World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

Check for updates

Socio-Economic Impacts of Wetland Exploitation in the Municipality of Adjohoun

Domiho Japhet KODJA [1,*], Serge DOSSOU YOVO [2], Alladé Pascal Souleymann LIGALI [3], Toussaint KAKA [4], Pascal GBENOU [5] and Cyr Gervais ETENE [1]

[1] *Laboratory Pierre PAGNEY Climate, Water, Ecosystem and Development (LACEEDE), 03 BP 1122, Cotonou, University of Abomey-Calavi, Republic of Benin.*
[2] *Laboratory of Biogeography and Environmental Expertise (LABEE), UAC, Republic of Benin.*
[3] *Laboratory for the Study of Urban and Regional Dynamics (LEDUR), University of Abomey-Calavi, Republic of Benin.*
[4] *National Water Institute (INE), University of Abomey-Calavi, Republic of Benin.*
[5] *National University of Agriculture, Republic of Benin.*

World Journal of Advanced Research and Reviews, 2025, 28(01), 1230-1247

Publication history: Received on 08 September 2025; revised on 14 October 2025; accepted on 17 October 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.1.3547

Abstract

An The development of wetlands plays a significant role in promoting sustainable economic activities that benefit local communities while protecting the environment. This study aims to analyze the socio-economic impacts of wetland valorization in the Municipality of Adjohoun. The methodological approach relied on documentary research and field investigations. The climatic data used include precipitation, evapotranspiration, and temperature for the period 1981–2021. These data were provided by Météo-Bénin, which constitutes the only comprehensive source of information for the study area. Hydrological data collected by the General Directorate of Water (DG-Eau) at the Adjohoun hydrological station between 1981 and 2021 were also utilized. The SWOT model was applied for data analysis and interpretation. The results indicate that, within the study area, wetlands are classified into four distinct categories: lowlands (54%), floodplains (24%), swampy areas (14%), and temporary marshes (8%). In the Municipality of Adjohoun, 86% of respondents believe that ecosystem exploitation gives rise to a variety of socio-economic activities conducted in the field, generating significant impacts. In pursuit of sustainable and integrated wetland management, users have implemented valorization measures such as awareness-raising and the promotion of local products, which are gradually showing their limitations, as noted by 72% of respondents. In light of these findings, several recommendations were formulated to enhance the valorization and sustainable management of wetland ecosystems, ensuring their effective preservation for the benefit of all stakeholders.

Keywords: Benin; Municipality of Adjohoun; Socio-Economic Impacts; Exploitation; Wetlands

1. Introduction

The environment is a dynamic and ever-changing system formed by the integration of natural and social components [7]. The natural components comprise biotic elements (fauna and flora) as well as abiotic elements (water, air, and soil). The biodiversity of environmental resources plays a significant role for humanity [13]. It is a milieu in which each element coexists with others, and its preservation is essential for our well-being and that of our planet [2].

Wetlands are remarkable spaces, both submerged and emergent, and/or alternating, characterized by a high richness of natural biotic resources [14]. Permanently or seasonally covered by water, in which numerous plants grow, they host varied habitats rich in nutrients. Wetlands thus constitute ecosystems that meet diverse human needs and provide substantial benefits to local populations [16]. They perform major ecological and landscape functions, including flood control, aquifer recharge, trapping of toxic chemical elements, and nutrient recycling [8]. The use of ecosystem

* Corresponding author: Domiho Japhet KODJA

resources by local populations is considered both a socio-economic and ecological activity, highlighting the need to promote the sustainable valorization of these environments to reduce harmful exploitation practices. Since 1971, the Ramsar Convention has defended the protection of wetland ecosystems worldwide and in West Africa, following the accession of multiple countries. Benin acceded to the convention in 1986 and has designated four sites as Ramsar sites of international importance, covering a total area of 1,179,354 hectares, including Ramsar sites 1017 (Western Complex) and 1018 (Eastern Complex) in the coastal zone, both listed on January 24, 2000, as well as the W Complex and the Pendjari River on February 2, 2007 [5]. This study focuses on Ramsar site 1018, specifically within the Municipality of Adjohoun, which hosts wetlands of critical importance to the local population.

Despite the long-standing recognition of the resources and their richness, these environments remain largely ignored and are subject to very few protective or valorization measures [20]. Likewise, the uncontrolled exploitation methods currently employed by local populations to harvest resources, combined with the rapid demographic growth characteristic of Beninese wetlands, place natural resources at significant risk [3]. Furthermore, when evaluating the dynamics of population growth in relation to climatic factors, the consumption or utilization of wetland products may experience fluctuations due to intermittent population needs. This situation affects all types of wetlands and their associated ecosystems. Therefore, to enhance productivity and ensure the preservation of wetlands and the environment more broadly, the valorization of these ecosystems proves essential.

These concerns raise the central question of this study: what are the social and economic consequences of wetland exploitation in the Municipality of Adjohoun?

2. Data and methods

2.1. Data

2.1.1. Climatic and hydrometric data

The data collection methods employed in this study primarily involved documentary research and field investigations to gather all the necessary data and information. Climatic data from the Cotonou synoptic station—including precipitation, temperature, potential evapotranspiration, wind, and sunshine—covering the period 1981–2021, were obtained from Météo-Bénin. Hydrometric data (daily water levels) were collected from the General Directorate of Water (DG-EAU). These data allowed for the analysis of hydro-climatic patterns and their influence on wetland environments.

2.1.2. Environmental and cartographic data

Land use data were sourced from the databases of the National Geographic Institute (IGN). These data facilitated the analysis of vegetation cover around wetlands and its interactions with the surrounding environment. They also contributed to understanding the hydrological functioning of wetlands, which serve as reference points for drainage, water flow, and the availability of surface water, as well as the nature of wetland vegetation.

2.1.3. Socio-economics data

Demographic statistics were derived from the results of the national population and housing censuses RGPH 1 (1979), RGPH 2 (1992), RGPH 3 (2002), and RGPH 4 (2013), collected from INStaD. In addition to these sources, data were collected through individual and group interviews, focusing on local populations' perceptions of climate change, wetland dynamics, and the socio-economic and environmental impacts of wetland exploitation.

2.2. Methods

The materials and methods should be typed in Cambria with font size 10 and justify alignment. Author can select Normal style setting from Styles of this template. The simplest way is to replace (copy-paste) the content with your own material. Method and analysis which is performed in your research work should be written in this section. A simple strategy to follow is to use keywords from your title in first few sentences.

2.2.1. Calculation of Rainfall Indices

The rainfall index (RI) allows for the identification of dry or deficit periods, wet or surplus periods, and average or normal periods over the study period (1981–2021). It is calculated using the formula:

$$RI = \frac{X_i - \bar{X}}{\sigma}$$

where:

- X_i: is the annual rainfall for year i
- $\bar{X}$: is the interannual mean rainfall over the reference period,
- σ : is the standard deviation of the series.

According to [22], this index measures the deviation of the studied variables relative to a long-term weighted mean. Negative (deficit years) or positive (surplus years) hydro-climatic anomalies [1] are used to analyze the water status of wetlands over the past 30 years. The WMO interpretation grid [19] was employed to classify years as surplus, average, or deficit (Table 1).

Table 1 Interpretation Grid of Standardized Rainfall Anomalies

Anomaly Index	**Characteristics**
2.0 and above	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Very dry
-2.0 and below	Extremely dry

Adapted from [19]

2.2.2. Calculation of the climatic balance

A climate is considered biologically dry when precipitation is lower than evapotranspiration and no water reserves are available. The climatic balance reflects the timing of water surpluses or deficits. It expresses the difference between total rainfall and the value of potential evapotranspiration (PET), which represents the surplus available for soil water recharge and runoff [24]. The formula for calculating the climatic balance is as follows:

$$BC = P - PET$$

Where:

- BC: Climatic balance
- P: Total annual rainfall
- PET: Potential evapotranspiration

PET represents the climatic demand for water vapor. The climatic balance thus highlights changes in climate through rainfall inputs and losses by evaporation.

Interpretation:

- $if\ P - PET > 0,\ BC$ si surplus
- $if\ P - PET < 0,\ BC$ si deficit
- $if\ P - PET = 0,\ BC$ si balanced

2.2.3. Method for determining climatic hazards

The probability of occurrence of hydro-climatic risks and their impacts was used to develop a criticality matrix, which provides information on the priority levels of drought risk in the Municipality of Adjohoun. Based on the classification of extreme years [19], four drought risk classes (1 to 4) were defined: normal, moderately dry, very dry, and extremely dry. The analysis and interpretation of these risks are summarized in Table 2.

Table 2 Risk typology

Identified Risks	Frequency of Occurrence	Rating	Severity	Rating	Criticality	Description
R1						
R2						
R3						
Rn						

The first step involved identifying and classifying the various drought hazards in the Municipality of Adjohoun based on their probability of occurrence, severity, and criticality (Table 3).

Table 3 Criticality Matrix

Impact severity / Risk probability	Limited	Moderate	Significant	Critical
1 (Unlikely)				
2 (Somewhat likely)				
3 (Likely)				
4 (Very likely)				

Source : [4]

The criticality matrix was used to assess the priority level of risks based on their probability (unlikely, somewhat likely, likely, and very likely) and impact severity (limited, moderate, significant, and critical) (Table 4).

Table 4 Risk and Action Matrix

Risks	Criticality	Presentation (Color Range)	Causes	Preventive Actions	Corrective Actions
R1					
R2					
R3					
Rn					

Source : [4]

2.2.4. Method for Assessing Vulnerability

To evaluate the degree of vulnerability, the sensitivity matrix technique was used, which first involves determining the exposure and impact units (Table 5).

Table 5 Sensitivity Matrix

Exposure Units	Droughts risks				
	Risk 1	Risk 2	Risk3	Exposure index	Rank
UE1					
UE2					
UE3					
Inpact Index (%)					
Rank					

2.2.5. Multi-criteria analysis

The wetland map was produced using a multi-criteria analysis. The following maps were combined: relief map, water accumulation zones, and the NDWI (Normalized Difference Water Index) map. Each dataset was classified according to its importance in determining wetlands [12]. The suitability of each layer was rated on a scale from 1 to 10. The "No Data" value was used to exclude areas that should not be considered. Classification was performed using the Reclassify tool. The Rescale by Function tool was used to reclassify relief altitudes according to the suitability scale, with low-relief areas corresponding to zones of high-water accumulation potential.

The final step in producing the wetland map involved combining the different map layers. To account for the varying importance of each factor, the transformed datasets were weighted as percentages. The relief map had a weight of 25%, the water accumulation map 25%, and the NDWI map 50% [17]. This weighting was followed by overlay using the Weighted Overlay tool to produce the final map, where higher values correspond to wetland areas.

2.2.6. Wetland inventory

Wetlands were inventoried based on fieldwork. The GPS ESSENTIAL device allowed georeferencing of the wetlands identified during field surveys. The area of each wetland was also determined using information from production groups and tracking, which enabled comparison between theoretical data and field-based observations. The sensitivity matrix will then be used to assess the exposure of certain natural resources and economic activities to hydro-climatic risks, thereby determining their impact rates.

2.2.7. Cartographic data processing

The GIS equipment used included a computer for data entry and report writing, GIS software (ArcGIS, QGIS, ENVI, etc.) for map production, and a vector database sourced from IGN, 2018. A GPS device was used to record the coordinates of vulnerable areas, and a camera was used for data collection and photographic documentation. For fieldwork, the materials included a GPS for capturing geographic coordinates, a camera for image collection, and the general map of Benin at a 1:600,000 scale (IGN, 1992) to facilitate comparison between field observations and existing maps.

2.2.8. Sampling

The sampling population consisted of agricultural households. To constitute the sample, all eight (8) districts of the Municipality of Adjohoun were considered. Respondents were selected to obtain the most diverse information possible. Selection criteria included:

- Engaging in at least one activity related to wetlands;
- Having exploited wetlands for at least the past ten (10) years;
- Having lived in the area for at least ten (10) years;
- Being at least thirty (30) years old.

The sample size was determined following [21]. It was calculated with a 95% confidence level and a margin of error of ±5% using the formula:

$$N = \frac{k^2 * p * q}{d^2}$$

Where:

N: Sample size per district
k: 1.96, Corresponding to a 95% confidence level
p: n/N, The proportion of agricultural households in the district relative to the total number of agricultural households in the municipality;

$$q = 1 - p$$

d = margin of error, set at 5%. ;

A total of 446 individuals were surveyed.

3. Results

3.1. Geographical Location and Biophysical and Human Characteristics of Adjohoun of Wetlands in the Municipality of Adjohoun

Located in the center of the Ouémé Department, the Municipality of Adjohoun lies between 6°37'20'' and 6°48'10'' north latitude and between 2°25'15'' and 2°35'20'' east longitude (Figure 1). Adjohoun is bordered to the north by the Municipality of Bonou, to the south by Dangbo, to the east by Sakété, and to the west by Abomey-Calavi. The municipality covers an area of 308 km^2 and is home to a population of 75,323 inhabitants [15].

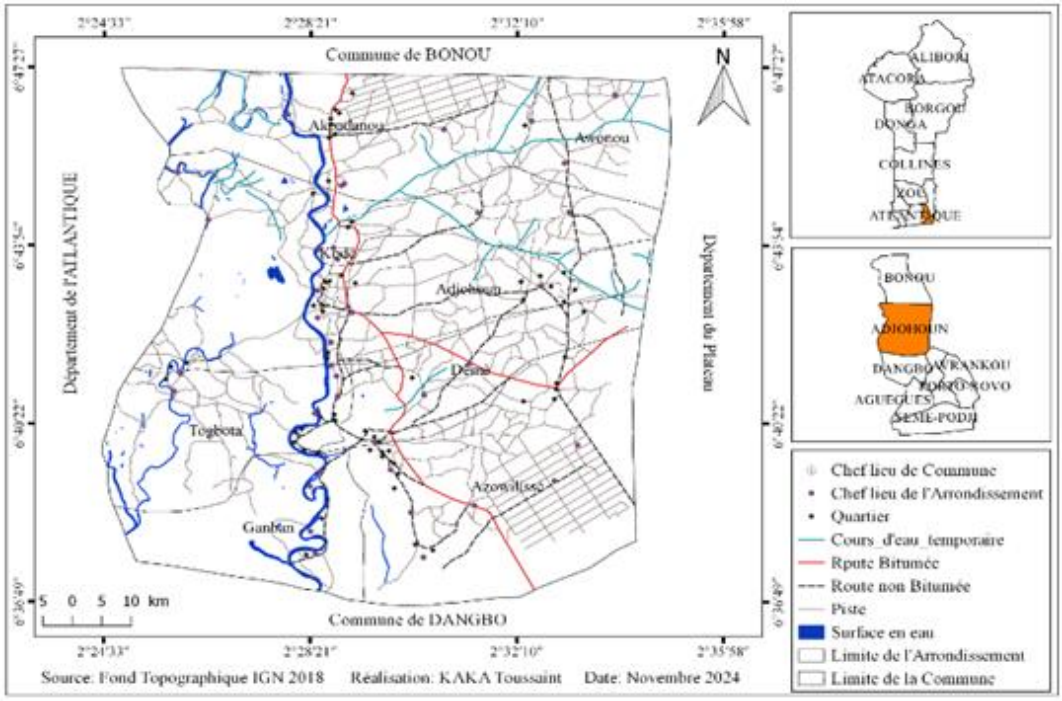
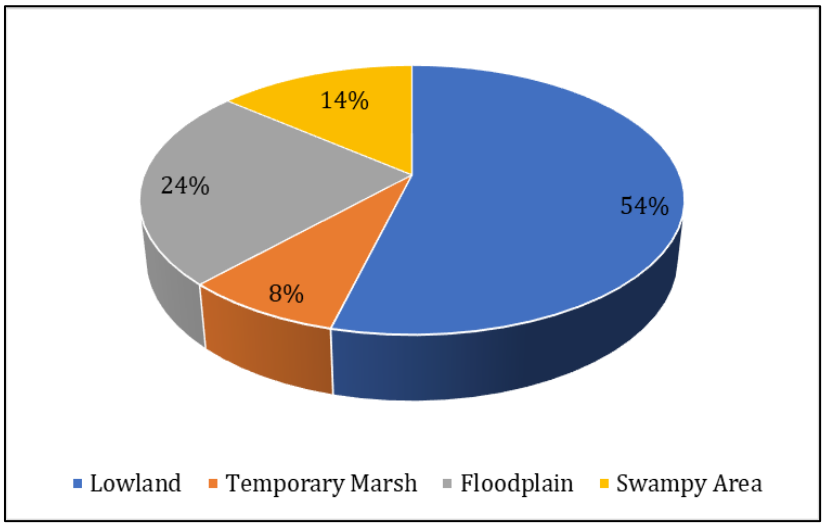


Figure 1 Geographical and Administrative Situation of the Municipality of Adjohoun

3.2. Typology of Wetlands in the Municipality of Adjohoun

Wetlands are divided into four main categories: lowlands, floodplains, temporary marshes, and swampy areas [11]. Figure 2 illustrates the diversity of these wetlands in the Municipality of Adjohoun.



Source: Field Survey, July 2024

Figure 2 Typology of Wetlands in the Municipality of Adjohoun/

Analysis of Figure 2 highlights the distribution of the different wetland categories, with a predominance of lowlands (54%) and floodplains (24%). These areas are particularly important for agricultural and fishing activities, providing income opportunities for local communities. The presence of swampy areas (14%) and temporary marshes (8%) also demonstrates the potential for valorization of these natural spaces. Thus, wetland valorization can not only enhance local livelihoods but also contribute to the economic sustainability of the Municipality of Adjohoun (Table 6).

Table 6 The wetlands identified in the Municipality of Adjohoun

Districts	Villages	Type	Flood start	Flood end
GANGBAN	Agonlin	Swampy Area	Juillet	Octobre
	Dannou	Lowland	Juillet	Novembre
	Gangban	Lowland	Juillet	Octobre
	Lowe	Swampy Area	Juillet	Novembre
AZOWLISSÈ	Abeokouta	Lowland	Juillet	Octobre
	Gbada	Floodplain	Juillet	Octobre
	Gbekandji	Lowland	Juin	Octobre
DEME	Fanvi	Lowland	Juillet	Octobre
	Ahlan	Temporary Marsh	Juillet	Octobre
TOGBOTA	Togbota-ague	Swampy Area	Juillet	Octobre
	Togbota-oudjra	Lowland	Juillet	Octobre
ADJOHOUN	Allanzounme	Floodplain	Juillet	Octobre
	Zoungome	Lowland	Juillet	Octobre
KODÉ	Gbannan	Temporary Marsh	Juillet	Novembre
	Hlankpa	Floodplain	Juillet	Octobre
	Gouke	Swampy Area	Juillet	Novembre
AWONOU	Abidomey	Lowland	Juillet	Octobre
	Awonou	Floodplain	Juillet	Novembre
AKPADANOU	Dekanme	Temporary Marsh	Juillet	Octobre
	Fonly	Temporary Marsh	Juillet	Octobre
	Houedo-wo	Floodplain	Juillet	Novembre
	Sokpetinkon	Lowland	Juillet	Octobre

Source: Field Survey, July 2024

An examination of Table VI shows that the majority of identified wetlands are lowlands, including Agbenou, Dogbotonou, Bazoumè, Aichahoun, Tovegbamè, Sô, and Tovè. Areas such as Sissepka, Egamè, Aloluè II, Sokpetinkon, and Hlan were identified as floodplains. Additionally, ponds include Sissepka, Aloluè I, Dovi, and Hounhoun. Locations such as Lolo, Agbaenou, Hlan, and Ganan are swampy areas, while Voti contains a temporary marsh.

It is also noteworthy that the flooding period in these zones generally spans from July to November each year, with most wetlands experiencing a flood duration of approximately four months.

Figure 3 presents the map showing the spatial distribution of geolocated wetlands in the Municipality of Adjohoun.

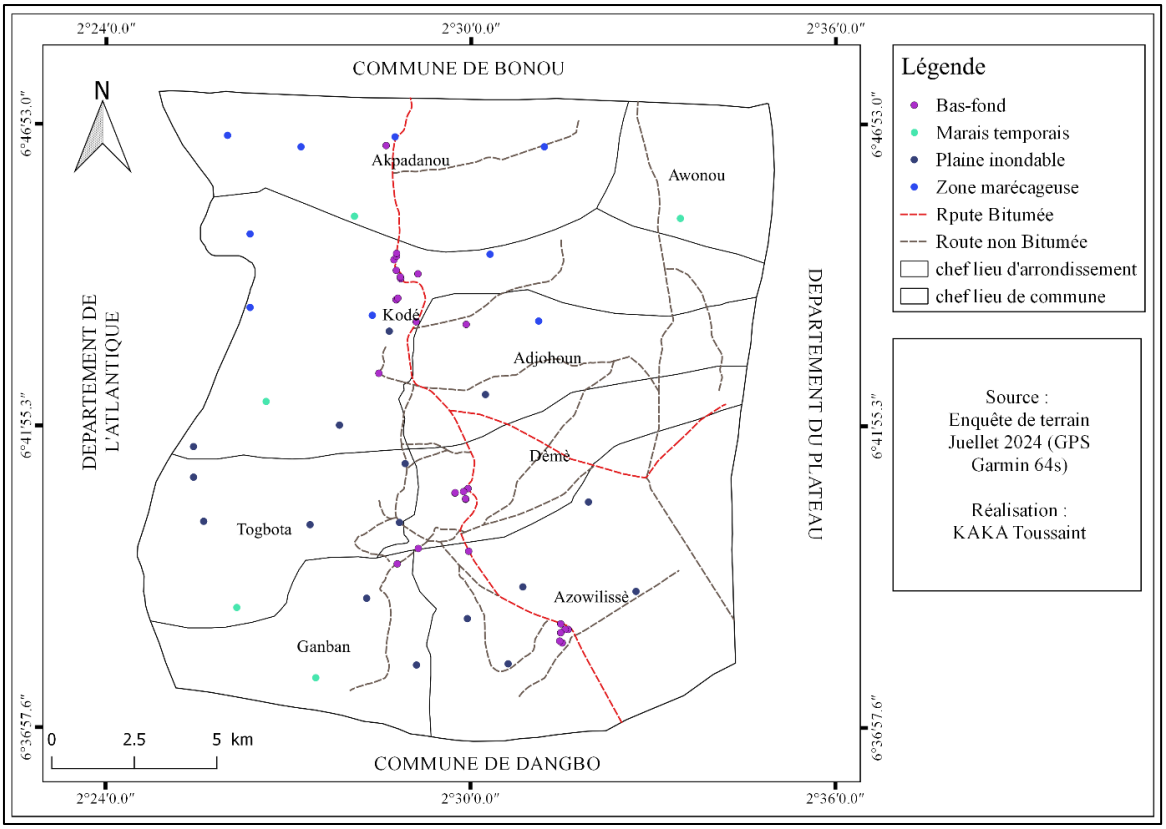


Figure 3 Spatial Distribution of Wetlands in the Municipality of Adjohoun

3.3. Forms of Wetland Utilization in the Municipality of Adjohoun

In the Municipality of Adjohoun, wetlands are of critical importance to the local community and are utilized through various economic activities. The main activities contributing to the use of wetlands include:

- Flood-recession and off-season agriculture

Agriculture is one of the main economic activities in the Municipality of Adjohoun. Rice cultivation predominates in floodplain areas, particularly due to the fertility of the soils. Besides rice, wetlands support almost the same crops as those grown on upland areas [25]. This type of agriculture is an important source of income for local farmers and contributes to food security (Figure 4).

Photo : KAKA Toussaint, July 2024

Figure 4 shows a rice field in the village of Agonlin.

Figure 4 illustrates rice cultivation in the village of Agonlin. This rice production represents a key strategy for the community of Adjohoun to valorize the municipality's wetlands. By using these wetlands for agricultural purposes, the community not only develops its economic activities but also enhances the socio-economic benefits associated with the preservation and sustainable management of these ecosystems. Rice cultivation in wetland ecosystems promotes economic growth while maintaining the ecological health of the Municipality of Adjohoun.

- Integrated Fish Farming

Some communities exploit wetlands for pond-based aquaculture, often integrated with rice cultivation [26]. This approach combines crop and livestock production, thereby maximizing the use of natural resources and increasing yields. Figure 5 shows a fishpond in Allandohou I.

Photo : KAKA Toussaint, July 2024

Figure 5 Lowland Fishpond in Allandohou I

Figure 5 illustrates a key economic activity linked to wetland utilization. This pond represents an important source of income for local residents, contributing to both their food security and livelihoods. Aquaculture practiced in these areas demonstrates how natural resources can be sustainably exploited while supporting the local economy and environmental conservation.

- Artisanal Fishing

Some wetlands in the Municipality of Adjohoun are rich in fish, and artisanal fishing is a major activity. It provides livelihoods for a large portion of the population, particularly during periods when agricultural activity is low [24]. Fishing also serves as an important source of income for women in the region. Figure 6 illustrates a fishing session in the village of Houedo-Wo.

Photo : KAKA Toussaint, July 2024

Figure 6 Income-Generating and Locally Resilient Aquaculture in the Village of Houedo-Wo

Figure 6 shows people engaged in fishing, a key sector in wetland utilization. In the Municipality of Adjohoun, fishing is an essential economic activity. Preservation and sustainable management of wetlands can enhance fish production, thereby increasing fishermen's incomes and strengthening food security in the municipality.

- Agro-Food Processing

Agricultural and fishery products from wetlands are often processed locally. For example, harvested rice is hulled before being sold in local and regional markets, while fishery products (fish, crayfish) are smoked or dried before commercialization. Similarly, wetland plants, such as water hyacinth, are exported to enhance soil fertility in upland areas (Figure 7).

Photo : KAKA, July 2024

Figure 7 Palm Fruit Processing in the Village of Goutin

Figure 7 illustrates artisanal processing of palm fruits to produce palm oil. This type of activity, often carried out within communities, plays a fundamental socio-economic role by generating income and employment, particularly for women and young people. Wetlands, with their fertile soils, support the cultivation of oil palms, highlighting the importance of these ecosystems for the local economy. This work demonstrates direct utilization of natural resources through traditional knowledge while also emphasizing the community's dependence on the stability and preservation of local ecosystems.

- Exploitation of Wood and Other Natural Resources

In the Municipality of Adjohoun, wetlands also provide construction materials (bamboo, reeds) used for building houses or crafting artisanal objects. Some areas offer mangrove wood or other useful species for fuel or handicrafts [1]. When carried out sustainably, this exploitation contributes to the local economy while respecting the environment. Figure 8 shows wood harvesting in the village of Fonly.

Photo Credit: KAKA, July 2024

Figure 8 Wood Harvesting in the Village of Fonly

In Figure 8, women are seen preparing wood harvested from wetlands for commercial purposes. This activity highlights the socio-economic importance of wetland resource utilization in the Municipality of Adjohoun. Sustainable wood harvesting generates income for local communities, particularly for women, while supporting local trade. However, it is crucial to ensure the rational management of forest resources to prevent the degradation of these vital ecosystems [23].

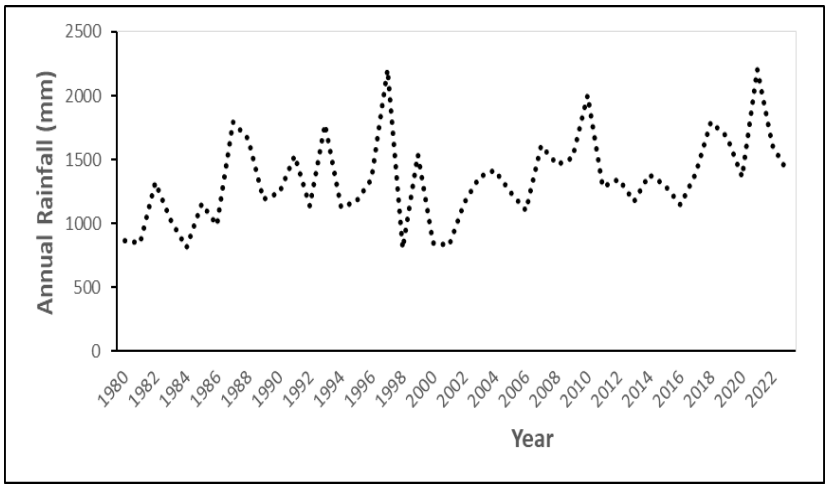
3.4. Impacts of Wetland Exploitation

3.4.1. Impacts of Wetland Exploitation

Climate plays a significant role in agricultural development, directly influencing seasonal crops [10].

- Interannual Evolution of Rainfall in the Municipality of Adjohoun

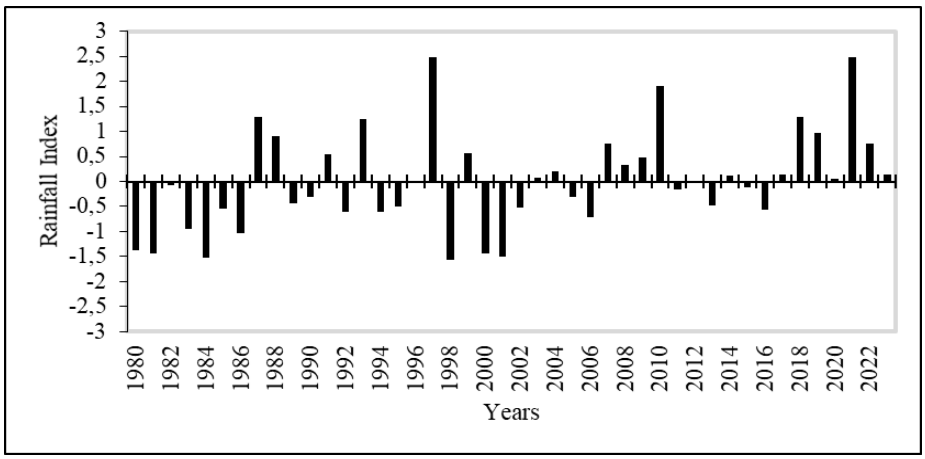
Fieldwork shows that 80% of respondents have observed increasing delays in rainy seasons over the past decade, with excessive rainfall causing devastating floods. The analysis of interannual rainfall variability in Adjohoun covers the period from 1981 to 2021. Figure 9 illustrates the interannual variability of precipitation in the municipality.



Source: Processed rainfall data, Météo-Bénin, 2024

Figure 9 Annual Rainfall Trends (1980–2021) in the Municipality of Adjohoun

The analysis of Figure 9 shows an increase in interannual rainfall variability over the period 1981–2023. After a decline between 1981 and 1986, indicating deficit years, an increase is observed between 1986 and 1997, followed by another decline until 2007. Since 2008, a marked upward trend indicates surplus years. The highest peak, 2,203.3 mm, was reached in 1997, while the years 2010, 2018, and 2021 recorded 2,005.6 mm, 1,790.4 mm, and 2,203.3 mm, respectively, confirming this trend. This variability has significant impacts on the Adjohoun community. Surplus years favor agriculture, particularly rice cultivation, increasing yields and income. Conversely, deficit years reduce water availability, compromising agricultural activities. Excessive rainfall also leads to flooding, affecting infrastructure and livelihoods. Effective management of this variability is essential to strengthen local resilience. Figure 10 presents the rainfall indices from 1980 to 2023 for the Municipality of Adjohoun.



Source: Processed rainfall data, Météo-Bénin, 2024

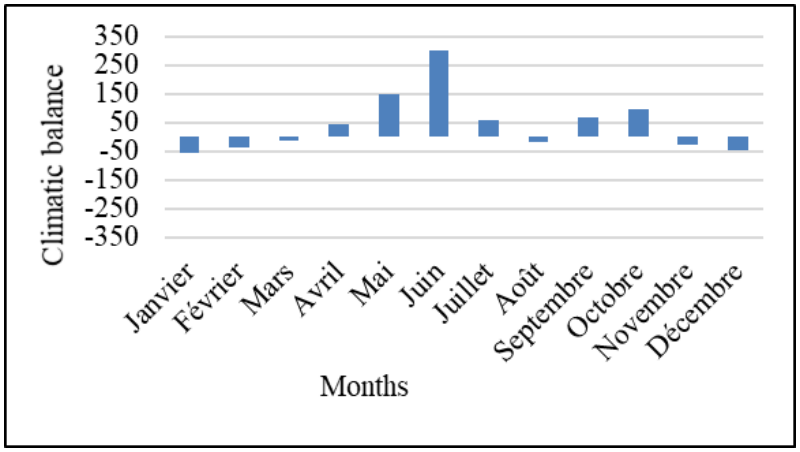
Figure 10 Annual Rainfall Index (1980–2023) in the Municipality of Adjohoun

The analysis of Figure 10 reveals substantial variability in annual rainfall, distinguishing two main sequences: surplus and deficit years. Periods of rainfall decline are marked by pronounced droughts, such as in 1981, 1983, 1984, 1986, and 1998. The years 2000 and 2001 also recorded significant rainfall reductions, reflecting a sustained degradation of the hydrological system, despite a gradual return to more favorable conditions afterward [24].

The results indicate that rainfall plays a key role in sustaining the wetlands of the Municipality of Adjohoun. During surplus years, better-watered wetlands support agricultural activities and strengthen food security. Conversely, deficit years reduce water availability, compromising agricultural productivity and exacerbating the community's economic difficulties. Thus, the annual rainfall index serves as a critical indicator for anticipating hydrological variations and their socio-economic impacts in Adjohoun.

- Climatic Balance

In this study, the climatic balance is calculated as the difference between total precipitation (P) and potential evapotranspiration (ETP). Figure 11 thus illustrates the monthly evolution of the climatic balance in the Municipality of Adjohoun.



Source: Processed rainfall and ETP data, Météo-Bénin, 2024

Figure 11 Seasonal Evolution of the Climatic Balance in the Municipality of Adjohoun

The analysis of Figure 11 shows that the climatic balance is surplus during the months of April, May, June, July, September, and October, whereas the other months record a deficit, due to evaporation exceeding precipitation. These periods correspond to the main dry season, during which reliance on wetlands is essential to cope with water stress. Such climatic conditions often restrict farmers to a single cropping season per year. Figure 12 presents the climatic challenges associated with wetland exploitation in the Municipality of Adjohoun.

Photograph: KAKA, July 2024

Figure 12 Climatic Challenges of Wetland Exploitation in the Village of HOUEDO-AGUE

Figure 12 highlights the climatic challenges associated with wetland exploitation, particularly flooding and delayed rainfall. These climatic phenomena have significant consequences for the well-being of local communities, affecting not

only food security but also economic stability. Therefore, effective management of wetlands is essential to mitigate these impacts and ensure sustainable socio-economic development in the Municipality of Adjohoun.

3.5. Assessment of the Critical Threshold of Hydro-Climatic Risks in Adjohoun

3.5.1. Assessment of the Critical Threshold of Hydro-Climatic Risks in Adjohoun

The probability of occurrence and severity of these hazards are classified into four levels: very probable, probable, unlikely, and highly unlikely for probability, and catastrophic, very severe, severe, and low for severity. Ratings (1 to 4) were assigned by the surveyed population (Table 7).

Table 7 Typology of Hydro-Climatic Risks

Identified Risks	Probability of occurence	Rating	Severity	Rating	Criticality	Description
Drought	Probable	2	Moyen	3	6	
Flooding	Very probable	4	Grave	3	12	
High water levels	Very probable	4	Grave	4	16	

Source: Results from fieldwork, July 2024

In the commune of Adjohoun, the wetlands are exposed to flood risks and rising water levels, with criticality thresholds of 12 and 16 and a very probable occurrence. In contrast, drought has a moderate severity with a criticality threshold of 6 and is often probable.

3.5.2. Criticality of Flood and Drought Risks

The criticality matrix is expressed as the product of probability and severity (Table 8).

Table 8 Criticality matrix of drought and flood risks

Impact severity / Probaility of risk	1 Limited	2 Moderate	3 Significant	4 Critical
4 (Very probable)	4	8	12	16
3 (probable)	3	6	9	12
2 (Fairly-probable)	2	4	6	8
1 (Low-probability)	1	2	3	4

Source: Field surveys, July 2024

Analysis of Table 8 indicates that the criticality indices, based on their magnitude, allow for the definition of risks (ranging from limited to critical). Thus, the severity of hydro-climatic risks in the commune of Adjohoun depends on rainfall and temperature levels. For instance, the higher these levels, the more significant the hydro-climatic risks, reaching critical levels (falling above the Farmer curve category) with probabilities of occurrence ranging from unlikely to very likely.

3.6. Biological Impacts

3.6.1. Biological Impacts

The biodiversity of Adjohoun's wetlands presents both benefits and challenges for the community. On one hand, it supports pollination, pest regulation, and provides essential resources such as fish and timber, contributing to income generation and food security. However, it also imposes constraints. Weed invasion of fields, exacerbated by manual tillage, complicates agricultural management. Granivorous birds, as well as pests such as cane rats, rats, and hares, cause significant losses, particularly in rice and maize crops. Figure 13 illustrates invasive weeds in the wetlands of the village of Sokpetinkon.

Photograph: KAKA, July 2024

Figure 13 Weeds in the wetlands of Sokpetinkon village

Figure 13 illustrates a field overrun by weeds, which reduces agricultural yields. This invasion negatively affects farmers' income and compromises local food security. Therefore, the exploitation of wetlands relies on effective management of these environments, notably through adapted agricultural practices such as agroecology. Adequate weed control can enhance productivity, ensure stable incomes, and strengthen the sustainable development of local communities.

3.6.2. Socio-Economic Impacts

The exploitation of wetlands in the commune of Adjohoun generates significant socio-economic impacts, both positive and negative. On the positive side, it contributes to improved agricultural income due to the natural fertility of the soils, which supports high yields for crops such as rice and vegetables. It also diversifies livelihoods through artisanal fishing, extensive livestock farming, and the collection of non-timber forest products, such as medicinal plants and timber.

These activities support food security and create employment opportunities, particularly for youth and women. Furthermore, wetlands provide essential ecosystem services, such as hydrological regulation, water filtration, and biodiversity conservation, which sustainably benefit local communities.

However, wetland exploitation can also lead to negative impacts. Intensive or poorly managed use may degrade natural habitats, threatening biodiversity. Conflicts between farmers, fishers, and other users can create social tensions. Additionally, poor wetland management can exacerbate flood risks, affecting homes and infrastructure. Finally, implementing sustainable management requires significant investments, which are often difficult for local communities to mobilize.

3.6.3. Analysis of Fluvial Sand Production and Profitability

The commune of Adjohoun hosts several sand extraction sites (both fluvial and lateritic), exploited by youth, women, and men. Fluvial sand extraction is labor-intensive, carried out in a three-group chain system: young men, commonly called divers, extract sand from the river and transport it to the shore by canoe; women unload the canoes; and a final team of young men handles truck loading. The technique is artisanal and involves diving to the riverbed to collect sand using buckets.

The canoe is immobilized using ropes tied to two long wooden stakes, one end anchored in the riverbed. Interviewed sand workers reported that each diver and direct extractor pays the wharf owners 1,000 CFA francs daily. According to surveys, a landowner can earn up to 120,000 CFA francs per month, or more during peak activity periods. Sale prices vary depending on the flood or low-water season, the distance transported, and applicable taxes.

The sand extracted in Adjohoun is primarily sold to buyers in various localities across the Ouémé and Plateau departments. The main transport methods are ten-wheel 12 m^3 trucks and six-wheel 7 m^3 trucks, with on-site loading prices varying according to flood or low-water periods. Table 9 summarizes the sale prices for loaded trucks during these periods, regardless of the buyer's origin.

Table 9 Sale prices of fluvial sand in Adjohoun per loaded truck (six-wheel and ten-wheel) during flood and low-water periods

Quantity / Period	Flood season / High-water period	Low-water period / Receding season
7 m^3	25000 à 30000	14000 à 20000
12 m^3	40000 à 50000	28000 à 30000

Source: Field survey, July 2024

In Adjohoun, divers, female unloaders, and loaders serve as laborers employed by the quarry operators. The average daily remuneration is 1,000 CFA francs per diver, 1,000 CFA francs per female unloader, and 1,500 to 2,000 CFA francs per six-wheel truck loaded by a group of 4 or 5 loaders. Each group can load up to 4 trucks per day; thus, an individual can earn between 1,500 and 4,500 CFA francs per day (Table 10).

Table 10 Average individual income per laborer for a six-wheel truck

Laborers	Average Daily Income
Divers	1 5000 à 2 000
Loaders	1 500 à 4 500
Female unloaders / Collectors	8 000 à 1 200

Source: Field survey, July 2024

The benefits derived from this activity help address certain social needs, such as the purchase of food, houses or land, motorcycles, canoes, furniture, or household appliances, as well as funding children's education, traditional bride price or ceremonies, and savings, among others.

3.7. Sustainable Measures for the Valorization and Exploitation of Wetlands

3.7.1. Traditional Measures

In the commune of Adjohoun, several deities play a significant role in the preservation of wetlands by combining spiritual, cultural, and environmental influences. These sacred figures impose environmentally respectful practices, promoting sustainability. Among them:

- Oro: Protector of forests and sacred natural resources, Oro strictly prohibits hunting, deforestation, and any activity that disrupts the ecological balance of wetlands. His cult helps preserve natural habitats and species.
- Egoun: Symbolizing ancestral spirits, Egoun is honored through rituals and offerings. These practices reinforce respect for the environment and wetlands, promoting sustainable ecosystem management.
- Zangbeto: A community guardian and protector of safety, Zangbeto positively influences the management of natural resources. His sacred presence encourages practices that integrate wetland protection into local traditions.
- Dan: Deity of water and fertility, Dan is invoked to preserve the purity of water and land. His rituals value wetlands as key habitats for biodiversity and sources of vital resources.
- Sakpata: God of the earth and health, Sakpata is venerated through purification and healing rites. These practices prohibit pollution and promote the health of terrestrial and aquatic ecosystems.

3.7.2. Modern Measures for Wetland Exploitation

For integrated and sustainable management of wetlands in Adjohoun, modern measures complement scientific approaches and traditional practices. These measures, adapted to current needs and challenges, include:

- Constructing retention basins to regulate water levels and reduce flood risks.
- Restoring natural retention areas to strengthen their role in water management.
- Using Geographic Information Systems (GIS) and hydrological modeling tools to monitor and anticipate water level variations.

- Integrating modern agricultural techniques, such as precision rice farming with soil sensors, automated irrigation systems, and drones, to optimize resource use while minimizing environmental impact.
- Encouraging intercropping systems to enhance soil resilience, reduce pesticide use, and increase biodiversity.
- Implementing rehabilitation projects for degraded wetlands, including planting local vegetation and restoring aquatic habitats.
- Adopting adaptive fisheries management, including stock monitoring and the establishment of protected areas for fish population regeneration.
- Developing sustainable aquaculture in controlled ponds to reduce pressure on natural habitats and enhance food security.
- Encouraging local tourism businesses to obtain ecological certifications and adopt environmentally friendly practices.
- Raising visitor awareness of the ecological value of wetlands and best conservation practices.
- Promoting collaboration among governments, NGOs, businesses, and local communities for coordinated and effective management.
- Creating mobile applications for water resource management, biodiversity data collection, and conservation education.

4. Discussion

The aim of this study is to contribute to the understanding of the socio-economic impacts of wetland exploitation in the commune of Adjohoun. According to 82% of producers, several types of wetlands characterize the study area, including lowlands (54%), floodplains (24%), marshes (14%), and temporary swamps (8%). These findings are consistent with those of [22], who report that in West Africa, wetlands include lakes, rivers, floodplains, temporary marshes, swamp forests, mangroves, intertidal areas, and coastal lagoons. Thus, the exploitation of these wetland ecosystems generates significant impacts in the study area due to their multiple functions. According to 85% of producers, this results in high yields due to soil fertility and the availability of diverse natural resources supporting socio-economic activities. This aligns with [6], who indicate that in southern Benin, wetlands impact local communes through their richness and diversity, grouped into four functions: ecological and regulatory, socio-economic, tourism, and domestic/medicinal uses.

To address negative impacts and promote sustainable and integrated management, measures for the valorization and management of wetlands have been developed, including the construction of hiking trails, ecological infrastructure, and the promotion of recession rice farming. These results align with the work of [26], who emphasizes that optimizing productive resources in wetlands requires strengthening the capacities of agricultural operators. This synthesis demonstrates that wetlands are not environments to be ignored but rather to be sustainably exploited and valorized. Such exploitation, however, is not without environmental impacts, particularly on the socio-economic sector, which justifies the proposed solutions mentioned above.

5. Conclusion

The research on the socio-economic impacts of wetland valorization in the Municipality of Adjohoun contributes to a better understanding of the importance and effects of wetlands. It highlights the presence of several types of wetlands, including lowlands, floodplains, ponds, swampy areas, and temporary marshes. These ecosystems provide both ecosystemic and socio-economic services to the users, who in turn exert significant pressure on these wetlands to meet their diverse needs, often without considering the resulting consequences.

For a long time, wetlands in Adjohoun were perceived by local residents and sustainable development specialists as sterile and unhealthy environments, breeding grounds for diseases, mosquitoes, and crocodiles. However, over the past few decades, they have been recognized as among the most important ecosystems on the planet. Their significance stems from numerous benefits and services, including biodiversity richness, habitat for migratory species, water filtration, flood reduction, protection of agricultural lands, increased income for various stakeholders, and reduction of extreme poverty within the community. To demonstrate the true value of wetlands, the community of Adjohoun has engaged in multiple valorization activities, such as recession and off-season agriculture, artisanal fishing, integrated aquaculture, exploitation of timber and natural resources, handicrafts derived from wetland resources, as well as various NGO and government projects. Nevertheless, intensive exploitation of these wetlands has led to environmental challenges, including soil degradation, progressive loss of biodiversity, water scarcity or excess during flowering or maturation periods, hydric stress reducing productivity, and the invasion of wetlands by invasive weeds. In light of these issues, and in pursuit of integrated and sustainable wetland management in Adjohoun, several valorization measures have been proposed, including: raising tourist awareness of the beauty and value of wetlands; constructing

ecological infrastructures; promoting local handicrafts and culinary specialties; organizing festivals and cultural events celebrating local traditions and wetland-related practices; encouraging recession rice cultivation; installing water management infrastructures; training farmers in sustainable agricultural practices; and fostering partnerships among the government, NGOs, businesses, and local communities to develop integrated projects that combine wetland conservation, sustainable agriculture, and tourism.

Compliance with ethical standards

Acknowledgments

The authors acknowledge their own contributions to the preparation of this article, including data collection, processing, analysis, as well as proofreading and translation into English.

Disclosure of conflict of interest

There is no conflict of interest among the authors of this article.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study

References

[1] Adigbegnon M, Totin Vodounon SH, Amoussou E, Houndenou C, Boko M. Facteurs climatiques et anthropiques de la désertification dans le domaine du climat de transition au Bénin. In : Les échelles spatiales et temporelles fines. Actes du XXXIe Colloque de Nice, 4–7 juillet 2018.

[2] Aspe C, Jacqué M. De l'approche patrimoniale à la gestion durable des forêts : l'entrée « biodiversité » comme nouveau canon d'appréhension du réel. Forêt méditerranéenne. 2012; 33(2):193–200.

[3] Attiyimi R. Gestion durable des zones humides du sud du Bénin : inventaire et dynamique des unités d'occupation du sol 1989 et 2019 [mémoire]. 2020. 69 p.

[4] Badolo M. Cahier des changements climatiques. Bull Mens Inf Chang Clim Inst Appl Vulgar Sci. 2009;(5):1–25.

[5] Biaou AO. Organisation sociale des communautés d'acteurs autour des forêts sacrées du site Ramsar 1018.

[6] Brun LE, Gibigaye M, Tente BA. Valorisation des zones humides de la commune d'Allada (Sud Bénin). Rapport. 2021. 18 p.

[7] Cakpo EA. Gestion de l'environnement du lac Ahémé [mémoire]. 2015. p. 7–15.

[8] Czamanski M, Nugraha A, Pondaven P, Lasbleiz M, Masson A, Caroff N, Tréguer P. Carbon, nitrogen and phosphorus elemental stoichiometry in aquacultured and wild-caught fish and consequences for pelagic nutrient dynamics. Mar Biol. 2011;158(12):2847–62.

[9] Dessaux N, Revillion S, Delchambre S. Stratégies d'exploitation et mutations du paysage dans la vallée de la Haute Deûle (Nord) : l'exemple du marais de Seclin du XIIIe au XIXe siècle. Rev Nord. 1998;326–327:531–71.

[10] Dhouib M. Effet de la connectivité hydrologique sur l'efficience de l'eau des cultures pluviales méditerranéennes : modélisation et analyse de scénarios – cas du bassin versant de Kamech. Rapport. 2023. 53 p.

[11] Dogbloué J. Impacts liés à la mise en valeur des zones humides dans la commune de Bopa [mémoire]. 2012. 95 p.

[12] Doukpolo B. Changements climatiques et productions agricoles dans l'Ouest de la République Centrafricaine [thèse de doctorat]. Cotonou : Université d'Abomey-Calavi; 2014.

[13] Gohouè S. Culture de contre-saison dans l'arrondissement d'Affamé (commune de Bonou). Rapport. 2017. p. 7.

[14] Hounkpalodo A. Diversité et importance socio-économique de la zone marécageuse de Sèmè-Kpodji : cas des arrondissements d'Ekpè, Djèregbé et Aholodjèmé [mémoire]. 2017. p. 7.

[15] Institut National de la Statistique et de l'Analyse Économique (INSAE). Quatrième Recensement Général de la Population et de l'Habitation (RGPH-4), Résultats définitifs. Cotonou : INSAE; 2013

[16] Missemer A, Levrel H. La mise en économie de la nature : contrepoints historiques et contemporains. Article. 2019.

[17] Mjejra M, Samaali H. Essai de cartographie du risque de stress hydrique dans la plaine deltaïque de l'Oued Majerda (Tunisie). In : Communication au 32e Colloque international de l'Association Internationale de Climatologie : Le changement climatique, la variabilité et les risques climatiques. 2019. p. 229–33.

[18] Organisation météorologique mondiale (OMM), Partenariat mondial pour l'eau (GWP). Manuel des indicateurs et indices de sécheresse. Genève : Programme de gestion intégrée des sécheresses; 2016. (Svoboda M, Fuchs BA, éditeurs). 2e série d'outils et lignes directrices.

[19] Organisation météorologique mondiale (OMM). Guide d'utilisation de l'indice de précipitations normalisé. Genève : OMM; 2012. 35 p.

[20] Saifoun A. État des lieux des zones humides et des oiseaux d'eau en Algérie. Rapport. 2006. 56 p.

[21] Schwartz D. Méthodes statistiques à l'usage des médecins et des biologistes. 4e éd. Paris : Flammarion Médecine-Sciences; 1995. 314 p.

[22] Skinner J, Beaumond N, Pirot JY. Manuel de formation à la gestion des zones humides tropicales. Vol. 272. Gland (Suisse) : UICN; 1994.

[23] Totin Vodounon SH. Sensibilité des eaux souterraines du bassin sédimentaire côtier du Bénin à l'évolution du climat et aux modes d'exploitation : stratégies de gestion durable [thèse de doctorat]. Cotonou : Université d'Abomey-Calavi; 2010. 283 p.

[24] Tsanga R, Assembe S, Lescuyer G, Vermeulen C, Andrew D. Les droits des populations locales et autochtones à l'épreuve des politiques forestières et de conservation. Rapport. 2022. 361 p.

[25] Vissin EW. Contribution à l'étude de la variabilité des précipitations et des écoulements dans le bassin béninois du fleuve Niger [mémoire de DEA]. Dijon : Université de Bourgogne; 2001. 53 p.

[26] Yolou M. Exploitation des bas-fonds dans la commune de Ouaké. Rapport. 2010. 72 p.

[27] Zare A. Variabilité climatique et gestion des ressources naturelles dans une zone humide tropicale : une approche intégrée appliquée au cas du delta intérieur du fleuve Niger (Mali). Rapport. 2015. 26 p.