

Research Article

Mapping and Surface Evolution of the Bacon Reservoir Using Satellite and Uav Imagery (Southeast Côte D'Ivoire, West Africa)

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Abstract

Surface water resources are fundamental to human survival and socioeconomic development, providing water for domestic consumption, agriculture, aquaculture, and hydroelectric energy production. In West Africa, and particularly in Côte d'Ivoire, small reservoirs constitute vital infrastructures that support rural livelihoods, sustain dry-season farming, and enhance water security. However, these systems are increasingly threatened by climatic variability-especially prolonged droughts and irregular rainfall patterns-as well as by anthropogenic pressures such as land-use change, deforestation, and agricultural expansion. This study focuses on the Bacon Reservoir, located in southeastern Côte d'Ivoire, with the objective of assessing the spatiotemporal dynamics of its surface area between 2016 and 2023. Multi-temporal Sentinel-2 satellite imagery and high-resolution unmanned aerial vehicle (UAV) data were processed and analyzed using geographic information system (GIS) and remote sensing techniques. The results show significant interannual variations in the reservoir's surface area: from 74,840 m² in 2016, it decreased to 67,900 m² in 2018 (a reduction of -9.27%) before recovering to 80,900 m² in 2023 according to Sentinel-2 observations. UAV-based measurements for 2023 yielded a slightly higher estimate of 87,404 m² representing an approximate 8% difference compared to satellite-derived values. This discrepancy highlights the importance of integrating high-resolution UAV imagery with freely available satellite data to enhance accuracy in monitoring small water bodies, whose spatial variability may be underestimated by medium-resolution sensors. The observed recovery trend of the Bacon Reservoir after 2018 reflects a certain degree of resilience, possibly linked to improved rainfall conditions or local management interventions. Overall, the study demonstrates the relevance of combining multi-source remote sensing data for long-term monitoring of small reservoirs in tropical regions. These findings provide essential insights for water resource managers and policymakers seeking to promote sustainable water use, strengthen climate resilience, and ensure the long-term viability of small-scale reservoirs across Côte d'Ivoire and West Africa.

Keywords

Bacon Reservoir, Surface Area Dynamics, Sentinel-2, UAV, Côte d'Ivoire, Remote Sensing

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1. Introduction

Surface waters cover a significant portion of the Earth, comprising approximately 98% marine water and 2% freshwater, including rivers, streams, and lakes [1]. Lakes are particularly important water reservoirs, serving multiple purposes such as hydroelectric power generation, drinking water supply, fisheries, and agriculture [2-4]. Despite their critical role in socio-economic development, lakes are increasingly vulnerable to both anthropogenic and climatic pressures [5]. In Sub-Saharan Africa, these aquatic environments-whether located within urban areas or on their outskirts-frequently receive untreated domestic effluents [6], industrial discharges, and stormwater runoff due to insufficient sanitation infrastructure [7]. Socio-economic human activities, combined with natural processes, accelerate the degradation of surface water resources.

In Côte d'Ivoire, various hydraulic structures-including village pumps, boreholes, and water reservoirs-have been developed to improve access to drinking water [8]. These resources are particularly sensitive to human pressures and climatic variability. Several studies have examined reservoirs intended for drinking water supply in Côte d'Ivoire. Research by [9-13] has shown that these waters, often carrying a wide range of substances, are prone to eutrophication.

Moreover, an increasing number of people have settled along the lake shores. This is the case for the Bacon Reservoir, originally created to meet the population's drinking water needs. Over the past two decades, rapid population growth and urban

expansion have led to the occupation of its banks for housing or market gardening. As a result, this previously isolated lake is now embedded within a densely populated area [14].

Studying the surface dynamics of such environments requires modern approaches, particularly satellite and drone imagery, which allow for spatial monitoring from space or aerial surveys. Investigating surface evolution provides a valuable means of understanding changes in these aquatic systems. To support conservation, sustainable management, and long-term protection of the Bacon Reservoir, this study was conducted to deliver precise and robust data on its surface dynamics using remote sensing and drone-based aerial surveys.

2. Methodology

2.1. Study Area

The Bacon Reservoir is located in the locality of Bacon, between latitude 6°20'30" and 6°22' N and longitude 3°54' and 3°55'30" W. It lies in the eastern part of the Mé region, specifically in the sub-prefecture of Akoupé (Figure 1). Drinking water supply for Akoupé and surrounding areas is provided by the Bacon treatment plant, which has a production capacity of 85 m³/h and was constructed in 1978.

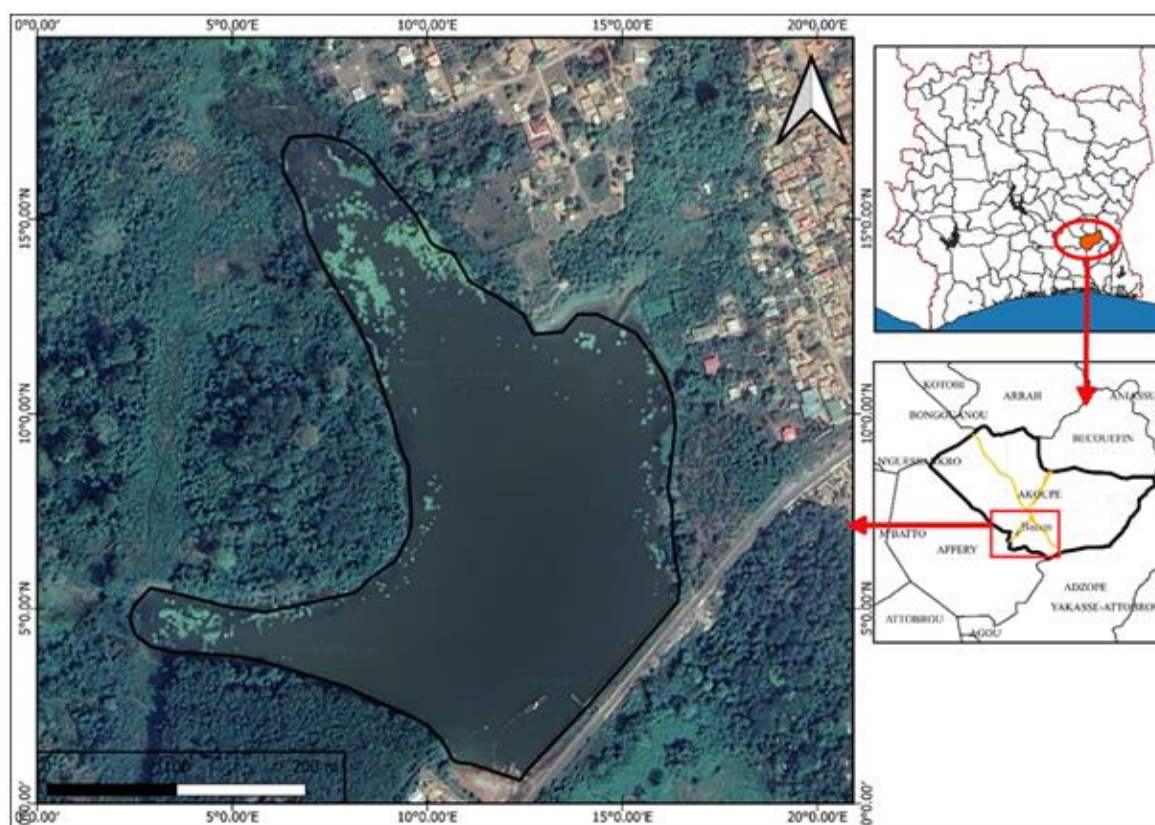


Figure 1. Geographic Location of the Bacon Reservoir.

2.2. Acquisition of Satellite and Aerial Data

The data used primarily consisted of Sentinel-2 images with a spatial resolution of 10 m, downloaded from the European Space Agency (ESA) website (<https://scihub.copernicus.eu>). Sentinel-2 imagery provides regular coverage of the Earth, allowing the monitoring of surface changes in the reservoir over long periods. Three images were used to study the surface dynamics of the Bacon Reservoir. The characteristics of these images are summarized in Table 1.

Table 1. Characteristics of Sentinel-2 Satellite Images.

Satellite	Acquisition Date	Bands	Spatial Resolution (m)	Wave length (μm)
Sentinel-2	26/01/2016	B1	60	0.443
		B2	10	0.490
		B3	10	0.560
		B4	10	0.665
		B5	20	0.705
	05/01/2018	B6	20	0.740
	04/01/2023	B7	20	0.783
		B8	10	0.842
		B8a	20	0.865
		B9	60	0.945
		B10	60	0.1380
		B11	20	0.1610
		B12	20	0.2190

An aerial data acquisition campaign was also conducted on April 25, 2024, using a DJI Phantom 4 Pro V2 drone, equipped with a 1-inch CMOS sensor with 20 MP resolution and capable of capturing 4K video at 60 fps.

2.3. Methods

2.3.1. Processing of Sentinel-2 Images

The acquired images, which were already geometrically corrected, underwent radiometric and atmospheric corrections [15]. The study area was extracted using the Region of Interest (ROI) tool in ENVI 5.3. Specific image processing, such as Color Composition (CC), was applied to map land use/land cover. To enhance visualization and highlight contrasts in features such as water, vegetation, and built-up areas, two specific band combinations were used:

- 1) Band Combination: 5-7-4

- 2) Band Combination: 4-7-3

The goal was to extract the water surface area from each image. Different classes were grouped according to their dominance on the ground, and classification was performed using the Maximum Likelihood method. Surface extraction after classification involved converting raster images into vector format to obtain polygons representing the boundaries of each feature. The classification and vectorization were based on Sentinel-2 raster pixels with a resolution of 10 m × 10 m. Surface areas were then calculated directly in QGIS, allowing the determination of the total water pixel area for each image. Figure 2 presents the workflow for generating the land use/land cover map of the Bacon Reservoir.

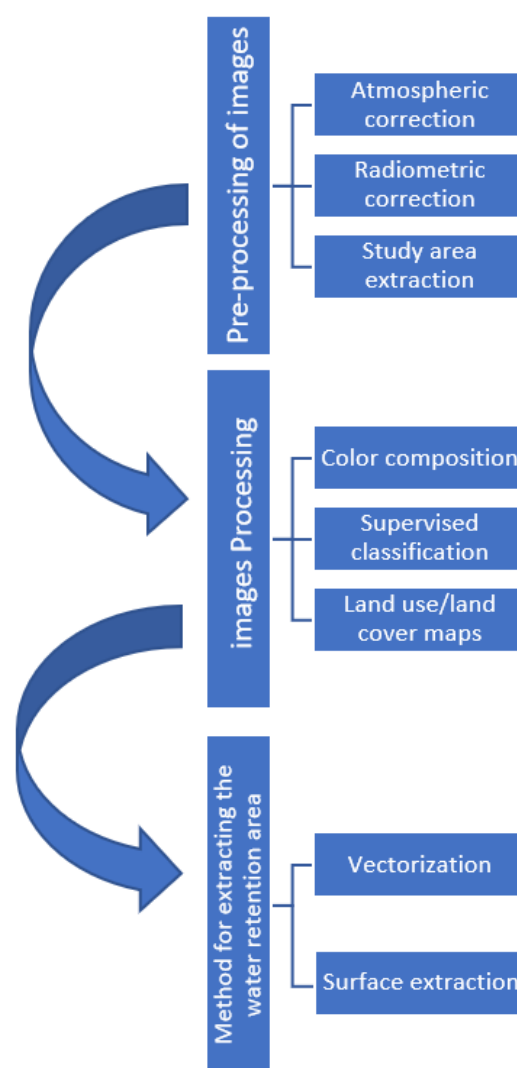


Figure 2. Workflow for Land Use/Land Cover Map Generation.

2.3.2. Processing of Drone Imagery (DJI Phantom 4 Pro)

Pix4D Mapper was used to process the drone images. A total of 137 images captured by the drone were processed. The

workflow began with careful flight planning to ensure 70-80% longitudinal and lateral overlap, ensuring high photogrammetric quality. The images were imported into Pix4D, where a new project was created with the appropriate coordinate system for the study area. Ground Control Points (GCPs) measured with GPS were integrated during initialization to accurately georeference the model and correct any GPS-related drift. After image alignment and calibration (aerotriangulation), the GCPs were manually marked on corresponding images to enhance spatial accuracy. The workflow continued with the generation of a dense point cloud, 3D mesh, and raster products such as the orthomosaic, Digital Surface Model (DSM), and Digital Terrain Model (DTM), which were then exported for further analysis.

3. Results

3.1. Land Use/Land Cover of the Bacon Reservoir

Processing of the Sentinel-2 images for the Bacon area produced three land use/land cover maps. These maps illustrate the degradation of the reservoir surroundings due to anthropogenic activities within the natural landscape (Figure 3). Land cover was classified into three main categories: vegetation, built-up areas, and water body. Vegetation is located along and upstream of the reservoir, while built-up areas, representing local housing, are concentrated in the northeast. The water body constitutes the final class.

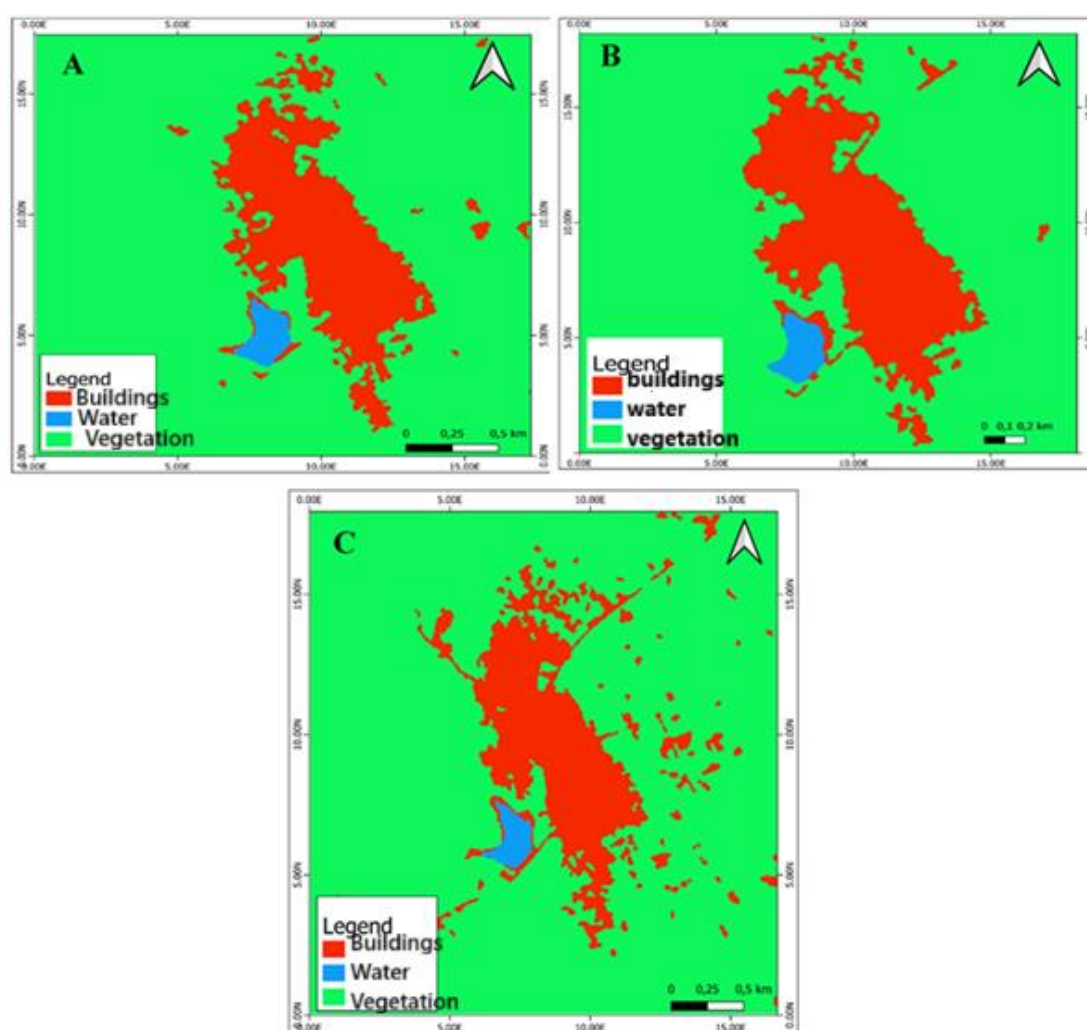


Figure 3. Land Cover Map of Bacon in 2016 (A), 2018 (B), and 2023 (C).

Moreover, there is a clear increase in housing between 2016 and 2023, leading to the regression of forested areas, expansion of bare soil, and reduction of the lake's surface in favor of agricultural and residential zones.

3.2. Mapping and Surface Evolution of the Bacon Reservoir Using Satellite Imagery

The analysis of the reservoir's surface area evolution shows

variations in the extent of the Bacon Reservoir between 2016 and 2023 (Figure 4). A detailed analysis of the "surface area" variable, presented in Figure 5, indicates that the water body decreased from 74,840 m² in 2016 to 67,900 m² in 2018, representing a reduction of 6,940 m² (4.86%). By 2023, the water surface had increased to 80,900 m².

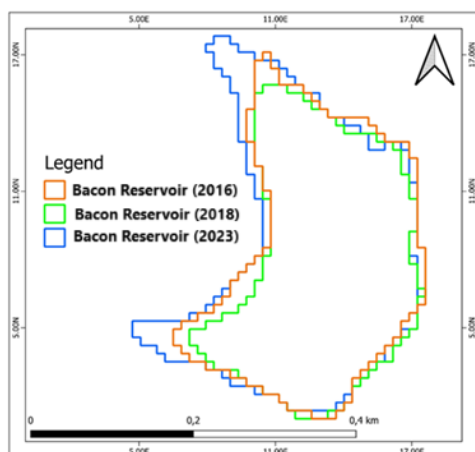


Figure 4. Variation of the Bacon Reservoir Water Surface from 2016 to 2023.

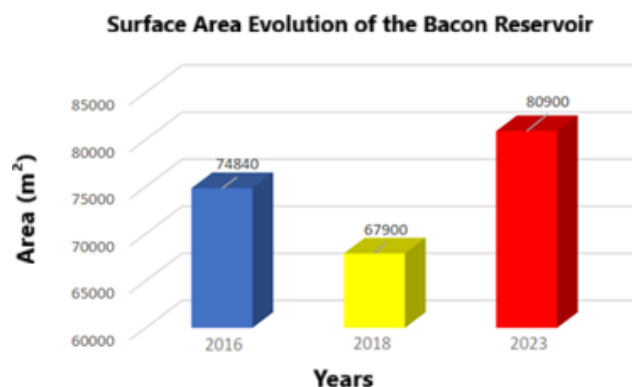


Figure 5. Evolution of the Bacon Reservoir Water Surface between 2016 and 2023.

3.3. Mapping of the Bacon Reservoir Using Aerial Imagery

The processing of drone-acquired aerial images produced a 2D orthomosaic of the reservoir surface, which was used to extract its surface area (Figure 6). This analysis revealed that the water surface area captured by the drone was approximately 87,404 m².

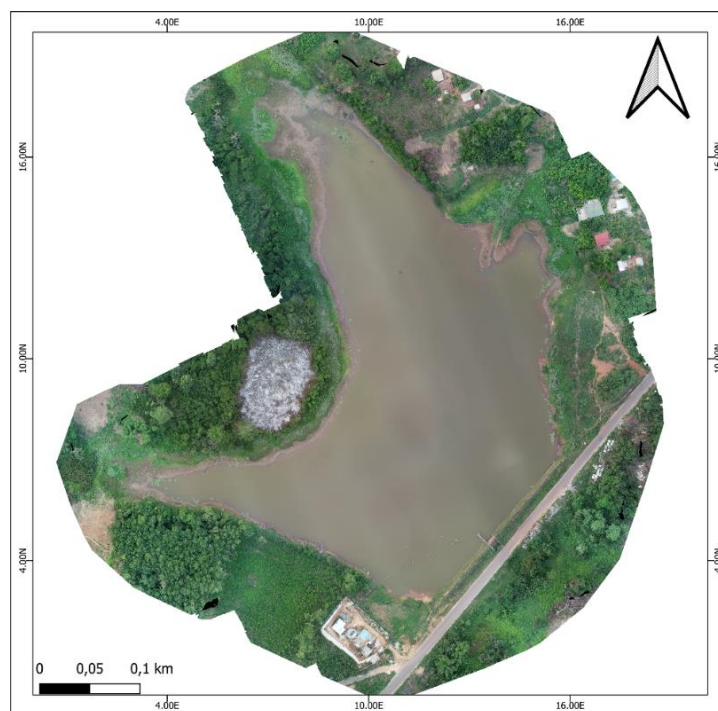


Figure 6. 2D Orthomosaic of the Bacon Reservoir.

3.4. Comparison of Sentinel-2 Images and Drone Aerial Imagery

Processing of Sentinel-2 images showed that the surface

area of the reservoir varied between 2016 and 2023. A similar trend was observed from drone-based aerial data, which indicated a surface area of approximately 87,404 m² (Figure 6). Between 2016 and 2018, a progressive decrease (-4.86%) in the water surface area was recorded, likely due to a com-

bination of local drought, reduced runoff, and/or anthropogenic withdrawals. In contrast, between 2018 and 2023, the reservoir's surface area increased by 19.15% according to Sentinel-2 data and by +28% based on drone imagery (Table 2). This increase may be attributed to a return to wetter climatic conditions, natural refilling of the reservoir, and the

higher accuracy of recent remote sensing tools. Furthermore, Table 2 highlights a difference of approximately 6,500 m² (about +8%) between Sentinel-2 and drone-derived estimates in 2023, mainly explained by the differences in spatial resolution and the finer detection capability of drone imagery.

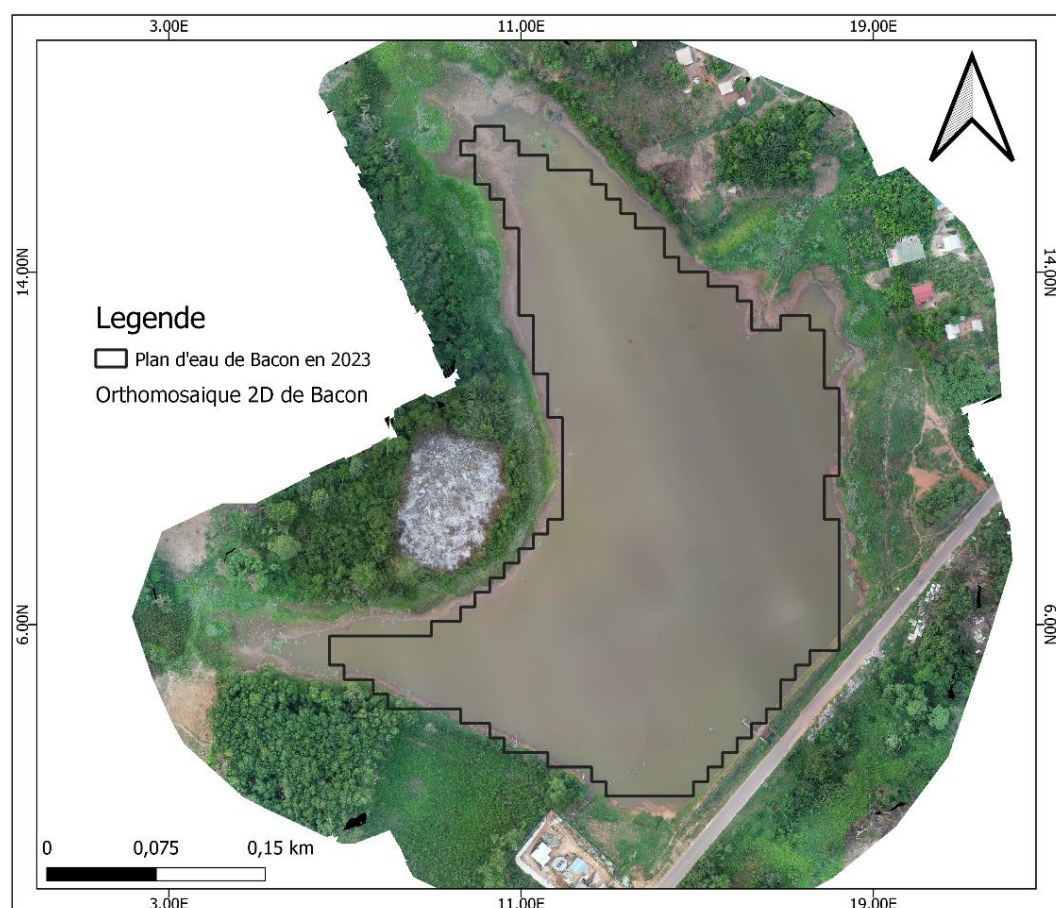


Figure 7. Overlay of the Bacon Reservoir from Sentinel-2 and Drone Imagery.

Table 2. Comparison of Bacon Reservoir Surface Area Variations Using Sentinel-2 and Drone Imagery.

Period	Initial Value (m ²)	Final Value (m ²)	Difference (m ²)	Variation (%)
2016-2018 (sentinel-2)	74840	67900	-6940	-9.27
2018-2023 (sentinel-2)	67900	80900	+13000	+19.15
2023 (sentinel-2 vs Drone)	80900	87404	+6504	+8.04

4. Discussion

The diachronic analysis of the Bacon reservoir highlights a significant variability in its surface area between 2016 and 2023. The water surface decreased from 74,840 m² in 2016 to

67,900 m² in 2018, representing a reduction of 9.27%. This contraction can be attributed to unfavorable climatic conditions, particularly reduced rainfall and increased evaporation. These findings are consistent with those of [16] and [17], who emphasized the sensitivity of reservoirs in Côte d'Ivoire to climatic variability and seasonal fluctuations. In addition, shoreline modifications and land reclamation also contributed

to the infilling of the Bacon reservoir, in line with the results of Atto (2018), who reported that the reservoir has been losing surface area due to considerable land encroachment. Conversely, a recovery was observed in 2023, with an estimated surface area of 80,900 m² from Sentinel-2 and 87,404 m² from drone imagery. This increase of 19.15% (compared to 2018) suggests a return to more favorable hydrological conditions, likely linked to higher rainfall. Similar findings were reported by Mutanda (2024), who systematically examined the impact of climate change on four major African lakes (Chad, Victoria, Tanganyika, and Malawi/Nyasa/Niassa) and identified ways to strengthen their resilience, thereby providing insights for the management of reservoirs in West Africa [18]. The difference between Sentinel-2 and drone estimates in 2023 (+8.04%) is explained by the spatial resolution of the data used. Sentinel-2 imagery (10 m) tends to underestimate fragmented or small water bodies, as noted by [19]. By contrast, drone surveys, with their centimeter-level resolution, provide much more detailed mapping and considerably reduce classification errors [20]. Our results therefore confirm the complementarity of satellite and UAV approaches for monitoring wetlands. From a methodological and practical perspective, these results are highly instructive. They demonstrate that Sentinel-2 data are well suited for long-term temporal monitoring due to their free accessibility and wide coverage, while drones represent an indispensable tool for high-precision, local-scale analyses. Integrating both approaches provide an optimal framework for monitoring and ensuring the sustainable management of water resources as suggested by [20]. In sum, the dynamics observed in the Bacon reservoir are consistent with broader trends documented across West Africa, confirming that small water bodies are simultaneously vulnerable to climatic and anthropogenic pressures but also exhibit a certain capacity for resilience.

5. Conclusion

The study of the Bacon reservoir between 2016 and 2023 revealed a contrasting dynamic, first marked by a reduction in water surface area between 2016 and 2018, followed by a notable recovery in 2023. This evolution underscores the high sensitivity of small reservoirs to climatic variations, particularly rainfall fluctuations and evaporation processes. It also highlights the potential influence of anthropogenic activities, such as water abstraction and shoreline modifications, on the availability of this resource. From a methodological standpoint, the comparison between Sentinel-2 imagery and drone surveys shows that the observed discrepancies are mainly due to differences in spatial resolution and classification accuracy. While Sentinel-2 proves to be an effective tool for temporal and regional monitoring of reservoirs, UAV-based surveys are essential for fine-scale and highly accurate delineation of water surfaces. Overall, these findings confirm previous studies in West Africa on the vulnerability and resilience of

small water bodies to both climatic and anthropogenic pressures. They also emphasize the need to integrate multi-source approaches (satellite and UAV) in order to strengthen monitoring reliability and support the sustainable management of water resources.

Abbreviations

GCPs	Ground Control Points
GPS	Global Positioning System
DSM	Digital Surface Model
DTM	Digital Terrain Model
CC	Color Composition
ROI	Region of Interest
ESA	European Space Agency
UAV	Unmanned Aerial Vehicle

Author Contributions

Ronald Sosthène Désiré Yapi Atto: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Kouadio Assemien François Yao: Formal Analysis, Methodology, Resources, Software, Validation, Visualization

Yeo Nahoua: Formal Analysis, Investigation, Methodology, Software, Visualization

Katie Drissa Coulibaly: Data curation, Formal Analysis, Investigation, Methodology, Software, Visualization

Sylvain Monde: Formal Analysis, Project administration, Supervision, Validation, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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