American Journal of Water Resources, 2023, Vol. 11, No. 4, 149-157
Available online at http://pubs.sciepub.com/ajwr/11/4/4
Published by Science and Education Publishing
DOI:10.12691/ajwr-11-4-4

Characterization of the Hydrological Functioning of the Nanan Agricultural Dam in the Department of Yamoussoukro (Côte D'Ivoire)

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Received September 15, 2023; Revised October 16, 2023; Accepted October 23, 2023

Abstract Rainfall decline trend observed since 1970s in Côte d'Ivoire is still putting a strain on the annual recharge of dams and the satisfaction of crop irrigation water requirements. The aim of this study is to analyze the hydrological functioning of the Nanan agricultural dam in a context of climate variability. Several approaches were used to collect the data, including direct measurements, visual observation, surveys, interviews, and documentary research. The method used for the water balance was the principle of volume conservation (continuity equation), applied over two years (2016, 2017). This analysis shows that runoff accounts for 92% of the annual recharge of the Nanan dam. Of the water mobilized, 63% was used for irrigation, and uncontrollable losses amounted to 38%, of which 25% by infiltration and 12% by evaporation. The variation in annual stock was different from one year to the next, with a variation of -104,000 m^3 in 2016 and +165,000 m^3 in 2017. In short, the hydrological regime of the dam is closely linked to the rainfall regime. This characterisation could be used in a future climate projection simulation to analyze the impact of climate change on the dam's capacity to meet crop water requirements.

Keywords: *climate change, hydrological regime, water balance, irrigation, Yamoussoukro*

Cite This Article: Sawadogo Zounabo Epouse Kouyate, Soro Gneneyougo Emile, Kouakou Koffi Abdelaziz, Goula Bi Tié Albert, and Brou Yao Casimir, "Characterization of the Hydrological Functioning of the Nanan Agricultural Dam in the Department of Yamoussoukro (Côte D'Ivoire)." American Journal of Water Resources, vol. 11, no. 4 (2023): 149-157. doi: 10.12691/ajwr-11-4-4.

1. Introduction

The rainfall deficit observed in Côte d'Ivoire since the 1970s have repercussions on the flow of major rivers and their tributaries, causing a considerable drop in their characteristics [1,2] [3] [4] At the scale of small watersheds and their lowlands, this deficit, combined with anthropogenic pressures, have significant alterations to the availability of water resources, in terms of both quantity and quality [5]

However, unlike large rivers, which have received a great deal of scientific attention, the rivers on which most agro-pastoral dams are located have received less attention [6]. Apart from Cecchi's [5] characterization of small dams in northern Côte d'Ivoire, there are few studies in this field. Yet these small rural hydraulic structures are more numerous and contribute to the fight against poverty, improving the living conditions of beneficiary populations by increasing national food production and their incomes [7].

Another observation is that most of these small hydraulic schemes, generally located at the outlets of small watersheds at the head of large hydrographic networks, do not have sufficient quantity and/or quality of information to assess and understand their hydrological functioning [8,9] The lack of information on surface runoff inputs and on the filling and emptying dynamics of small reservoirs hampers decision-making for their planning and sustainable management in the face of this climate variability [10,11]

The present study, entitled "Characterization of the hydrological functioning of the Nanan agricultural dam in the Yamoussoukro-Côte d'Ivoire department", is designed to address these issues.

The choice of the Nanan dam is motivated by its geographical location in the city of Yamoussoukro. Formerly on the outskirts of the city with a rural watershed, the city's accelerated urbanization has affected its watershed [12]. This dam was built on the Attrokoba River, a right-bank tributary of the Kpoussou River, itself a left-bank tributary of the Bandama River. The dam is also an example of a small development built at the head of a large watershed. To ensure the long-term viability of this downstream agricultural development, it is therefore important to understand its hydrological functioning by characterizing and updating hydrological data.

The main objective of this study is therefore to analyze the hydrological functioning of the Nanan agricultural dam in a context of climatic variability.

Specifically, it will involve:

- Evaluate the various hydrological balance factors,
- Analyze the dam's filling and emptying dynamics,
- Characterize the hydrological functioning of the dam.

2. Materials and Methods

2.1. Study Area

Yamoussoukro, the political capital of Côte d'Ivoire, is located in the center of the country, approximately 248 km north of Abidjan, between longitudes 5°9'36" and 5°31'48" west and latitudes 6°32'24" and 7°4'12" north (Figure 1). The Nanan dam is located to the south-east of the town of Yamoussoukro, about 2 km from the village of Nanan. The dam is fed by a watershed located between parallels 6° 46.1' and 6° 49.7' north latitude, and meridians 5° 13.64 and 5° 15.44 west longitude (Figure 1). With a surface area of 8 km², the dam's watershed encompasses part of the Millionnaire, Kpankpassou and 220 housing districts, as well as the administrative area.

Average annual rainfall in Yamoussoukro department is 1142 mm, with an average number of rainy days not exceeding 70 per year. Daily potential evapotranspiration varies between 3 mm and 5 mm, with an interannual average of 1457 mm.

2.2. Materials and Data

Several approaches were used to collect data, including visual observation, direct field measurements, surveys and interviews, and documentary research. For the most part, this required the use of a variety of equipment and tools.

The climatic data collected were rainfall and potential evapotranspiration. They come from Yamoussoukro synoptic station and were obtained from the ‘’ Société d'Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique (SODEXAM)’’.

The bathymetric data consist of the height/surface curve of the 2018 dam (Figure 2).

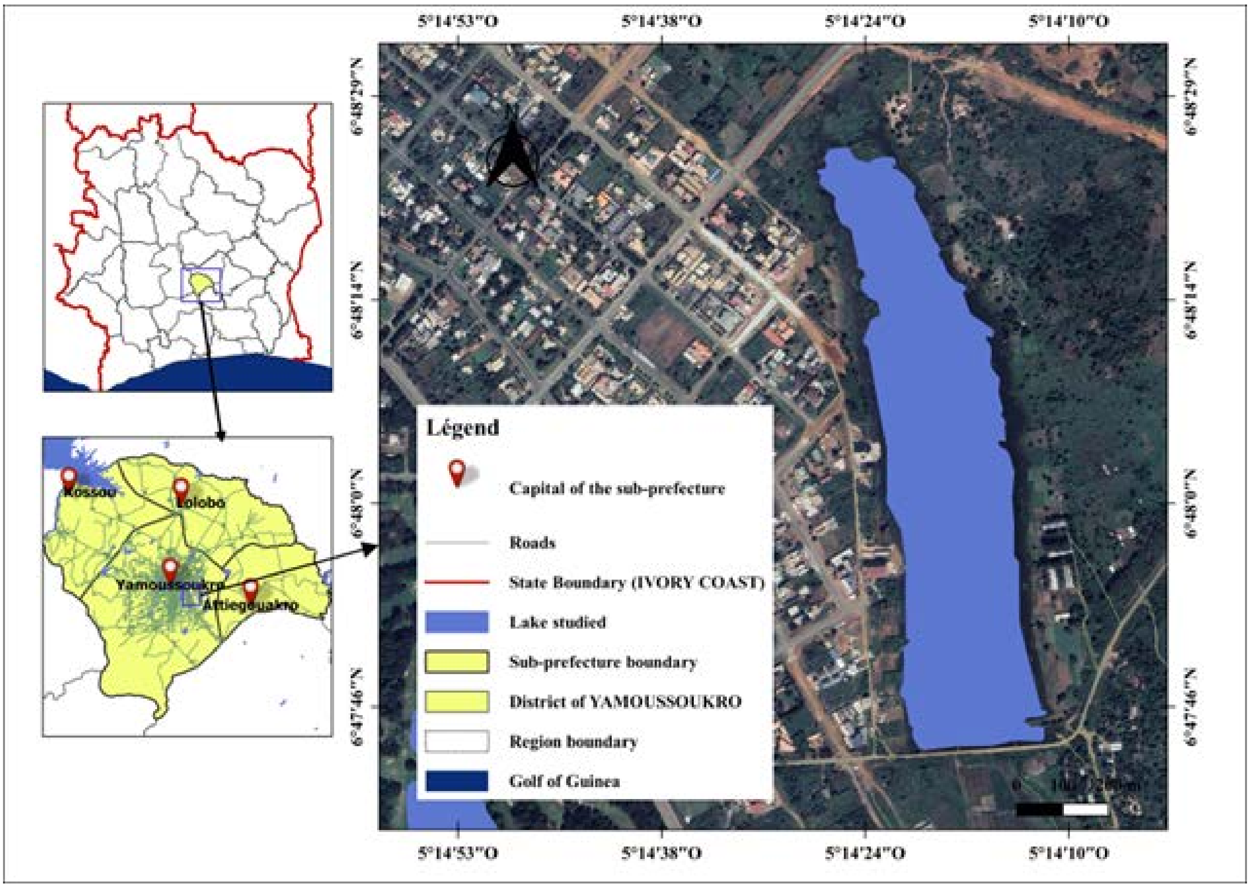

Figure 1. Location of study area [12]

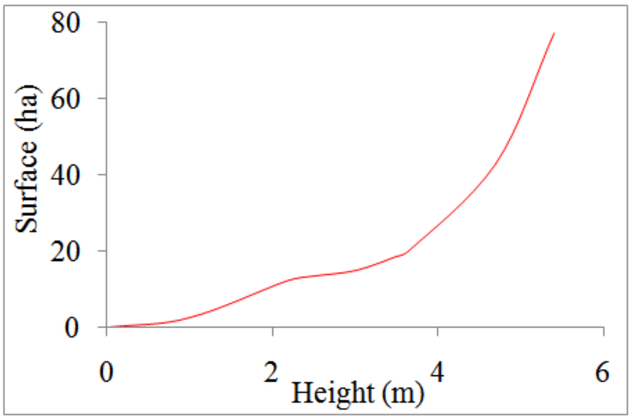

Figure 2. Nanan dam height-area curve, February 2018

Two daily readings of the dam's water level were taken on the limnimetric scale at 8 a.m. and 6 p.m., from January 2016 to April 2018. The number of gate turns at each opening was also recorded, along with the day and time of opening and closing at the main canal intake.

Hydrometric data were obtained following two (2) 7-day gauging sessions at the level of the watercourse feeding the reservoir and 5 gauging sessions at the level of the main canal feeding the rice-growing perimeter. The gauging campaign was carried out using an OTT/C31 "10 001" type reel, a Garmin etrex10 type GPS (Global Positioning System), a decameter, a notebook for taking notes and a pole to hold the propeller. Streamflow observation was also carried out during the two years of measurement.

Survey and interview sheets, an observation guide and a stopwatch were used for data collection. The questions on the survey sheets focused on the use and management of water on the perimeter. The observation guide focused on the practical organization of water users and the method of resource management.

2.3. Methods

Before taking stock of the hydrological functioning of the reservoir, it is important to determine the various terms of the hydrological cycle, which [13] defines as the counting of the inflows and outflows of a water system over a given time interval. This gives an idea of how the reservoir is filled and emptied.

2.3.1. Water Balance Method

The water balance has been studied using the principle of conservation of water volumes, also known as the continuity equation [14], [15] and [7]. This approach uses an indirect method whereby knowledge of certain components of the balance enables the unknowns to be determined [15]**.** It compares the total quantity of water arriving at a dam with the quantity of water leaving to estimate the unknown terms. It is written in the form of equation (1):

$$\Delta V = Vincoming - Voutflow$$

$$\Delta V = Vec + Vp - (Vev + Vid + Vif + Vd + Vu) \quad (1)$$

Where ΔV represents the change in water stock in the reservoir over the time interval Δt. With as :

- Incoming volumes

The volumes of water entering the reservoir include:

Vp: inflows due to precipitation falling directly into the reservoir.

Vec: inflows from tributaries (m3) (possibly including underground inflows);

- Outgoing volumes

Outgoing water volumes consist of:

Vev: volume of water evaporated,

Vid: seepage losses at dam height,

Vinf:: seepage losses at the bottom of the reservoir,

Vd: volume of water leaving the reservoir per discharge,

Vu: volume of water withdrawn for various uses (irrigation, livestock feed, etc.).

Some balance terms can be combined. For example, seepage losses at dam height and seepage losses at the bottom of the reservoir make up the seepage loss (Vin).

Based on strong assumptions made on certain balance terms, daily limnimetric monitoring, monitoring of runoff periods, sampling periods, monitoring of valve turns, field surveys and observations, and the updated height-volume-surface curve, the unknowns in the balance were estimated.

2.3.2. Estimation of Water Balance terms

2.3.2.1. Direct Contribution by Precipitation

To estimate the volume of direct rainfall input over a given time interval Δt, we need to know the average of rain that has fallen, we need to estimate the average surface area of the reservoir. This surface area is determined as a function of the water level measured at the level of the limnimetric scale, related to the height/surface area curve of the dam. The volume of precipitated water is obtained as shown in equation 2:

$$Vp = Sret \times P \quad (2)$$

Where:

Sret: surface area of the water body corresponding to the day's water level (hectare)

P: rainfall on the reservoir (m^3 /ha) based on conversion; 1mm=10 m^3/ha

2.3.2.2. Runoff Input

Three different methods were used to determine runoff contributions. They are:

- Monitoring of runoff from the watercourse to determine periods with no input, i.e. periods during which there was no input by runoff. Vrui = 0.
- Taking into account days when rice growers do not collect water (generally Sundays and rainy periods), and the absence of discharge. In this case, runoff inputs are estimated using equation 3:

$$Vrui = \Delta V - Vp + Vev + Vinf \quad (3)$$

- Gauging sessions using a reel to take direct measurements of flow velocities. From these velocities, flows were determined using the mean cross-section method. The flow rate obtained in m^3/s is taken as the average flow rate and multiplied by (24*3600) to estimate the daily inflow volume (Equation 4).

$$Vrui\ (m^3/d) = Q^* \ 24*3600 \quad (4)$$

2.3.2.3. Water Loss Through Spillage

During the 25 months of monitoring the dam's water level, no spillage occurred.

2.3.2.4. Loss Through Evaporation

Evaporation values can be estimated in various ways (direct, indirect, analytical, and empirical). The lack of equipment for direct measurement of evaporation on the water body necessitated the use of an indirect method for this study. This posed the problem of transposing evapotranspiration and evaporation from the trough near the water surface, on the one hand, and evaporation values from the trough and the water surface, on the other. However, the transposition of tank measurements with direct measurements of the water body has been widely developed in the literature [16]. The first step is to calculate the evapotranspiration of the reference crop (ET_0). In hot climates, evapotranspiration is, after precipitation, the most important term in the water balance [13], and at the same time one of the most complex and difficult to determine. This is because it usually involves several climatic parameters. The ET_0 is estimated using the modified Penman formula. It is then increased by 15% by transposition to determine evaporation from open water table (equation 8) [17] and [18] (Equation 5).

$$E_{ret} = 1.15ET_0 \tag{5}$$

Where:
ET_0: the evapotranspiration of the reference crop and Eret, the evaporation of the free water table.
Evaporation losses in a reservoir are roughly proportional to the surface area of the water body (equation 6). This surface is determined from the height/surface curve of the reservoir.
Where:
S_{retj} is the surface area of the reservoir on day (ha)
E_{retj} is the evaporation of the reservoir on day (m^3/ha, with 1mm=10 m^3/ha)
V_{ej} is the volume of water evaporated on day (m^3).

2.3.2.5. Seepage Losses

Infiltration is one of the unknown terms in the balance. It is often not considered in reservoir water balances, as it is a difficult component to estimate [19]. However, by making certain strong assumptions about the balance terms, it is possible to approximate the value of infiltration. Thus, starting from periods with no input (no runoff) and low or no abstraction, the water balance equation can be used, as in the studies carried out by [20] and [7], to determine the volume infiltrated. Thus, the infiltrated volume is estimated by equation 7:

$$V_{inf} = -\Delta V - V_{ev} \tag{7}$$

By replacing the change in reservoir volume (ΔV) with the change in elevation Δh, small enough for the change in reservoir surface area to be negligible, the infiltration rate can be estimated by Equation 8 assuming negligible reservoir bottom tilt (Fowe, 2015).

$$If = -\Delta h - Ev \tag{8}$$

With:
If: infiltration rate (mm/Δt),
Δh: variation in elevation per unit time (mm/Δt) and
Ev: evaporation rate (mm/Δt).
For the purposes of this study, Δt corresponds to one day and the infiltration rate will be in mm/d.

In addition, infiltration per unit area of the water body is determined by averaging over periods with no inflow and negligible outflow. The volume infiltrated is obtained by multiplying the infiltration per unit area by the surface area of the reservoir.

Looking at the terms in equation 8, only water level really has an effect on infiltration.

2.3.2.6. Estimated Usage

In the case of the Nanan dam, the various uses consist of irrigation and animal watering. Even if there are other users (abstraction for brick making, etc.), they are considered negligible. Withdrawals for irrigation include pumping for market gardening and withdrawals for rice growing.

a. Withdrawals for rice cultivation

A 200 mm diameter pipe feeds the primary canal from the downstream right bank intake tower installed on the main canal at the entrance to the rice-growing perimeter. This type of withdrawal can be likened to a calibrated orifice withdrawal from a large reservoir (the dam) [21] (Equation 9).

$$Q = f(n) \tag{9}$$

where n is the number of valve revolutions
Next, the formula for calculating the flow taken through an orifice was applied to determine the value of the orifice coefficient (C) [14] (Equation 10).

$$Q = C*S*\sqrt{2gh} \tag{10}$$

Where:
S, orifice cross-section in m²
g, the acceleration of gravity, 9.81 m/s².
h, the water load above the orifice

Once C is known, along with S and hj, the maximum flow that can be withdrawn if the valve is fully open has been thanks to equation 11:

$$Qmaxj = C*S*\sqrt{2gh}_j \tag{11}$$

h_j is the upstream water level on day d

Next, we determine the actual flow rate for day d Q_j such that

$$Q_j = \frac{Qmaxj}{13} * n_j \tag{12}$$

Qj represents the actual flow rate on day d
nj, the number of valve turns on day d

Finally, we calculate the daily volume withdrawn for rice cultivation (Equation 13),

$$Vj\text{-}irr\ (m^3/jour) = Q_j * t_f * 3600 \tag{13}$$

Where, tj, is the daily valve opening time (hours).

b. Pumping systems for market gardening

By monitoring the pumping of six market gardeners, we were able to understand and estimate the average quantities of water withdrawn by them. This monitoring involved pumping time and the number of daily pumpings per surface unit. Equation 14 can be used to estimate withdrawals per pumping operation:

$$\mathrm{Vwithdrawn} = \mathrm{Dp}^{*}\mathrm{Qpomp} \qquad (14)$$

Where Qpomp is the motor pump flow rate and Dp the pumping time.

A summary of this monitoring made it possible to determine the average daily volume pumped by farmers and the average volume of water withdrawn for market gardening.

c. Water withdrawal for animal watering

By monitoring the passage of transhumant herds over a one-week period, we were able to estimate the average number of transhumant herds per day and the average number of heads per herd. Thus, by considering the specific consumption per head, we can determine the daily consumption for watering the animals. The specific consumption of an ox is taken to be equal to 39.2 litres/day/head [22].

3. Results and Discussion

3.1. Analysis of Water Balance Terms

In 2016 and 2017, the reservoir received 859.8 mm and 1152.3 mm respectively (Table 1). These values compared with the average over the 1975-2015 period of1142 mm [21] show that 2017 was moderately rainy and 2016 was very deficient (dry year). A comparison of first-quarter rainfall for 2016, 2017 and 2018 shows that 2018 had a wetter 1er quarter. There were also more rainy days (14 days) than in 2016 and 2017. The volume of water precipitated in the first quarter of 2018 was 5 times greater than in 2016 and 2017. This is because it is this first rainfall that feeds the river's first runoff, which is then fed by the main rainy season. When these first rains are consistent, the water in the reservoir remains at an acceptable level. However, despite the higher rainfall and number of rainy days in 2017 compared with 2016, the volume of direct rainfall received in the first quarter of 2017 was lower than in the 1er quarter of 2016. This is due to the low surface area receiving this rainfall as a result of the lower water levels caused by the drought of 2016. So, the previous year's rainfall pattern influences the volume of water received directly into the dam during rainfall unless the dam is an unincised flat basin.

Table 1. Annual and quarterly characteristics of rainfall and direct inputs into the reservoir

Parameters	2016	2017	2018
Cumulative annual rainfall (mm/year)	859,8	1152,3	
Number of rainy days (Days)	52	76	
Direct precipitation volume (m^3)	60 352,3	157 857,2	
Cumulative rainfall for 1st quarter (mm)	142	232	286,3
Number of rainy days in the 1st quarter (days)	6	10	14
Precipitated volume in the 1st quarter (m^3)	9364	9000	50 169,7

3.2. Analysis of Runoff Feeding the Dam

Figure 3 shows the evolution of daily runoff. Two periods without runoff were observed from 09 February to 29 February 2016 and from 26 December 2016 to 13 January 2017. These two periods follow a cessation of precipitation or a significant drop in precipitation over a period of more than two months. The lack of precipitation appears to be the main cause of the river drying up.

In 2016, two peaks (0.312 m3/s, 0.391 m3/s) were observed and in 2017, five peaks (0.496 m3/s; 0.587 m3/s; 0.387 m3/s; 0.516 m3/s and 0.633 m3/s) were observed. These peaks follow heavy rains or short showers. Runoff is fed by precipitation, which determines how it is maintained throughout the year. Rainfall patterns have an impact on runoff trends over the course of the year.

The runoff feeding the Nanan watercourse is characterised by flows that begin following rainfall, are maintained with the regularity of showers and are cancelled when precipitation ceases for more than two months.

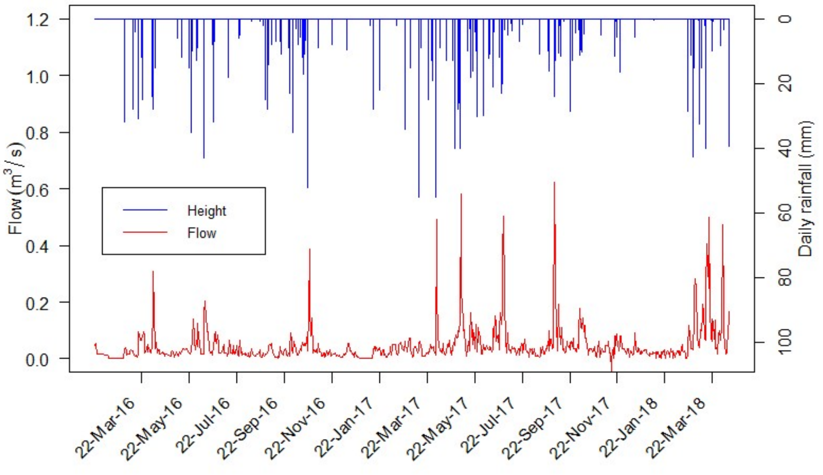

Figure 3. Daily variation in flows and rainfall from January 2016 to March 2018

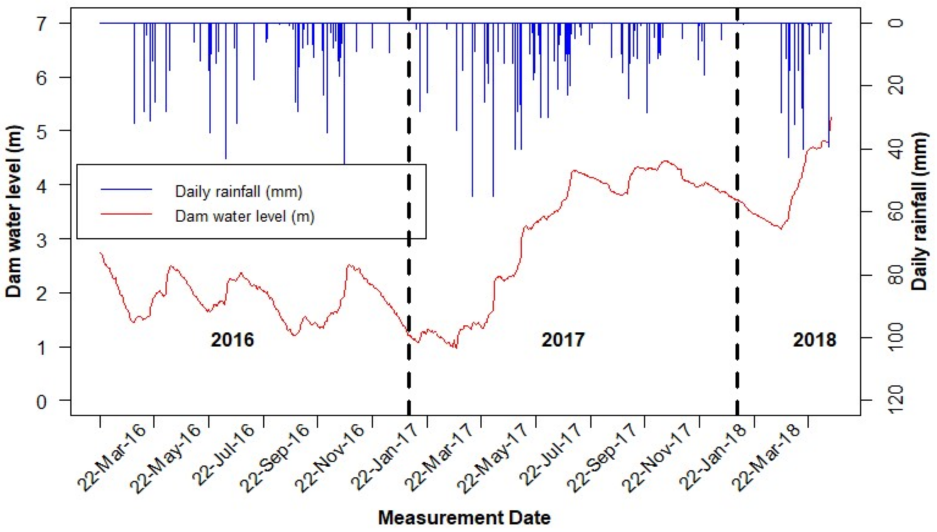

Figure 4. Daily variation in rainfall and dam filling status over the period January 2016 to March 2018

3.3. Variation in water level at the dam

Figure 4 shows the daily variation curve for the water level and rainfall over the monitoring period (January 2016 to April 2018). The limnimetric levels in 2016 remained below 3 m, while those in 2017 only remained below this value for the first five months.

In 2016, there were seven very regular phases consisting of three floods and four ebbs in the reservoir, each lasting an average of two months. In contrast, the 2017 hydrological regime is made up of two phases, a very long discontinuous flood phase from January to September and a short flood phase from September to December. The two years show a major difference in the duration of the flood and recession phases of the reservoir.

The three peaks in 2016 were approximately equal to 2.80 m, while in 2017 saw two peaks equal to 4.30 m. During the two years of monitoring, the minimum water height in the reservoir were observed in February 2017 (0.98 m). This value is very close to the dam’s dead water level of 0.5 m. Each peak follows a succession of rainfall events.

Thus, it appears that the rainfall regime has greatly affected the evolution of the dam's water level. The tighter the histograms (successive rainfall events), the faster the dam level rises. Conversely, discontinuous rainfall has no discernible effect on water level variation.

3.4. Evaporation on the Water Body

The annual potential evapotranspiration values calculated for 2016 and 2017 are 1512 mm and 1345 mm respectively. These values compared to the average ETP (1458 mm) over the period (1980-2015) show an increase in evapotranspiration in 2016 of 4% and a decrease in 2017 of 8%. The evaporation from the water body obtained in 2016 and 2017 are equal to 1623.67 mm and 1431.5 mm respectively (Table 2). This resulted in the loss of 140,953.6 m^3 and 226,239 m^3 of water in 2016 and 2017 respectively.

The heads of water evaporated during the 1st quarter of 2016, 2017 and 2018 represent 553.3 mm, 533.8 mm and 559.2 mm respectively. This represents evaporated volumes of 55,550.75 m^3, 20,400.17 m^3 and 114,222.20 m^3. This shows that despite the difference between the annual evaporation values, the intensity of evaporation during the 1st quarter remains very close. Evaporation intensity varies very little over the 1st quarter, while volume losses vary enormously. The surface area of the water body therefore has a significant influence on the volume of water evaporated from a dam. The deeper the reservoir and the smaller its surface area, the lower the evaporation losses, in contrast to a less deep reservoir with a larger free surface area.

Table 2. Annual and quarterly (1st Quarter) characteristics of evaporation from the water body (2016-2018)

Parameters	2016	2017	2018
Annual evaporation (mm/year)	1623,7	1431,5	
annual evaporation volume (m^3/year)	140 953,6	226 239	
Evaporation for the 1st quarter (mm)	553,3	533,8	559,2
volume evaporated in the 1st quarter (m^3)	55 550,7	20 400,2	222,2

3.5. Analysis of Infiltration Losses

The period without runoff was used to determine the daily infiltration water levels over this period. Establishing a correlation between the water level in the dam and the volumes of water infiltrated (Figure 5), we obtain a linear equation Vinf=936.56 *h-900.15. This correlation is established with a coefficient of determination $R^2=0.9$. This shows that there is indeed a relationship between the water level in the dam and the daily volume of water infiltrated. This equation can be used to obtain the daily volume of water infiltrated over other periods.

Also, the analysis of the infiltrated water heights for the two periods without inputs yielded an infiltration rate varying between 3.31 and 13.10 mm/d with an average over the two periods equal to 7.37 mm/day. This value is too high compared with 2.1 mm/d obtained by [7] on the Boura dam in Burkina Faso.

The cumulative annual volumes infiltrated in 2016 and 2017 are estimated at 238,950 m^3 and 517,440 m^3 respectively. The volume infiltrated in 2017 is more than twice the volume infiltrated in 2016. This fact can be justified by the impact of the height of the water body on the volumes infiltrated obtained in the correlation equation. The water level at the dam exceeded 4.00m in 2017, whereas it did not reach 3.00m in 2016.

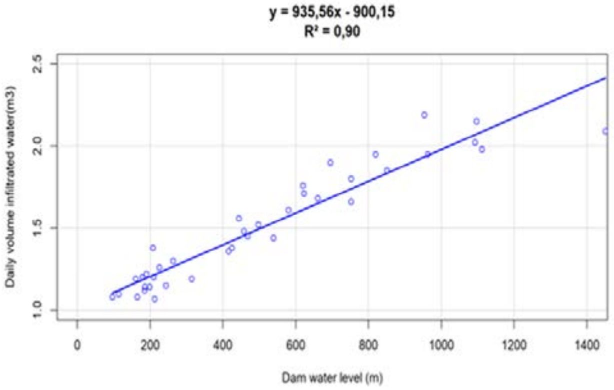

Figure 5. Correlation between infiltrated volume and water level in the dam during periods with no inflow

3.6. Water Withdrawals from the Reservoir

Water is drawn from the Nanan dam in a number of ways. These include releases from the left bank primary canal for rice cultivation, direct pumping into the reservoir for market gardening, and cattle watering.

3.6.1. Water Withdrawal for Rice Cultivation

Withdrawals from the primary canal are part of the known balance terms, as they were determined in a previous study [21].

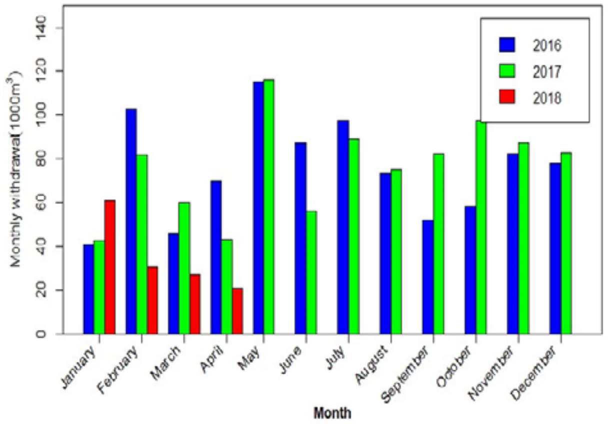

Figure 6. Monthly variation in water withdrawals to the rice-growing perimeter over the three years of measurement (2016-2018)

Figure 6 shows the monthly variation in water withdrawals from the rice-growing perimeter. Monthly withdrawals from the reservoir vary between 20,000 m^3 and 120,000 m^3. However, maximum values are observed in the month of May for both years.

The total volume withdrawn during the 2016 and 2017 seasons is estimated at 876,493.7 m^3 and 888,617 m^3 respectively. These two volumes are virtually identical, which means that withdrawals to the rice-growing perimeter do not take into account rainfall-related inputs, since the years had different rainfall patterns.

Rice harvesting is independent of rainfall patterns. This is wasteful since irrigation water has to be mobilized to compensate for rainfall deficits. This wastage was also highlighted in the studies by [21].

The abundant rainfall in May 2017 did not influence rice growers' abstractions. The rice growers justified this during the surveys by systematically emptying the reservoir every May to avoid overflowing the reservoir.

3.6.2. Levy for Market Garden Crops

During the surveys, the priority crops identified by market gardeners were onions, cabbage, and lettuce. The surveys showed that there are 24 market gardeners, 15 of whom use a motor pump. There are no rules for drawing water. The duration of watering varies between 1 and 5 hours. The pumps used have a flow rate of 1 $m^{3/}$ h. Estimates of average water pumped yielded 15-75 m^3 /d, with a daily average of 45 m^3/d. This corresponds to a monthly withdrawal of 450 to 2,250 m^3 /month, with an average of 1,350 m^3. Use for market gardening is much lower than for rice growing. Market gardening only uses an average of 2.5% of water withdrawals.

3.6.3. Withdrawals for Cattle Watering

When monitoring the use of dam water by transhumant herds, only cattle feed in the reservoir. Table 3 shows the average daily number of cattle feeding in the reservoir. It shows an average of five herds with an average number of sixty-one head, i.e. a total of 305 head per day. This gives a daily pastoral consumption of 11.956 m^3/day, or 4,364 m^3/year. Pastoral consumption represents only 0.5% of water withdrawals and is therefore very low.

Table 3. Average number of cattle feeding in the dam reservoir

Day	Number of herds	Maximum number	Minimum number	Average
1	5	80	33	57
2	7	72	48	60
3	3	80	52	66
4	5	80	48	64
5	3	72	44	58
6	4	80	48	64
7	4	72	33	53
Mean/day	5	77	44	61

3.7. Summary of Water Balance Terms

Figure 7 shows the monthly hydrological balance for the dam. The most visible and predominant terms are runoff, abstraction, and infiltration. Runoff in March and April 2018 is the highest of the observation period, with lower abstraction than infiltration and evaporation.

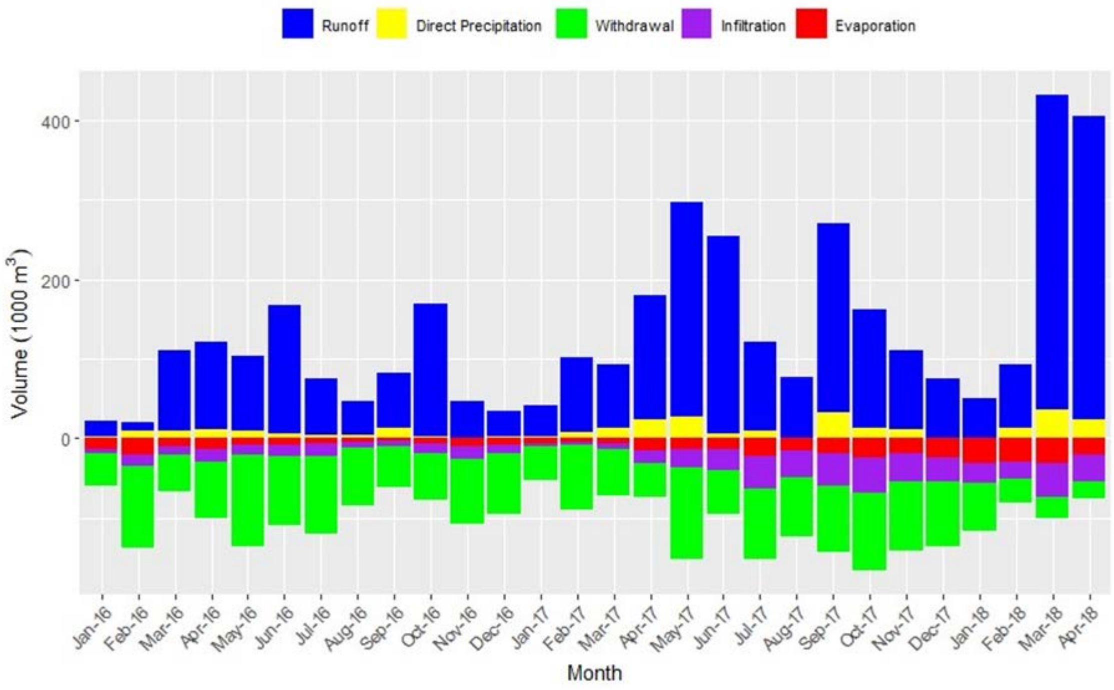

Figure 7. Monthly water balance for the Nanan dam from January 2016 to April 2018

Variations in withdrawals are independent of runoff contributions and rainfall, as high runoff values do not necessarily correspond to periods of low withdrawals. However, withdrawals in the 1er quarter of 2018 were very low during the first rains. This reduction can be justified by the abundance of inputs in the first quarter of 2018, which overwhelmed the rice-growing plots. On the other hand, the seasonality of inflows was maintained throughout the two years.

Figure 8 shows the Nanan dam's water balance for the 1st quarters of 2016, 2017 and 2018. Stock variations for the 1st quarters of 2017 and 2018 are positive, with the 2018 stock (+85.10^3 m^3) representing more than double that of 2017 (+35.10 m^3). These two periods thus show a surplus balance. These surpluses are due to higher inflows in 2018 than in 2017. 2016 showed a deficit (-34. 10^3 m^3) and lower inflows. These stock variations in the 1er quarter follow the same trend as rainfall. Thus, the 1er quarter water stock is influenced by the first rains to feed the dam.

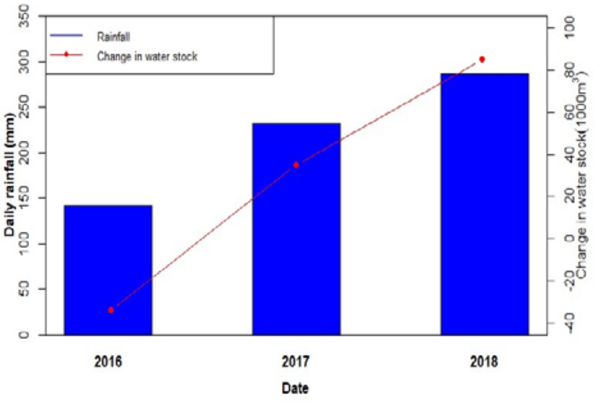

Figure 8. Change in water stock at Nanan dam from January 2016 to April 2018

Table 4 shows the annual balance and water balance terms for the Nanan dam over the two monitoring years. During 2016, a negative annual variation in the reservoir water stock (-104,000 m^3) was observed and a positive annual variation in the reservoir stock (+165,000 m^3) was observed in 2017. This difference is due primarily to the difference in rainfall levels, but also to variations in the volumes withdrawn, evaporated, and infiltrated.

2016 was a deficit year and 2017 was a surplus year. In the annual balance, direct inputs by precipitation are very low compared to inputs by runoff. Runoff inputs account for over 92% of total inputs. In fact, in 2016 and 2017, direct precipitation accounted for 5.50% and 7.70% of inflows respectively. Runoff from the slopes accounts for the bulk of the dam's inflow.

With regard to losses, for the years 2016 and 2017, withdrawals are the most important (respectively 901.30. 10^3 m^3 and 916.17. 10^3 m^3) representing respectively 70.40% and 55%, followed by infiltrations which represent respectively 18.60% and 31%. However, the volumes of water abstracted were more or less the same as in the 1er quarter. This indicates that rainfall had no impact on withdrawals.

Table 4. Summary of reservoir water balance components over two full years of monitoring (January 2016 - December 2017)

Balance sheet (10^3 m^3)	2016	2017
Precipitation input	60,35	157,857
Runoff input	1030,1	1 891,8
Incoming volume	1 090,46	2 049,66
Withdrawals	901,30	916,10
Evaporation losses	140,95	226,24
Seepage losses	238,64	517,440
Outgoing volume	1280,90	1 659,77
Initial dam volume	134,00	30
Final dam volume	30,00	195
Change in inventory	-104,00	+165,00

Evaporation from the water is the least significant loss. This was also the case in the 1er quarter. Evaporation losses are the lowest, around 11% to 13% of losses. This is contrary to the findings of **[7]** [23] for whom evaporation is the predominant factor in the depletion of reservoir water stocks. This loss is in fact a natural loss of water independent of human action.

Seepage losses are almost twice as high as evaporation losses. This could be explained by the probable presence of leakage zones at the bottom of the basin and through the foot drain. In fact, when observing the foot of the slope, an unusual water passage was identified. Such a water passage may increase the amount of water infiltrated.

4. Conclusion

Determining the balance terms enabled us to characterize the hydrological functioning of the Nanan dam through its filling and emptying dynamics. The overall balance sheet for the two years of monitoring showed that 92% of the water mobilized in the reservoir comes from runoff from the banks and, above all, from the upstream sub-watershed. Runoff from this sub-watershed is continuous, except when a fairly long dry spell occurs. Of the water mobilized by the reservoir, 63% is used for various purposes, then 25% is lost through infiltration and 12% through evaporation. These results show that, even over a short monitoring period, the Nanan dam exhibits great variability in its hydrological regime, mainly due to irregularities in inflows, which are controlled by rainfall. A probable foxing phenomenon needs to be better evaluated in future studies to better understand infiltration at the dam.

References

[1] Goula B.T.A., Kouassi F.W., Fadika V., Kouakou K. E., Kouadio G. B., Koffi K., Bamory K., Doumouya I. & Savane I. “Impacts du changement et de la variabilité climatiques sur les eaux souterraines en zone tropicale humide: cas de la Côte d’Ivoire,” *iash publication,* vol. 3, no. 34, pp. 190-202, 2009.

[2] Kouassi A.M., Kouame K.F. Yao, K.B., Dje,K.B. Paturel J.E. and Oulare S. “Analyse de la variabilité climatique et de ses influences sur les régimes pluviométriques saisonniers en Afrique de l’ouest: cas du bassin versant du N’zi (Bandama) en Côte d’Ivoire.,” *Revue européenne de géographie (cybergéo), Environment, Nature, Landscap,* vol. 5, p. 13, 2010.

[3] Soro T.D., Soro N., Oga Y.M-S., Lasm T., Soro G., Ahoussi K.E., Biemi J “La variabilité climatique et son impact sur les ressources en eau dans le degre carre de grand-Lahou (sud-ouest de la Côte d’Ivoire),” *Géographie physique et environnement,* vol. 5, pp. 55-73, 2011.

[4] Sorokoby V. M., ., Saley M.B., Kouame K.F., Djagoua E.M.V., Affian K. and Biemi J.“Variabilité spatio-temporelle des paramètres climatiques et son incidence sur le tarissement dans les bassins versants de Bo et Debo (département de Soubré au sud-ouest de la Cote d’Ivoire,” *International Journal of Innovation and applied Studies,* vol. 2, no. 3, pp. 287-299, 2013.

[5] Cecchi P., L’eau en partage. Les petits barrages de Côte d’Ivoire, Paris, France: IRD Edition, 2007.

[6] Mustapha M.K., “Problems, challenges and management of small, shallow tropical African reservoirs: a case study of Oyun reservoir, Offa, Nigeria,” *International Journal of lakes and rivers,* vol. 2, no. 1, pp. 163-174, 2009.

[7] Fowe. T., *Simulation et optimisation du fonctionnement du barrage de Boura en zone soudanienne du Burkina Faso,,* Ouagadougou- Burkina Faso: Thèse de Doctorat en sciences et technologie de l’eau, de l’énergie et de l’environnement, Institut International d’Ingénierie de l’eau et de l’environnement, 2015.

[8] Liebe J.R., Van De Giesen N., Andreini M., Walter M.T., & Steenhuis T.S, “Determining watershed response in data poor environments with remotely sensed small reservoirs as runoff gauges,” *Water resources research,* vol. 7, p. 45, 2009.

[9] Rakhmatullaev S., “Improvement of operational methods for the assessment of the water reservoir useful storage capacity using géo-information systems.,” France, , 2010.

[10] Peel M.C. and Blöschl G., “Hydrological modelling in a changing world,” *Progress in physical geography,* vol. 35, no. 2, pp. 249-261, 2011.

[11] Salami Y.D. and Nnadi F.N, “reservoir storage variations from hydrological mass balance and satellite radar altimetry,” *International journal of water ressources and environnemental engineering,,* vol. 4, no. 6, p. 201–207, 2012.

[12] Sawadogo K. Z., Brou Y. C., Soro G. E., Goula Bi T. A., “Impacts of urbanisation on the morphological characteristics and water inflows of the Nanan hydro-agricultural dam in the Yamoussoukro department (Côte d'Ivoire),,” *European Scientific Journal,* vol. 14, no. 12, pp. 89-110, 2018.

[13] Roche M., Dictionnaire français d’hydrologie de surface., Masson, Paris, 1986, p. 288 .

[14] Nouvelot J., “Guide des pratiques hydrologiques sur les petits bassins versants ruraux en Afrique tropicale et équatoriale.,” ORSTOM, 1993.

[15] Abdellaoui B., Merzouk A., Aberkan M., et Albergel J., “Bilan hydrologique et envasement du barrage Saboun (Maroc),,” *Revue des sciences de l'eau,* vol. 15, no. 4, pp. 737-748, 2002.

[16] Lowe L.D., Webb J.A., Nathan R.J., Etchells T., and Malano H.M., “Evaporation from water supply reservoirs: an assessment of uncertainty.,” *Journal of hydrology,* vol. 376, pp. 261-274, 2009.

[17] Chuzeville B., “Hydrologie tropicale et appliquée en Afrique Subsaharienne, Ministère de la coopération et du développement,,” Paris, 1990.

[18] Compaoré M. L., *barrages en terre,* École Inter États des Ingénieurs de l’Equipement Rural (EIER), Ed., Ouagadougou, 1996, p. 277.

[19] Piper B.S., Plinston D.T., & Sutcliffe J. V., “The water balance of Lake Victoria,” *Hydrological sciences journal,* vol. 31, no. 1, pp. 25-37, 1986.

[20] Lacombe G. (2007), “Évolution et usages de la ressource en eau dans un bassin versant aménage semi-aride.,” Université Montpellier 2, France, 2007.

[21] Sawadogo K. Z., Brou Y. C., Soro G. E., Goula Bi T. A., Traore F. “Optimization in Water Management for Sustainable Irrigated Rice Production in Central Côte d’Ivoire Under Rainfall Variability,” *Agriculture, Forestry and Fisheries,* vol. 9, no. 3, pp. 86-96, 2020.

[22] Diagana B., “Étude des consommations en eau en milieu rural,” Ouagadougou, 1983.

[23] Liebe J.R. (2002), “Estimation of water storage capacity and evaporation losses of small reservoirs in the upper east region of Ghana,” University bonn, germany, 2002.