

# Climate variability impact on groundwater resources in the Highest Bandama watershed at Tortiya (Northern Côte D'Ivoire)

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**Abstract:** The present study carried out in the Highest Bandama watershed at Tortiya, in the northern of Côte d'Ivoire, aims to evaluate climate variability impact on groundwater resources in order to best management. It is based on rainfall and runoff data exploitation. Thus, application of low-pass filter of Hanning and statistic tests (Pettitt, Lee and Heghinian) shows a rainfall regime modification occurred around the seventies years. This modification reveals a decrease of rainfall between 12% and 22% according the stations, with an average of 16.5%. This decrease is very high for runoff (62.5%) at Tortiya station. The isohyets plots confirm the decrease of rainfall during five decades. Coefficients of depletion obtained by Maillet method become very high (more than  $8 \cdot 10^{-2} \text{ j}^{-1}$ ) after the seventies years. Groundwater recharge decreases with an average efficace infiltration of 212 mm in decade 1980-1989, and 184 mm in the decade 1990-1999.

**Keywords:** Climate Variability, Groundwater Resources, The Highest Bandama Watershed at Tortiya, Côte d'Ivoire

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## 1. Introduction

Climatic change and its influence on the environment and the society are at the heart of the preoccupation political and scientific present [1]. For a region already vulnerabilised like West Africa, this question is vital. In fact, West African area was unregistered one of the most important drought of twentieth century among the 1970-1990 years. The dependence of major part of agriculture to rainfall cultures makes it one of region particularly vulnerable to rainfall regime changes. The Highest Bandama watershed at Tortiya in north of Côte d'Ivoire, agricultural region, was very well integrated in the presented situation. In these soudano-sahelian areas,

agricultural activities, that represented food guaranteed safety [2] for populations, are developed accordingly water resources with a specific seasonal availability rythm. This is the reason for why the present study evaluates the climate variability impacts on groundwater resources. This attempt will help to best management of basin water resources.

### 1.1. Study Area

The Highest Bandama watershed at Tortiya is an under basin of white Bandama basin. It is located between longitudes 5° and 6°20' west, and latitudes 8°40' and 10°20' north (figure 1). It stretches on Korhogo, Katiola, Niellé, Tengréla and Boundiali square degree, and covers an area

estimated to 14,500 km<sup>2</sup>. The most part of basin area (86%) is centered on Korhogo square degree.

In it whole, the basin is a huge plateau characterized by areas surfaces aplaned with altitudes ranges from 300 to 400 meters. However, this monotonous of tray was interrupted by granitic domes presented allure of inselbergs.

The basin was largely drained by the Bandama and its principal tributaries (Solomougou, Lopkoho, Yoréloro, Lafigué, Badénoú). Hydrographic network appears like a dense water pattern in rainy seasons (Coulibaly, 1978 *in* [3]). Network hydrographic pattern has a curvilign tendency, and sometimes rectangular. In Korhogo area, there are several small dams on Bandama affluents for agriculture uses and breeding. Agriculture is the main activity followed by breeding.

The climate is soudano-sahelian type (tropical regime of transition) with two contrasting seasons: one rainy season from May to October, and one drought season from November to April with a rainfall average evaluated to 1230 mm (period 1950-2000). Runoff regime was traced on this of rainfall. It was distinguished one period of low runoff (lower flow) from November to April, and one period of high runoff (flood) from May to October. The most important flood was unregistered in September with

300 m<sup>3</sup>/s on 1962-1994 period.

Average relative humidity varies between 35 and 79%. Insolation values are spread over 160.6 hours (July month) to 273.8 hours (January month).

Average temperature unregistered on 1972-2000 period is 26.6°C. Netherless, the highest values were obtained during drought season with a pick on March (29.5°C) and the lowest values during rainy season with minimum on August (24.7°C) (figure 2).

The basin is constituted in major part of ferralitic soils averagely and strongly desaturated. It was encountered nearly the latest ones, ferralitic complex of soils weakly desaturated and brown-eutroph tropical soils derived from basic rocks [4].

On geological plan, the low intensity of metamorphism allows to distinguish two main groups of formations [5]: originated sedimentary formations, and those originated volcanic and very accessorily eruptive (figure 3).

Originated sedimentary rocks are essentially composed of variety schists and mica schists associated to greywacks to form a flysch. Originated volcanic rocks are represented by « rocks » (footrace of amphibolites, albite, chlorite and epidote), in other term, basic volcanic rocks or eventually neutral to which added some basic granular rocks.

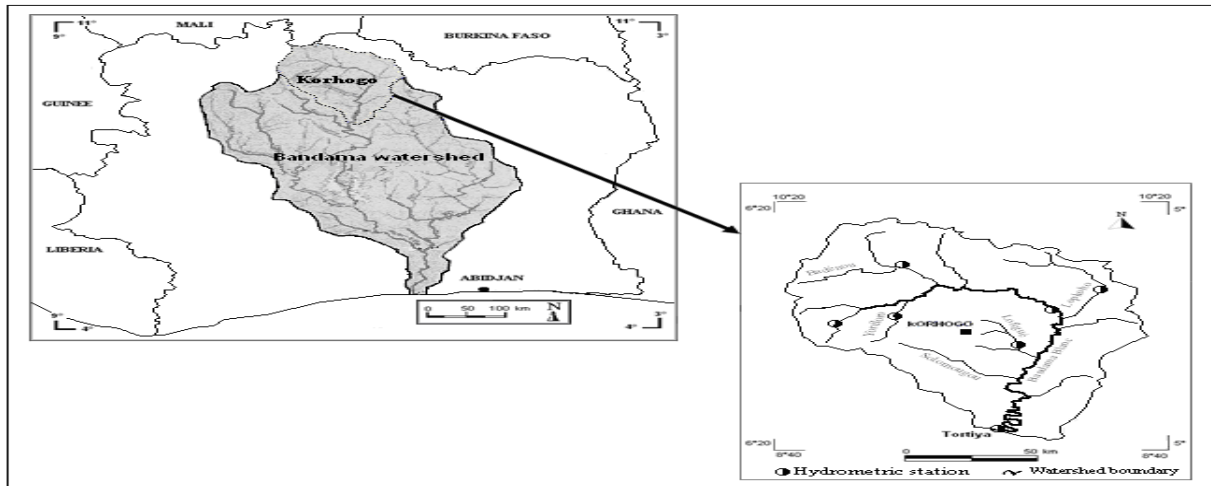


Figure 1. Location map of the study area

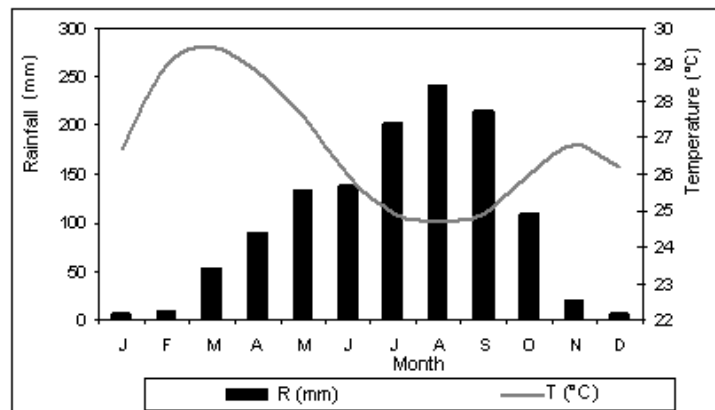


Figure 2. Ombro-thermal diagram of Korhogo synoptic station from 1972 to 2000

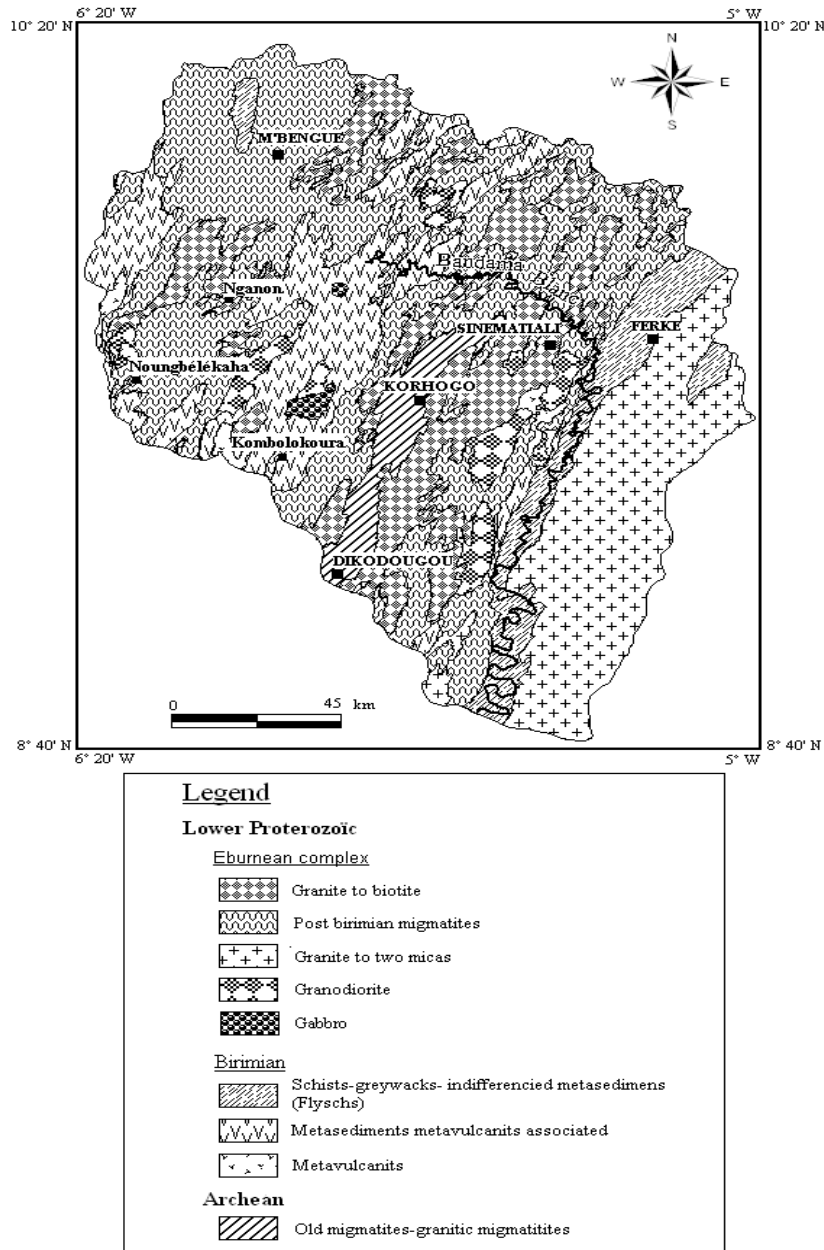


Figure 3. Geological map of the Highest Bandama watershed at Tortiya to scale 1/200000 modified ([6])

## 2. Material and Methods

### 2.1. Hydroclimatology

#### 2.1.1. Data of Study

Data consists of daily and monthly rainfall and runoff sets. Rainfall data used are those of Korhogo, Ferkessédougou, Ouangolodougou, Boundiali, Tafiré and Niakaramandougou. There are extended on 1950-2000 period and come from Society of Development and Exploitation Aeroportuary, Aeronautic and Meteorological (SODEXAM) which is the main management on Ivory country. Also, the temperature data from Korhogo synoptic station are been used and extended to the entire watershed.

Data runoff of eight (08) hydrometric stations have been

used for study. The last data are given by Hydrology Direction, sub- directory of Human Hydraulics.

Only, hydrometric data of Tortiya station (outlet) have been used for climate variations study because this dataset is the longest (from 1962 to 1994). The data of other stations have been used to fill gap in Tortiya dataset.

#### 2.1.2. Critic Dataset

Some gaps have been remarked in chronic data of rainfall and runoff along some years or month of a year. The utilization of these data to raw state is error sources. It is necessary to correct these data before treatment.

### 2.2. Rainfall Data Correction

Rainfall data are good in the whole but have some gaps

in general for Tafiré and Niakaramandougou posts. We have used double mass (double cumulus) method to fill gap in order to verify dataset homogeneity for all network rainfall stations. The principle of this graphical method consists to verify homogeneity of measured values of the station, to test by correlating those values to reference station values. This operation allows to fill gap lacunas, to test homogeneity, and to critic raw data of rainfall network. This comparison uses, to time step chosen, not individual values observed but their cumulus (Meylan and Musy, 1998 *in* [7]).

The evaluation of missing data to a station has been determined based on neighbour station data presenting the best correlation coefficient and functioning during the missing month. The most simple formula to fill gap, without major error, or lacunas of dataset, is to replace missing value by a ponderated average which is monthly trend station (Musy and Laglaine, 1992) cited by [7]. In our case, double cumulus test has showed that different rainfalls are homogenous with high strong correlation coefficient. In this case, it can be used neighbour station data. Thus, monthly missing data for Ferkessédougou rainy station along 1981, 1982, 1994 and 1995 years had been filled with Ouangolodougou station data. Data missing for October (1966), May (1967), November and December (1979) and January - February (1980) months at Boundiali station had been reconstituted based on Korhogo airport station data.

$$x_{(t)} = 0.06 x_{(t-2)} + 0.25 x_{(t-1)} + 0.38 x_{(t)} + 0.25 x_{(t+1)} + 0.06 x_{(t+2)} \text{ for } 3 \leq t \leq (n-2) \quad (1)$$

Where  $x_{(t)}$  is total ponderated rainfall of term  $t$ ,  $x_{(t-2)}$  and  $x_{(t-1)}$  are total rainfall of two terms immediately preceding the term  $t$ , and  $x_{(t)}$  and  $x_{(t+1)}$  are total rainfall of two terms following immediately the term  $t$ .

Total ponderated rainfall for the two first terms [ $x_{(1)}, x_{(2)}$ ] of dataset, and the last two terms of set [ $x_{(n-1)}, x_{(n)}$ ] are calculated using the following expressions ( $n$  has been the size of set):

$$X_{(1)} = 0.54 x_{(1)} + 0.46 x_{(2)} \quad (2)$$

$$X_{(2)} = 0.25 x_{(1)} + 0.50 x_{(2)} + 0.25 x_{(3)} \quad (3)$$

$$X_{(n-1)} = 0.25 x_{(n-2)} + 0.50 x_{(n-1)} + 0.25 x_{(n)} \quad (4)$$

$$X_{(n)} = 0.54 x_{(n)} + 0.46 x_{(n-1)} \quad (5)$$

The reduced and centered indexes for annual rainfall ponderated level obtained are calculated to distinguish well deficit and excedentary rainfall periods.

Runoff dataset are been submitted to the same calculation procedures like rainfall dataset.

### 2.5. Statistical Tests for Detection of Breaks

In statistical scientific literature, there are several

### 2.3. Runoff Data Correction

In literature, there are several techniques to reconstitute the missing data. In the case of hydrometric stations located on the same hydrographic river (geographic transposition, volume conservation, etc.), it can use analogue proportionality yardsticks. Methods based on linear regression and coefficients (relation rainfall-rainfall or rainfall-runoff, interpost relations) can be use for that (Musy and Higy, 2003 *in* [8]). In our study, it had been used analogue proportionality yardstick method to reconstitute runoff data of Tortiya station. Different areas of under basins were calculated, and reports had been used. In tropical regimes, runoff flows (dry up flow) are very weak (even zero) and can be replaced for most time, by annual average, without using monthly correlations or daily runoff [9]. This method was used like complement to the first method.

### 2.4. Climate Variability Methods Study

*Low- pass filter of Hanning of second order or ponderated average mobile method*

A best observation of inter annual fluctuations are obtained by eliminating seasonal variations. In this case, total annual rainfall is ponderated using the following equations' set recommended by [10]:

methods for detection of breaks in time series (Pettitt test, Buishand statistic, and Lee and Heghinian bayesian procedure, Hubert segmentation). In this study, it has been retained Pettitt test, Lee and Heghinian bayesian method for their power and robustness. We used the software Khronostat 1.00 from Institute of Research and Development (IRD), for statistical analysis.

#### 2.5.1. Pettitt Test

The Pettitt test [11] is a non-parametric. It derives from Man-Whitney test. Lake of break in time series ( $X_i$ ) of  $N$  sizes constitutes null hypothesis. The application of test supposes that at any time  $t$  including between 1 and  $N$ , the time series ( $X_i$ )  $i=1$  to  $t$  and  $t+1$  to  $N$  belong to the same population. The variable to test is the maximum in absolute value of variable variable  $U_{t,N}$  defined by:

$$U_{t,N} = \sum_{i=1}^t \sum_{j=t+1}^N D_{ij} \quad (6)$$

where  $D_{ij} = \text{sgn}(X_i - X_j)$  with  $\text{sgn}(X) = 1$  if  $X > 0$ ;  $0$  if  $X = 0$  and  $-1$  if  $X < 0$ .

In the case where null hypothesis is rejected an estimation of break date is given by  $t$  instant defining the maximum in absolute value of variable  $U_{t,N}$ .

**2.5.2. Lee and Heghinian Bayesian Method**

Lee and Heghinian bayesian method [12] aims to confirm or unconfirm the hypothesis of average change in time series. Break absence in time series constitutes the null hypothesis. The procedure is based on the following model:

$$X_i = \begin{cases} \mu + \varepsilon_i & i=1, \dots, \tau \\ \mu + \delta + \varepsilon_i & i=\tau+1, \dots, N \end{cases}$$

where the  $\varepsilon_i$  are independents and normally distributed, with null average and  $\sigma^2$  variance.

The  $\tau, \mu, \delta$  variables and  $\sigma$  are unknown parameters.  $\tau$  and  $\delta$  represent the break position in time and the change amplitude on average, respectively. The method gives therefore the likelihood that break occurs at  $\tau$  moment in time series where it was supposed at priori that it is a change at un-determined moment.

**2.6. Averages Variations Calculation**

For hydroclimatic variables which chronologic time series presents a break, it is interesting to calculate average variations of a part of break. According [9], the following formula was used:

$$D = \frac{\bar{x}_j}{\bar{x}_i} - 1 \tag{7}$$

where  $\bar{x}_j$  represents the average period after break;  
 $\bar{x}_i$  the average period before break.

**2.7. Isohyets Plots**

Knowing P rainfall in many points (stations) of (X; Y) coordinates, it was extrapolated it on entire study area using Surfer 8.0 software by krijing method. This method allows having an idea on rainfall spatial and temporal evolution on study area.

**2.8. Depletion of Rivers Network and Volumes of Water Mobilized by Study of Aquifers**

**2.8.1. Coefficient of Depletion: Maillet Law and Dichotomic Method**

For coefficient of depletion calculation, it was used Maillet method improved by dichotomic resolution and proposed by [13]. This method is based on Maillet law which expression is the following:

$$Q_t = Q_0 e^{-k} \tag{8}$$

where:

$Q_t$  = flow at t instead given;  $Q_0$  = initial flow (flow at the beginning of drying);  $k$  = Maillet drying coefficient.

In dichotomic method, it is estimated that annual recession curb is the expression of ground storage discharge.

The water quantity recovered at jauging station

corresponds exclusively to dynamic volumes (V) of water mobilized by all watershed aquifers. The depletion of coefficient (k) is written as:

$$\frac{e^{-kt}}{k} + \frac{V}{Q_0} - \frac{1}{k} = 0 \tag{9}$$

**2.8.2. Volumes of Water Mobilized by Aquifers Evaluation**

The mobilized volume by all aquifers is given by the equation:

$$V_{mobilis} = \int_0^{+\infty} Q_0 e^{-kt} dt = \frac{Q_0}{k} \tag{10}$$

$Q_0$  is expressed in [m<sup>3</sup>/s] and  $k$  in [j<sup>-1</sup>].  $Q_0$  is multiplied by 86,400 for compatibility of units.

**2.9. Evaluation of Aquifers Recharge**

It is Thornthwaite classic method that was used regarding availability data. Alone excedentary values again called efficace infiltration were retained at water table final of each station during different periods.

**3. Results**

**3.1. Hydroclimatic Variability**

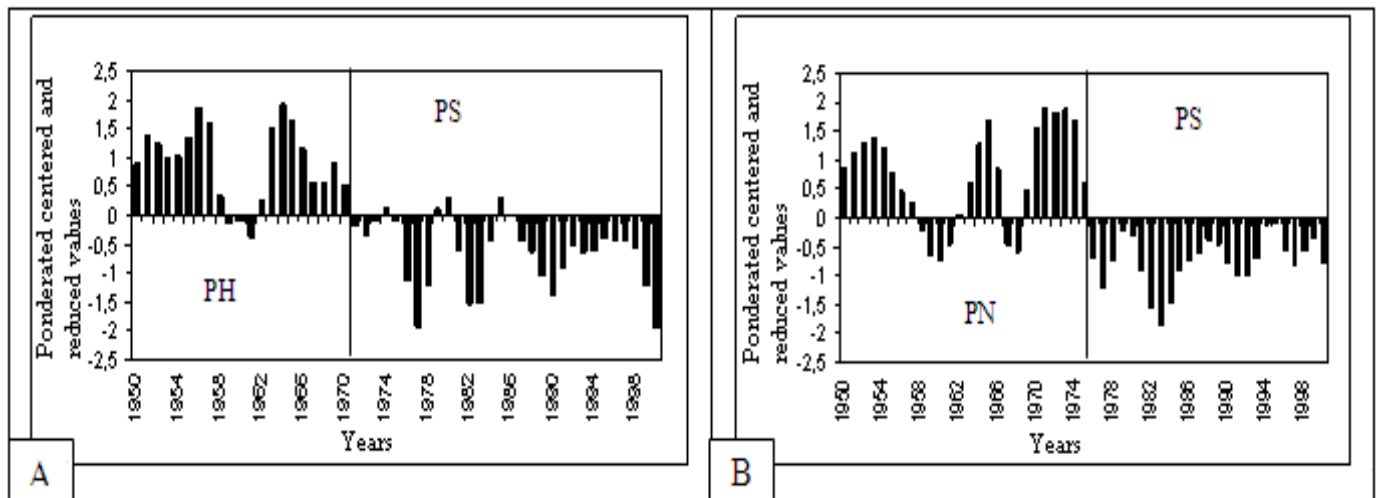
The application of reduced centered index in particularly Hanning second order low-pass filter allows following the watershed climatic fluctuations. There have been marked by succession of humid periods (PH) between 1950 and 1970, and drought periods (PS) after year 1970 for majority rainfall station. For Boundiali rainfall station, one normal period is noted from 1950 to 1975 followed by drought period (1976-2000).

Near these different periods, some trends to reprise were observed from years 1996, 1998 and 1999 respectively for Tafiré, Ferkessédougou and Niakaramandougou stations. The table 1 recaps these results, and figure 4 illustrates the delimitation obtained to Korhogo and Boundiali stations.

**Tableau 1.** Different trends obtained by application of ponderated average mobiles (1950-2000)

Station	PH	PS	PN
Korhogo	1950-1970	1971-2000	-
Ferkessédougou	1950-1970 ; 1998-2000	1971-1997	-
Ouangolodougou	1950-1970	1971-2000	
Boundiali	-	1976-2000	1950-1975
Tafiré	1950-1968 ; 1996-2000	1969-1995	-
Niakaramandougou	1950-1967 ; 1999-2000	1968-1998	-

PH= Humid Period; PS= Drought period; PN= Normal period



**Figure 4.** Interannual rainfall evolution with reduced and centered indexes of total annual rainfall ponderated (A) to Korhogo station, and (B) to Boundiali station for 1950-2000 period

The application of break tests has allowed to situate the periods that marks a modification of climate regime in chronological series. The breaks occurred majority between 1968 and 1970 for watershed (table 2). Rainfall deficits have been calculated of a part of break year. The results show that rainfall deficits are situated between

12% (Niakaramandougou) and 22% (Ouangolodougou) with an average of 16.5% for entire watershed (table 2). It is remarked that the most rainfall deficits are enregistred at Ouangolodougou and Boundiali, and the lowest at Niakaramandougou in South part of watershed.

**Table 2.** Break and rainfall deficits of watershed stations (1950-2000)

Station	Break year	Average before break (mm)	Average after break (mm)	Variation (%)
Korhogo	1970	1405	1218	-13
Ferkessédougou	1970	1401	1161	-17
Ouangolodougou	1970	1300	1011	-22
Boundiali	1975	1674	1299	-22
Tafiré	1968	1206	1047	-13
Niakaramandougou	1968	1225	1072	-12

As for hydrometric times series, the low-pass filter of Hanning of second order highlight a humid period (PH)

from 1962 to 1974 followed by drought period (PS) from 1975 to 1994. The modules before and after break are 101.6 m<sup>3</sup>/s, and 38.1 m<sup>3</sup>/s respectively, with 62.5% of deficit (table 3).

**Table 3.** Hydrometric deficit of Tortiya station (1962-1994)

Station	Reference	Annual module before break (m <sup>3</sup> /s)	Annual module after break (m <sup>3</sup> /s)	Variation (%)
Tortiya	1974	101.6	38.1	-62.5

### 3.2. Spatio-Temporal Variability of Rainfall

The watershed rainfall spatio-temporal evolution has been studied during five decades (figure 5). The analysis of isohyets values map shows a gradient that is east-west increasing. The decades 1950-1959 and 1960-1969 are the most wetted, as witnessed respectively, with isohyets values of 1530 mm and 1470 mm encountered on the watershed. The decade 1970-1979 appears with regular curves of isohyets values. Nevertheless, during this decade, the watershed rainfall is in net decreasing. This decreasing is underlined by 1250 mm isohyets apparition around Korhogo. The decades 1980-1989 and 1990-1999 are the most deficit. During these decades, it can remark irregular lines of isohyets. The apparition of 1300 mm isohyet around Boundiali, and downward trend of 1200 mm isohyet to Korhogo western translates the decrease of rainfall during the last two decades.

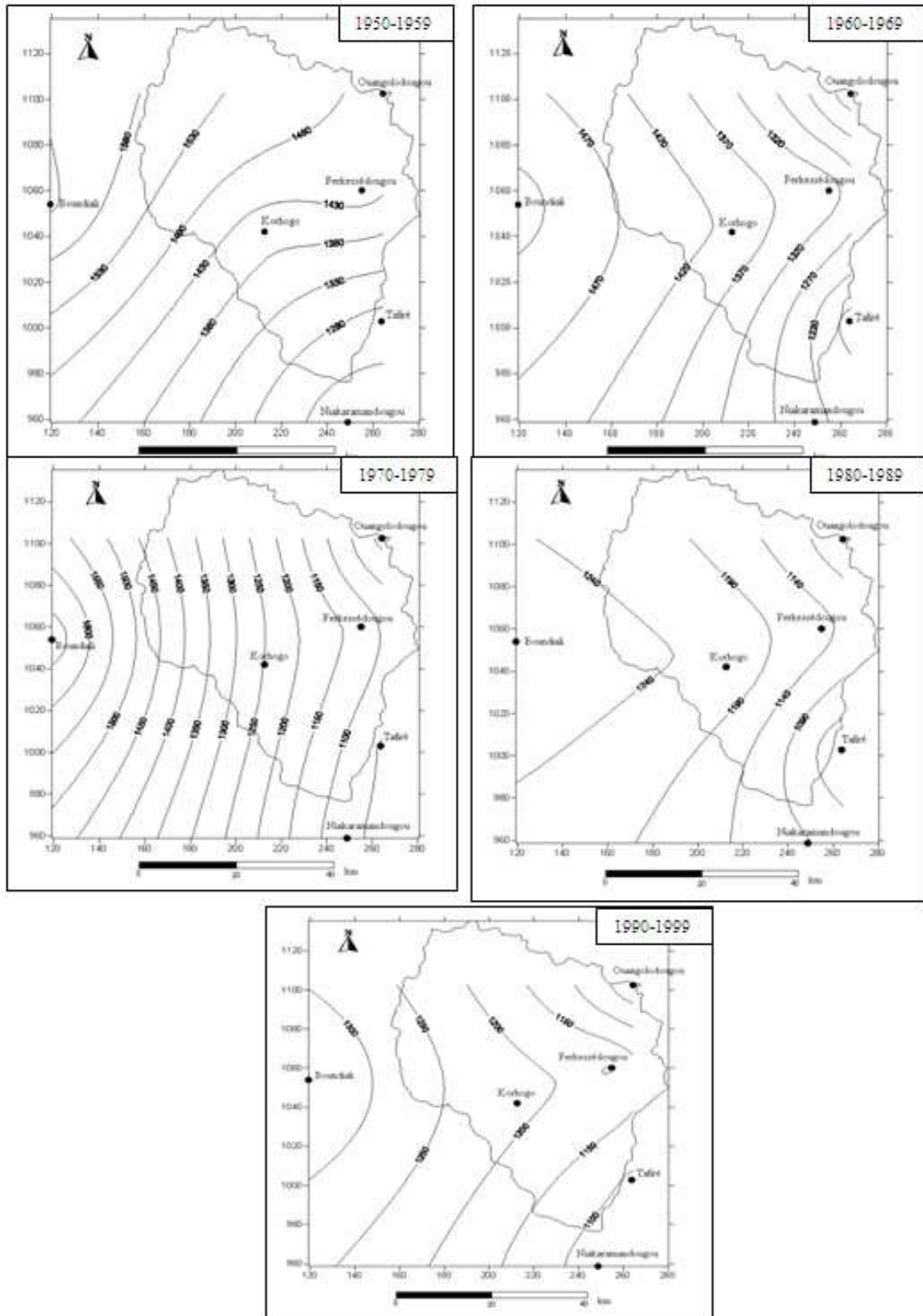


Figure 5. Spatio-temporal evolution of watershed during five decades

3.3. Depletion of Rivers Network, Volumes of Water Mobilized by Aquifers and Efficace Infiltrations.

3.3.1. Variations of Coefficients of Depletion and Volumes of Water Mobilized

The figure 6 shows the evolution of recession

coefficients and volumes of water mobilized per years calculated on 1962-1994 period for Tortiya station (outlet).

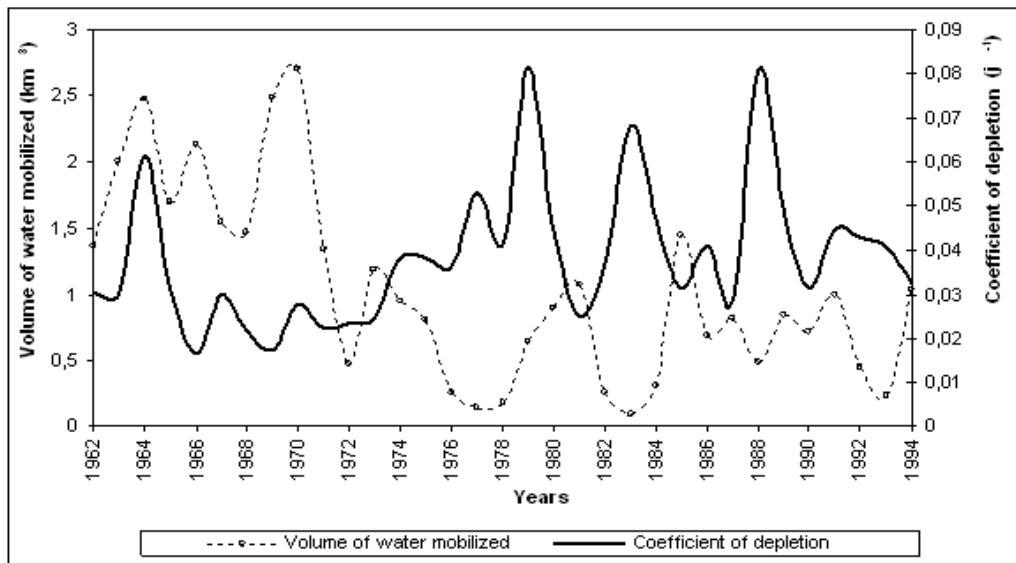


Figure 6. Coefficient of depletion and volume of water mobilized evolution from Bandama watershed in Tortiya (1962-1994)

An important variation of coefficient of depletion and volume of water mobilized resorts through plots analysis of figure 6. The coefficient of depletion values are situated between  $1.63 \cdot 10^{-2} \text{ j}^{-1}$  and  $8.16 \cdot 10^{-2} \text{ j}^{-1}$  with an average of  $3.84 \cdot 10^{-2} \text{ j}^{-1}$ . As for volumes of water mobilized, extend from  $0.08 \text{ km}^3$  to  $2.71 \text{ km}^3$ . It can be remarked that coefficient of depletion and volumes of water mobilized are inversely varied since 1972. In other term, when coefficient of depletion increases, volume of water mobilized decreases, and vice versa. The highest

values of recession occur after 1970s most precisely in 1979 ( $8.16 \cdot 10^{-2} \text{ j}^{-1}$ ), 1983 ( $6.8 \cdot 10^{-2} \text{ j}^{-1}$ ) and 1988 ( $8.12 \cdot 10^{-2} \text{ j}^{-1}$ ).

### 3.3.2. Evaluation of Aquifers Recharge

For the most appreciation of recharge variations, the water table has been evaluated for every station on the last two decades 1980-1989 and 1990-1999. Repeted results of rainfall values and efficacy infiltration (i.e), called again exceden , are been consigned in the table 4.

Table 4. Evolution of rainfall and efficacy infiltration of watershed

Station	1972-2000	1980-1989	1990-1999
	P(mm) i.e.(mm)	P(mm) i.e.(mm)	P(mm) i.e.(mm)
Korhogo	1222 232	1236 279	1211 219
Ferkessédougou	1259 278	1162 217	1203 249
Ouangolodougou	1012 143	1049 173	1012 137
Boundiali	1487 486	1267 307	1351 368
Tafiré	1056 110	999 134	1092 104
Niakaramandougou	1084 83	1094 162	1072 28

i.e : efficacy infiltration

The analysis of table 4 shows accordingly the general way, efficace infiltration and rainfall evaluate in the same direction in watershed during the lastest two decades except Tafiré station. Along these two decades (1980-1989) and (1990-1999), it can be remarked that efficace infiltration is in decrease for Korhogo station (-21.50%), Ouangolodougou (-20.81%), Tafiré (-22.39%), and Niakaramandougou (-82.72%). In spite of, for Ferkessédougou and Boundiali stations, it can be unregistered an increase of (+14.75%), and (+19.87%) respectively.

## 4. Discussion

### 4.1. Hydroclimatic Variability of Watershed

The application of low-pass filter of Hanning for second order allowed to establish different tendencies beyond the hydroclimatic times series. It has been generally marked the alternance of drought and wet periods. The wet (humid) periods are situated before seventies years (1970). The break dates given by statistical tests are ranged between 1968 and 1970, and coincide with the delimitations given by the low- pass filter. These breaks mark thus a modification of rainfall regime. The impact of these modifications of rainfall regime is translated in rainfall deficits ranging from 12 to 22%. These results are in conformity with many other authors' studies in African sub-region in whose the present study is noted ([14]; [9]), particularly in Côte d'Ivoire ([15]; [16]; [17]) whose were obtained some breaks around seventies years (1970).

For Tortiya outlet hydrometric time series, the breaks occurred in 1974. Runoff flow deficit resulted was 62.5% and represented about three times precipitations deficit. In the same idea [18] underlines a decrease of more than 80% at Bani to Douna in Mali since 1950, consequences'



persistence of rainfall decreased since 1970.

Outdoor of West Africa area, climate variability has reached north Africa. In Algeria, the studies of [19] showed annual rainfall decrease overlying 36% in Mascara area and to west extreme. [20] noted rainfall deficit around 1970 for 44 stations in septentrional Morocco during 1935-2004 period. The pluviometric reduction was 30%, 25% and 15% respectively for "oriental" region, both the "atlantic southern" and "mountain" sub-regions, and finally both sub-regions "atlantic northern" and "Tangéroise". In the same idea, in Australia, the studies of [21] showed that change and variability led to a several drought on 1996-2007 period. This drought has lead to water use restriction for more than 90% of the population, perturbed agricultural production, decreased cattle provision, and lead to failure of some agricultural ranches. Again, some large Australian territory portions had been their surface runoff flow to stop or to decrease.

#### 4.2. Depletion of Rivers Network, Volumes of Water Mobilized and Recharge of Aquifers

The study of depletion shows an increasing trend of coefficient of depletion after 1970 s. Some studies carried out by some authors in West Africa whom [22], [18] leads to the same conclusion. This increase of depletion coefficient has been signaled on some Ivorian river by some authors whom [15] at Flampleu station in the west area on Cavally watershed and [23]. In the same ideas, [16] and [24] noted an increase of depletion coefficient in N'zi watershed. For the last author, depletion coefficient ranged between  $2.78 \cdot 10^{-2} \text{ j}^{-1}$  and  $3.91 \cdot 10^{-2} \text{ j}^{-1}$  before 1968, year identified like break year in hydrometric time series.

[22] had shown that depletion is considerably accelerated since 70 years leading to fast discharge of aquifers. As proof, this coefficient had passed from  $0.02 \text{ j}^{-1}$  to  $0.04 \text{ j}^{-1}$  for Sénégal and the Niger. [25] has also noted this phenomenon on different watersheds, like the Chari in lac Tchad, the Sanaga in Central Africa, for whose the author talks of «hyper depletion». According Darcy law, depletion coefficient is directly proportional to hydraulic conductivity (permeability), to porosity, to river-aquifer exchange and controversially proportional to aquifer dimensions ([22]). The considerably increase of coefficient depletion in drought season corresponded essentially to aquifer reduction and therefore aquifer versant.

The decrease of rainfall was repercutated on aquifers recharge. As proof average efficace infiltration passed from 212 mm during 1980-1989 to 184.17 mm for 1990-1999 decade, in other term a deficit of 13.13%.

## 5. Conclusions

The study of hydroclimatology is useful. It has shown, from a long chronologic rainfall data series, on 1950-2000 a climatic variability marked by wet and drought periods. The statistic tests signaled some breaks that marked rainfall regime modification between 1968 and 1970. The deficits

that resulted range between 12% and 22% with an average of 16.5%. For hydroclimatic series of Tortiya station (outlet) of watershed, the break has occurred in 1974 with runoff flow deficit estimated to 62.5%, in other terms about the triple of this of rainy.

Isohyets analysis maps during five decades reveals a west-east rainy gradient increasing. The excedentary characteristic of 1950-1959, and 1960-1969 decades is again confirmed by the apparition of 1530 mm and 1470 mm isohyets. In opposite, the last two decades 1980-1989 and 1990-1999 are the most deficient. The apparition of 1300 mm isohyets around Boundiali and the download of 1250 mm isohyets to Korhogo west confirmed the decrease of rainfall for the last decades. Depletion coefficient values ranged between  $1.63 \cdot 10^{-2} \text{ j}^{-1}$  and  $8.16 \cdot 10^{-2} \text{ j}^{-1}$  with an average of  $3.84 \cdot 10^{-2} \text{ j}^{-1}$ . Concerning volumes of water mobilized the values ranged from  $0.08 \text{ km}^3$  to  $2.71 \text{ km}^3$ . The impact of this rainfall decrease is repercutated on aquifers recharge. As proof, an average of efficace infiltration was passed from 212 mm (1980-1989) to 184 mm (1990-1999) that is a 13.13% deficit.

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