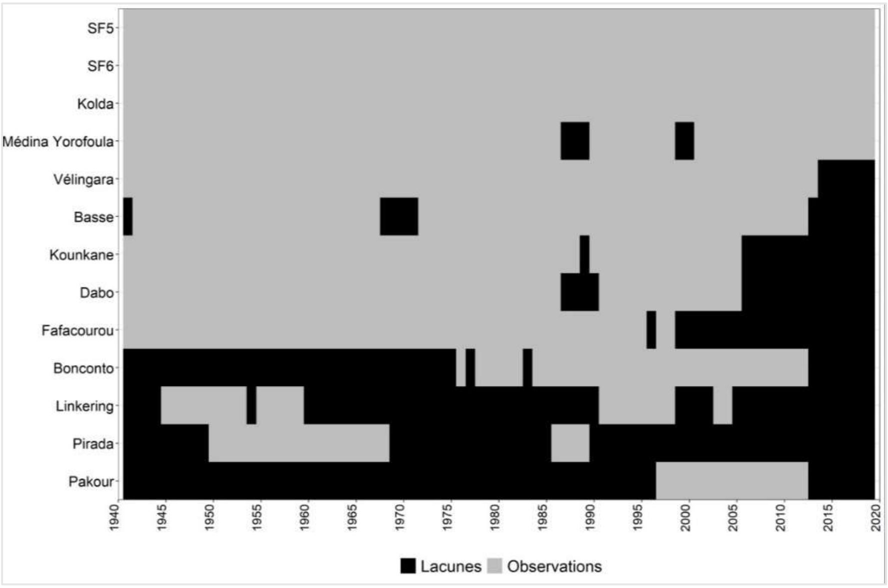

Figure 4: Inventory of available annual rainfall data

Figure 4 below gives the inventory of annual rainfall data available over the period 1940-2020. We note that only the Kolda station has complete data without gaps over the period selected. The stations of Pakour, Pirada in Guinea Bissau, Linkéring and Bonconto have the highest rates of gaps in the series collected. Before their use for the analysis of the spatiotemporal variability of precipitation at the scale of the Kayanga basin, the annual rainfall data from the various reference rainfall stations are homogenized using the Regional Vector Method (VRM) [11] [12] to obtain a common study period over the period 1940-2020. This method is integrated into the Hydraccess software [13].

1.2. The Standardized Precipitation Index (SPI)

From homogenized annual rainfall series, the temporal variability of annual rainfall is analyzed, over the period 1940-2020, by calculating the annual rainfall indices defined as a reduced centered variable [14]:

$$SPI_t = \frac{P_{t - \bar{P}}}{\sigma_P}$$

With $\boldsymbol{SPI_t}$: Standardized rain index of the year **t**; $\boldsymbol{P_t}$: Rainfall in year **t**; $\boldsymbol{\bar{P}}$: Average rainfall over the reference period **1940-2020** and $\boldsymbol{\sigma_P}$: standard deviation of rainfall over the same reference period.

1.3. Average surface rainfall of the basin

The average rainfall of the watersheds will be determined using the kriging method. It is “a stochastic method of spatial interpolation which estimates the value of a variable at unobserved points by a linear combination without bias and a minimum variance of observations of the phenomenon at neighboring sites” Baillargeon (2005). The estimate of errors it produces is more reliable than those produced by other spatial interpolation methods, because its basic postulates better model reality for spatially referenced data [15] [16] [6]. Data are processed using R Studio software.

2. Global Climate Models

The temperature and precipitation data used to characterize the future climate of the study area come from the multi-model ensemble average – out of a total of more than 35 Global Climate Models (GCM) – from the CMIP5 (Coupled Inter-comparison Project, Phase 5) [17]. The data collected covers the entire Kolda Region and was obtained through the Climate Change Knowledge Portal. The choice focused on two Representative Concentration Pathways (RCPs) developed by the Intergovernmental Panel on Climate Change (IPCC):

- the RCP4.5 intermediate scenario and,
- one scenario with very high GHG emissions (RCP8.5).

The RCPs represent the global mean radiative forcing in watts per square-meter (W/m2) achieved in each of the scenarios by the year 2100.

IV. RESULTS AND DISCUSSIONS

1. Filling gaps using the Regional Vector Method (RVM)

The Regional Vector Method (RVM) was designed by HIEZ [20] and improved by BRUNET-MORET [21], the difference residing in the use of the mode, or the average of the rainfall series analyzed. The vector Regional is a simple model that allows you to represent the rainfall information of a station by a sequence of annual indices, representative of precipitation in the region, and by coefficients characteristic of each observation post [18]. For each station rainfall index is calculated (fig.5), ratio of annual rainfall to annual rainfall average, therefore greater than one when the year is surplus and less than one when it is deficit. The average of the indices obtained for all the stations constitutes the representative value of the study area considered. The annual index series representative is called Regional Vector because it considers the information of a region assumed to be climatically homogeneous [19]. Two methods are commonly used to apply the Regional Vector: the method of [20] and that of [21]. There first is based on mode (most frequent value); the second on the average, eliminating the values that are too specific, to avoid contaminating the estimates with data that are clearly erroneous. For this study, considering that the average is the best estimator [22], the Brunet-Moret method [21] was used.

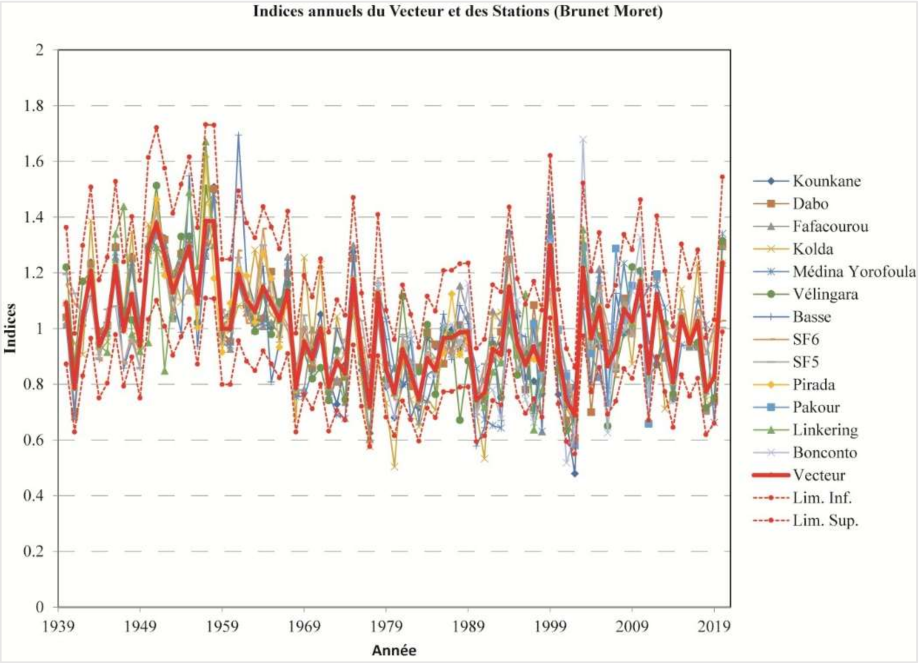

Figure 5: Annual Vector and Station Indexes

Based on these results, in the processed annual rainfall files, the years gaps were filled in by the calculated data, which made it possible to have data complete over the period 1940-2020 for all the stations selected. It is from these homogenized data, that the spatio-temporal variability of annual rainfall will be analyzed. In addition, this file will be used for the calculation of the average annual rainfall of the watershed.

2. Temporal variability of annual rainfall

The graphical representation of the calculated annual SPI highlights the succession of periods of marked dry years and wet years (fig.6). Over the period 1940-2020, the analysis of SPI and the PETITT test show three periods: from 1940 to 1967 characterized by a very humid period; from 1968 to 2002 characterized by a deficit period and finally from 1993 to 2020 characterized by a slight recovery of annual rain but with high inter-annual variability of rain.

The temporal variation of the rainfall across Senegal was analyzed by [8] [23]. These works showed that the drought of the 1970s led to a 23.4% drop in rainfall [8] on a national scale; at the level of the Kayanga basin, the deficits are between 9% and 20,2% (fig.6). This drop in precipitation has generally resulted in the depletion of water resources [24] [25], the modification of natural ecosystems and socio-economic systems [26].

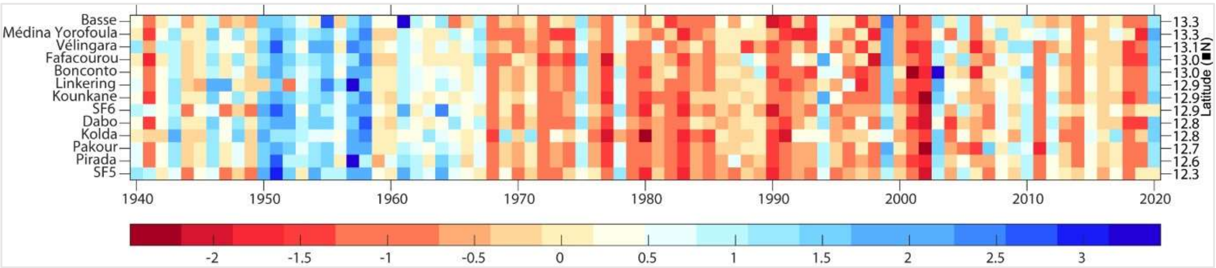

Figure 6: Temporal variation of Standardized Precipitation Indices (SPI) of rain gauge stations retained over the period 1940-2020

3. Spatial variability of annual rainfall

In addition to temporal variations, spatial variations in precipitation must be considered. This spatial variability is illustrated by the mapping of thirty-year and ten-year isohyets (Tables 2 and 3). These maps provide visualization and summary support. They make it possible to leave the vision reduced to a point for a global vision of the rain at the scale of the catchment area. Figures 7 and 8 highlight the fluctuation of decennials and rainfall normals.

For the different periods studied, the general shape of the isohyets is maintained over the entire basin, but we note their shift towards the south. Some findings emerge from this spatial analysis annual rains. First, the mapping of isohyets (thirty and ten years) shows spatial variability of rainfall with a general tendency to shift from isohyets towards the south (for example isohyets 1100 and 1000mm); even if in recent years we have witnessed a slight rainfall recovery. Thus, the south of the basin is generally more watered. This situation can be explained by the fact that this area is the first to be affected by the monsoon flow which therefore stays there longer a long time. Then, a subdivision into three distinct periods: a wet period, a dry and a period characterized by a slight increase in rainfall even if the quantities received remain lower than those before the great drought, thus confirming the observations on the analysis of the temporal evolution of annual rainfall.

Table 2: Ten-year rainfall in the Kayanga basin

P (mm)	Decennial 41-50	Decennial 51-60	Decennial 61-70	Decennial 71-80	Decennial 81-90	Decennial 91-2000	Decennial 2001-2010	Decennial 2011-2020
Kounkane	1063	1260	1034	898	895	968	922	925
Dabo	1109	1315	1103	957	965	1013	916	974
Fafacourou	1033	1225	1002	877	928	1023	965	927
Kolda	1199	1371	1204	1002	944	1071	1042	1090
Médina Y.Foula	956	1133	938	825	819	790	874	922
Vélingara	1007	1189	989	830	851	871	870	869
Basse	910	1116	1019	898	830	870	912	878
SF6	1250	1489	1325	1158	1099	1175	1174	1218
SF5	1436	1693	1539	1354	1274	1336	1362	1388
Pirada	1199	1420	1244	1068	1052	1108	1105	1106
Pakour	1228	1468	1253	1093	1076	1152	1139	1125
Linkering	1067	1244	1059	923	909	910	979	956
Bonconto	1070	1279	1092	949	978	928	983	979

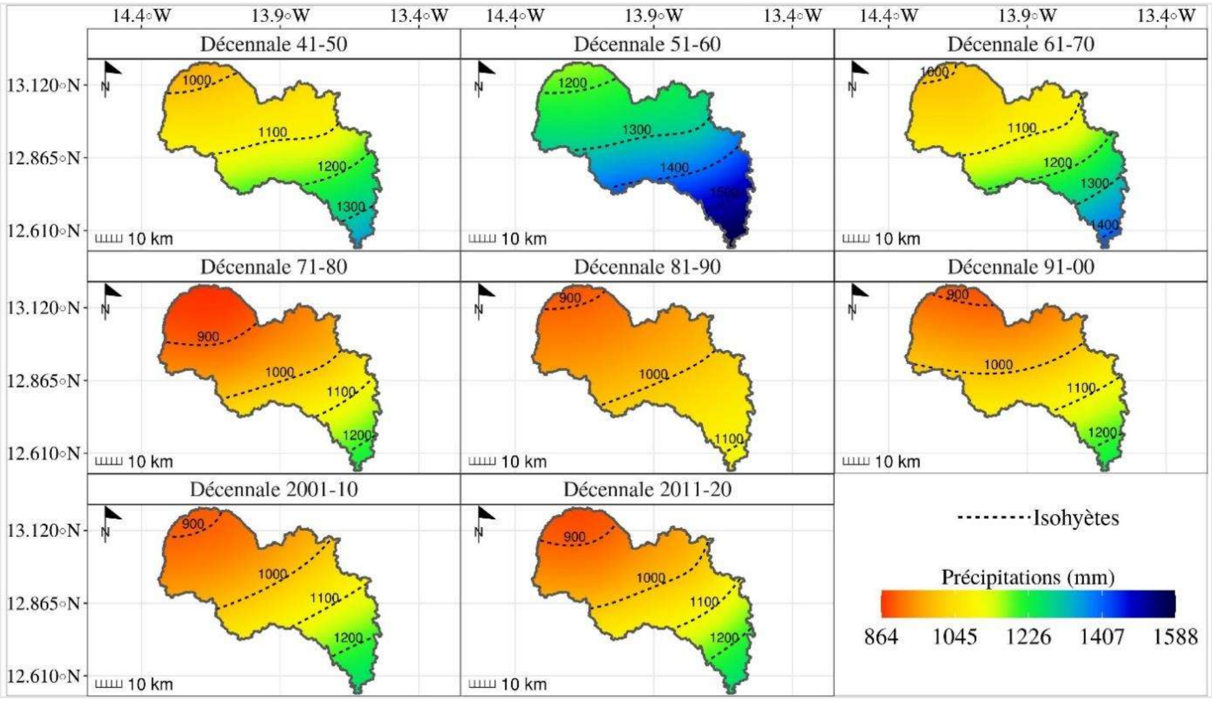

Figure 7: Spatial distribution of ten-year rainfall in the Kayanga basin

Table 3: Rainfall normals in the Kayanga watershed

P (mm)	Normal 41-70	Normal 51-80	Normal 61-90	Normal 71-2000	Normal 81-2010	Normal 91-2020
Kounkane	1110	1042	926	902	924	939
Dabo	1163	1103	990	966	966	975
Fafacourou	1082	1024	929	933	969	973
Kolda	1254	1164	1025	983	1021	1075
Médina Y. foula	999	949	852	810	831	867
Vélingara	1053	986	874	840	865	877
Basse	1011	994	893	849	867	892
SF6	1347	1299	1169	1127	1148	1196
SF5	1545	1501	1364	1307	1326	1371
Pirada	1281	1226	1102	1062	1088	1113
Pakour	1308	1250	1122	1096	1124	1147
Linkering	1105	1056	947	903	934	955
Bonconto	1139	1085	983	938	970	980

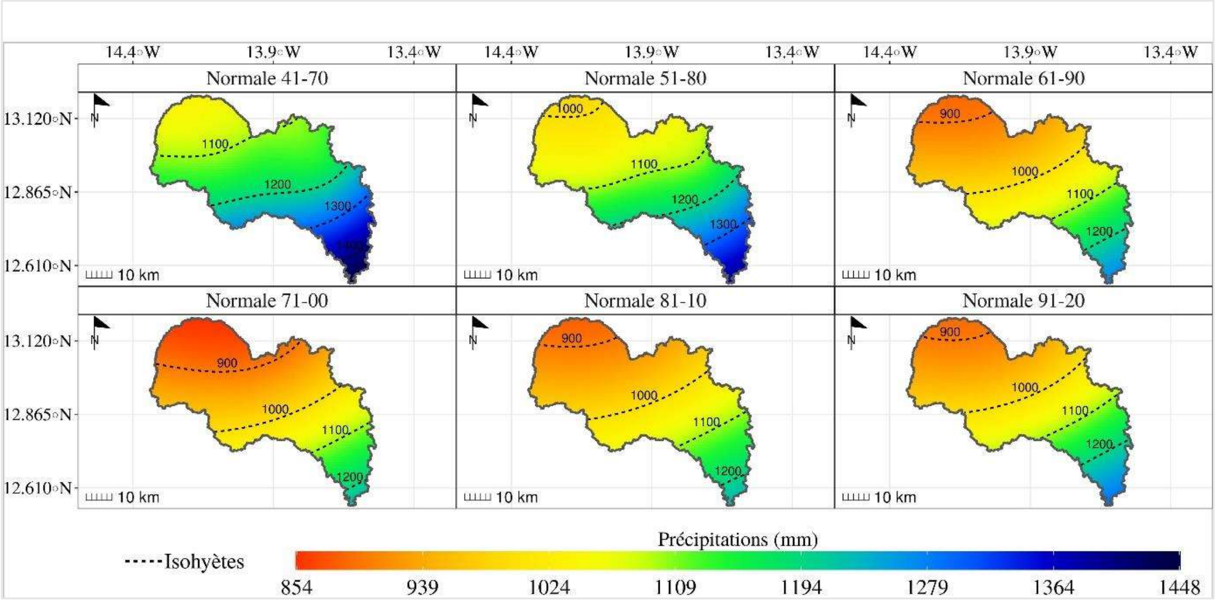

Figure 8: Spatial distribution of rainfall normals in the Kayanga watershed

4. Analysis of monthly rainfall

The study of the distribution of rainfall throughout the year and in particular the monthly height of precipitation poses the problem of heterogeneity of basic data [4]. Indeed, not all stations have the same observation period on the one hand, and on the other hand, for the same station, there may be gaps at the monthly scale resulting in monthly readings of different sizes. This study of monthly precipitation is of great importance. It makes it possible to refine the analysis of annual rainfall by highlighting the seasonal distribution and inter-monthly. Because if the annual total is important, the monthly distribution of this contribution gives a monthly rainfall distribution and their respective contribution to the annual total.

Figure 9 gives the statistical characteristics of monthly rainfall at the level of the different selected stations. Except for the Medina Yoro Foula station located further north, the season rains last 6 months, from May to October. In general, the maximum rainfall is always located in August (possible shifts in September for certain years), the months of July, August and September being the heart of the season.

To highlight the variation in monthly rainfall, the monthly averages were mapped. Thus, a choice was made for the months of May to October. This is justified by the fact that the largest amounts of precipitation observed are distributed between these months. Thus, we get six maps of spatial distribution of monthly rains (fig.10). The analysis of the May map shows that during this month, the rains are effective over the entire basin with, however, values less than 10 mm in the north. This is when the Meteorological Equator shifts towards the North on the surface and at altitude. The quantities recorded are between 8 mm and 56 mm on the entire basin.

The increase in rainfall, which began in June, continued in July, because the thickness of the monsoon over the study area increases. Usually August registers the maximum, but it can sometimes be in September for certain years. Over the whole study period and for all the stations in the basin, the maximum is reached in August. It may be explained by the fact that it is precisely during this month that the active part of Ecuador Meteorological, located in the middle layers of the troposphere (2000 - 5000 m), manifests itself by dense cloud formations [27]. These are responsible for the highest rainfall in the study area. Thus, the rainfall recorded is between 251 mm to the north and 392 mm to the south of the basin. From September, Ecuador Meteorological begins its descending phase of migration. This results in a reduction in the rains compared to August, while remaining higher than those of June and July. They are between 214 and 332 mm. In short, the analysis shows that whatever the month considered, the southern zone receives the highest amounts of monthly rainfall.

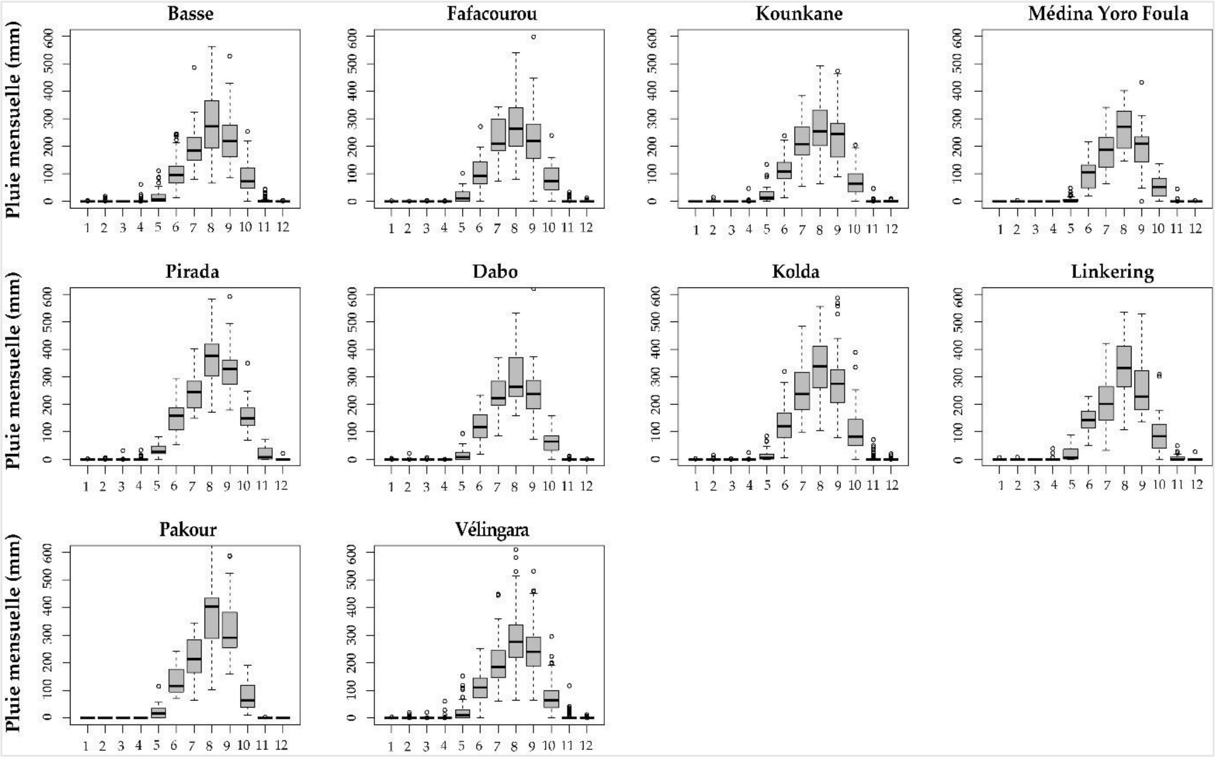

Figure 9: Seasonal cycle of rainfall in the Kayanga basin

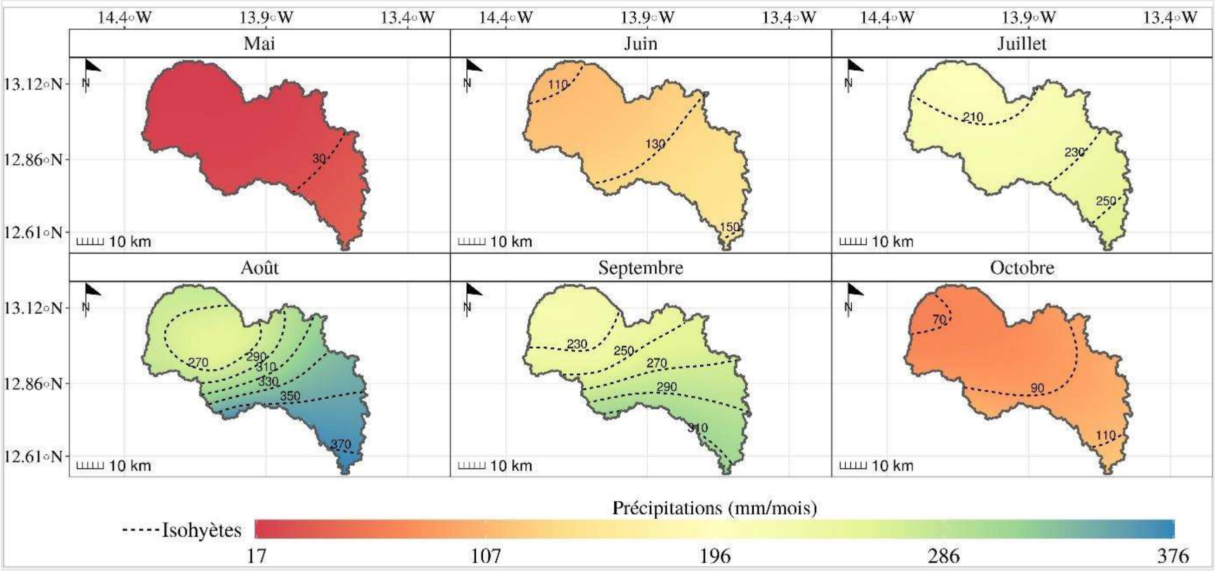

Figure 10: Spatial distribution of monthly rainfall

5. Analysis of future climatic conditions

In the Kayanga watershed, the ensemble average of global climate models predicts an increase in temperatures. Indeed, for the average annual temperatures projected at 2100, it is to be expected in the Kayanga basin, a temperature rises of between +1.13°C (under the RCP4.5 scenario) and +2.02°C (under the RCP8.5 scenario), i.e., an average of 1.57°C. The following sequences of their evolution have been highlighted (fig.11&12):

- +0.93°C between 2021 and 2050,
- +2.08°C between 2051 and 2080 and,
- +2.93°C, over the period 2081-2100.

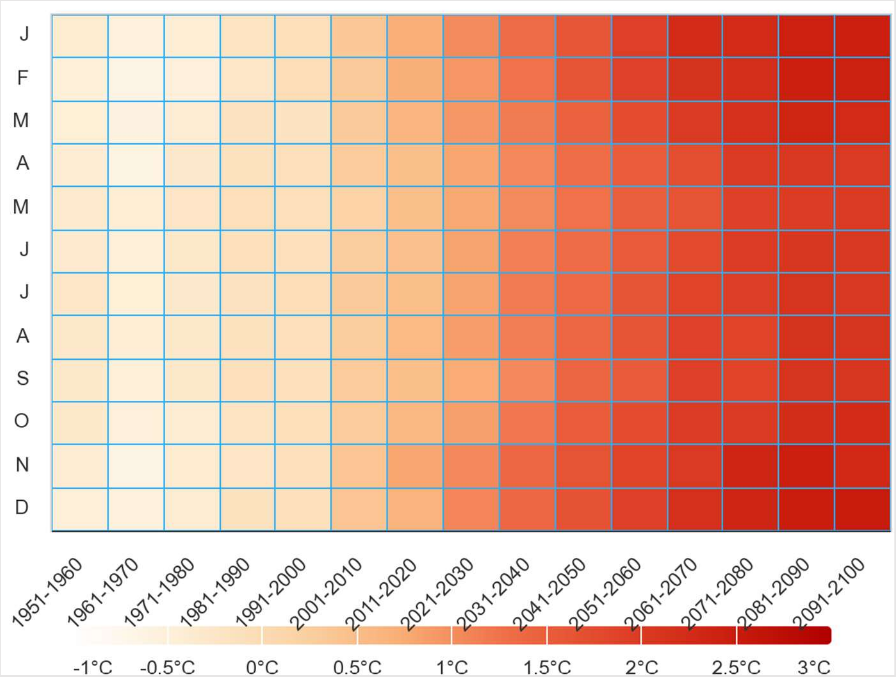

Figure 11: Temporal variation of mean temperature in the Kayanga basin according to the RCP4.5 scenario (Multi-Model Ensemble)

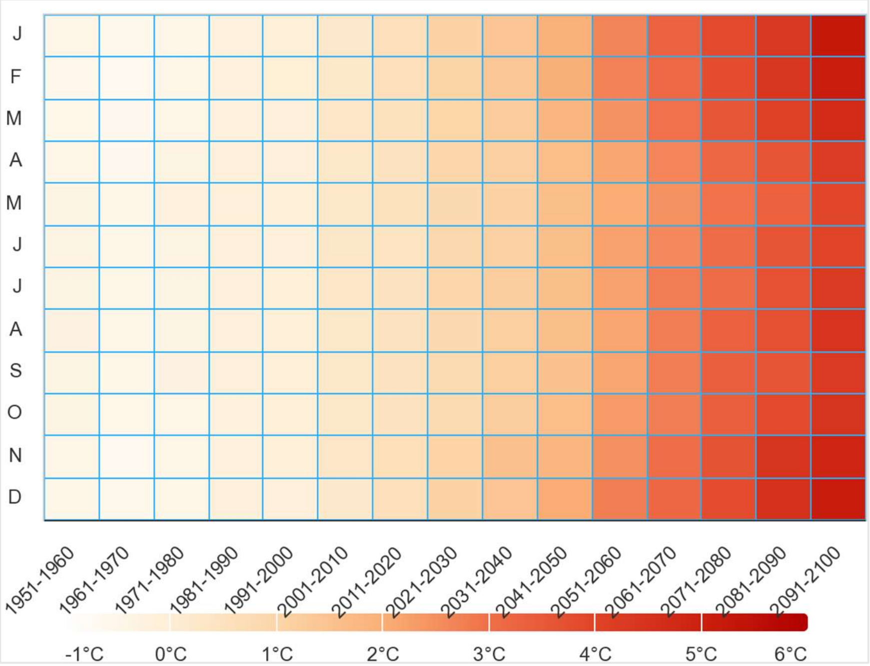

Figure 12: Temporal variation of mean temperature in the Kayanga basin according to the RCP8.5 scenario (Multi-Model Ensemble)

The rise in temperatures is accompanied by a more frequent occurrence of heat waves with its induced effects (thermal stress, heat stroke, etc.), but also by the increase in evaporation demand which can lead to the early drying up water surface.

For future rainfall conditions in the Kayanga watershed, the two reference scenarios chosen, RCP4.5 & RCP8.5, highlight the following developments (fig.13&14):

- a dry period which extends between 2021 and the mid-2050s, with deficits of between 22 mm (RCP4.5) and 50 mm (RCP8.5);
- a very wet period that began in the early 2060s; Climate models predict, over the period 2060-2100, an average increase in rainfall of between 21 mm (RCP4.5) and 58 mm (RCP4.5).

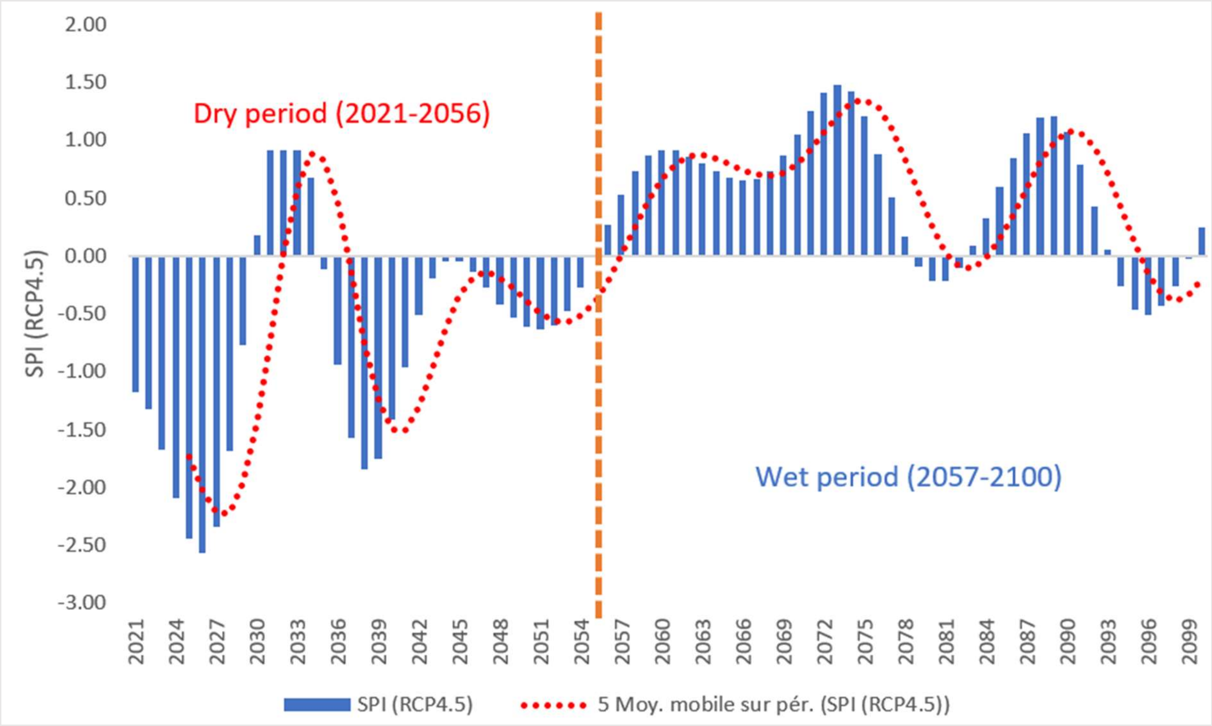

Figure 13: Temporal variation of Standardized Precipitation Indices in the Kayanga basin over the period 2021-2100, according to the RCP4.5 scenario (Multi-Model Ensemble)

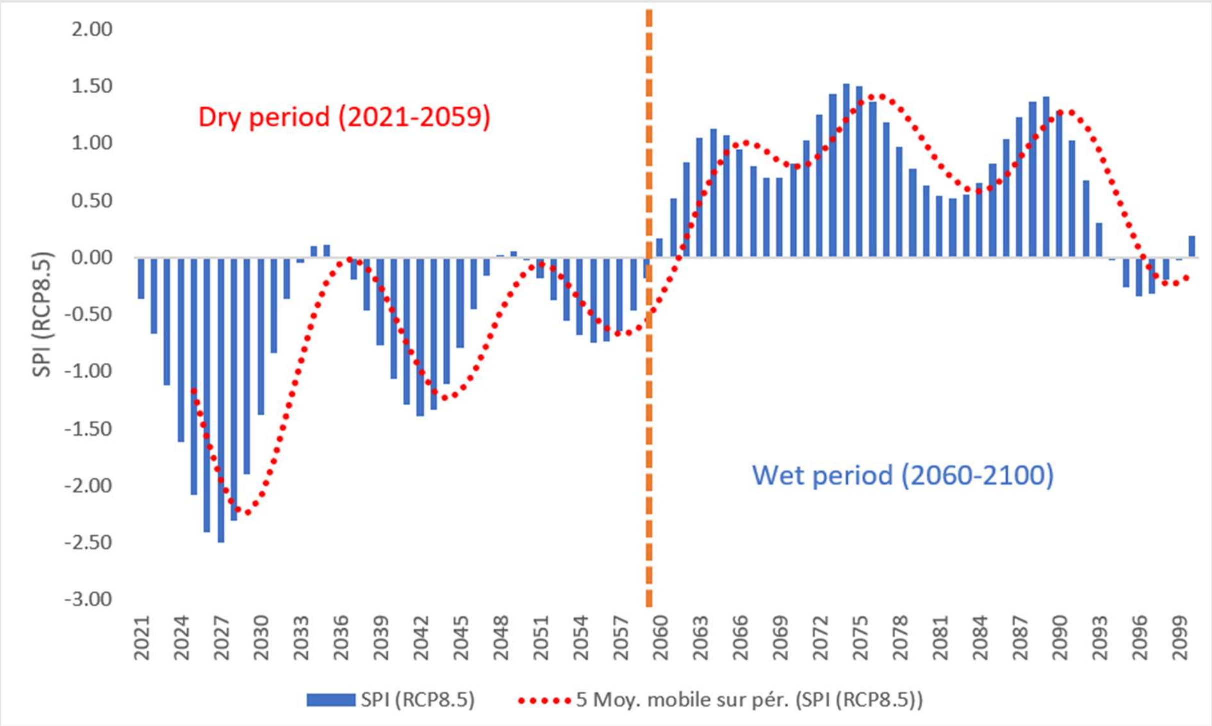

Figure 14: Temporal variation of Standardized Precipitation Indices in the Kayanga basin over the period 2021-2100, according to the RCP8.5 scenario (Multi-Model Ensemble)

Thus, it clearly appears that the downward trend in rainfall in the Kayanga basin – despite its slight recovery over the period 1993-2020 – will continue until the mid-1950s. The resumption of rainfall will only be effective from 2060. This variability noted on the rains will induce a similar variability on the flows and the agricultural productions since they are largely dependent on it.

Consequently, these results suggest that the climate be considered in policies for the sustainable management and exploitation of Kayanga's water resources (hydraulic and hydro-agricultural development design, definition of appropriate adaptation strategies, etc.) with a view to reduce their vulnerability to the irregularity of rainfall and the variability of flows.

Most of the Kayanga hydro-agricultural structures such as those of Niandouba, the Confluent and the Kounkané dam, as mentioned above, were built during periods of drought. However, the strong irregularity noted on the rains is inevitably accompanied by impacts such as:

- The Silting Up Of Rice Paddies And Water Retention Dikes,
- The Strong Variation In Flows And Water Bodies, Largely Dependent On Rainfall,
- The Waterlogging Of The Plots And The Sedimentation Of The Dams.

It would therefore be necessary, with a view to optimal development of the resources of Kayanga river, to repair all the retaining structures, considering the non-stationary nature of the rainfall; in addition to dam cleaning operations to optimize their water retention volume.

V. CONCLUSION

This article aimed to study recent spatial and temporal changes in rainfall in the Kayanga-Anambé complex, as well as their potential hydrological implications.

The analysis of the pluviometry made it possible to evaluate the pluvial resources (which constitute one of the inputs of the watershed system) of the Kayanga basin. The evolution of rainfall in the basin slope of the Kayanga is reflected by a fact specific to the intertropical zone, in this case the variability precipitation. This variability, when it is temporal, is similar either to the difference of the totals interannual, thirty-year or ten-year periods or at the position of the maximum monthly rainfall. In space, rainfall variability results in lower totals from south to north and this is illustrated by the spatial distribution of annual and monthly rainfall. The variability of precipitation is also perceptible through frequential rains. The recurrence of certain totals and periods to which it corresponds makes it possible to better understand the temporal and spatial evolution of the rainfall. Analysis of future climatic conditions have shown that the resumption of rainfall in the Kayanga basin will only be effective from 2060. These different variations also affect the average rainfall received by the different sub-basins that determine the nature of the flow of Kayanga basin.

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