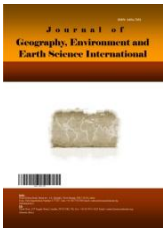

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Characterization of Agropastoral Dam Lakes in the Bounkani Region, Côte d'Ivoire

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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 North-East region (Bounkani) of Côte d'Ivoire is the least watered region of the country with an average annual rainfall of 945 mm. The rainfall deficits observed in Côte d'Ivoire since 1970s could constitute a real threat to the environment and to water resources in general, and to dam lakes in particular. The main aim of this study was to follow the evolution of the dam lakes in the region over the years, i.e,(1986, 2002 and 2017) with reference to their spatial distribution (their densities and their limnological ratios). The approach adopted consisted of mapping and monitoring through remote sensing technology which involves processing satellite images for automatic extraction of these agropastoral structures on the various images. The results showed that these dam lakes were unevenly distributed both at the level of the departments and the watersheds, with 73.43% in the Black Volta and 28.57% in the Comoé. The density was higher in Doropo and varied from one department to another from 1986 to 2017, for the department of Bouna, it ranged from $9.34.10^{-4}$ to $3.74.10^{-3}$ per km2. The departments of Doropo and Tehini showed $1.51.10^{-3}$ to $1.01.10^{-2}$ per km^2 and $1.05.10^{-3}$ to $4.53.10^{-3}$ per km^2 respectively. Nassian department displayed a value of $1.42.10^{-3}$ per km^2 and remained constant from 2002 to 2017. Like the density, Doropo Department had the

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highest limnological ratio which changes from $7.09.10^{-5}$ to $2.71.10^{-4}$ per km^2 over the same period. The mapping of these agropastoral structures showed 18 agropastoral structures where 57 (28.07%) were functional or even contained water in the dry season in the region in 2017 including 2 in Nassian; 4 in Tehini; 9 in Doropo and 3 in Bouna.

Keywords: Characterization; Dams lakes; agropastoral; Bounkani; mapping.

1. INTRODUCTION

During the 1970s, West Africa was marked by a severe drought. During this period, Fulani pastoralists and their herds of zebu cattle arrived in increasing numbers and penetrated the interior of the Ivorian territory [1]. In Côte d'Ivoire, as in most developing countries, the combination of poverty and population growth in the watersheds contribute to numerous problems including degradation of natural resources such as soil, forests and water [2]. The surface waters of Côte d'Ivoire cover about 4,462 km2 (1.38% of its surface area), including numerous rivers and a relatively large reservoir of 1,760 km2 of water for agro-pastoral activities and for the production of hydro-electric power [3]. In parallel with the vagaries of climate, the demand for water is steadily increasing in developing countries. Faced with demographic pressure and the growing need for water, it becomes necessary for each country to make an inventory and quantitative assessment of its water resources in order to ensure rational management. Also, the sedimentation of dams is a very complex natural phenomenon that has important consequences upstream and downstream of the dams, but also at the reservoir level [4]. In order to promote growth in national cattle production, the Ivorian government, through the Society for the Development of Animal Productions (SODEPRA), built "small dams" for pastoral purposes between 1980 and 1990 in the north and northeast of the country [5]. These dams were real assets for the development and modernization of the agropastoral system for local herders and transboundary transhumance herders. Approximately three decades after the disappearance of SODEPRA, most of these dams are experiencing varying problems and the quest for water resources is still problematic in dry periods. Today, we are witnessing a progressive colonization of the banks of these dam lakes by market garden crops, pastures, cashew nuts, etc. These water bodies are experiencing eutrophication and sedimentation. This situation raises the issue of the sustainability of dam lakes in the region. In order to have data and information on the current state of the agropastoral dam lakes, we have carried out a cartographic study of these agropastoral structures. This study becomes an essential cog in the wheel to provide answers to the following concerns. Where are these agropastoral structures located? What is the density and the limnological ratio of these lakes at the level of the departments (regions)? What is the current state of these agro-pastoral structures?

The main goal of this study was to monitor the evolution of the dam lakes in the region with respect to their spatial distribution, i.e., their densities and limnological ratios.

2. MATERIALS AND METHODS

2.1. Presentation of the Study Area

Bounkani region, located in the northeast of Côte d'Ivoire in the Zanzan District, has Bouna as its capital and covers an area of approximately 22,091.5 km², or 6.9% of the national area. However, half of its area is occupied by the Comoé National Park which covers 11,090 km². The region had 178,769 inhabitants with a density of 8hbts/km^2 [6]. Administratively, it includes the departments of Tehini, Doropo, Bouna and Nassian and is bordered by the Republics of Ghana to the east and Burkina Faso to the north, the Gontougo region to the south and the Tchologo and Hambol regions to the west. In spite of a dynamic population and strong potential, it remains very deprived. It covers 72% of the agropastoral works of the Zanzan district, that is 13% of the works of the country. Bounkani is subject to the Baulean climate located in the south of the region and the Sudanese climate in the north [7]. The relief of the Bounkani region is relatively uneven and therefore monotonous, characterized by plateaus, armor and hills [7]. It is the least watered region of the country with a geology consisting of an Eburnian granitoid complex, a volcanic-sedimentary complex and a complex ancient migmatites (Fig. 1).

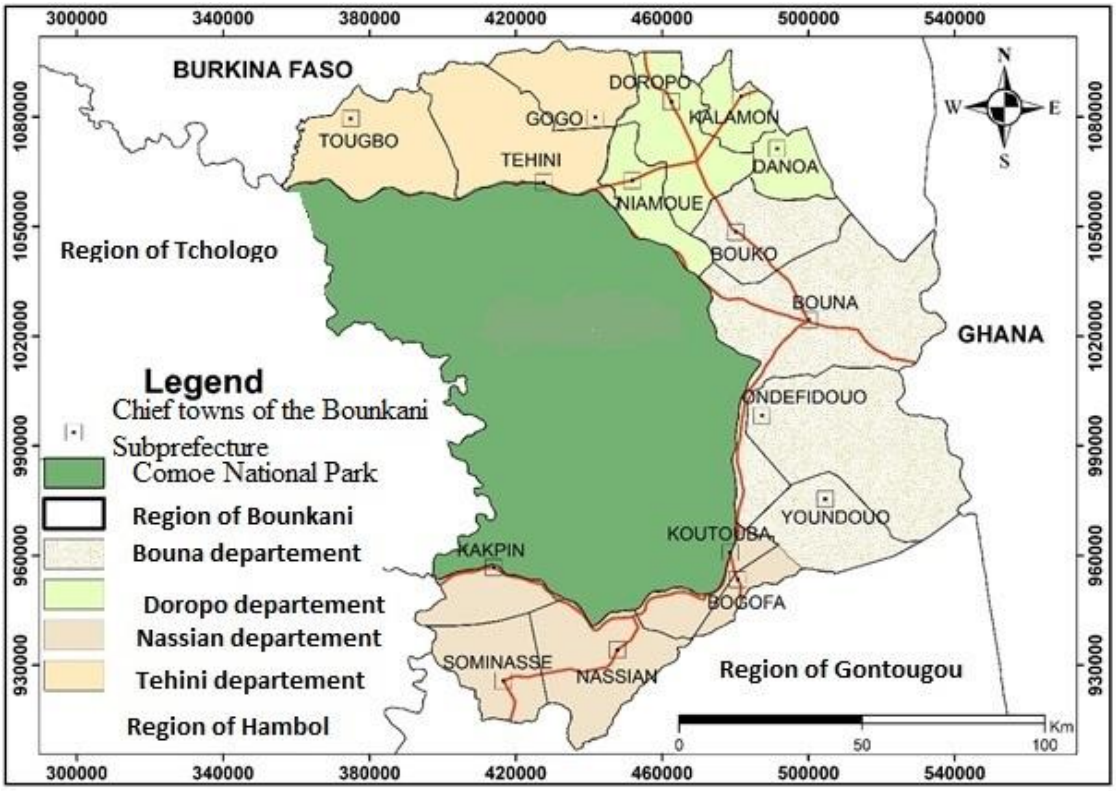


Fig. 1. Geographical location of the Bounkani region

2.2 Material Used

The authors used material composed of image data and data collected on the ground. The image data are Landsat TM satellite images of 1986 acquired on 09/01/1986, 18/01/1986; Landsat TM+ of 2002 acquired on 02/02/2002, 09/02/2002 and Landsat Oli of the year 2017, acquired on 08/02/2017 and 30/01/2017. To cover the entire study area, it was necessary to juxtapose the scenes 195-053; 195-54; 196-53 and 196-54. Numerous software programs were used in order to achieve the study objectives base on the methodological approach adopted. All the ETM+ image processing works leading to the production of the various maps of these structures were carried out using ENVI 5.1 and ARC GIS 10.5 software.

2.3 Methods

2.3.1 Preprocessing of satellite images

The pre-processing of satellite images is a process to improve the visual interpretation of images to allow them to be recognized [8]. The purpose of these pre-processings is to increase the readability of the data, to facilitate their interpretation and a better extraction of information [9]. Image preprocessing was possible using ENVI 5.1. The TM (Landsat 4) and ETM (Landsat 7) sensors have seven spectral bands, while the OLI_TIRS (Landsat 8) have 11 bands. For each satellite image, all bands were selected and used to create a stacked layer called "composite images". These images were then geo-referenced by projecting them into the World Geodetic System 1984. The mosaic is an image created from different scenes combined into one. The Bounkani region was processed into the mosaic made up of four scenes (196-053; 196-054; 195-053; 196-054). The colored image exposes the water reservoirs. For the landsat5 and 7 images, a composition was made with bands 7-4-5 and bands 7-5-4 for the landsat OLI image.. These arrangements giving false colored combinations allowed to better appreciate the regions of interest and to easily differentiate the different surface states.

2.3.2 Detection and delineation of dam lakes in the region

Detection and delineation of surface water bodies are environmental management issues that heavily engage geomantic approaches,

especially for large-scale approaches [10,11]. The question of cumulative impact implies taking into account several water bodies and in particular pre-existing reservoirs within a region. Therefore, the use of this approach was necessary for the present study because of the distribution of lakes over almost the entire Bounkani region with the exception of Comoé National Park. For this study, data generated by remote sensing were used and also taken into account previous studies concerning dam lakes on a regional, national and even international scales. It is common in remote sensing to use indices to combine radiometric values and differentiate the nature of the observed targets. The indices were use to provide a better identification water bodies [12,13]. With this in mind, the Modified Normalized Difference Water Index (MNDWI) was used. This index of Xu [14] is a modification of the NDWI of Mc Feeters [15] in which the near infrared (PIR) has been replaced by the mid infrared (MIR). Given the spectral characteristics of water, it absorbs more of the long wavelengths and reflects more of the small ones. The calculation of this index as well as the processing of satellite images were carried out on ENVI 5.1 and ARC GIS 10.5 for the different maps.

This index is expressed by the following formula:

$$MNDWI = \frac{(V - MIR)}{(V + MIR).} \quad (1)$$

MIR: pixel value
n the mid-infrared channel
V: pixel value in the green channel
MNDWI: Modified Normalized Difference Water Index

2.3.3 Automatic extraction of dam lakes

The file resulting from the extraction being in an EVF file under Envi was converted into Shape file and exported on Arc GIS for exploitation. Once on Arc GIS, these water retention areas were projected on the satellite image according to the corresponding years. At this stage, an elimination of these water retentions in a first time by the drowned surface included between 1 to 20 ha was proceeded and then the presence or not of the dam was verified. Thanks to the GPS coordinates of the structures of the campaign in 2017, the images were projected to confirm the real positions of these lakes as well as the structures with empty water.

2.3.4 Characterization of the spatial distribution of agropastoral dam lakes in the Bounkani region

Characterization consists of giving distinctive features and characteristics to the dam lakes. In short, to collect information on these water reservoirs in terms of number, surface area and also spatial and temporal distribution. For this spatial distribution of lakes, two parameters are generally used: the density and the limnological ratio of dam lakes.

- **Limnological ratio of dam lakes by watershed**

The surface areas of agropastoral dam lakes are essential for monitoring their spatial evolution over time. Once the identification of these dam lakes under ArcGIS software and in the attribute table were done, the surface area field is created and the calculator geometry tool was used to know the surface area of each water body. The limnological ratio is defined as the ratio between the sum of the surface of the lakes and the total surface of the studied area (km2/km2 or %). From this indicator, we can know the share of the area of the region occupied by lakes in percentage tams. The limnological ratio depends on three independent factors: climate, tectonics and lithology. The surface coverage rate of the lakes was calculated according to the following formula

$$\text{Lake surface coverage rate} = \frac{\text{cumulative area of water bodies}}{\text{area of the departement}} \quad (2)$$

- **Density of dammed lakes by sub-watershed**

The number of agropastoral dam lakes is also an important parameter for their characterization. This parameter was already known during the study we carried out in the field. Under ArcGIS software, the different identities of the lakes are mentioned automatically, according to the sub-departments and the years. Therefore, it is sufficient to open the attribute table contained in the software and the number of lakes is indicated. The density is simply defined as the number of dam lakes in a given area divided by its area (number/km^2). The Geographic Density of Reservoirs is an index that is calculated in order to know the hydrological impact of the reservoirs in question in the region.

$$\text{Density} = \frac{\text{Number of water bodies}}{\text{area of the department}} \quad (3)$$

3. RESULTS

3.1 Mapping of Dam Lakes in the Bounkani Region

Fig. 2 shows the spatial distribution of the dam lakes in the Bounkani region. These structures were distributed unevenly both in the watersheds and in the departments. There were 16 structures, or 28.07% of the lakes in the region, in the Comoé watershed, including 11 lakes in Tehini (19.30%), 2 lakes in Doropo (3.51%) and 3 lakes (5.26%) in the department of Nassian.The Volta basin had the majority of structures (41 lakes), i.e. 71.93% of the structures in the region, distributed as follows: 2 lakes (3.51%) in Tehini; 1 lake (0.02%) in Nassian; 20 lakes (35.09%) in Bouna and 18 lakes (31.58%) in the department of Doropo.

3.2 Characterization of the Spatial Distribution of Dam Lakes in Bounkani

3.2.1 Evolution of the number of lakes in the region in 1986; 2002 and 2017

The evolution of the number of dam lakes in Bounkani is shown in Fig. 3. The Bounkani region had 12 dam lakes in 1986. This number is made up of 3 dam lakes in Tehini, 5 in Bouna and 3 in Doropo. These lakes increased from 12 to 56 in 2002, distributed as follows: Tehini Department increased from 3 to 13 lakes; in Doropo Department, the number of lakes increased from 3 to 20. The departments of Bouna and Nassian had 19 and 4 lakes respectively in 2002. In 2017, the number of lakes remained the same as in 2002 with the exception of the department of Bouna whose number of lakes increased from 19 to 20 lakes. This makes a total of 57 dam lakes in the Bounkani region (Fig. 3).

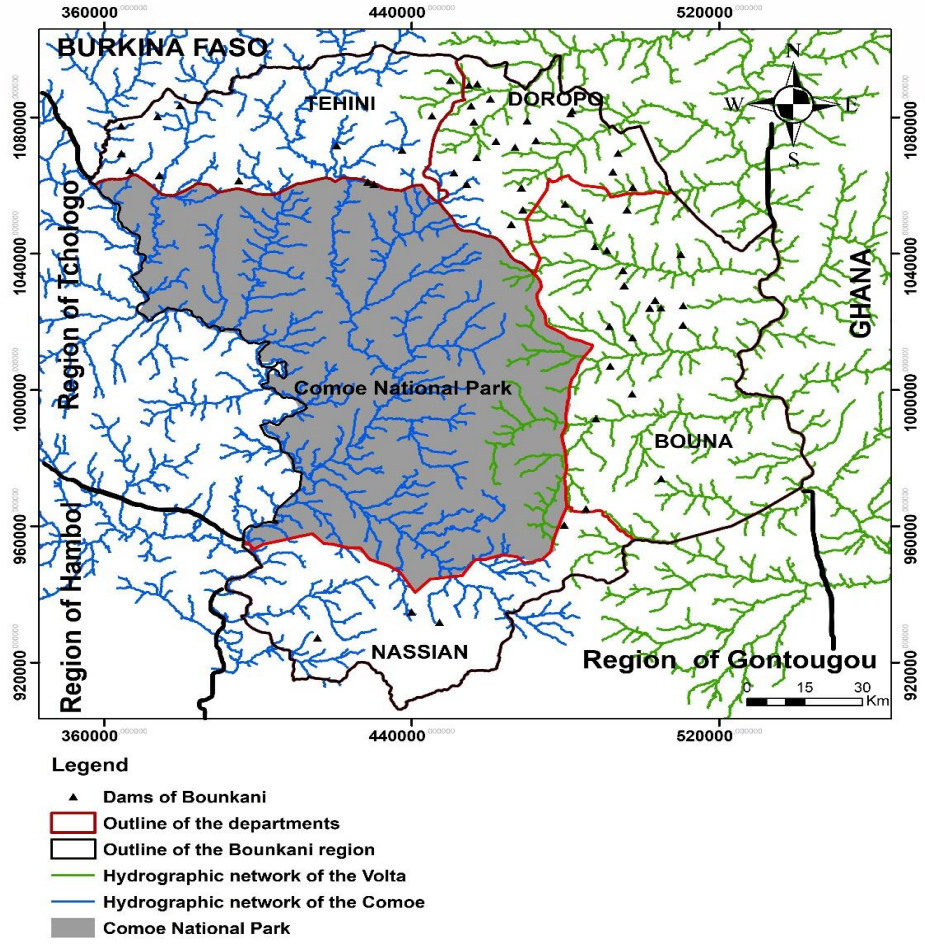


Fig. 2. Spatial distribution of dam lakes in Bounkani region

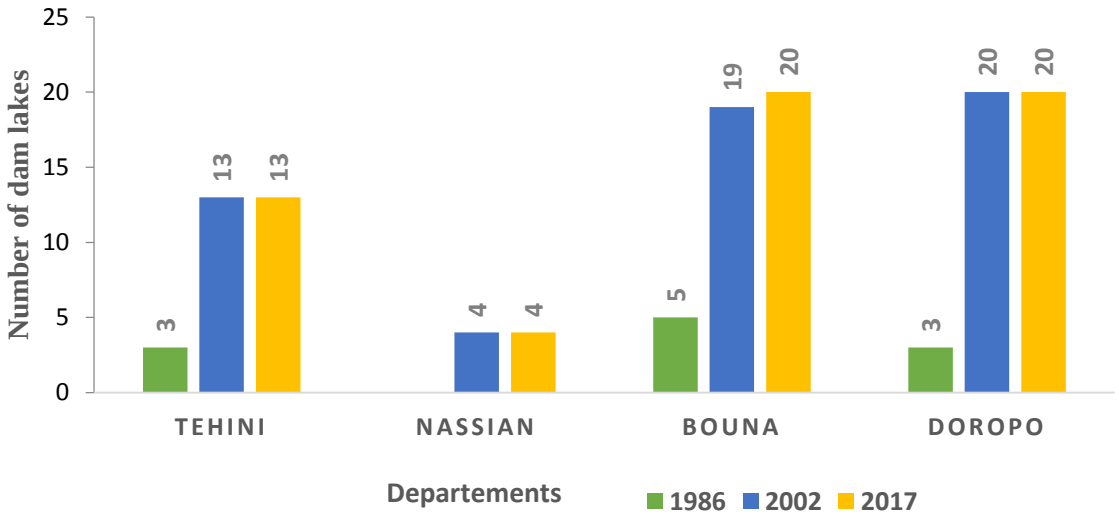


Fig. 3. Temporal evolution of the number of dam lakes in the different departments

3.2.2 Density of dam lakes by department

In 1986, the departments of Bouna, Doropo and Tehini (Fig. 4) had density values of $9.34.10^{-4}$, $1.51.10^{-3}$ and $1.05.10^{-3}$ per km2 respectively. In 2002, the departments of Bouna, Doropo, Nassian and Tehini had the densities increased to $3.55.10^{-3}$; $1.01.10^{-2}$; $1.42.10^{-3}$ and $4.53.10^{-3}$ per km^2 respectively. Unlike the other departments that maintained their densities in 2017, that of Bouna department had a density of $3.74.10^{-3}$ per km^2.

3.2.3 Evolution of lake areas in the region in 1986; 2002 and 2017

The evolution of the area of the dam lakes is shown in Fig. 5. The lakes of the dams occupied an area of 0.14 km^2, 0.20 km^2 and 0.14 km^2 in 1986 for the departments of Tehini, Bouna and Doropo respectively. These areas reached their peaks in 2002 with respective values of 0.47 km2 ; 0.76 km^2 for Tehini and Bouna repectively with the departments of Tehini and Doropo then remained constant in 2017. Bouna department increased from 0.67 km^2 in 2002 to 0.71 km^2 in 2017. The department of Nassian, which had no lakes in 1986, had a water surface area of 0.17 km^2 in 2002 and remained constant in 2017.

3.2.4 Limnological ratios of dam lakes by sub-watershed

In 1986, the departments of Bouna, Doropo and Tehini (Fig. 6) had limnology values of $3.64.10^{-5}$, $7.09.10^{-5}$ and $4.71.10^{-5}$ respectively. In 2002, the departments of Bouna, Doropo, Tehini and Nassian had limnology values of $1.26.10^{-4}$; $3.82.10^{-4}$ in ; $1.62.10^{-4}$ and $5.87.10^{-5}$. Unlike the other departments that remained constant in terms of limnology values, the department of Bouna showed $2.52.10^{-4}$ in 2017.

3.3 Characterization of the Spatial Distribution of Agropastoral Dam Lakes with Water Presence

Figs. 7; 8 and 9 shows us the different lakes by departments with a resource in the years 1986; 2002 and 2017. With the exception of Nassian department which had no dam lake, we find that there was no drying up of the water content of these Agropastoral structures in 1986. The departments of Tehini and Doropo each had three lakes, while the department of Bouna had five dam lakes (Fig. 7).

In contrast to 1986, the year 2002 had lakes that did not appear on the departments. The departments of Tehini, Nassian, Doropo and Bouna respectively had 8 out of 13 lakes, i.e., 61.64% of these lakes; 2 out of 4 lakes, i.e., 50% of these lakes; 8 out of 20 lakes, i.e., 40% of these lakes; and 5 out of 19 lakes, i.e., 26.32% of these dam lakes that did not appear in the year 2002. In the region's watersheds, Comoé had 10 out of 16 lakes, i.e., 62.5% of its lakes or 17.88% of the region's lakes; the Black Volta lost 13 out of 40 lakes, i.e., 32.5% of its lakes or 23.21% of the region's lakes.(Fig. 8)

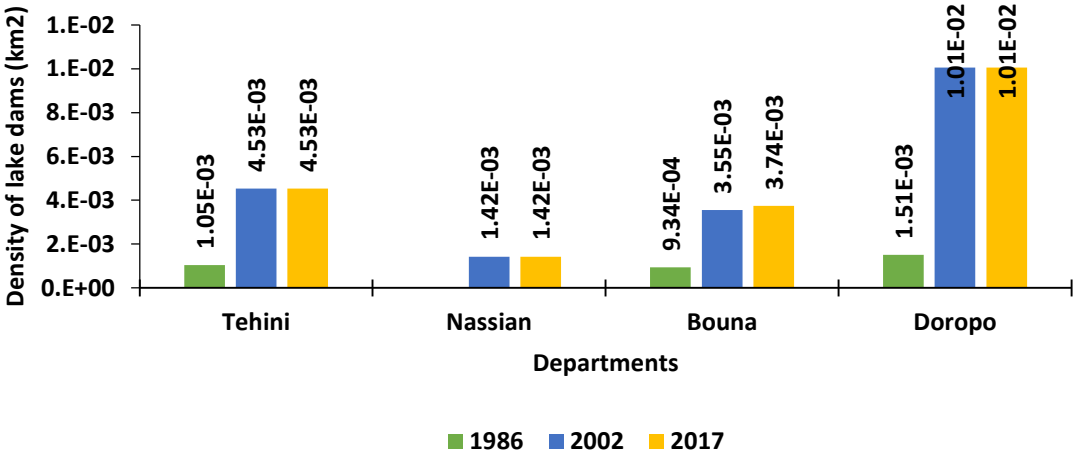


Fig. 4. Evolution of the density values of dam lakes by department

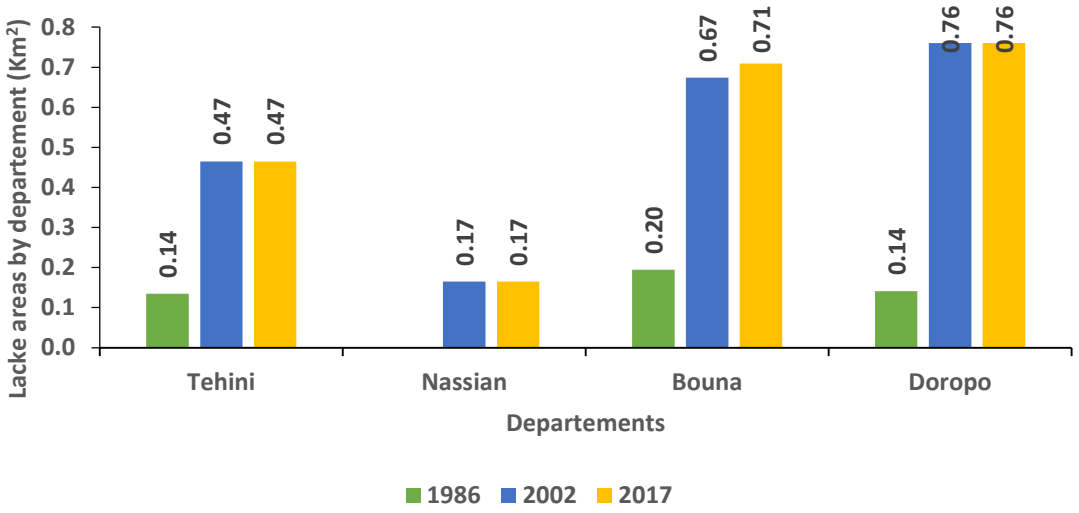


Fig. 5. Evolution of dam lake areas by departement

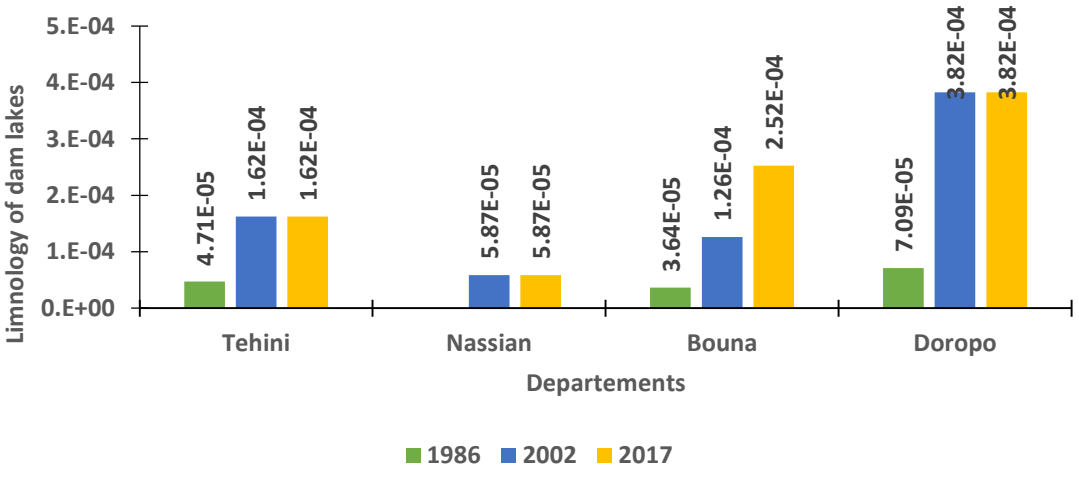


Fig. 6. Evolution of the limnological ratio of the lakes of dams by department

This disappearance of dam lakes was accentuated in 2017 compared to other previous years.

In the department of Tehini, 9 lake dams or 69.23% were no longer operational. As for the departments of Doropo, Bouna and Nassian, respectively 11 dam lakes or 55%; 17 dam lakes or 85% and 2 dam lakes or 50% were no longer operational. At the watershed level, the Comoé basin had 13 out of 16 dam lakes, i.e. 81.25% of these lakes, and 22.81% of the dam lakes in the Bounkani region were also inoperable. In the Volta basin, 26 out of 41 dam lakes, i.e. 63.41% of its lakes, were inoperable (Fig. 9).

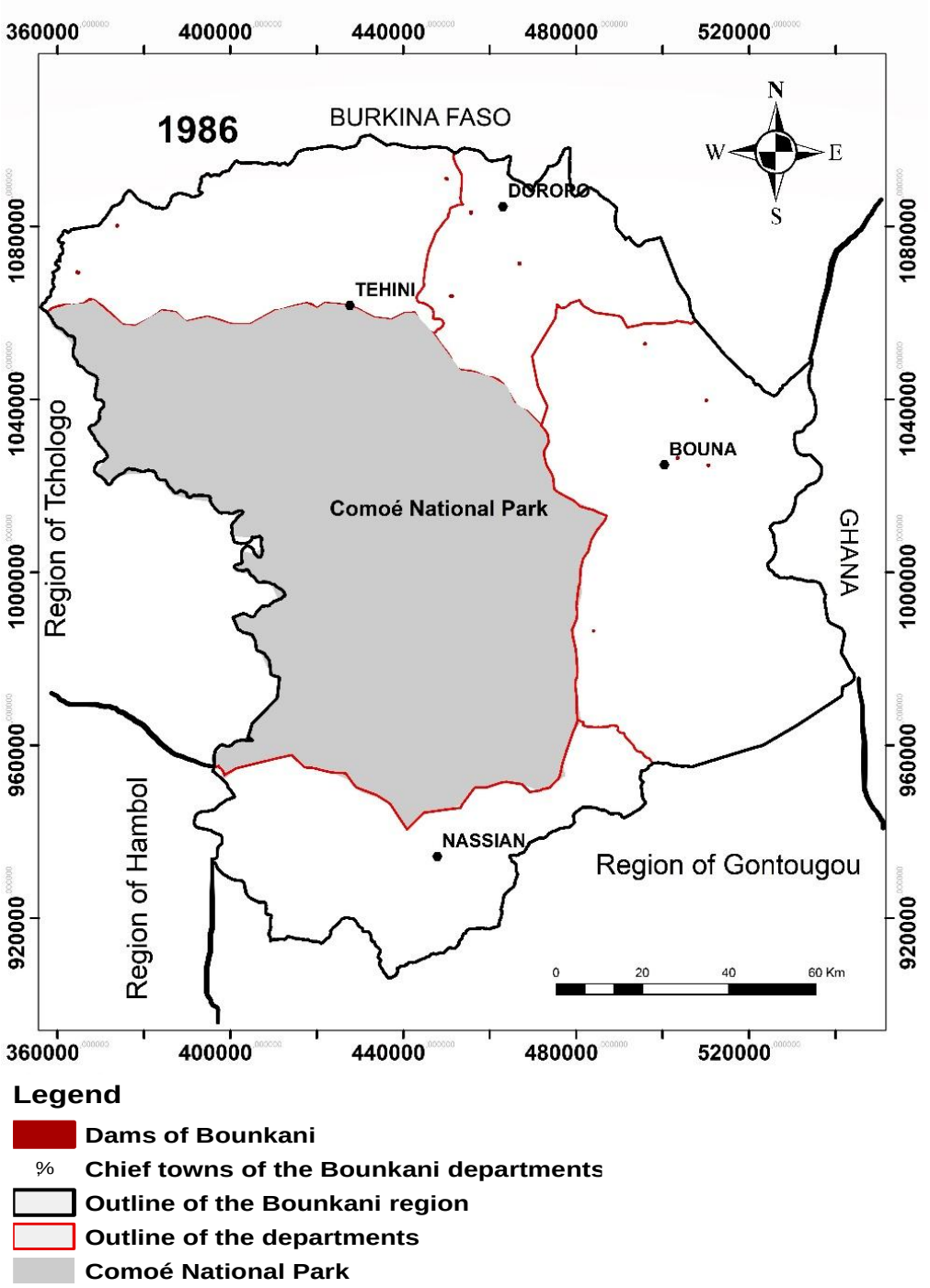
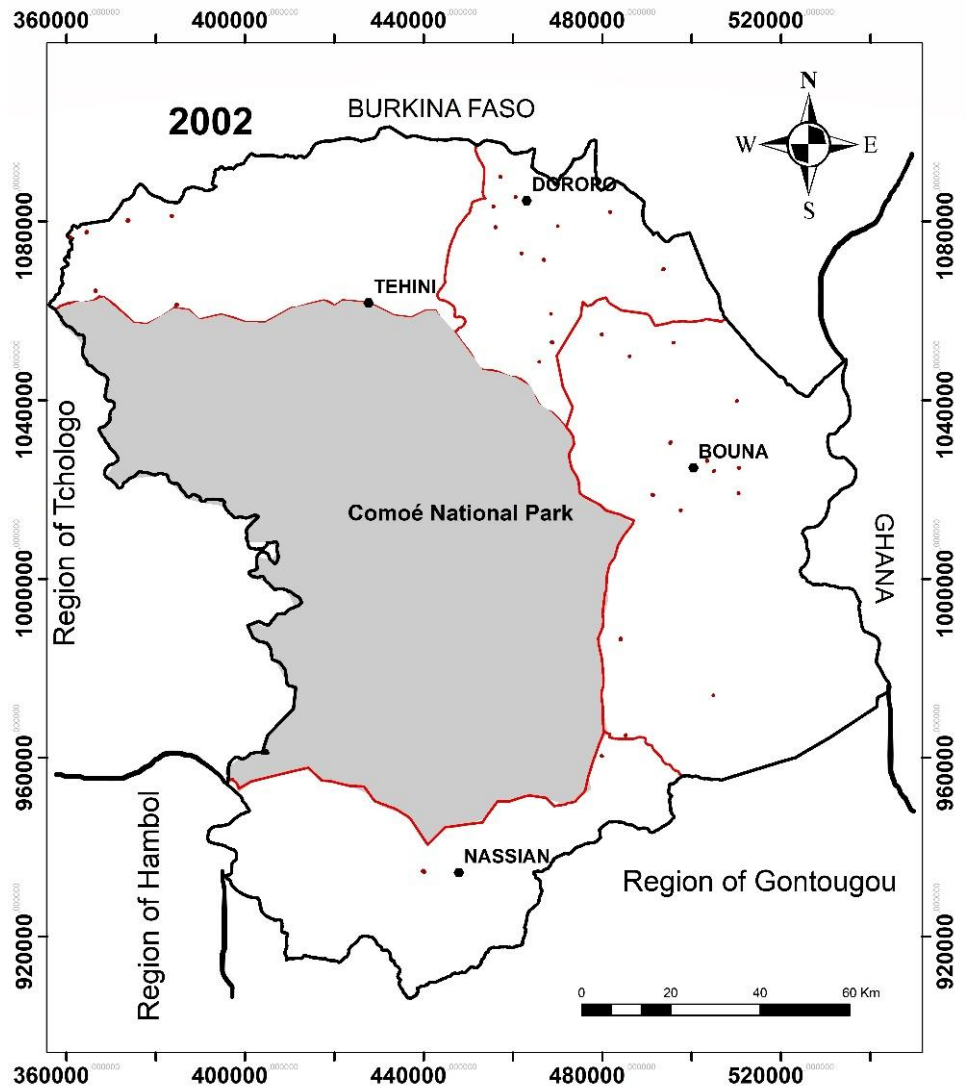


Fig. 7. Spatial distribution of lakes with water present in 1986 by department



Legend

- Dams of Bounkani
- % Chief towns of the Bounkani departments
- Outline of the Bounkani region
- Outline of the departments
- Comoé National Park

Fig. 8. Spatial distribution of lakes with water present in 2002 by department

4. DISCUSSION

The cartographic study allowed us to dicover an increase in the number of agropastoral lakes over the years. During the period 1986 to 2002, the number of dam lakes in the Comoé Basin evolved from 4 to 16 dam lakes, i.e., three times the number in 1986, and from 8 to 40 dam lakes in 2002 for the Black Volta Basin, i.e., more than four times the number in 1986, with a density ranging from 9.34.10-4 to 1.01.10-2 lakes/km2 depending on the department, and a limnology ratio varying between . 3.64.10-5 and 3.82.10-4 .

This evolution induced by the demographic growth and its corollary of need in water for the various users from where the creation of several agropastoral lakes was accentuated. It is this

pressing need of the users that has allowed the Ivorian state to build several dam lakes whose priority has been given to the sedentarization of Fulani herders; all these factors have been essential in the growth of dam lakes in the region over the years. On the other hand, these numbers of dam lakes have remained practically constant, with the exception of the Black Volta Basin (41 dam lakes) during the period 2002 to 2017, which can be justified by the dissolution of SODEPRA and also by the socio-political crisis that the country has experienced. This finding is in agreement with the work of Ibrahim et al, [16] on the Loumbila basin in Burkina Faso, this author indicates that the number of water reservoirs has increased from 21 in 1986 to 37 in 1998, an increase of 76.2%.

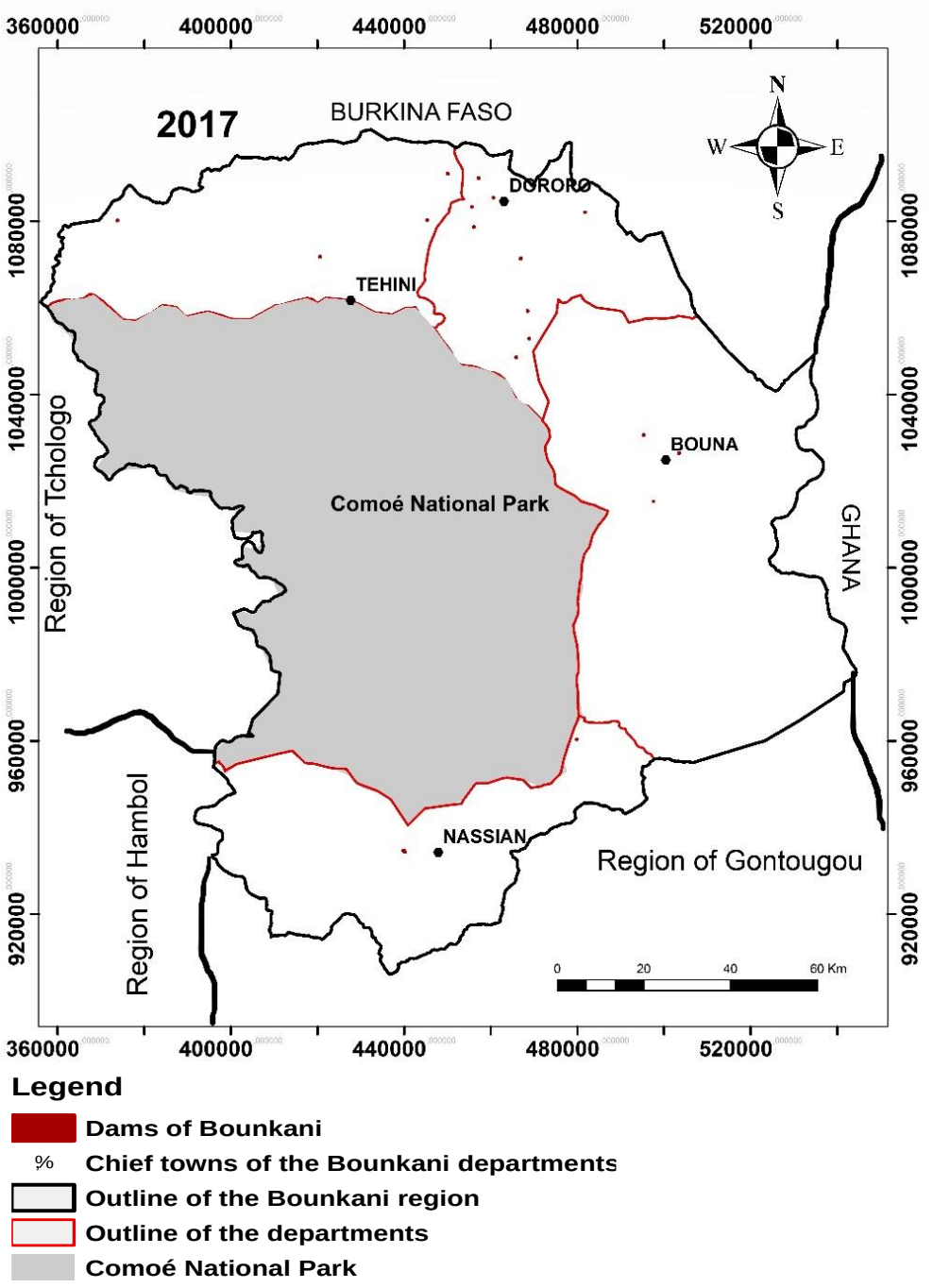


Fig. 9. Spatial distribution of lakes with water present in 2017 by department.

The Comoé basin has within it 81.25% and the Volta basin 63.41% of their lakes are in ruins, or 70.18% of the dam lakes in the region during the period 1986 to 2017. This degradation of the lakes of dams evolves from one year to another. Also other authors [17] like write in the same sense that the water bodies undergo seasonal variations that are not the same from one year to another. This dysfunction can be explained mainly by the temporal and spatial structure of the driving forces around these structures. These are climatic conditions, morphometric parameters and anthropic activities that evolve to the detriment of the vegetation cover. Indeed, the vegetation cover having been destroyed during the establishment of crops, causes the transport of sand and mud by runoff water. Also, the earth debris from the destruction of the external face of the dike is found in the form of mud at the bottom of the lake following rainfall, since the recharge of these lakes is done seasonally. At the level of certain structures, the dams constituted places of reproduction and rest of the crocodiles which lay eggs there, for lack of the material of construction. Many dams were damaged by crocodiles, such as at Panzarany and Niamoin 2 (result not shown). Thus, during periods of flooding, generally from the month of August, these holes constitute passageways for water upstream until the dam is washed away if the torrent of water is strong. The invasion of the dike as well as the external facades of the dikes are invaded by trees or even forest islands. The roots of these trees in their development will constitute multiple points of cracks thus entraining the passage of the water upstream of the dam. When high winds occur, the tree can be uprooted and constitute a water leakage point that will widen and damage the dam. The bad practices perpetrated on these structures also contribute to the destruction or even the silting of these structures. These practices can be summarized as the use of the dike as a passageway for motorized vehicles to transport luggage or people on tricycles. The ascent and descent of animals, especially oxen, which weaken the resistance of the dike's facades; these attitudes can cause hollows which, under the effect of erosion, weaken the dike's resistance. The extraction of sand from the dike for washing dishes has been observed in some localities, particularly in Niandegué. Also the exploitation of the banks for agricultural purposes, most of the dams visited whose banks are exploited for agricultural purposes are experiencing a higher level of silting. In addition to the progressive silting up of these structures, we must add the pollution of the water by chemical products (herbicide, insecticide, etc.) used for the maintenance of agricultural plots. Also, animals contribute to water pollution by their dejecta and to the silting up of the dam by the crumbling of the banks. This is one of the causes of silting of the dams. This finding is in agreement with the work of authors such as Yerima; Razanamahandry and Saouto, [18-20] who have shown a decrease in the amount of water in dam lakes.

5. CONCLUSION

The cartographic study of the water potential of these dam lakes has shown that these dam lakes are unevenly distributed in the region's basins. The density of these dam lakes is low in the Bounkani region but more concentrated in the Black Volta basin than in the Comoé basin. The mapping has challenged the sustainability of the dams which are marked by degradation and even disappearance in the region. The majority of the dam lakes in the region were failing, the Comoé basin has more dam lakes in ruins. In view of the difficulties faced by these structures, it is urgent to define the ways of rehabilitation for an efficient management of the possible dam lakes for a sustainable development in the region.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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