Journal of Geographical Research
https://ojs.bilpublishing.com/index.php/jgr

ARTICLE

Determination of the Thresholds of the Climatic Classification According to the Discharges in the Upper Senegal River Basin

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ARTICLE INFO

Article history
Received: 11 November 2021
Revised: 14 December 2021
Accepted: 24 December 2021
Published Online: 04 January 2022

Keywords:
Limits
Climatic classification
Flow elapsed
High basin
Senegal River basin

ABSTRACT

Floods are the most common type of natural disaster in the world and one of the most damaging. Changes in weather conditions such as precipitation and temperature result in changes in discharge. To better understand the floods and eventually develop a system to predict them, we must analyze in more detail the flow of rivers. The purpose of this article is to analyze the discharges in the upper Senegal River Basin by focusing on determining the limits of the climatic classification according to past discharges. The daily discharges from May 1, 1950 to April 30, 2018 were chosen as the study period. These flow data have been grouped into annual discharges and classified as very wet, moist, medium, dry and very dry each year. Then, the flow data were divided into two seasons or periods each year: high water and low water. The statistical variables used in this study are the average, the standard deviation, the coefficient of variation and the skewness. The results of the climate classification that corresponds to a log-normal distribution indicate a total of 17 years classified as averages (25% of the series), 14 classified as wet (20.6%), 29 classified as dry (42.6 %) and 8 classified as very wet (11.8%), very dry classifications being nil. Seasonal analysis showed that the months of the high water period, such as September, had the highest flow, and the period of low water, such as May, had the lowest flow. The results of the flow analysis were then compared with changes in rainfall. The results obtained show similar climatic classifications between rainfall and flow in the basin.

1. Introduction

Floods are the most common natural disaster in the world, with 40% of natural disasters being floods [1]. Floods have claimed millions of lives and caused the complete destruction of property and natural habitats. For example, in 2010, according to the Emergency Events Database [2], floods caused the loss of more than 8,000 lives and affected about 180 million people. The flood disasters in Pakistan and Australia are the most recent

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DOI: https://doi.org/10.30564/jgr.v5i1.4088

examples of increased human exposure to flood risk. The ability to predict floods would be an extremely valuable benefit to the world, saving thousands of lives and avoiding billions of dollars of damage [3].

The risk of flooding is expected to increase further due to many factors, such as demographic change, land use, climate variability and change, technological and socio-economic conditions, industrial development, urban expansion and infrastructure construction in flood-prone areas, and unplanned human settlements in flood-prone areas [4]. To mitigate the increasing flood risks, the approach currently proposed is integrated flood management (which is more about "living with floods") which has replaced the more traditional approach of flood defence ("flood control"). This approach aims to minimise the human, economic and ecological losses from extreme floods while maximising the social, economic and ecological benefits of ordinary floods [4].

One method of determining the risk of flooding is to carry out a flow analysis. Flow analyses have been carried out all over the world. A study of the impact of climate variability on the flow of the Yellow River in China showed that precipitation and temperature affected the flow [5]. Their study of annual precipitation in La Nina and El Nino years showed that, for small increases in precipitation, the percentage change in streamflow is less than that of precipitation for the Yellow River. These results provide a resource for watershed water resource planning and management to keep the river functioning properly. Another study was conducted in an arid region of northwest China. It was found that climate variability accounted for about 64% of the reduction in mean annual flow, with most of the reduction due to reduced rainfall [6]. Their findings also concluded that the discharge of the Shiyang River is more sensitive to variations in precipitation than its potential evaporation.

In view of the succession of extreme climatological (droughts and floods) and hydrological (high and low water) episodes, numerous studies have been carried out on the Senegal River basin [7-10]. These different studies have therefore analysed the data to characterise climate change in this basin. The Senegal River basin has experienced climatic variability since the 1970s, marked by a decrease in precipitation [7], which has resulted in a significant decrease in surface discharge [10], as illustrated by the years 1983 and 1984, when discharge even stopped in Bakel. This decrease in discharge has had a negative impact on many sectors of activity (agricultural production, industry, drinking water supply, navigation, etc.), placing the basin in an unprecedented ecological crisis [11].

In keeping with its mission to preserve the balance of ecosystems in the Senegal River basin, the Organisation pour la Mise en Valeur du fleuve Sénégal (OMVS) monitors the river's water levels on a preventive basis through regular hydrometric surveys. In order to remedy this drop in discharges, ensure better control of water resources and encourage development actions, the OMVS has carried out major developments on the Senegal River, notably the Diama (1986) and Manantali (1988) dams. In this context of hydrological deficit, the implementation of these works allowed the control of discharges on the Bafing section and the management of floods in the downstream part of the Senegal River basin (from Bakel). However, new studies have highlighted the increase in rainfall and discharge in the area, which points to an improvement in the hydrological regime [10,12,13] and an increase in flooding.

Changes in climatic conditions such as precipitation, temperature, wind and evaporation can therefore cause large and rapid changes in river flow [14], hence the need to predict and analyse river floods based on historical data. In order to conduct a streamflow analysis, it is necessary to collect sufficient streamflow data. Entities such as OMVS collect flow data along the Senegal River and store it in databases.

In a climatic context marked by a possible increase in the occurrence and impact of floods in the coming years, it is essential to be able to analyse hydrological variables in order to propose adaptation measures to the populations. It is within this framework that the present study was initiated in the upper Senegal River basin. The aim of this article is to analyse the discharges in the upper Senegal River basin by classifying the climate of each river basin according to the discharges. This is of paramount importance because floods are natural risks against which it is necessary to protect oneself by prevention as well as by forecasting. Moreover, the rational management of the Senegal River basin and the Manantali dam, and the control of floods in the valley requires a better knowledge of the discharges in the basin.

2. Study Area

The Senegal River, some 1,700 km long, drains a basin of 300,000 km^2, straddling four countries: Guinea, Mali, Senegal and Mauritania (Figure 1). It runs from 10°20' to 17° N and from 7° to 12°20' W and is made up of several tributaries, the main ones being the Bafing, Bakoye and Falémé rivers, which have their sources in Guinea and form the upper basin [15] (Figure 1). The Senegal River thus formed by the junction between the Bafing and the Bakoye, receives the Kolimbiné and then the Karokoro on the right and the Falémé on the left, 50 km upstream from Bakel. In the southern part of the basin, the density of the hydrographic network bears witness to the impermeable nature of the land [16,17].

The Senegal River basin, like the entire intertropical belt, has experienced climatic upheaval since the 1970s [8]. Various studies on this basin have already shown the effects of climate change with modifications of its hydrological regime from 1970 onwards [7-10,18-23]. In order to remedy the effects of climate change and to cope with changes in the hydrological regime, a series of developments (Diama and Manantali) were initiated, completely transforming the hydrological dynamics of the Senegal River basin.

The basin is generally divided into three entities: the upper basin, the valley and the delta, which are strongly differentiated by their topographical and climatological conditions. The upper basin, our study area, extends from the sources of the river (the Fouta Djalon) to the confluence of the Senegal and Falémé rivers (downstream of Kayes and upstream of Bakel). It is roughly made up of the Guinean and Malian parts of the river basin and provides almost all the water inflow (more than 80% of the inflow) from the river to Bakel, as it is relatively wet [15]. The rains fall between April and October in the mountainous southernmost part of the basin, particularly in the Guinean part of the basin, and cause the annual flooding of the river between July and October.

3. Data and Methods

3.1 Data

The database of stations to be retained in the upper Senegal River basin for this study should contain daily flow series that meet two important criteria: the length of the chronicles on the one hand (covering the longest possible period of time), and the quality of the data on the other (as few missing data as possible). This was the case at the station selected for this study. The hydrometric data were made available to us by the Organisation pour la Mise en Valeur du Fleuve Sénégal (OMVS). These data relate to the daily flows (from 1950 to 2018) from which the annual and seasonal flows are calculated. From the annual and seasonal flows the climatic classification was made.

3.2 Methods

3.2.1. Statistical Analysis

Average

The average of a list of numbers is the sum of the list divided by the number of elements in the list [24]. The average is the most commonly used type of average and is often simply called the mean. Averaging is used to calculate the seasonal average flow. The average (μ) is defined as follows:

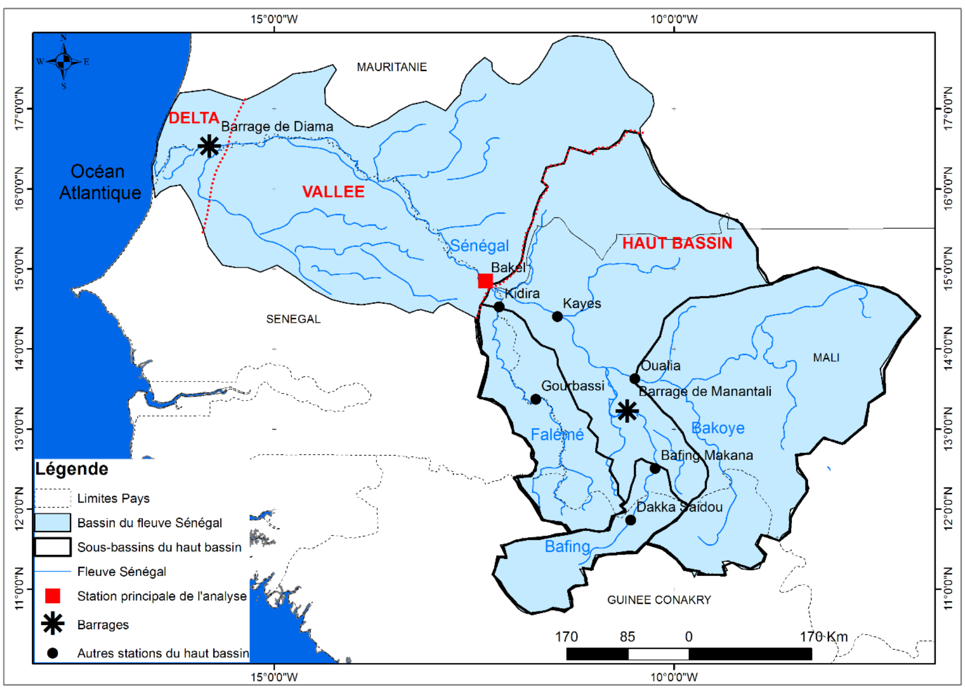

Figure 1. Location of the Senegal River watershed and its upper basin

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Standard deviation

The standard deviation (σ) of a data set is the square root of its variance. The variance of a data set is the average of the squared deviation of that variable from its expected value or mean. Variance is simply the measure or amount of variation in the values of a set [24]. In other words, the standard deviation is the calculation of the deviation of a data set from its mean. The standard deviation was used to define the climate classification for the annual analysis.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{1}(x_i - \mu)^2}$$

Variability

Variability is the amount by which data points in a statistical distribution or data set diverge from the mean value, as well as the extent to which these data points differ from each other [25]. Variability was used to determine which season (or period) was most different from other seasons.

$$Variability = \frac{\sigma}{\mu}$$

Asymmetry

In probability and statistics, skewness is a measure of the degree of skewness of a distribution [24]. A distribution is considered skewed if the tail on one side of the distribution is longer than the tail on the other side. If the data are skewed in the direction of higher values, there is positive skewness. If the opposite is true, there is a negative skewness. In a perfect distribution, there will be no skewness and the skewness value will be zero. The skewness was used to determine whether the data corresponded to a normal or log normal distribution.

3.2.2 Definitions

This section will discuss how a water year was defined and then discuss how the annual cumulative streamflow was divided into climatic classifications. Finally, the way in which the data was divided into seasons will be explained.

Climate classification

To determine the limits of the climate classification, the mean and standard deviation of the annual discharge of the data set were manipulated. Table 1 shows the limits of the climate classification as a function of discharge [3].

Table 1. Limits for climate classification as a function of discharge

Limits	Parameters	Classification
Below	Mean - 1.5 X Standard deviation	Very dry
Between	Mean - 0.5 X standard deviation & Mean - 1.5 X standard deviation	Dry
Between	Mean + 0.5 X standard deviation & Mean - 0.5 X standard deviation	Average
Between	Mean + 1.5 X standard deviation & Mean + 0.5 X standard deviation	Wet
Above	Average + 1.5 X Standard deviation	Very wet

Seasonal classification

In order to carry out a seasonal classification, a segmentation of the data series on a monthly scale was carried out. For this data segmentation, the analysis of the monthly evolution of the basin's discharge and the monthly flow coefficient (MFC, ratio between monthly and annual flow) (Table 2) at the Bakel station over the period 1950-2018, divides the series into two components: a low water period (May-July and November-April) and a high water period (August-October). For this study, although the month of July has a CMD <1 (0.90), it is counted in the period of high water. This choice is explained by the importance of its average flow (which is 530 m^3/s).

After determining the character of each year (very

Table 2. Monthly values of discharge and CMD at Mako station (1950-2018)

	M	J	J	A	S	O	N	D	J	F	M	A	AN
Q (m^3/s)	87,1	152	530	1627	2396	1150	437	226	154	121	107	94,5	590
CMD	0,15	0,26	0,90	2,76	4,06	1,95	0,74	0,38	0,26	0,21	0,18	0,16	1,00
Periods	Low water		High water				Low water						

humid, humid, medium, dry or very dry), an analysis was carried out on the period of high water and that of low water. It should also be noted that in the tropical environment of the northern hemisphere, a hydrological year is defined from May 1 to April 30. Once the data was separated by year, the daily data for each year were added together to obtain a cumulative flow for that water year. The seasons or periods were compared with each other in relation to their respective climatic classifications. Finally, all the results were compiled in a single graph in order to visually compare the seasonal flows in different climatic classifications.

4. Results and Discussion

4.1 Analysis of the Flow on an Annual Scale

Figure 2 presents the annual flow or modulus of the Senegal River basin from 1950 to 2018. The results indicate that the year 1950-51 recorded the highest flow with 1156 m^3/s (i.e. a volume of 36,466,640,687 m^3). On the other hand, the year 1987-88 had the lowest annual modulus with a value of 226 m^3/s (i.e. a flow volume of 7,125,906,466 m^3). Depending on the flow rate of each year from 1950 to 2018, Figure 2 shows the threshold for a very wet, humid, average, dry or very dry year, as defined in Table 1. The average annual discharge is 590 m^3/s (or a volume of 18,605,561,755 m^3). Any year in which the discharge is greater than the mean plus one and a half times the standard deviation (represented by the red line) is considered a very wet year. Any year with a discharge between the mean plus one and a half times the standard deviation (red line) and the mean plus half the standard deviation (represented by the green line) is considered a wet year. Years with an elapsed discharge between the mean plus half the standard deviation (green line) and the mean minus half the standard deviation (represented by the blue line) are considered average years. Years with cumulative discharge between the mean minus half the standard deviation (blue line) and the mean minus one and a half times the standard deviation (represented by the orange line) are considered dry years. Years with discharge below the mean minus one and a half times the standard deviation (orange line) are considered very dry years.

Threshold indicators are lines on the graph that indicate threshold values for very wet (above the red line), wet (between the red and green lines), medium (between the green and blue lines), dry (between the blue and orange lines) and very dry (below the orange line).

The results of the climatic classification (Tables 3 and 4) which correspond to a log-normal distribution indicate a total of 8 years classified as very humid (11.8% of the series have an annual flow> 969 m^3/s), 14 years classified as wet (20.6% of the series have an annual flow between 716 and 969 m^3/s), 17 years classified as average (25% of the series have an annual flow between 464 and 716 m^3/s) and 29 years classified as dry (42.6% of the series have an annual flow between 211 and 716 m^3/s). On the other hand, there is no year included in the category of dry years (no year recorded an annual flow <211 m^3/s).

4.2 Seasonal Flow Analysis

From the information collected during the annual-scale analysis of the flow over the upper Senegal River basin,

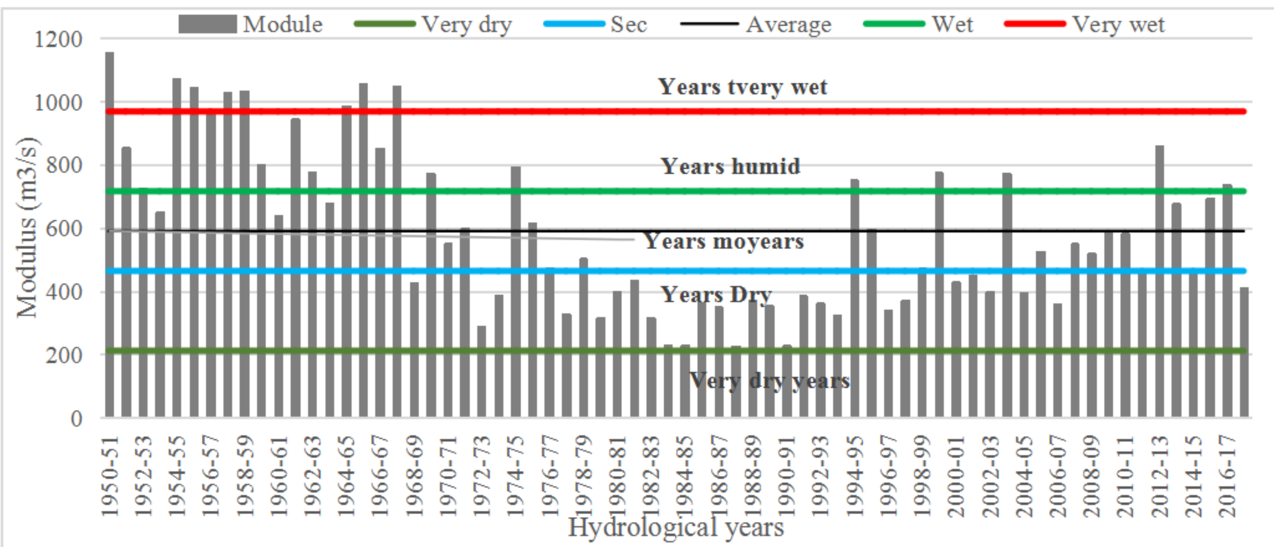

Figure 2. Annual discharge of the upper Senegal River basin from 1950 to 2018 with threshold indicators.

the seasonal-scale analysis could be carried out. The annual scale analysis was mainly based on the climate classification for each year given in Table 3 (very humid, humid, medium, dry or very dry). Each year has been divided into two seasons or periods: high water period (July to October) and low water period (November to June). Due to the absence of hydrological years classified as very dry, the years in the series were divided into four different series according to their climatic classification (very humid, humid, medium and dry) on which certain parameters (such as volume mean and total flow rates, and standard deviation) were calculated (Tables 5 and 6). Figure 3 was compiled from these tables, using the cumulative seasonal average volume of each classification, to visually compare the seasonal differences within each classification.

Table 3. Classifications of very wet, wet, medium, dry and very dry climate according to the annual flow of the upper Senegal River basin from 1850 to 2018

Very wet	Wet	Average	Dry		Very dry
1950-51	1951-52	1953-54	1968-69	1992-93	-
1954-55	1952-53	1960-61	1972-73	1993-94	-
1955-56	1956-57	1963-64	1973-74	1996-97	-
1957-58	1959-60	1970-71	1977-78	1997-98	-
1958-59	1961-62	1971-72	1979-80	2000-01	-
1964-65	1962-63	1975-76	1980-81	2001-02	-
1965-66	1966-67	1976-77	1981-82	2002-03	-
1967-68	1969-70	1978-79	1982-83	2004-05	-
-	1974-75	1995-96	1983-84	2006-07	-
-	1994-95	1998-99	1984-85	2011-12	-
-	1999-00	2005-06	1985-86	2014-15	-
-	2003-04	2007-08	1986-87	2017-18	-
-	2012-13	2008-09	1987-88	-	-
-	2016-17	2009-10	1988-89	-	-
-	-	2010-11	1989-90	-	-
-	-	2013-14	1990-91	-	-
-	-	2015-16	1991-92	-	-

Table 4. Threshold values for climatic classifications of annual discharge in the upper Senegal River basin from 1950 to 2018

Parameters	Discharge in m3/s	Volume in m3	Classification	Number of years
Mean - 1.5 X Standard deviation	211	6 667 245 162	Very dry years	0
Mean - 0.5 X Standard deviation	464	14 626 122 891	Dry years	29
Average	590	18 605 561 755	Average years	17
Mean + 0.5 X Standard deviation	716	22 585 000 619	Wet years	14
Average + 1.5 X Standard deviation	969	30 543 878 347	Very wet years	8

Of the series of very wet years (8 in total), the high water period had the highest average cumulative discharge volume, with an average value of 28,508,577,481 m^3. The highest seasonal volume for the high water period was 32,480,447,043 m^3 in 1950-51. The lowest seasonal volume for the high water period was recorded in 1964-65 and amounted to 26,982,296,643 m^3 (Table 5).

The season with the lowest average flow in the very wet years was the low water period, with an average value of 4,811,405,037 m^3. In contrast to the high water period, the year 1950-51 had the lowest cumulative flow volume of the low water period, with a value of 4,080,835,212 m^3. The highest value of cumulative flow volume was recorded in 1958-59 with a value of 5,568,263,796 m^3 (Table 5).

Similar to the very wet years, of the series of wet years (14 in total), the high water period had the highest average cumulative discharge volume, with an average value of 20,863,591,136 m^3. The highest seasonal volume for the high water period was 26,724,790,081 m^3 in 1962-63. The lowest seasonal volume for the high water period was reached in 1994-95 and was 14,261,782,778 m^3 (Table 5).

The season with the lowest average flow for wet years was also the low water period with an average volume of

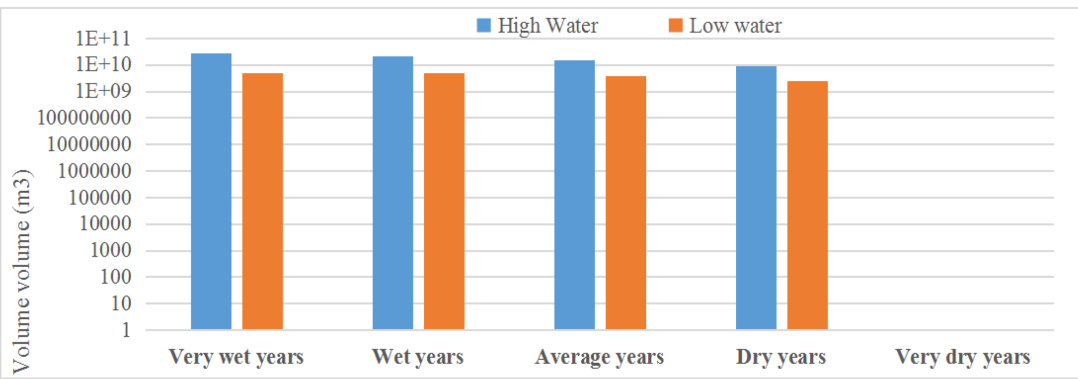

Figure 3. Comparison of the average seasonal volume of the upper Senegal River basin according to the climatic classifications of the annual flow from 1950 to 2018

4,869,886,574 m^3. In contrast to the high water period, 2018 had the highest cumulative volume of the low water period in 1994-95, with a value of 9,490,712,162 m^3. The lowest value of cumulative discharge volume was recorded in 1974-75, with a value of 1,942,349,044 m^3 (Table 5).

Of the average year series (17 in total), like all other climatic classifications, the high water period had the highest average cumulative discharge volume, with an average value of 14,459,817,733 m^3. The highest seasonal volume for the high water period was 18,191,977,926 recorded in 1963-64, while the lowest seasonal volume is recorded in 2004-05 with a value of 8,062,053,136 m^3 (Table 6).

Again, the low water period was the period with the lowest average flow volume for average years, with a value of 3,740,751,795 m^3. The year 2015-16 had the highest cumulative flow volume for the low water period with a value of 6,126,983,474 m^3. The lowest cumulative volume value for the low water period was in 1971-72, with a value of 1,798,816,713 m^3 (Table 6).

Finally, in the dry year series (the longest in the series with a total of 29 years), like all other climatic classifications, the high water period had the highest average cumulative discharge volume, with an average value of 8,915,192,861 m^3. The highest seasonal volume for the high water period was recorded in 1981-82 with a value of 12,529,035,933 m^3, while the lowest seasonal volume is recorded in 1990-91 with a value of 5,128,414,555 m^3 (Table 6).

The season with the lowest average flow in the dry years was the low water period, with an average value of 2,564,206,494 m^3. Here, the year 1985-86 had the lowest cumulative flow volume of the low water period, with a value of 760,601,473 m^3. In contrast, the highest cumulative flow volume was noted in 2014-15 with a value of 5,256,428,025 m^3 (Table 6).

All climatic classifications were grouped together to visually compare each (Figure 4.a). The high water period indicates the highest level and the low water period the lowest flow. The highest mean volume during the high water period was 20,863,591,136 m^3 in very wet years and the lowest mean volume was 8,915,192,861 m^3 in dry years. There is therefore a clear difference between the period of high water and that of low water. Over both periods, very wet years have the highest average volume followed first by wet, then medium and finally dry years.

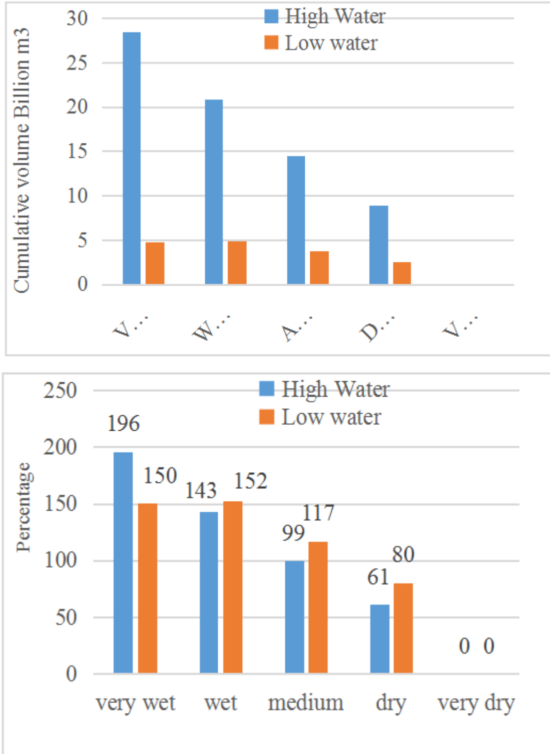

Figure 4. Cumulative elapsed volume for each season in the respective climate classification (a) and percentage of volume in their respective climate compared to the period average (b)

To determine the most variable period according to the classification, the period of high water and that of low water were represented in the form of a percentage relative to the mean volume flowed over the series (Figure 4b). The results show that the months of the high water period are the most variable for the very humid and dry type of climate and less variable than those months of the low water period for the humid and medium type climates.

The largest positive difference was observed during the high water period of very wet years, with the average seasonal flow representing 196% of the overall average high water period, or 1.96 times the overall average seasonal flow. The largest negative difference was also observed in the high water period of dry years, with the average seasonal flow volume being 61% of the overall average high water period, or 0.61 times the overall average seasonal flow volume. The average seasonal volume closest to the overall average was found in the middle years, in both the high and low water months. In these average years, the average seasonal volume in the high water period is 99% of the overall average, or 0.99 times the overall average seasonal volume. This indicates that the high water months had the greatest effect on the climate classification of a year [3].

Table 5. Comparison of cumulative seasonal discharge volume in very wet and wet years in the upper Senegal River basin from 1950 to 2018

Very wet years			Wet years		
Date	**High water**	**Low water**	**Date**	**High water**	**Low water**
1950-51	32480447043	4080835212	1951-52	20714356815	6353683152
1954-55	28814235841	5122270874	1952-53	19772536314	3292613032
1955-56	27923797451	5191262891	1956-57	26557865280	3878324395
1957-58	27071297278	5447003585	1959-60	21795583686	3541566286
1958-59	27197648646	5568263796	1961-62	26724790081	3123741336
1964-65	26982296643	4142754401	1962-63	20961789128	3621121418
1965-66	29244412795	4103528654	1966-67	22370091842	4659990766
1967-68	28354484152	4835320887	1969-70	19982851205	4470555493
			1974-75	23193114906	1942349044
			1994-95	14261782778	9490712162
			1999-00	19132055625	5410795246
			2003-04	19074951354	5421971669
			2012-13	20060015038	7154887851
			2016-17	17488491846	5816100191
Total	**228068619848**	**38491240300**	**Total**	292090275898	**68178412040**
Average	**28508577481**	**4811405037**	**Average**	**20863591136**	**4869886574**
Standard deviation	**1808321356**	**621086276,2**	**Standard deviation**	**3271786322**	**1939180436**
CV	**0,06**	**0,13**	**CV**	**0,16**	**0,40**

(Purple = Lowest cumulative seasonal elapsed volume value; Green = Highest cumulative seasonal elapsed volume value; Yellow = Average cumulative seasonal elapsed volume value)

4.3 Comparison of the Climatic Classification of Discharge and Precipitation

The climatic classifications of discharge in the upper Senegal River basin were compared with the evolution of rainfall (Figure 5). The results obtained show similar climatic classifications between rainfall and discharge in the basin. The analysis of Figure 5 shows that the discharge of the rivers gradually changes with changes in rainfall. The study of the climatic framework is fundamental, as indicated by the work of Faye [26] and Faye and Mendy [27]. Precipitation indices highlight a great climatic variability in Senegal with the presence of two periods: a very rainy period marked by abundant rainfall during the 1950s and 1960s and a dry period characterised by drought during the 1970s and 1980s. On the other hand, during the 2000s, it was noted in the basins that an increase in rainfall predicted improved rainfall patterns in the basin compared to the dry period of the previous decades (Faye, 2018) [26]. However, the persistence and sustainability of the increase has yet to be proven, as the sufficiently long climatological scale is thirty years [28]. For the discharge indices, they are positive for very wet and wet years and negative for dry years, while for average years, the indices alternate between positive and negative values, while being close to 0.

From the graph, it can be seen that the discharge in the very wet and wet years (with discharge indices up to 2.2 in 1950-51) generally coincides with the years with the most surplus rainfall (with rainfall indices up to 2.14 in 1954-55). These years are located in the decades (1950s and 1960s) of abundant rainfall and in the 2000s when a return to rainfall is noted (with rainfall indices as

Table 6. Comparison of cumulative seasonal discharge volume in average and dry years in the upper Senegal River basin from 1950 to 2018

Average years			Dry years		
Date	**High water**	**Low water**	**Date**	**High water**	**Low water**
1953-54	17298472319	3259551379	1968-69	11068202897	2413370185
1960-61	17060388481	3192811096	1972-73	7353846142	1748689181
1963-64	18191977926	3287002732	1973-74	10591240337	1648253793
1970-71	15352579549	2083562393	1977-78	9330249886	1049473124
1971-72	17174579913	1798816713	1979-80	8511751289	1494356589
1975-76	17437245800	1989714616	1980-81	11509050208	1125116632
1976-77	11404551873	3608206129	1981-82	12529035933	1266345430
1978-79	13834100567	2132674264	1982-83	8905830239	1089442354
1995-96	13845593058	4981265100	1983-84	6361865272	958040527
1998-99	11998513995	2864857395	1984-85	6480336962	787259306
2004-05	8062053136	4446905544	1985-86	10750196412	760601473
2007-08	13484301126	3892337038	1986-87	9829392611	1226270513
2008-09	12177025916	4271745608	1987-88	5942798167	1201907530
2009-10	13660415078	4884842204	1988-89	10380274263	1364635854
2010-11	12867387843	5510811789	1989-90	9229165033	1964603864
2013-14	16154259846	5260693049	1990-91	5128414555	2079370393
2015-16	15813455035	6126983474	1991-92	8520723509	3663431017
			1992-93	6893231297	4473568271
			1993-94	7271636566	2918726743
			1996-97	7763706163	2998131661
			1997-98	9491320821	2253688804
			2000-01	10265275573	3270922208
			2001-02	10079693583	4126031897
			2002-03	8787377664	3771500222
			2005-06	11435592970	5210938884
			2006-07	7083953249	4250448138
			2011-12	9811074251	4864271127
			2014-15	9385441932	5256428025
			2017-18	7849915197	5126164576
Total	**245816901461**	**63592780523**	**Total**	**258540592980**	**74361988321**
Average	**14459817733**	**3740751795**	**Average**	**8915192861**	**2564206494**
Standard deviation	**2703191991**	**1334183053**	**Standard deviation**	**1849120722**	**1513949112**
CV	**0,19**	**0,36**	**CV**	**0,21**	**0,59**

(Purple = Lowest cumulative seasonal elapsed volume value; Green = Highest cumulative seasonal elapsed volume value; Yellow = Average cumulative seasonal elapsed volume value)

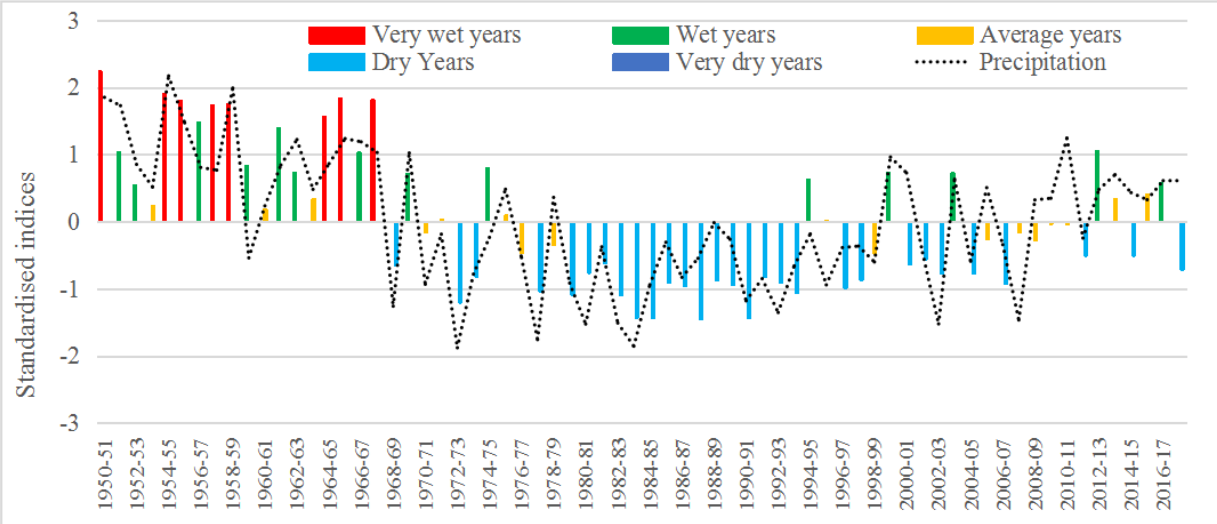

Figure 5. Comparative evolution of rainfall and climate classification of discharge in the upper Senegal River basin from 1950 to 2018 (For ease of comparison, rainfall and discharge have been standardised through the mean and standard deviation of the series)

high as 1.24 in 2010-11). In contrast, dry year discharge (the longest series) is noted over the decades (1970s and 1980s) characterised by a rainfall deficit due to drought. However, some climatic discharge classifications can sometimes be contradicted by rainfall analysis. For example, in 1959-60, the discharge is classified as a wet year (with a discharge index of about 0.84), while there was a rainfall deficit (with a rainfall index of -0.54). The same is true for the year 1978-79, where rainfall is surplus to the series average (rainfall index of 0.36), while discharge is deficit (with a discharge index of -0.34 and a year classified as average).

5. Discussion

Annual scale

The objective of the annual discharge analysis of the upper Senegal River basin was to be able to classify each year as very wet, wet, average, dry or very dry. After analysing the results, this could be achieved. The cumulative annual discharge volume was used for the classification by year, as opposed to the average annual discharge volume. The reason for this was to more accurately represent the stream discharge for each year of the analysis [3]. The cumulative annual discharge data did not correspond to a normal distribution. In addition, the normal distribution was skewed to the left, meaning that more years would be classified as dry years (29 in total) than wet years. Thirty-eight years (38) out of sixty-eight (68) were below the average with a normal distribution. This is due to the very high cumulative river discharge values of the very wet years, resulting in an asymmetry in the data.) The number of years is classified as dry years was 29, 17 years as average years, 14 years as wet years and 8 years as very wet years.

Seasonal scale

The objective of the seasonal analysis of the discharge in the upper Senegal River basin was to detect any trends, or lack thereof, that might occur within the climate classification. In the seasonal analysis, the cumulative mean seasonal discharge volume was used. Thus, the high water period had the highest discharge. In order to better understand the evolution of the seasonal discharge for each climate classification, a percentage of the average analysis was performed for each season in each climate classification. It is clear from this analysis that the seasonal discharges in the high water period show the greatest variation. Note that all seasons in the dry (and sometimes even average) climate classification were below 100. This is due to the large discharge volumes in wet and very wet years, which bias the average value towards higher discharges. The importance of this finding lies in the possibility of creating more accurate seasonal discharge simulations. The simulations can consist of estimating missing data from previous years or making future seasonal forecasts. Due to the variability of precipitation in each season, future seasonal precipitation should be forecast rather than annual forecasts [3].

The concordance of the classifications of very wet and wet years of discharges and the evolution of rainfall are in line with the work of Sow [7] and Faye [26] who highlighted the abundance of rainfall in the 1950s and 1960s. Similarly, the importance of the dry years noted in this study confirms the work of Sow [7] and Faye *et al.* [10] in the Senegal River basin and Faye and Mendy [27] in the Gambia River basin. The hydrological deficits indicated are therefore in the same magnitude as those obtained by several authors who have conducted hydrological studies, either in the same catchment or in other basins in Senegal, or in Africa. For example, the work of Kouassi *et al* [29] in the Bandama catchment indicates hydrological deficits of -16.32% for mean rainfall, -31.49% for effective rainfall, -59.94% for discharge potential and -15.17% for infiltration potential. Studies carried out in Africa by Sighomnou [30] and Goula *et al.* [31] have highlighted the hydrological deficits following the decrease in rainfall.

The return to rainfall noted in the 2000s and coinciding with the classification of wet years in terms of discharge is also in line with the work of Ali and Lebel [32] on the Sahelian zone, Ouoba [33] on Burkina Faso, Ozer *et al.* [34] on Niger and Faye [35] on Senegal, which indicated the improvement in rainfall conditions since the 2000s, with its corollary of increased discharge. Thus, beyond the drought of the 1970s, this new hydrological change occurred again in the mid-1990s and is marked by an increase in river discharges. This similarity between the variations in climatic conditions and the hydrological response of the basins would therefore be on a global scale [36].

Based on the seasonal analysis of this study, it was determined that the volume of high season flows is the highest for each climate classification. This corresponds to the flooding phenomena noted in the valley. Devastating floods occur due to heavy rainfall in many parts of the basin. Studies have shown that the Senegal River basin is prone to frequent floods and droughts due to the high interannual variability of rainfall [37]; the most devastating effects of these extreme events, especially floods, are the washing away of agricultural land, affecting agricultural production and food security, destruction of homes, increased health risks and the spread of infectious diseases [38].

6. Conclusions

Through the annual analysis of the discharge of the upper Senegal River basin, the years have been classified into five categories. This study focused on the annual classification and the seasonal study of the flow of the upper Senegal River basin. The annual classification and seasonal analysis involved the collection of historical daily flow data (from 1950 to 2018) from the OMVS. These data were converted to volume flowed, then summed into annual cumulative volume data, and correspond to a lognormal distribution. The mean and standard deviation were then calculated and manipulated to determine the climatic classification ranges of the flow rates. Each year was classified as very humid, humid, medium, dry or very dry. The years in the classifications were then analyzed. A seasonal analysis was then performed and the annual data was divided into two periods (the high water period and the low water period). The cumulative volume for each season of each year was then calculated. Then, the seasonal average volume flow for each classification was calculated and analyzed. Trends were observed and noted, and additional analyzes, such as percent of mean and percent of total runoff volume, were performed each season.

It was found that the seasons of the high water period had the highest flow, regardless of their climatic classification. It was also found that the period of high water was the one with the most variability and that it influenced the classification by providing large volumes of flows. The months of the high water period had some of the highest flow volume values. This could be because the more rainy the year, the longer the runoff during the low water period will last and the more groundwater will be stored and contribute to the flow of the stream. The data were then compared to the evolution of precipitation data in the Senegal area. Strong correlations were established from these comparisons and it was noted that it is possible to relate the annual classifications of the basin's flow volume to the variability of precipitation. However, it is necessary to proceed to annual classifications of precipitation in the Senegal area to better represent them. This study presented the results of the flow analysis of the upper Senegal River basin. To deepen this work for future work, the following are suggested: A more in-depth analysis of precipitation in the Senegal River basin and its comparison with the flow analysis of the present study; A study of groundwater storage and its effects on runoff and stream flow. Such studies could be beneficial for flood forecasting, because the more information we have about seasonal and climate change in flow, the more accurately it will be possible to predict stream flow. .

Many adaptation strategies on the agricultural sector and water demand in the face of declining water resources can be noted: the adoption of short-cycle crops, the abandonment of certain crops and the introduction of new crops. The first spontaneous adaptation consists in adjusting the cropping calendar to the climatic conditions of the year. Currently, the trend is to abandon long-cycle speculations that no longer respond to the climatic context. Also, farmers practice the intercropping system to mitigate the risk of low yield. In addition, they are obliged to modify their agricultural calendar as well as the cultivation technique, to practice multiple sowing, dry or late, and to reduce their sowing.

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