Hydrological Investigation and Characterization of Sokouraba Watershed, Burkina Faso

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The purpose of this study is to determine the hydrological characteristics and the morphometric parameters of the Sokouraba watershed (BV) where the climatic hazards make the water resource increasingly insufficient. This watershed has never been the subject of morphometric and hydrological characterization in the past. The present study made it possible thus, to better understand the functioning of the hydrographic networks as well as the quantity of water likely to be used for the construction of a dam in this watershed. According to the hydrologic analysis results, from 1960 to 2019, the annual precipitation values range from 347,3 to 1596,6 mm with an average of 1099,28 mm. The maximum daily rainfall values for the same period vary between 42 and 287 mm with an average of 82.85 mm. The values of wet decennial and wet quinquennial rainfall are respectively 1380 and 1280 mm. The dry five-year and dry ten-year rainfall values are 917 mm and 821 mm respectively. According to the watershed characterization results, the calculated Sokouraba watershed surface is 77,34 Km² and its perimeter is 44,3 Km. The values of the length and the width of the equivalent rectangle of the basin are respectively 17,81 Km and 4,34 Km. The longitudinal slope and the overall slope index values are 3.24 m/km and 3.20

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m/Km respectively. The value of the corrected overall slope index of the watershed is 7.05 m/Km while the Gravelius compactness index is 1.42. This value of K_G higher than 1 indicates that the watershed of sokouraba is of elongated shape. The specific gradient value of the watershed is 61.99. This value is included between 50 and 100 m, thus according to the classification of the reliefs the latter, the relief of the catchment area of Sokouraba can be qualified as moderate. The values of the length of the main watercourse and the total length of the watercourses calculated are respectively 15,41Km and 63,25 Km. The calculated value of the drainage density of the catchment area is 0.21 Km^{-1}. The value of the attenuation coefficient and the ten-year rainfall calculated in this study are 0,78 and 100,062 mm respectively. The value of the decennial runoff coefficient thus calculated is 27,83%.

1. INTRODUCTION

In Africa, the economic development of most countries is dependent on agriculture and livestock. Modernization of the primary sector, which is highly dependent on rainfall, is necessary to boost development. This is why the mobilization of surface water is a major concern for developing countries and more particularly for Sahelian countries where rainfall is relatively low but also characterized by an unequal spatial and temporal distribution [1]. Indeed, in most of these Sahelian countries, the water problem is one of the greatest concerns that threaten economic and social development. The rainfall deficit due to insufficient and irregular rainfall intensifies the difficulties related to access to water. The control of the hydrological functioning of watersheds is one of the solutions that can allow coherent and adequate control and management of surface water resources. Most watershed studies were aimed at good control of water for its conservation and protection against the risks it can cause [2].

Burkina Faso, a landlocked country in the Sudano-Sahelian zone, is not immune to this situation of rainfall precariousness to the point of being placed in a situation of water stress. This rainfall deficit has led to a situation of severe water stress in the region in general and in Burkina Faso in particular, which has been affected by this continuous drought situation [3]. The country is further subject to climatic hazards that make water resources unavailable [4]. In addition, the population size has increased from 10,312,000 in 1996 to about 20,000,000 in 2019 [5,6,7]. One of the corollaries of this galloping demography is the increased demand for water. In this country, which is representative of the Sudano-Sahelian zone, since it is framed in latitude by the 400 mm and 1300 mm interannual isohyets, an in-depth study of the long-term rainfall series and its repercussions is essential [8].

In this country, climate specialists predict an increase in average temperatures of 0.8°C by 2025 and 1.7°C by 2050, a decrease in rainfall of -3.4% in 2025, and -7.3% in 2050 [9]. The consequences of these climate changes include a marked decrease in water availability, a regression in biomass potential, a drastic reduction and degradation of pastures The work carried out by Mahé et al. [10] about the climatic and anthropogenic impact on the Nakambe runoff in Burkina Faso shows that the Nakambe basin in Wayen occupies an area of nearly 21,000 km2 in the Sahelian domain. Despite the decrease in rainfall since 1970, its peak flows and flow coefficients are increasing regularly. Floods are earlier - in August instead of September and more intense. This increase is also observed for other neighboring Sahelian rivers. The maximum daily flows increase by almost 100%, but the number of days when the flow is higher than half the maximum flow varies a little over the same period, reflecting a flood that is not very spread out over time. Thus Climate change affecting most countries in the world in general and developing countries, in particular, today requires a better understanding of the hydrological behavior of watersheds to implement effective measures to regulate surface runoff, or less, to build resilience (Gbohoui et al. [11]. In West Africa, a change in climatic conditions since the 1970s has resulted in a decrease in average annual rainfall and an increase in temperature [12]. Okafor et al. [13] realized research to study climate change and Spatio-temporal variations in extreme climate indices of the Dano watershed in Burkina Faso using historical data for the period 1981-2010 and projections for the period 2020-2049. According to the results of their study, the climate change signal in the future based on the

ensemble mean of the regional climate models a decrease in the mean annual rainfall by 25.2% and 25.6% for Representative Concentration Pathways 4.5 and Representative Concentration Pathways 8.5 respectively. The work realized by Traore et al. [14] to assess the evolution of irrigated areas with Landsat images in the Kou watershed highlighted that for several years, the pressure on the water resources of the Kou has increased, partly due to the extension of irrigated agricultural perimeters. He further demonstrated that over the past 10 years the irrigated area has increased by almost 70% in 20 years, with most of this expansion occurring. The work realized by Belemtougri et al. [15] to identify environmental variables that best explain the geographic variations of the flow intermittency regime, focusing on intermittency duration, suggested that catchment permeability and catchment areas are the most critical variables in determining flow intermittency classes in Burkina Faso, as the effect of precipitation can be overruled by the ones of permeability, catchment area, and Strahler order.

The work carried out by Ouedraogo [16] in 2012 on the impact of climate change on agricultural income in Burkina Faso showed that agriculture is very sensitive to rainfall in Burkina. A 1% increase in rainfall leads to a 14.7% increase in agricultural income. However, a 1% increase in temperature leads to a 3.6% decrease in farm income. Sensitivity analyses showed that farmers will lose 93% of their income following a 5°C temperature increase. Thus, the Burkinabe government is attempting to alleviate the problem of water deficits by conducting a vast program of maintenance, rehabilitation, and construction of surface water reservoirs. It is in this context that the construction of several dams is planned, including that of Sokouraba. Located in the province of Kénédougou, it is a hydro-agricultural dam that aims to increase agricultural and pastoral production capacities. The realization of this dam requires a hydrological study and characterization of the catchment area of sokouraba is essential. Remote sensing tools and geographic information systems are the most efficient means to determine the hydrological and morphometric characteristics of the watershed. The determination of the physiographic characteristics of a watershed is necessary to determine and analyze the hydrological behavior of a watershed (precipitated water wave, stream flow, balance [17,18]. The use of geographic information systems (GIS) in the study of watersheds allows

nowadays to make the management of water balances of a rainfall-receiving area and to evaluate of its contribution to runoff to the redistribution of water in the soil and towards the water table and its consumption by vegetation [19]. Thus, the present study focuses on the hydrological study and the characterization of the Sokouroba watershed in order to better understand the functioning of the hydrographic networks as well as the quantity of water likely to be used for the realization of a dam in this watershed. In this region, no sufficient study has been conducted in the past to understand the hydrological behavior of the watershed as well as its hydrological functioning. Sokouraba is a village in the Kangala Commune in the Hauts Bassins Region. This village has 4196 inhabitants. The economic activities of the population of this village, like the rural world in Burkina Faso, are based on agriculture and breeding which are strongly dependent on the availability of water resources.

2. MATERIALS AND METHODS

2.1 Study Area

Sokouraba is a village in the Kangala Commune located in the Hauts Bassins Region. This village had 4196 inhabitants. This locality is accessible from Ouagadougou by taking the national road number one (Ouaga-Bobo) long of 360 Km, then the national road number 8 (Bobo-Orodara-Diéri-Mahon) long of 122Km, then the RD 69 road from Mahon to Kangala over a distance of 9 km and finally the track leading from Kangala to Sokouraba over a distance of about 15 km. It is also accessible from Diéri via the RR20 road for 25 km through Samogohiri. The travel distance from Ouagadougou is about 506 km, passing through Diéri. Moreover, Sokouraba is located at about 40 km from the Malian border. According to the phytogeographical division of Guiko [20], Sokouraba belongs to the Southern Sudanian domain and receives an average of 1000 mm of water per year. The climate of this locality is of Sudanian type. It is characterized by the alternation of two seasons: The dry season which is cool from November to February then hot from March to April. The dry season is characterized by the continental trade wind known as harmattan, a hot and dry continental wind coming from the Sahara anticyclone. However, low rainfall occurs annually during the second half of the dry season; the rainy season which begins in May and ends in October. It lasts on average 150 to 175 days with an average

annual rainfall of 900 to 1200 mm. The wettest month is August, while December and January are the least rainy months. The average temperatures in the municipality vary between 24 and 30°C with a relatively small temperature range of 5°C. Air humidity in the dry season is around 25%, while in the wet season it is around 85%. The average annual evaporation varies between 1500 and 1700 mm [21]. During the period from 2004 to 2013, the annual rainfall in the commune varied between 982 and 1357 mm. The year 2006 was the wettest year (1357 mm) during this time interval, while the minimum was recorded in 2008.

2.2 Methods

To carry out this study, a set of tools was used in the framework of our work, among which we can mention the geographic information system (GIS) software ArcGis used for the characterization of the watershed and the edition of the various maps; Google Earth Pro used for the geolocalization of the outlet and Hyfran Plus software used for the frequency analysis of the rainfall data. In addition, data essential to the study, notably climatic data such as rainfall and evaporation from the rainfall and synoptic stations of Orodara and Bobo Dioulasso respectively were also processed.

Data from the Orodara rainfall station was selected for the frequency analysis of rainfall due to its geographical position in the watershed. Maximum daily and annual rainfall series over a period from 1960 to 2019 was used as the basis for this frequency analysis. For the analysis of a rainfall data series, the minimum recommended size is a sample of at least thirty (30) years. With a sample size of fifty-nine (59) years, the condition for conducting this analysis is therefore met. For dam sizing, two models, namely the Normal or Gauss law and the double exponential law or Gumbel law, are used to validate the results of the frequency analysis of rainfall. The objective of this frequency analysis is to determine the different rainfall quantiles that are essential for the rest of our study and that correspond to given return periods. The fit is checked by establishing that at least 95% of the points are within the confidence interval. In addition, this analysis was used to determine the climate regime associated with the study area. All of these analyses are performed using HyfranPlus software, which is a tool adapted to the analysis of rainfall data.

The Normal or GAUSS law for fitting annual mean rainfall is based on the following function (Equation 1) [22]:

$$F(x) = \frac{1}{\sqrt{2\pi}}e^{-\frac{z^2}{2}}$$

(1)

Where F(x) is the distribution function and $= \frac{x-\bar{x}}{}$ is the variable, $\underline{x}$ is the reduced mean and represents the standard deviation.

The double exponential or GUMBEL law for the adjustment of maximum daily rainfall is based on Equation 2. Considering the highest rainfall "X" over a time interval of any calendar period of the year, the distribution follows a distribution function represented in Equation 2 above [23].

$$F(x) = e\left(-e\left[-\frac{(x-x_0)}{\alpha}\right]\right)$$

(2)

Where F(x) represents the distribution function, x_0 represents the position parameter and α corresponds to the scale parameter.

The DTMs established from the digitized contour lines of the basin were used as a basis for the determination of the morphological characteristics of the watershed feeding the Sokouraba dam. Then the ArcGis software was used for data processing. The result of this treatment made it possible to characterize the Sokouraba watershed through its surface, its shape, and its relief and to know thus the type of hydrographic network to which our basin belongs. The determination of longitudinal slope of the basin was determined after having traced the longitudinal profile of the main watercourse and made the ratio between its variation in altitude and its length (Equation 3).

$$I_l = \frac{\Delta H}{L_c}$$

(3)

Where I_l represents the longitudinal slope (m/km), ΔH represents the elevation change (m) and L_c corresponds to the length of the main river.

The geological map of Burkina was used to identify the different soil types in the watershed. The ORSTOM experiments allowed to define the permeability indices of the watershed. Thus, after having identified the nature of the soil of the Sokouraba watershed, it was classified according to the classification of RODIER and AUVREY.

The specific gradient of the watershed was determined by multiplying the corrected overall slope index by the square root of the watershed area. The Gravelius Compactness Index (K_G), the equivalent rectangle length ($L_{éq}$), the overall slope index (I_g), the corrected overall slope index, the gradient (D), and the Density of Drainage ge (D_d) of the watershed were determined using the following relationships (Equation 4 to 8):

$$K_G = \frac{P}{2\sqrt{\pi S}} \; 0,28 \frac{P}{\sqrt{S}} \qquad (4)$$

Where K_G represents the compactness index, P is the watershed perimeter and S represents the watershed area.

$$L_{éq} = \frac{P + \sqrt{P^2 - 16S}}{4} \qquad (5)$$

Where $L_{éq}$ is the length of the equivalent rectangle expressed in Km, P is the perimeter of the catchment area expressed in Km and S is the area of the catchment area given in km^2.

$$I_g = \frac{D}{L_{éq}} \qquad (6)$$

Where Ig represents the global slope index expressed in m/km, D corresponds to the difference in altitude separating the altitudes having 5 % and 95 % of the basin area above them given in m and Léq represents the length of the equivalent rectangle expressed in Km.

$$Ig_{cor} = \frac{(n-1) * I_g + I_t}{n} \qquad (7)$$

Where Ig_{cor} corresponds to the global index of corrected slope expressed in m/km, I_g represents the global index of slope expressed in m/km, I_t corresponds to the transverse slope given in m/Km, and n represents the coefficient according to the length of the equivalent rectangle.

$$D_d = \frac{\sum L_t}{S} \qquad (8)$$

Where D_d represents the drainage density expressed in km^{-1}, $\sum L_t$ corresponds to the total length of the hydrographic network expressed in km and S represents the surface area of the watershed given in Km^2.

The decennial runoff coefficient can be determined by calculating the ratio of runoff volume to precipitation volume. Very difficult to estimate, its evaluation is based on relatively subjective criteria. Two methods were used for the determination of the coefficient Kr_{10} namely that of the ORSTOM and the CIEH. The hypsometric curve which is a curve that shows the distribution of the surface of the watershed according to the altitude was also carried out within the framework of the present work.

Determination of the design flood consists of estimating the flood flow for which the structure must be able to discharge without damage. The design of any structure on a Sahelian river, be it a bridge or a dam, should be carried out with a minimum of knowledge of flood flows [20]. As the BV is not gauged (no flow measurement device installed), the empirical methods implemented for small BVs in West and Central Africa are those used for determining flood flows. The methods used are the deterministic ones of Rodier [24] of 1986, the linear regression of Puech and Chabi (CIEH), and the exponential gradient of Gresillon et al (GRADEX). Thus, the rainfall series of the Orodara station made it possible to determine the decadal daily rainfall P_{10} and the centennial daily rainfall P_{100} through statistical adjustment methods.

The peak coefficient is defined as the ratio of the maximum runoff to the average runoff. It is expressed by the following relation (Equation 9):

$$\alpha_{10} = \frac{Qr_{10}}{Qmr_{10}} \qquad (9)$$

Where α_{10} corresponds to the peak coefficient, Q_{r10} expresses the maximum runoff given in m^3/s and Q_{mr10} represents the average runoff expressed in m^3/s. Whatever the area of the watershed, the peak coefficient α_{10} is admitted to be close to 2.6.

The abatement coefficient corresponding to the reduction coefficient that allows passing, for a given frequency, from a point rainfall to an average rainfall calculated on a certain surface, located in a rainfall homogeneous area was also determined within the framework of the present study. It is used to determine the ten-year average rainfall P_{m10}. It is obtained using the following relationship (Equations 10 and Equation 11):

$$A = 1 - \left(\frac{162 - 0,042 * P_{an}}{1000} * \log \log S \right) \qquad (10)$$

$$P_{m10} = A * P_{10} \qquad (11)$$

Where A represents the abatement coefficient, P_{an} expresses the average annual rainfall (mm), S corresponds to the surface area of the watershed (km^2), P_{m10} : average ten-year rainfall (mm) and P_{10} represents the ten-year rainfall (mm).

The basic time Tb_{10} and the time of rise Tm_{10} of water at the outlet of the dam are deduced from the charts of the method of AUVREY and RODIER. The basic time is the time included between the beginning and the end of the fast runoff. In a dry tropical zone, the base time is expressed by the following relation (Equation 12):

$$Tb_{10} = a * S^{0,36} + b \qquad (12)$$

Where Tb_{10} represents the basic time, a and b are parameters depending on the global slope index, the permeability, and the climatic zone of the watershed.

The rise time corresponding to the time between the beginning of the runoff and the maximum of the flood was determined using the following formula (Equation 13):

$$Tm_{10} = \frac{1}{3} * Tb_{10} \qquad (13)$$

Where Tm_{10} is the rise time and Tb_{10} is the base time.

The determination of the ten-year flood was carried out using the ORSTOM and CIEH methods. The ORSTOM method is resolutely deterministic and was developed by Rodier [24] in 1986. The proposed approach is that of a global rain-flow model based on the unit hydrograph theory [21]. For this model, the peak flow corresponding to the surface runoff of the decennial flood is defined by the following relation (Equation 15 and Equation 14):

$$Qr_{10} = A * Kr_{10} * P_{10} * \alpha_{10} * \frac{S}{Tb_{10}} \qquad (14)$$

$$Q_{10} = m * Qr_{10} \qquad (15)$$

Or Qr_{10} represents the peak flow of the decennial surface runoff, Q_{10} represents the decennial flood flow, m corresponds to the coefficient of majority taken equal to 1,05, A expresses the coefficient of abatement of VUILLAUME, Kr_{10} corresponds to the ten-year runoff coefficient, P_{10} corresponds

to the ten-year maximum daily rainfall, α_{10} represents the peak coefficient taken equal to 2.6, S represents the surface area of the catchment area and Tb_{10} the base time of the ten-year flood.

The CIEH method was proposed by PUECH and CHABI-GONNI and was based on 162 watersheds coming essentially from the collection of the experimental basins. The expression of the peak flow of the decennial flood is based on a multiple regression scheme and is presented in the following form (Equation 16) [24]; [25].

$$Q_{10} = a * S^s * P_a^p * I_g^i * K_{r10}^k * D_d^d ... \qquad (16)$$

Where a, s, p, i, k, d correspond to the coefficients to be determined, S represents the surface area of the catchment area, I_g represents the global slope index, P_{an} corresponds to the average annual rainfall, Kr_{10} represents the ten-year runoff coefficient and D_d corresponds to the drainage density. The list of parameters to be included in the model is not exhaustive. This method is made of statistics with several variants depending on the belonging of the basin to a climatic division, a geographical position, a division for a country or a group [26]; [27].

The estimation of the peak flows of the flood of return period higher than 10 years was made according to the GRADEX theory. The principle on which this method is based consists in assuming that beyond a certain return period, any rain that falls will run off. The 10-year period, corresponding to the precipitation that generated the ten-year flood, is used as a threshold. Thus, any extreme precipitation beyond the 10-year period generates an additional flow equal to the additional rainfall compared to the 10-year period. The additional flow is translated by a multiplier coefficient C (Equation 17) higher than 1. This coefficient was proposed in 1977 by and is based on the GRADEX method of GUILLOT and DUBAND after a critical study of the various proposed coefficients.

$$C = 1 + \frac{P_{100} - P_{10}}{P_{10}} * \frac{\left(\frac{Tb10}{24}\right)^{0,12}}{Kr_{10}} \qquad (17)$$

Where C is the surcharge factor, P_{10} is the maximum daily wet decadal precipitation, P_{100} is the maximum daily wet centennial precipitation, T_{b10} is the base time and Kr_{10} is the decadal runoff factor. This method makes it possible to pass from the decennial flow to the project flow

thanks to a linear relation. Thus the project flow corresponding to the 100-year flood is given by the following equation (Equation 18):

$$Q_{100} = C * Q_{10} \qquad (18)$$

Where Q_{100} is the project discharge, C is the design factor and Q_{10} is the 10-year flood discharge.

3. RESULTS AND DISCUSSION

3.1 Rainfall Data

The treatment of the annual mean and daily maximum rainfall data from the Orodara station by the GAUSS and GUMBEL laws respectively can be summarized in Table 1. With a sample size greater than 30 years representing the minimum duration defined for frequency analysis, the samples are sufficiently representative for the validation of the meteorological analysis. Analysis of this table shows that for the period 1960 to 2019, annual precipitation values range from 347.3 to 1596.6 mm with an average of 1099.28 mm. The maximum daily rainfall values for the same period vary between 42 and 287 mm with an average of 82.85 mm.

The analysis carried out on the annual rainfall trends revealed that 91.50% of the rainfall is observed between May and October and that August, July, and September are the rainiest months with 25.70%; 19.80%, and 17.50% respectively (Fig. 1).

The results of the quantiles from the frequency analysis that will be used in the rest of our study are shown in Table 2. The Sokouraba watershed with its hydrographic network is represented in Fig. 2. The average annual rainfall recorded is about 1100 mm/year. The values of wet decennial and wet quinquennial rainfall are respectively 1380 and 1280 mm. The dry five-year and dry ten-year rainfall values are 917 mm and 821 mm respectively (Table 2).

3.2 Morphometric Characteristics of the Watershed

Table 3 presents the values of the various morphometric parameters of the Sokouraba watershed determined within the framework of the present study. The delimitation of the watershed gave a surface of 77,34 Km² and a perimeter of 44,3 Km. The values of the length and the width of the equivalent rectangle of the basin are respectively 17,81 Km and 4,34 Km. The value of the longitudinal slope was determined from the longitudinal profile of the main river represented in Fig. 3. This slope is then deduced from the ratio of the difference in altitude that can be read in the same Fig. 2, i.e. 546 m for the highest point and 496 m for the lowest point, and the length of the main river estimated at 15.41 Km. The longitudinal slope thus calculated is equal to 3.24 m/Km. It is between 2 ‰ and 5 ‰. This value indicates that this watershed is ranked in the R2 class. In other words, this watershed corresponds to a low-slope watershed consisting of the plain. The cross slopes are calculated in six (06) different cross profiles that are three (03) taken on the left bank and the other three (03) on the right bank. Then, an average is established by the bank and thereafter we deduced the global average in order to obtain the value of the index of the transverse slope of all watersheds of Sokouraba. The value thus calculated of the average cross slope index of Sokouraba is 14.75 m/Km. This value is different from its longitudinal slope index by more than 20%. It is then necessary to proceed to a correction of the global slope index [28]. The value of the corrected overall slope index of the watershed is 7.05 m/Km. The value of the Gravelius compactness index of the watershed calculated in this way is 1.42. This value of KG higher than 1 indicates that the watershed of Sokouraba is of elongated shape. The drawing of the hypsometric curve (Fig. 4) allows us to determine the altitudes at 5% and 95% of the cumulative surface percentages, which are respectively 562 m and 505 m. These curves are a useful tool for comparing several basins together or the various sections of a single basin. In addition, they can be used to determine the average rainfall over a catchment area and provide information on the hydrological and hydraulic behavior of the catchment and its drainage system. The value of the overall slope index calculated in this way is 3.20 m/Km. The value of the specific gradient of the watershed is 61.99. This value is included between 50 and 100 m, thus according to the classification of the reliefs the latter, the relief of the catchment area of Sokouraba can be qualified as moderate. The total length of the watercourses as well as the area are determined with the help of ArcGIS software. The values of the length of the main watercourse and the total length of the watercourses calculated are respectively 15,41 Km and 63,25 Km. The calculated value of

the drainage density of the catchment area is 0.21 Km^{-1}. This value is determined by the knowledge of the total length of the watercourses of the basin and its surface.

The value of the attenuation coefficient and the ten-year rainfall calculated in this study are 0.78 and 100.062 mm respectively. This coefficient of abatement corresponds to the reduction coefficient which allows passing, for a given frequency, from a height of punctual rain to an average height calculated on a certain surface, located in a homogeneous rainfall area. The values of the base time and rise time determined are 915.33 minutes and 305.11 minutes

respectively. The value of the decadal runoff coefficient was determined using the CIEH method (Table 4). This method is a function of the climatic zone and substrate and uses regression results obtained on the basis of the geological substrate and annual precipitation. The soil map of the Sokouraba watershed shown in Fig. 5, indicates that the geology of Sokouraba is heterogeneous and consists of 76.68% clay and 23.32% sandstone (58%). Can be used in our case, the relations K_4 for clays and K_2 for sandstones. Based on these relations, the value of K_{r10} determined by the CIEH method is 33.21% (Table 5).

Table 1. Rainfall characteristics of the Orodara station

| Designation result unit	Designation result unit		Designation result unit
Station	Orodara		-
Sample	Annual rainfall	Maximum daily rainfall	-
Size	59	59	Number
Period	1960 - 2019	1960 - 2019	Year
Minimum value	347,3	42	mm
Maximum value	1 596,6	287	mm
Variance	46 773,76	1 286,69	mm
Average	1 099,28	82,85	mm
Standard deviation	216,27	35,87	mm
Median	1 099,28	76	mm
Coefficient of variation	19,67	43,29	-
Confidence interval	95	95	%
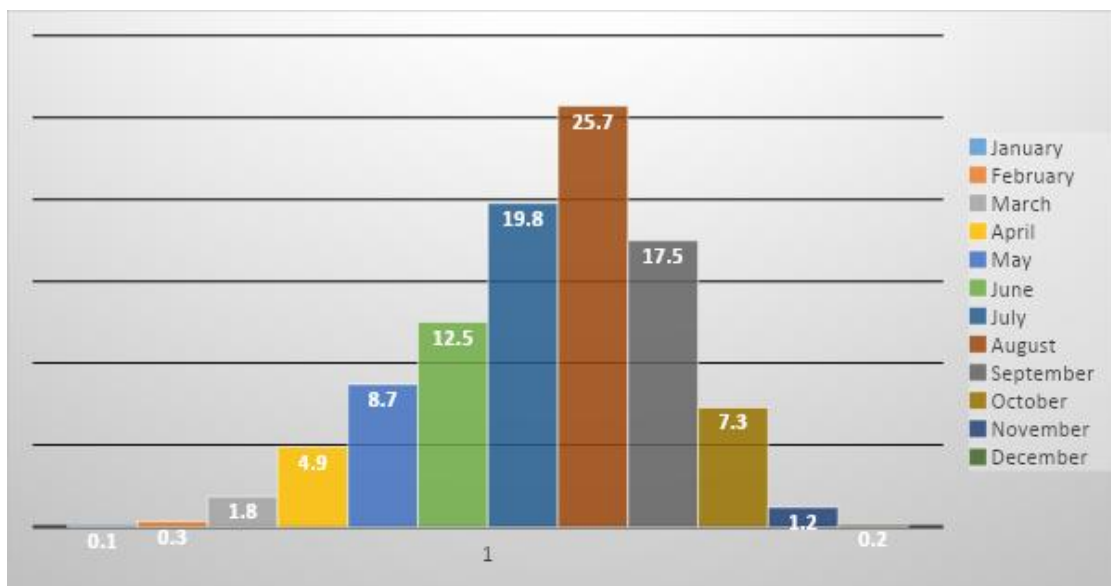
Fig. 1. Histogram of annual rainfall for Orodara from 1960 to 2019

Table 2. Summary of rainfall in Orodara

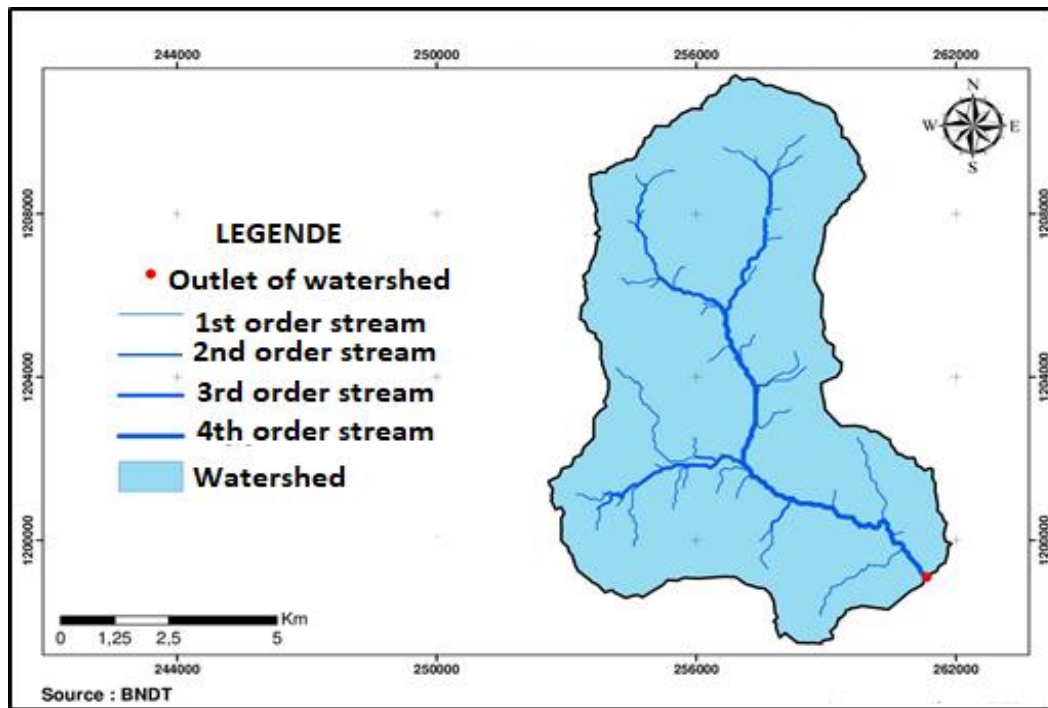| Periodic rainfall	Value	Unit
Average annual rainfall (P_{an})	1100	(mm)
Wet ten-year rainfall	1380	(mm)
Wet five-year rainfall	1280	(mm)
Five-year dry rainfall	917	(mm)
Dry ten-year rainfall	821	(mm)
Maximum daily rainfall of wet decadal frequency (P_{10})	129	(mm)
Maximum daily rainfall of 100-year wet frequency (P_{100})	195	(mm)

Fig. 2. Sokouraba watershed and its hydrographic network

Table 3. Characteristics of Sokouraba watershed

| Designation	Symbol	Values	Unit
Watershed perimeter	P	44,3	Km
Area of the BV	S	77,34	Km².
The difference in elevation of mainstream	ΔH	50	m
Length of mainstream	L_c	15,41	Km
The total length of the watercourse	$\sum L_t$	63,25	Km
Longitudinal slope	I_l	3,24	m/Km
The Gravelius compactness index	K_G	1,41	-
Drainage density	D_d	0,82	Km^{-1}
Length of the equivalent rectangle	$L_{éq}$	17,81	Km
Width of the equivalent rectangle	$l_{éq}$	4,34	Km
Overall slope index	I_g	3,20	m/Km
Cross slope	I_t	14,75	m/Km
Corrected overall slope index	I_{gcor}	7,05	m/Km
Specific gradient	D_s	62,00	m
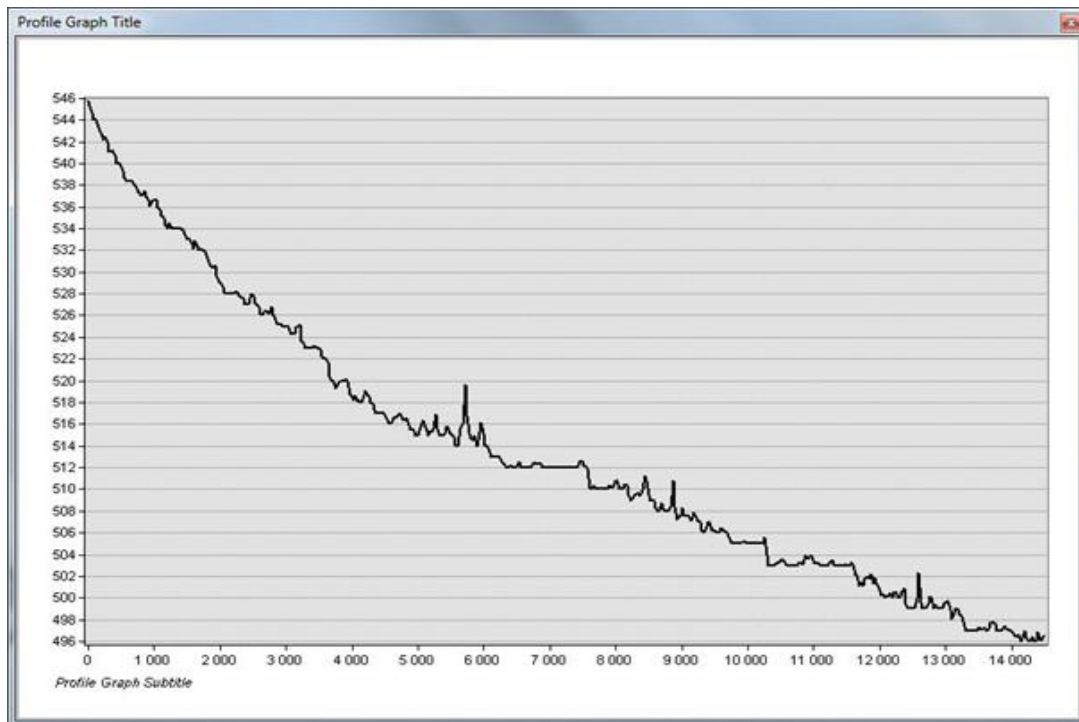
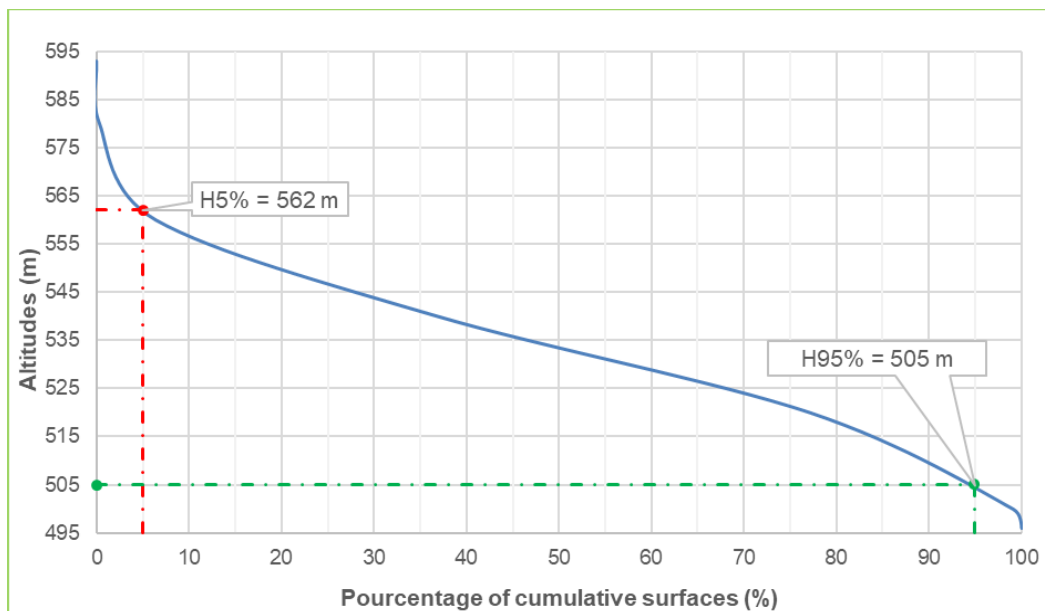**Fig. 3. Longitudinal slope of the Sokouraba watershed**

Fig. 4. Hypsometric curve of Sokouraba watershed

The value of the 10-year runoff coefficient was determined again using the ORSTOM method. On the basis of the general form analytical equations presented in Table 6, the runoff coefficients Kr were determined for P_{10} = 70 mm and P_{10} = 100 mm (Table 6). In a dry tropical regime, for watersheds whose surface is higher than 10 km^2 with a class of permeability P3 or RI and with a global corrected slope index of 7,05 included between 7 and 10, the parameters a, b, and c of kr_{70} and kr_{100} necessary to the determination of the runoff coefficient Kr_{10} by the ORSTOM method are presented in tables x and x. For a ten-year rainfall P_{10} = 129 mm higher than 100 mm the value of Kr_{10} is obtained by extrapolation between the values of Kr for P_{10} =

70 mm and P_{10} = 100 mm. The value of the decennial runoff coefficient thus calculated is 27.83% (Table 7).

The value of the decennial flow was determined initially by using the CIEH method (Table 8). For the case of Burkina Faso eight (08) regression equations are presented in Table 8 which will allow approaching the decennial flood according to the most representative parameters which are the surface of the basin S, the average annual rainfall P_{an}, the global index of corrected slope Ig_{cor}, the decennial runoff coefficient Kr_{10} and the drainage density D_d are generally used (Table 8) [29]. Expression N° 3 of Table 8 judged much more representative of the parameters of the catchment area of Sokouraba was used for the estimation of this decennial flow. The

value thus calculated of this decennial flow is 70,41 m^3/s.

The ten-year peak flow rate Q10 is deduced by multiplying the peak flow rate corresponding to surface runoff by the surcharge coefficient m. This coefficient, which is a function of the class of inflitability of the basin and its climatic zone, is taken equal to 1.05 within the framework of the present study. The peak flow corresponding to the surface runoff of the decennial flood is defined by the parameters presented in Table 9. The value of this peak flow calculated in this way is 122.54 m^3/s and that of the decennial peak flow Q10 deduced is estimated at 128.67 m^3/s. The value of the project flow corresponding to the 100-year flow determined in this study was estimated at 173.16 m^3/s.

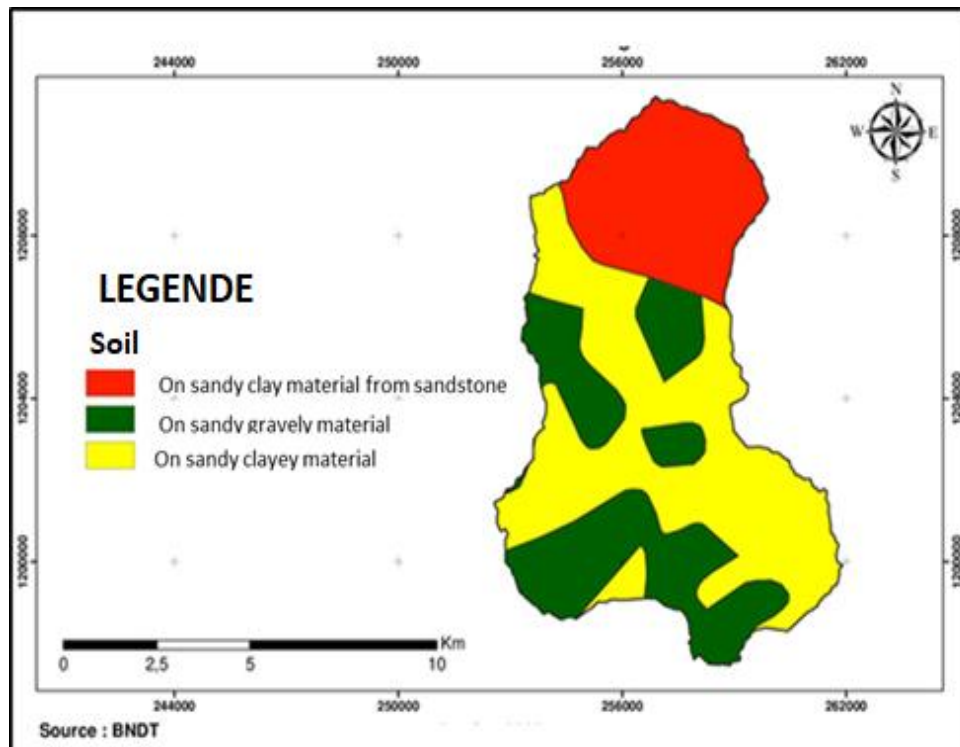**Fig. 5. Soil map of Sokouraba watershed**

Table 4. Method for determining the 10-year runoff coefficient value

Category	Formula
Granites	$K_1 = 2300 P_{an}^{-0.67}$
Sandstone	$K_2 = 300 P_{an}^{-0.375}$
Sands	$K_3 = 2{,}10^7 P_{an}^{-2.2}$
Clay + marl	$K_4 = 300 P_{an}^{-0.3}$
Shale	$K_5 = 370 P_{an}^{-0.375}$
$K_{r10} = \sum_{i=1}^{n} a_i K_i$	n = 1...5 $\qquad a_i = \%\ de\ sol\ de\ type\ i$

Table 5. Runoff coefficient calculation method over 10 years

Material	Area (km^2)	Percentage of soil (%)	K_i	Kr_{10} (%)
Clay	35,94			
Clay	5,13			
Clay	3,17	76,68	36,70	28,14
Clay	1,46			
Clay	13,61			
Sandstone	18,04	23,32	21,71	5,07
Total	77,34	100	-	33,21

Table 6. Calculation of runoff coefficient Kr for P_{10} = 70 mm and P_{10} = 100 mm

$Kr_{70} \ ou \ Kr_{100} = \dfrac{a}{S+b} + c$	Kr_{70} : runoff coefficient for a 10-year rainfall equal to 70 mm Kr_{100} : runoff coefficient for a 10-year rainfall equal to 100mm S : Watershed area (Km²) a, b and c: parameters depending on the slope index and infiltrability

Table 7. Calculation of 10-year runoff coefficient equal to 70 mm and 100 mm

10-year runoff coefficient equal to 70 mm					
Ig_{cor}	S (km^2)	a	b	c	Kr_{70} (%)
7		200	20	18,5	20,55
7,05	77,34	200,32	20	18,52	20,58
15		250	20	21,7	24,27
10-year runoff coefficient equal to 100 mm					
Ig_{cor}	S (km^2)	a	b	c	Kr_{100} (%)
7		240	30	22	24,24
7,05	77,34	240,54	30	22,03	24,27
15		325	30	26	29,03

Table 8. Ten-year flow calculations according to CIEH

Number	Expression	Ten-year flow rate	Unit
1	$2,01 * 77,34^{0,649} * 7,05^{0,066} * 0,82^{0,824}$	32,57	m^3/s
2	$0,41 * 77,34^{0,425} * 33,21^{0,923}$	65,98	m^3/s
3	$0,254 * 77,34^{0,462} * 7,05^{0,101} * 33,21^{0,976}$	70,41	m^3/s
4	$0,407 * 77,34^{0,532} * 33,21^{0,941}$	111,09	m^3/s
5	$0,0912 * 77,34^{0,643} * 7,05^{0,399} * 33,21^{1,019}$	115,56	m^3/s
6	$35600 * 77,34^{0,342} * 1100^{-1,808}$	37,59	m^3/s
7	$203 * 77,34^{0,459} * 1100^{-1,301} * 33,21^{0,813}$	63,76	m^3/s
8	$22400 * 77,34^{0,363} * 1100^{-1,748} * 7,05^{0,059}$	38,35	m^3/s

Table 9. Calculation of the peak flow corresponding to the surface runoff of the 10-year flood and the peak flow

Parameters	A	Kr_{10} (%)	P_{10} (mm)	α_{10}	S (Km^2)	Tb_{10} (hours)
Values	0,78	33,21	129	2,60	77,34	15,26

$$Qr_{10} = 0,78 * 0,3321 * 129 * 10^{-3} * 2,60 * \frac{77,34 * 10^6}{15,26 * 3600}$$

$$Qr_{10} = 122,54 \ m^3/s$$

$$Q_{10} = m * Qr_{10}$$

$$Q_{10} = 1,05 * 122,54$$

$$Q_{10} = 128,67 \ m^3/s$$

4. CONCLUSION

This study focuses on the hydrological study and the characterization of the Sokouroba watershed. The determination of hydrological and morphometric parameters values of this watershed has made it possible to better understand the functioning of the hydrographic networks as well as the quantity of water likely to be mobilized within the framework of the construction of a hydro-agricultural dam in this region from Burkina Faso. The hydrologic analysis highlighted that in the period 1960 to 2019, annual precipitation values range from 347.3 to 1596.6 mm with an average of 1099.28 mm. The maximum daily rainfall values for the same period vary between 42 and 287 mm with an average of 82.85 mm. The analysis carried out on the annual rainfall trends revealed that 91.50% of the rainfall is observed between May and October and that August, July, and September are the rainiest months with 25.70%; 19.80%, and 17.50% respectively. The average annual rainfall recorded is about 1100 mm/year. The values of wet decennial and wet quinquennial rainfall are respectively 1380 and 1280 mm. The dry five-year and dry ten-year rainfall values are 917 mm and 821 mm respectively. These rainfall values sufficiently confirm the rainfall deficit that hinders the socioeconomic and social development of Burkina Faso mentioned by several research works. The delimitation of the watershed gave a surface of 77,34 Km² and a perimeter of 44,3 Km. The values of the length and the width of the equivalent rectangle of the basin are respectively 17,81 Km and 4,34 Km. The longitudinal slope thus calculated is equal to 3.24 m/Km. It is between 2 ‰ and 5 ‰. This value indicates that this watershed is ranked in the R2 class. In other words, this watershed corresponds to a low-slope watershed consisting of the plain. The value of the corrected overall slope index of the watershed is 7.05 m/Km. The value of the Gravelius compactness index of the watershed calculated in this way is 1.42. This value of K_G higher than 1 indicates that the watershed of sokouraba is of elongated shape. The value of the overall slope index calculated in this way is 3.20 m/Km. The value of the specific gradient of the watershed is 61.99. This value is included between 50 and 100 m, thus according to the classification of the reliefs the latter, the relief of the catchment area of Sokouraba can be qualified as moderate. The values of the length of the main watercourse and the total length of the watercourses calculated are respectively 15,41Km and 63,25 Km. The calculated value of the drainage density of the catchment area is 0.21 Km^{-1}. The value of the attenuation coefficient and the ten-year rainfall calculated in this study are 0.78 and 100.062 mm respectively. The value of the decennial runoff coefficient thus calculated is 27.83%. The value of peak flow is 122.54 m^3 /s and that of the decennial peak flow Q10 deduced is estimated at 128.67 m^3 /s. The value of the project flow corresponding to the 100-year flow determined in this study was estimated at 173.16 m^3 /s. It should be noted that other additional work such as the estimation of the water needs of the population of this region, the sizing of the dam, the estimation of the actual and potential evapotranspiration, the determination of the breaking and safety flood; will be necessary for a better understanding of the hydrological behavior of the Sokouraba watershed.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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