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Research Article

# Impacts of Climate Variability on Wetland Ecosystem Provisioning Services in the Diang Sub-Division, East Region of Cameroon

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## Abstract

Wetland provisioning services are vital for rural livelihoods in Sub-Saharan Africa, yet they face severe risks from climate variability and unsustainable resource extraction. This study evaluated the impact of climate variability on wetland provisioning services across five communities in the Diang Sub-Division, East Region of Cameroon. The study integrated 35-year meteorological reanalysis data (1990–2025) with questionnaires administered to 150 service extractors including key informant interviews, and field observations. Long-term climate trends, spatial reliance patterns, commodity price inflation, and ecological stress drivers were assessed using Pearson Chi-Square tests and Pearson Product-Moment Correlation. Meteorological analysis revealed significant inter-annual rainfall volatility (averaging 118.43 mm/month with a 96.24 mm deficit between extreme years) and acute dry-season precipitation instability, peaking in January (CV=127.90%), alongside a steady temperature trend ($3.14^0$C range across the series). Household reliance since 1992 was highest for non-timber forest products (NTPs) (70.00%), fuelwood (66.66%), and floodplain agriculture (61.33%). Pearson Chi-Square test confirmed significant spatial disparity in service use across communities ($X_2$=48.62, p <0.001), driven by distance to the Lom River mainstream and local infrastructure deficits. Long-term valuation (1992–2023–Present) demonstrated commodity price expansions between 441.7% and 900.0%. Pearson correlation showed strong positive links between temperature and porcupine prices (r = 0.835, p = 0.005) as well as charcoal (r = 0.749, p = 0.031). Hence, climate variability acts as an environmental multiplier for resource scarcity and climate-induced water table has drops interact with anthropogenic pressures primarily slash-and-burn clearing (61.33%), over-harvesting of raffia stands (67.33%), destructive chemical fishing, and informal mineral panning to drive bank collapse, channel siltation, and deforestation. Consequently, mitigating climate risks on wetland services requires enforcing 50-meter non-clearing riparian buffer zones, formalizing NTFP value addition, deploying low-cost rainwater harvesting/solar irrigation and embedding community conservation bylaws into the Communal Development Plan (*CDP*).

## Keywords

Climate Variability, Socio-Ecological Systems, Resource Governance, Lom River Basin, Wetland Provisioning Services, Diang Sub-Division, Cameroon

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## 1. Introduction

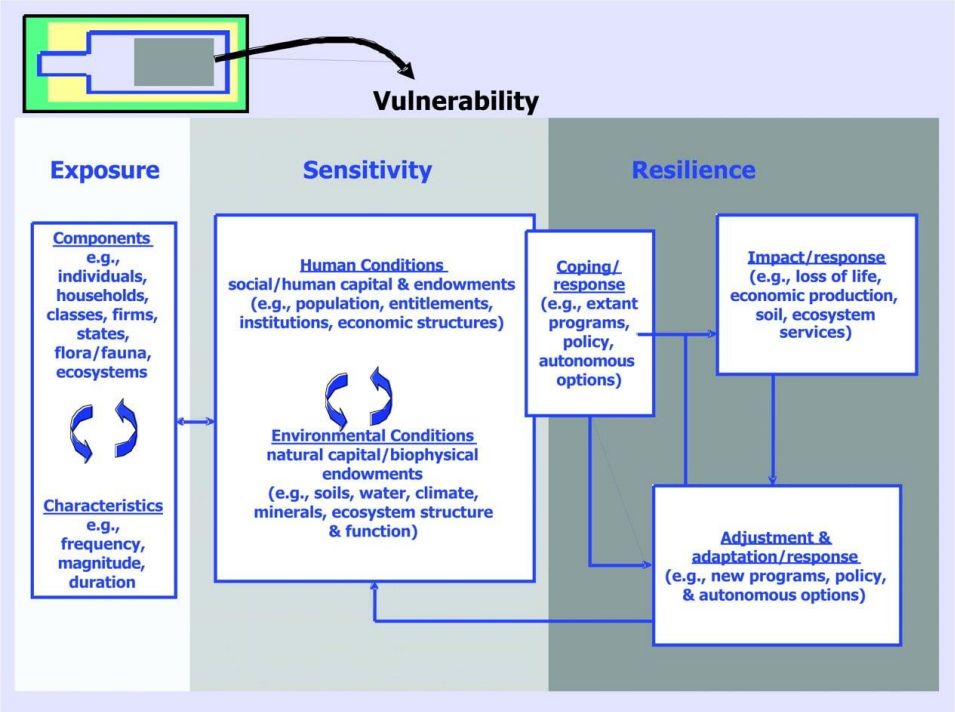
As life-support systems of the biosphere, natural ecosystems generate vital biophysical processes through which natural systems sustain human life and ecologically functions [1, 2]. Under the Ramsar Convention on Wetlands (Article 1.1), wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. Globally, wetlands occupy a critical connection within the dynamic system of the biosphere by regulating flows, filtering nutrients, and storing carbon [3, 4], while hosting over 40% of world biological diversity [5]. The structural character and socioeconomic valuation of wetland provisioning services such as potable water supply, artisanal fisheries, fuelwood, timber, NTFPs, and fertile recession-agriculture land vary across spatial and development gradients. In developed regions across Europe and North America, [6, 7] have documented how industrial expansion severely degraded natural wetland functions, forcing community reliance on capital-intensive engineering and market-based Payment for Ecosystem Services (PES) schemes to restore lost capacity. Across developing contexts, wetland ecosystems serve as immediate safety nets. For instance, [8, 9] have revealed how rural populations depend directly on wetland provisioning services as primary capital inputs for daily survival, food security, and income. In Sub-Saharan Africa, this reliance though vital for rural livelihoods, is acute resulting due to severe risks from climate variability and unsustainable resource extraction. [10, 11] stressed that wetlands operate as socio-ecological oases that face sensitive exposure due to acute poverty, rain-fed agricultural reliance, and climate variability.

Despite their ecological and socioeconomic value, global wetlands now face accelerated degradation from the dual pressures of anthropogenic land-use change and climate variability [12, 13]. Climate variability directly destabilizes wetland ecosystem provisioning services by disrupting localized temperature and hydrological regimes; shifting precipitation patterns and rising temperatures accelerate evapotranspiration, alter seasonal streamflows, and shrink surface water extents [14, 15]. In turn, the degradation of these biophysical processes by human actions diminishes provisioning service yields reducing domestic water availability, depleting fish stocks, lowering wild harvest volumes, and causing crop failure which undermines community-level sustainability efforts, food security, and adaptive capacity [16, 17]. At the national scale, Cameroon lost about 28.3% of its total wetland area between 1980 and 2005 (declining from 272,000 ha to 195,000 ha) [5], corresponding with a national mean temperature rise of 0.7 ℃ and shifting rainfall regimes [18, 19]. Although Cameroon encompasses roughly 92% of African wetland typologies [20], these ecological systems experience severe operational strain as extreme weather events increase [18]. In Diang Sub-Division of the East Region, the relationship between climate variability, provisioning service, and compromised community sustainability presents an urgent socio-ecological challenge. Within the Lom River basin and its surrounding floodplains, rural households depend directly on wetland provisioning services for crop irrigation, artisanal fishing, NTFPs harvesting, and domestic water extraction [18, 21]. However, recent climate projections indicate a shift toward short, violent rainfall events separated by extended dry spells [18, 22]. This climate variability alters localized hydrological regimes, triggering alternating cycles of floodplain inundation and acute water scarcity that lead to declining crop yields, depleted fish stocks, dried domestic water sources, loss of sacred cultural sites, and an increased incidence of waterborne diseases like cholera [18, 21].

This socio-ecological vulnerability in Diang is further compounded by critical literature and multi-scalar policy gaps across diversified governance levels. Globally, frameworks such as the Ramsar Convention on Wetlands and the United Nations Sustainable Development Goals (SDGs 13 and 15) emphasize wetland conservation but fail to establish binding mechanisms or funding streams tailored to non-protected, inland rural floodplains in developing countries [5]. The African Union's Agenda 2063 and Ramsar Regional Initiatives prioritize macro-level transboundary river basins, leaving smaller, sub-national sub-basins without institutional oversight or climate-resilient management guidelines [23, 24]. The Ministry of Water Resources and Energy (MINEE) and the Ministry of Environment, Protection of Nature and Sustainable Development (MINEPDED) concentrate policy implementation on industrial, urban, or coastal environments [18, 25], omitting inland forest-savanna transition zones like Diang Sub-Division from national adaptation agendas. Local authors such as [26], overwhelmingly focuses their study on coastal, estuarine, leaving a void regarding how climate variability directly alters rural household resource extraction patterns and provisioning service yields in inland transition zones over time while (2022) [27] investigate the impact of precipitation variability and land use change on the hydrological dynamics of the Nyong river and its tributaries. Consequently, lack of localized literature exists indicating how ongoing climate variability impacts wetland provisioning services and frustrates community sustainability efforts. The authors fill an important data gap by highlighting how the lack of centralized infrastructure in peripheral villages increases direct ecosystem dependency. This study also bridges this gap by assessing the impacts of climate variability on wetland ecosystem provisioning services in the Lom River floodplains of the Diang Sub-Division. This paper delivers actionable; community-level adaptation strategies that can help stakeholders safeguard, manage wetland provisioning services, support sustainability efforts, and secure rural livelihoods.

## 2. Theoretical Framework

The Vulnerability Framework for Sustainability Science [28] embedded in Intergovernmental Panel on Climate Change (IPCC) assessments was used to conceptualize human communities and ecological systems as coupled socio-ecological systems (SES). This model recognizes that environmental perturbations ripple dynamically through social structures, directly influencing household resource security, agricultural productivity, and rural livelihoods [28, 29]. The framework hypothesized that the overall vulnerability (V) of a socio-ecological system is a function of exposure, sensitivity, and adaptive capacity. Exposure measures the degree, duration, and spatial extent to which a system experiences physical climate perturbations or long-term environmental stress, such as rising thermal trends, shifting precipitation regimes, or severe droughts [30]. Sensitivity represents the degree to which a socio-ecological system is affected, either adversely or beneficially, by climate-related stimuli. This component is dictated by intrinsic system characteristics, including structural resource dependence and infrastructure availability [28]. Adaptive capacity however, denotes the ability of institutions, human communities, and ecosystems to adjust to environmental change, mitigate potential damage, take advantage of emerging opportunities, or cope with functional disruptions [29]. A central mechanism of the framework is dynamic feedback loops, wherein human pressures such as riparian vegetation clearing and resource over-extraction amplify biophysical sensitivity. When exposed to climate shocks, a degraded ecosystem loses its structural buffer capacity; triggering negative feedback loops that result in degradation and rural poverty.




Source: Adapted from [28].

***Figure 1.*** *Details of the exposure, sensitivity, and resilience components of the vulnerability framework.*

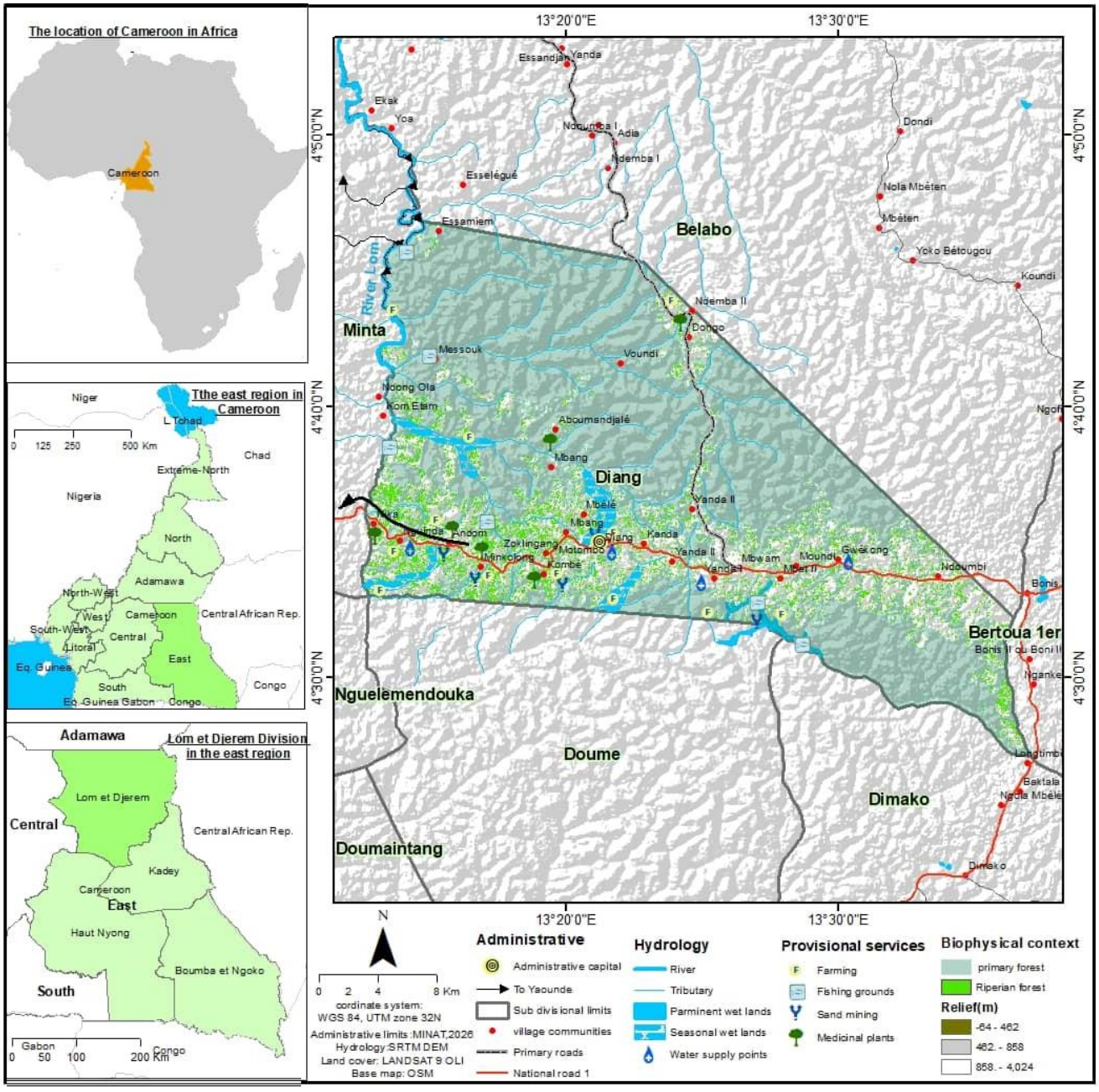
The socio-ecological dynamics give rise to vulnerability in the wetlands of the Diang Sub-Division includes regional temperature increases, shifting onset dates of seasonal rains, and prolonged dry spells. These climatic shifts have directly stressed the hydrological regimes of River Lom, its secondary tributaries, and low-lying valley floodplains across communities like Diang, Bouam and Moundi. As a transitional environment the local populations in the study area have exhibited high sensitivity due to their direct reliance on wetland, rivers and the floodplains for domestic freshwater, recession agriculture, artisanal fisheries and NTFPs like raffia (*Raphia sp.*). The absence of piped water networks and alternative food distribution channels heightens household sensitivity to hydrologic fluctuations. Amidst these sensitivities, individuals and communities have adopted several coping strategies, traditional resource management practices, and formal institutional oversight. However, currently, unsustainable land management such as riparian deforestation and destructive agricultural practices has eroded the natural capacity of wetlands to attenuate floods and filter pollutants. This has created a negative feedback loop where extreme rainfall triggers flash floods, washes away crops, and water pollution. To overcome these

challenges, institutional responses from local traditional councils and MINPADD was used to provide baseline adaptive capacity to the communities.

## 3. Methodology

### 3.1 Study Area

Diang Sub-Division is located in Lom and Djérem Division of the East Region of Cameroon (Figure 2). It is situated between Latitudes 4°30' and 4°50' N and Longitudes 13°10' and 13°40' E and covers almost 3,500 km ²and covering 25 distinct settlements with a population of nearly 20,000 inhabitants [31, 32]. The area falls within a Guinean equatorial forest-savanna transition zone drained by the primary axis of the Lom River and secondary tributaries including the Nyan, Sess, Medoumdang, and Tsang streams. Bounded by hydromorphic soils in valley bottoms and low-lying floodplains, these riverine zones sustain extensive marshy vegetation (Maranthaceae, Zingiberaceae, and Raphia sp.) that provides vital provisioning ecosystem services for local agricultural, domestic, and artisanal extractive activities.




Source: Adapted from the Administrative Map Unit of Cameroon, 2016.

***Figure 2.*** *Location of Sampled wetland ecosystems and provisioning services survey Study Sites in Diang Sub Division, Lom-et Djerem Division, East Region of Cameroon.*

## 3.2. Sampling Framework and Justification

A multi-stage non-probability sampling technique was used to capture household-level resource reliance among active wetland users. In the first stage, five wetland-adjacent communities (Table 1) were purposively selected based on their spatial proximity to Lom River basin and their high economic dependence on seasonal floodplain resources. In the second stage, active resource extractors (farmers, fishers, hunters, fuel/timber harvesters, and craftspeople) were identified using municipal registration records from the Diang Council, establishing an accessible target frame of about 6030 primary extractors from an estimated local population of 6030 inhabitants [31]. To maximize field operational efficiency and ensure representative coverage across dispersed working environments, convenience sampling was deployed to select 150 respondents from this accessible frame. This yielded a sampling intensity of 60% of active extractors, ensuring sufficient statistical power for sub-division level descriptive and inferential analyses. Questionnaires were administered proportionally across the five sites based on localized population densities and extraction activity levels (Table 1).

***Table 1.*** *Administration of Questionnaire to Respondents across Selected Wetland Sites.*

| Wetland Site | Estimated active Resource Extractors | Number of Questionnaires | Percent (%) | Primary Extraction Activities |
|---|---|---|---|---|
| Yanda | 8,00 | 20 | 13.33 | Intensive market-oriented recession agriculture, major artisanal fishing and heavy NTFP extraction |
| Mbeth | 3,60 | 9 | 6 | Heavy reliance on wetland provisioning services, water supply, urban-fringe vegetable cultivation and fuelwood collection. |
| Bouam | 2,500 | 62 | 41.33 | Floodplain crop irrigation, small-scale subsistence fishing, and timber/fuelwood harvesting. |
| Diang | 2,050 | 51 | 34 | Low-intensity, subsistence farming, wild fruit/medicinal plant harvesting, and domestic water sourcing. |
| Mundi | 3,20 | 8 | 5.33 | Subsistence resource extraction, low-volume seasonal fishing, and smallholder floodplain farming. |
| Total | 6,030 | 150 | 100 | - |

Source: Fieldwork, 2026.

As shown in Table 1, Bouam (41.33%) and Diang (34.00%) account for 75.33% of the households, reflecting their status as the principal demographic and socio-economic centers of the Lom River floodplain in Diang Sub-Division. Conversely, peripheral communities such as Yanda, Mbeth, and Mundi were allocated smaller sample sizes proportional to their smaller population baselines and lower overall extraction volumes, ensuring a balanced representation across the study area.

## 3.3. Data Collection Instruments

Primary data were collected through structured household questionnaires, key informant interviews, and systematic direct field observations. The administered questionnaire instruments comprised standardized closed- and open-ended modules designed to measure household demographic profiles, types of provisioning services extracted, reliance trends, and observed environmental changes. The face-to-face key informant interviews were conducted with traditional quarter heads and local council representatives. Their responses were used to contextualize the historical resource management practices and institutional governance. Field observations which involved photo-documentation were used to identify and determine the extracted goods such as raffia crafts, timber, and irrigation infrastructure used by households. Secondary climate data comprising monthly total precipitation and mean surface temperature spanning 1990 to 2025. These data were acquired from the NASA Prediction of Worldwide Energy Resources (POWER) meteorological database and was used to establish baseline climate trends for the sub-division.

## 3.4. Statistical Analysis and Multi-Response Metrics

Meteorological data were processed to compute annual/seasonal mean trends, moving averages, and climate variability metrics, with rainfall reliability evaluated using the Coefficient of Variation ($CV = \sigma/\mu x100$). Socio-economic questionnaire data were analyzed using SPSS (Version 26.0). Due to

multiple provisioning services harvested by households to sustain their livelihoods (a single household engaging in farming, fuelwood collection, and freshwater fetching), the surveyed questions regarding resource utilization were structured as multiple-response items. Consequently, category frequencies (N) represent the total number of households utilizing a specific service, and reported proportions (%) reflect the percentage of total respondents (150) engaging in that activity. Absolute counts across categories do not sum to 150 questionnaires, and cumulative percentages exceed 100%. To quantitatively validate the relationship between historical climate variability, localized environmental stress, and the economic dynamics of wetland provisioning services, inferential statistical models were executed. Chi-Square ($X_2$) tests of independence were deployed to evaluate spatial differentiation of resource extraction across communities, while Pearson Product Moment Correlation was used to test the relationship between climate variable and wetland services weekly market price volatility for key wetland provisioning goods (NTFPs, fish, and raffia products) across local markets.

### 3.5. Limitations of the Study and Ethical Considerations

Assessing historical changes in ecosystem service provisioning across extended retrospective timeframes (1992 -2025) relies on self-reported respondent memory, which is subject to recall decay and temporal imprecise perception. The non-probability sampling design targeted known, active resource extractors (150 out of 6,030 registered extractors) rather than a simple random sample of the general sub-divisional population (20,000). While this maximizes data richness regarding extraction practices, results reflect the dynamics of active wetland-dependent groups rather than non-extractive rural households. Gridded NASA POWER climate datasets were utilized to overcome the absence of functional, continuous ground-level meteorological stations in Diang. Although validated for regional climate trends, gridded reanalysis data may introduce minor spatial smoothing compared to localized micro-climate variations within valley floodplains. Prior to field data collection, formal administrative authorization was secured from the Diang Municipal Council and local traditional village authorities. Informed consent was verbally obtained from all survey respondents and key informants after explaining the research objectives, ensuring voluntary participation and the right to withdraw at any time without penalty. To safeguard participant privacy, all socioeconomic data were anonymized, stored securely, and processed strictly in aggregate form.

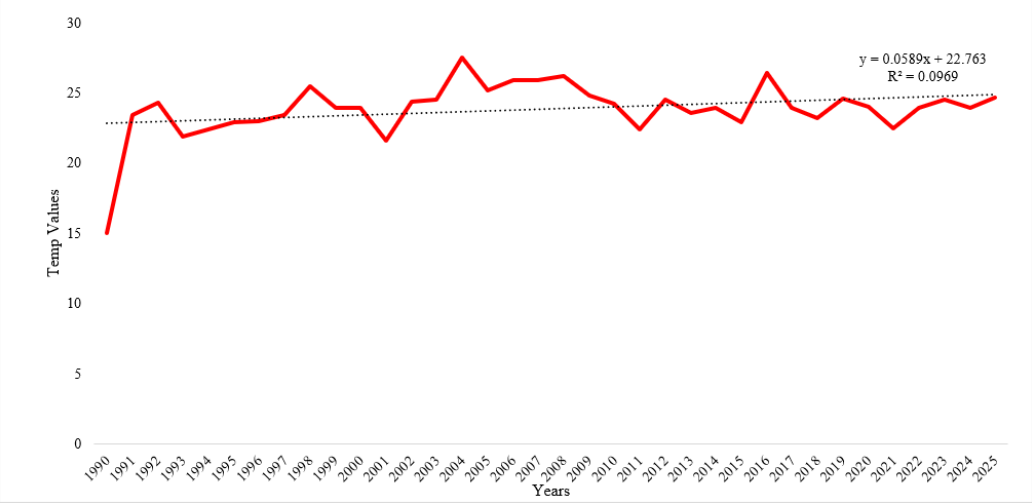
## 4. Results and Discussions

### 4.1. Climate Variability (1990–2025)

Diang Sub Division has two distinct seasons that is raining and dry season. Rains set from between mid-March and last till mid-November where the dry season begins from mid-November to mid-March. The rainy season is characterized by heavy downpours while the dry season is characterized by little or no rainfall. Temperatures also fluctuate with respect to season, and yearly differences. The variations in the climate of Diang in the past 30 years (1990 to 2020) are elaborated as follows.

#### 4.1.1. Annual Temperature Variability

Through a full examination of annual temperature variability, the study seeks to provide a deeper understanding of the dynamics at play and their implications for climate trends and variability over time. Temperature has been variable over Diang Sub Division during the period of study (1990-2020). Figure 3 showed the annual mean temperature variability over the study area.



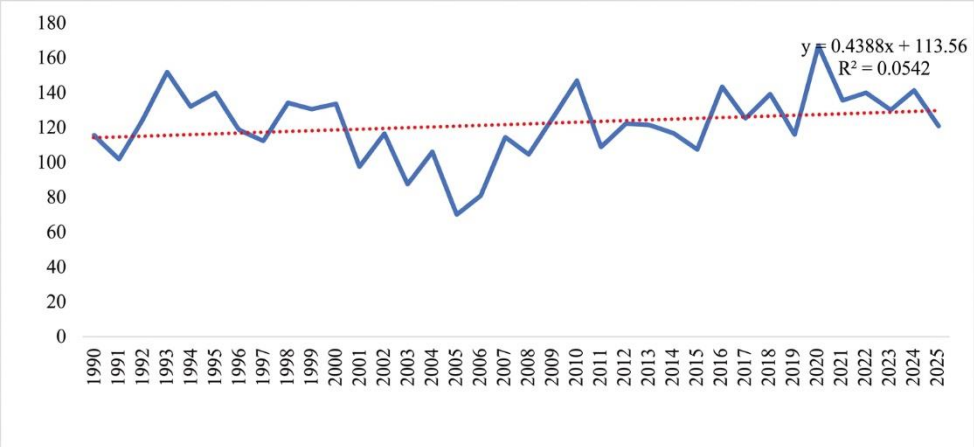

Source: Fieldwork, 2026 from NASA.

***Figure 3.*** *Annual Mean Temperature Variability.*

Figure 3 showed that temperature was highly variable during the study period (1990–2020), with mean annual temperature ranging from 22.78 ℃ to 25.92 ℃. The lowest temperature was recorded in 1992 (22.78 ℃), while the highest occurred in 2005 (25.92 ℃), representing a difference of 3.14 ℃ between the coolest and warmest years. Despite these fluctuations, the trend line indicates a general increase in temperature, suggesting a gradual warming of the study area. This reflects the [33] report which noted a widespread increase in global surface temperature and associated changes in hydrological processes which has increase evapotranspiration and alter water availability, potentially affecting provisioning services. [34] similarly noted that temperature changes can influence wetland hydrology and ecological functioning.

### 4.1.2. Annual Rainfall Variability

In Diang Sub-Division, variations in rainfall from year to year affect the amount of water available for agriculture, fishing, domestic use and other wetland-based activities. The annual rainfall pattern for the study period is presented in Figure 4.



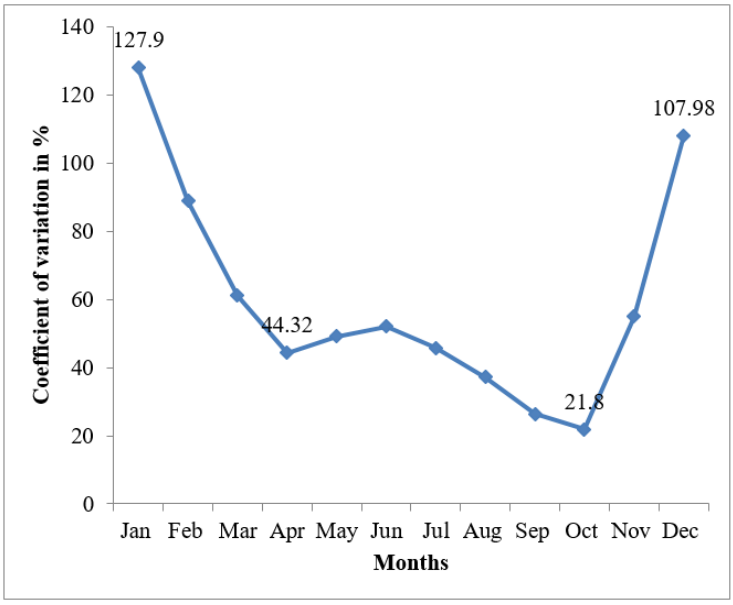

Source: Fieldwork, 2026 from NASA.

***Figure 4.*** *Changes in Annual Mean Rainfall in the East.*

As seen on Figure 4, the annual mean rainfall was highly variable in Diang Sub-Division during the study period, with an overall mean of 118.43 mm. The highest annual rainfall was recorded in 2020 (166.55 mm), followed by 1993 (151.61 mm) and 2010 (147.21 mm), while the lowest occurred in 2004 (70.31 mm), giving a difference of about 96.24 mm between the wettest and driest years. This marked variation indicates that the amount of rainfall available to wetlands changes considerably from year to year. Such variability is important for provisioning services because rainfall determinant their reliability, availability and quality. [34] noted changes in precipitation patterns and resultant effects on agriculture. Similarly, [5] stressed that changes in rainfall and water regimes affects the capacity of wetlands to maintain services.

### 4.1.3. Seasonal Rainfall Variability

Seasonal rainfall plays an important role in determining water availability and the functioning of wetlands in Diang Sub-Division. The area experiences two main seasons, namely the rainy season and the dry season, with rainfall patterns varying considerably between these periods. During the rainy season, moisture-laden south-westerly winds from the Atlantic Ocean contribute to rainfall, which is further influenced by the surrounding relief. These seasonal variations in rainfall support agriculture, fishing, freshwater collection and others. The seasonal pattern of rainfall variability is presented in Figure 5.




Source: Fieldwork, 2026 from NASA.

***Figure 5.*** *Changes in Monthly Rainfall CVs in Diang Sub Division.*

Figure 5 showed substantial variation in the reliability of monthly rainfall in Diang Sub-Division. The coefficient of variation (CV) was highest in January (127.90%), followed by December (107.98%), while relatively high variability was also recorded in February (about 88%). In contrast, rainfall was more consistent from April to October, with the lowest CV recorded in October (21.80%). The sharp increase in CV from October through December and January indicates that rainfall becomes considerably less reliable during the transition into the dry season. This variability has important implications for wetland provisioning services because less reliable rainfall reduces wetland water availability and affects freshwater supply, fishing, wetland agriculture and the availability of wetland vegetation. [35] emphasized that wetland functioning is strongly dependent on hydrological variability, while [5] noted that changes in precipitation and water regimes can affect the ecological character and services provided by wetlands. The patterns observed in December and January suggests a period of greater water stress for Diang's wetlands, potentially reducing the reliability of water-dependent provisioning services.

## 4.2. Identification and Spatial Distribution of Wetland Provisioning Services

Wetlands in Diang Sub-Division provide a range of vital provisioning services that contribute directly to the livelihoods enhancements of individuals and communities over time with distinct spatial variations. These services include food, freshwater, fuelwood, timber, medicinal plants, agricultural products and other materials obtained from the wild. The importance of these services changed over time in response to variations inhuman and environmental conditions. Table 2 presented the reported provisioning services across four periods, allowing changes in their occurrence or use to be examined from 1992 to 2025.

***Table 2.*** *Changes in Wetland Ecosystem Provisioning Services.*

| **Year/ Provisioning services** | **1992** | | **1992-2002** | | **2003-2022** | | **Current** | |
|---|---|---|---|---|---|---|---|---|
| **Service Type** | **N** | **%** | **N** | **%** | **N** | **%** | **N** | **%** |
| Hunting preys | 6 | 4 | 31 | 20.66 | 32 | 21.33 | 81 | 54 |
| Gathering/picking up goods | 5 | 3.33 | 7 | 4.66 | 33 | 22.00 | 105 | 70 |
| Fishing | 7 | 4.66 | 13 | 8.66 | 57 | 38 | 73 | 48.66 |
| Timber | 7 | 4.66 | 5 | 3.33 | 59 | 39.33 | 79 | 52.66 |
| Fuel/wood | 1 | 0.6 | 3 | 2 | 51 | 34 | 100 | 66.66 |

| Year/ Provisioning services | 1992 | | 1992-2002 | | 2003-2022 | | Current | |
|---|---|---|---|---|---|---|---|---|
| **Service Type** | **N** | **%** | **N** | **%** | **N** | **%** | **N** | **%** |
| Medicinal and cosmetic plants | 8 | 5.33 | 12 | 8 | 47 | 31.33 | 83 | 55.33 |
| Livestock | 1 | 0.6 | 4 | 2.66 | 58 | 38.66 | 87 | 58 |
| Agriculture | 5 | 3.33 | 4 | 2.66 | 49 | 32.66 | 92 | 61.33 |
| Fresh water | 3 | 2 | 7 | 4.66 | 61 | 40.66 | 82 | 54.66 |
| Fiber crops | 3 | 2 | 5 | 3.33 | 41 | 27.33 | 101 | 67.33 |
| Tree plantations | 0 | 0 | 0 | 0 | 69 | 46 | 81 | 54 |

Fieldwork, 2026.

Table 2 indicated a marked increase in the reported importance or use of wetland provisioning services from 1992 to the present. In 1992, all services recorded relatively low proportions, with medicinal and cosmetic plants having the highest percentage (5.33%), followed by fishing and timber (4.66% each). During 1992–2002, the proportions remained generally low, although hunting increased to 20.66%. A substantial increase occurred during 2003–2022, particularly for tree plantations (46%), fresh water (40.66%), timber (39.33%), fishing (38%), livestock (38.66%) and fuelwood (34%). Currently, gathering/picking up goods (70%), fuelwood (66.66%), fibre crops (67.33%), agriculture (61.33%) and livestock (58%) are among the most reported provisioning services. This pattern suggested that wetlands have become increasingly important for a broad range of livelihood resources. The results agreed with [1, 8] who identified wetlands as important sources of livelihood. However, [5] noted that climate change can alter wetland ecological conditions and services delivery to the population. Thus, the increasing range and reported use of provisioning services in Diang Subdivision have demonstrated the important livelihood role of wetlands, while also highlighting the need for their sustainable management.

### 4.2.1. Freshwater Provisioning Services

Freshwater is an important provisioning service provided in Diang Sub-Division, with 54.66% of respondents reporting its current availability (Table 2). The service is particularly critical for the population of Mbeth, Yanda and Moundi communities, where functional water supply infrastructures from CAMWATER are limited. In Bouam Community for instance, residents are reported trekking into the valley of the CFR de Bouam to fetch water from wetland streams for diverse household purposes due to water scarcity during the dry season (Figure 6).




Source: Fieldwork, 2026.

***Figure 6.*** *Community members washing clothes directly in a stream in Bouam.*

Figure 6 showed domestic water use in a stream provided by the wetlands. Although streams were historically larger and provided relatively good-quality water, declining water-table levels due to climate and environmental changes have increasingly affected agricultural irrigation. Furthermore, farmers have consequently adopted motor pumps and boreholes constructed through interventions by IITA Enable Youth Cameroon and other NGOs as alternative strategies to supplement water availability. The importance of freshwater provisioning in Diang is consistent with the established role of wetlands in storing, regulating and supplying water to surrounding communities [1, 5]. However, the reported decline in water availability and increasing dependence on pumping are important in the context of the rainfall variability. Changes in the amount and timing of rainfall can affect streamflow, groundwater recharge and wetland water levels, thereby influencing the reliability of freshwater for domestic and agricultural use. [35] argued that changes in wetland hydrological regimes can significantly affect ecosystem functioning and the services derived from wetlands. Thus, the 54.66% current dependence on freshwater provisioning demonstrated the continued livelihood importance of wetlands while also highlighting their vulnerability to changing hydrological conditions.

### 4.2.2. Food Provisioning Services

Wetlands have contributed substantially to food provisioning in Diang Sub-Division through fishing, hunting and agriculture. Fishing was reported by 48.66% of respondents, while hunting prey was reported by 54% (Table 2). Fish resources include Nile tilapia, catfish and other aquatic species, while hunting provides rodents, reptiles, birds and other wildlife used for household consumption and sale. The availability and use of these resources are influenced by seasonal conditions. Fishing is closely dependent on adequate water levels and suitable aquatic habitats, whereas hunting was reported to increase during the rainy season when hunters spend more time within wetland areas. This demonstrated how seasonal climatic conditions influence both the availability of wetland food resources and the timing of their exploitation. Agriculture represents a major food provisioning service, with 61.33% of respondents reporting this activity in the wetlands (Table 2). Subsistence farming predominates, with approximately 60% of production consumed by households and 40% sold. Major crops include cassava, plantain, sweet banana, maize, macabo and sweet potato. Figure 7 showed an irrigated pipe connected to the stream for farming activities in Mbeth.




Source: Fieldwork, 2026.

***Figure 7.*** *Wetland water use for irrigation in Mbeth.*

The irrigation activity shown in Figure 7 demonstrated the importance of wetland water resources in maintaining agricultural production, particularly where rainfall becomes unreliable. Irrigation enables farmers to supplement natural rainfall and increase the continuity and productivity of food production, thereby strengthening the contribution of wetlands to household food security. These findings are consistent with the [1], which identified wetlands as important sources of food through fisheries, wildlife and agricultural production. [35] noted that wetland productivity and their services delivery were strongly influenced by hydrological conditions. In Diang Sub division, the observed rainfall variability has implications for fishing, hunting and crop production. Although irrigation provides an adaptation mechanism for agriculture, increasing pressure through farming, vegetation clearing and resource extraction are continuously undermining the sustainable use

of wetland resources and their capacity to support food security under changing climatic conditions [5].

### 4.2.3. Fuelwood, Timber and Fibre/Raw Material Services

Fuelwood, timber and fibre crops constituted important wetland provisioning services in Diang Sub-Division. Table 2 showed that 66.66% of respondents currently reported fuelwood, 52.66% reported timber and 67.33% reported fibre crops (Figure 8). There are used for domestic energy, construction and household and commercial materials. In Yanda Community these are collected and processed for different purposes generating income to families in addition to welfare and local livelihoods. Groot et al. (2012), identified biomass and fibres as vital ecosystem services. In Diang Sub-Division these services are under increasing pressure from illegal miners. Sand used for construction is also sold for settlement construction. Kaolin is used for whitewashing houses, and clay is used in pottery, while laterite contributes to road maintenance. Respondents reported the presence of gold and diamond deposits which constituted additional livelihood resources from wetland environments especially in Yanda II. Their extraction has however alteration the drainage patterns and the ecological capacity of wetlands.



Source: Fieldwork, 2026.

***Figure 8.*** *Transitioning from Raffia and fibre-based wetlands services to housing and tourism products in Bouam.*

Figure 8 provided visual evidence of how wetland services are converted into useful products including homes materials, bags and baskets for livelihood enhancements and cultural tourism. Their harvesting requiring little financial investment but they generate hugged incomes that support families. [36] revealed that maintaining wetland ecosystem services requires management approaches that recognize ecological functioning and the livelihood enhancements. In Diang Sub-Division, sustainable harvesting of raffia and timber could offer an important sustainable approach for the present and future population through poverty alleviation strategies .

### 4.2.4. Medicinal Plants and NTFPs

Medicinal plants and other NTFPs constitute important services derived from wetland in Diang Sub-Division. As shown in Table 2, 55.33% of respondents currently reported medicinal and cosmetic plants as a wetland provisioning service. The study identified a diverse range of NTFPs, including moabi (*Baillonella toxisperma*), wild mango (*Irvingia gabonensis*), kola, okok (*Gnetum africanum*), raffia (*Raphia* sp.), (Figure 9), bitter kola (*Garcinia kola*), djansang (*Ricinodendron heudelotii*) and various medicinal plants. Nearly 75% of these products are reportedly intended for marketing and use in traditional pharmacopoeia, indicating that their importance extends beyond household consumption to income generation and healthcare.



Source: Fieldwork, 2026.

***Figure 9.*** *Wetland ecosystem services providing medicinal resources in Bouam.*

Figure 9 revealed how plant materials are collected and incorporated into traditional healthcare practices. This is particularly significant in communities where accesses to formal healthcare facilities are limited. Respondents reported the use of young raffia leaves in treating mumps, raffia fibre for swollen legs and bamboo ash as an insecticide in vegetable farms. The medicinal importance of these resources is consistent with

[37] noted that NTFPs contribute significantly to health outcomes of the population, particularly through subsistence use and income generation. [38] revealed that forest products can provide important livelihood benefits while supporting local economies, particularly in tropical forest communities. Results showered that nearly 75% of the identified products are marketed due to high demands. The continued availability of NTFPs depends on their regeneration abilities. [39] noted that NTFPs in Central African forest landscapes have vital medicinal value but are sensitive to climate variability and anthropological forces are affecting their sustainability over time [40].

### 4.2.5. Spatial Distribution of Provisioning Services

The distribution of provisioning services differs among communities, reflecting changes in resource availability and livelihood dependence (Table 3). Field results indicated particularly high concentration in fuelwood and agriculture in Bouam and Diang, while gathering/picking was prominent in Bouam. Fishing was strongly concentrated in Diang and Bouam, medicinal plant use was highest in Yanda, and freshwater use was more pronounced in Bouam and Diang. These differences revealed variations in resources availability, accessibility, settlement conditions and the livelihood practices of local populations.

***Table 3.*** *Distribution of selected wetland provisioning services by Wetland Sites.*

| Provisioning services | Yanda | Mbeth | Bouam | Diang | Moundi | Total |
|---|---|---|---|---|---|---|
| Hunting preys | 7 | 4 | 15 | 29 | 6 | 61 |
| Picking and gathering | 13 | 6 | 42 | 29 | 7 | 97 |
| Fishing | 4 | 0 | 15 | 30 | 0 | 49 |
| Timber | 2 | 0 | 16 | 10 | 8 | 36 |
| Fuel wood | 18 | 7 | 51 | 39 | 8 | 123 |
| Medicinal and cosmetic plants | 10 | 2 | 6 | 7 | 3 | 28 |
| Livestock | 0 | 0 | 2 | 3 | 2 | 7 |
| Agriculture | 16 | 7 | 40 | 42 | 8 | 113 |
| Freshwater | 2 | 2 | 25 | 30 | 5 | 64 |
| Fiber crops | 0 | 0 | 3 | 5 | 1 | 9 |
| Total | 72 | 21 | 215 | 224 | 48 | 578 |

Source: Fieldwork, 2026.

This distribution was important when considering the implications of climate variability in Diang Subdivision, indicating that any reduction in water availability would lead to greater implications for communities relying heavily on agriculture fishing and freshwater. Climate variability should consequently be understood as a spatially differentiated livelihood concern, with the vulnerability of each community shaped by the particular wetland services on which its population depends. A Pearson Chi-Square test confirmed statistically significant spatial heterogeneity in household reliance on specific services ($X_2$= 48.62, df =16, p<0.001). Livelihood reliance on artisanal fishing ($X_2$ = 28.14, p<0.001) and fetching freshwater ($X_2$= 22.31, p < 0.01) all exhibited strong spatial clustering in Diang and Bouam due to proximity to the Lom River main steam and secondary tributaries. Conversely, medicinal plant harvesting ($X_2$= 18.75, p <0.01) and fiber exploitation ($X_2$= 15.42, p <0.05) all showed dominant reliance in Yanda and Mbeth, reflecting localized hydrologic variations, forest cover density, and severe tap infrastructure deficits in peripheral settlements. It is argued that climate change does not affect ecosystems and human livelihoods uniformly; rather, impacts vary according to local environmental conditions and patterns of resource dependency [41].

### 4.2.6. Relationship Between Price and Wetland Provisioning Ecosystem Services

Prices of wetland services showed a continuous upward trend from 1992 to the present, reflecting price inflation, local resource scarcity, and growing market demand as well as the influences of climate and accessibility. The overall growth rate measures the total percentage increase from 1992 to the present period (2023–Present) and the date presented on Table 4.

*Table 4. Price Growth Analysis (1992 – 2023–Present).*

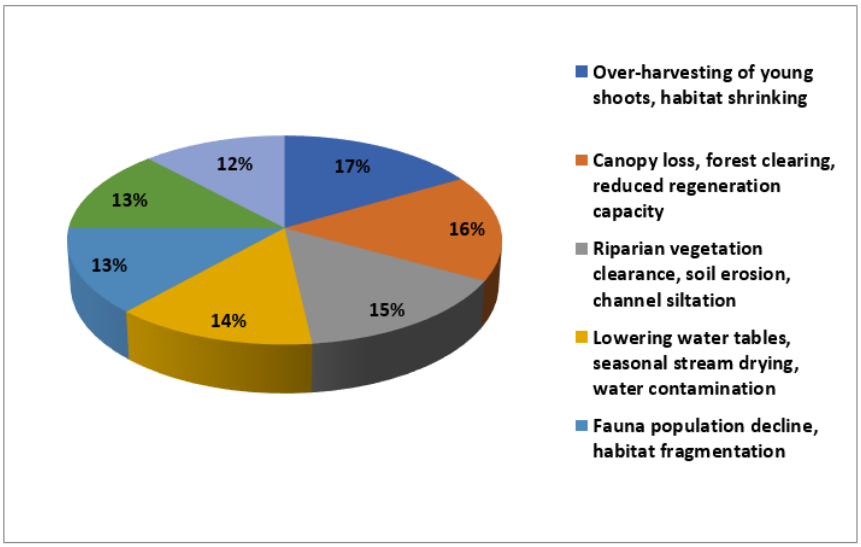
| Provisioning Service | Example Species / Commodity | 1992 Average (FCFA) | 2023–Present Average (FCFA) | Total Growth Rate (%) |
|---|---|---|---|---|
| Gathering / Non-Timber | Bush Mango (Irvingia gabonensis) | 400 | 3,500 | +775 |
| | Eru / Okok (*Gnetum africanum*) | 100 | 1,000 | +900 |
| | Njansang (*Ricinodendron heudelotii*) | 300 | 2,500 | +733.3 |
| Hunting / Bush-meat | Cane Rat (*Thryonomys swinderianus*) | 1,000 | 7,000 | +600 |
| | Porcupine (*Hystrix cristata*) | 1,200 | 6,500 | +441.7 |
| Fishing | Fresh Tilapia (*Oreochromis niloticus*) | 300 | 2,400 | +700 |
| | Fresh Catfish (*Clarias gariepinus*) | 350 | 2,750 | +685.7 |
| Agriculture | Fresh Cassava Tubers (*Manihot esculenta*) | 40 | 325 | +712.5 |
| | Plantains (*Musa paradisiaca*) | 250 | 2,100 | +740 |
| Medicinal Plants | Bitter Kola (*Garcinia kola*) | 200 | 1,750 | +775 |
| | Prunus Bark (*Prunus africana*) | 250 | 2,250 | +800 |
| Fiber Crops | Rattan Cane (*Laccosperma secundiflorum*) | 350 | 3,250 | +828.6 |
| Fuel / Wood | Hardwood Charcoal (50 kg) | 600 | 5,750 | +858.3 |
| | Firewood Bundles | 100 | 850 | +750 |
| Timber | Mahogany / Sapelli Plank | 1,500 | 12,000 | +700 |

Source: Fieldwork, 2026.

From Table 4, the economic valuation of local wetland provisioning services over the past three decades in the study area revealed a substantial cost escalation across all commodities, with overall market prices increasing between 441% and 900% from 1992 to the present day. The highest rates of price expansion occurred in wild-harvested forest goods most notably Eru/Okok (+900%), Hardwood Charcoal (+858.3%), and Rattan Cane (+828.6%). These changes were a direct reflection of severe ecological depletion, habitat fragmentation, and intensified regional trade pressure. Similarly, valuable NTFPs and medicinal plants like Prunus Bark (+800%), Bush Mango (+775%), and Bitter Kola (+775%) outpaced cultivated agricultural staples, pointing to escalating resource scarcity and high market reliance on dwindling natural stocks. At the same time, core agricultural commodities like Plantains (+740%) and Cassava Tubers (+712.5%), along with freshwater fish species like Tilapia (+700%) and Catfish (+685.7%) experienced steady, high-level inflation. This strongly revealed that wetland services have become significantly more costly. Overall, the continuous price increase across wild, cultivated, and animal resources highlighted a compounding mixture of inflation, population growth, and unsustainable harvesting rates across local ecosystems. [42] on Cameroonian coastal and inland wetlands highlighted how habitat fragmentation, siltation, and overfishing have diminished freshwater fish nursery functions, creating sharp supply shocks that elevate market prices for local protein sources.

## 4.3. Impacts of Climate Variability and Anthropogenic Pressures

The compound effects of climate variability and human activities have disrupted local ecosystem reliability, severely compromising their ability to function effectively in Diang Sub-Division. Results (Figure 10) showed how specific vulnerability intersects directly with key provisioning domains to drive resource decline affecting the livelihoods.




Source: Fieldwork, 2026.

***Figure 10.*** *Ecological Stress due to the Influence of Climate Variability.*

As seen on Figure 10, over-harvesting of immature shoots and habitat shrinking constituted the predominant ecological stressor resulting from climate variability, reported by 17% of respondents and severely impairing building materials and fiber supply. Widespread forest clearing and canopy loss followed closely (16%), waning forest regeneration capacity and destabilizing fuelwood and biomass energy security. Hydrological and agricultural systems exhibited marked degradation, driven by riparian clearance, bank erosion, and channel siltation, which affected 61.33% of households and directly compromised floodplain agricultural viability. Rising temperatures and dry-season rainfall volatility (CV=127.90% in January) caused secondary streams to dry up, forcing households to fetch water from stagnant open pools, which heightens exposure to waterborne pathogens. Corroborating this fact, an interview analysis with the Traditional Quarter Head of Mbeth revealed that *"Functional public water taps do not exist here; our families depend entirely on natural wetland streams. In the past, secondary streams like the Nyan and Sess were wide and deep, but now rising temperatures and long dry spells cause them to shrink into stagnant pools."* Also, a Women's Leader/Farmer from Bouam village commenting on water fetching burden and agricultural adaptation noted that *"When primary water holes dry up during prolonged dry periods, women and children must walk deep into the CFR de Bouam valley to collect domestic water. Farmers without motorized pumps cannot irrigate their crops and lose everything when dry spells stretch on."* This showed that ephemeral streams have limits water availability use for crop irrigation as noted by 54.66% of respondents combined with destructive fishing practices which threatened artisanal fisheries for 48.66%.

The terrestrial biodiversity and timber sectors experienced degradation as forest fragment and wildlife declines impacted 54% of households reliant on game resources, whereas deforestation reduced timber and NTFPs yields for 52.66% of the households. Collectively, these patterns prove that unsustainable extraction of wetland services habve amplifies climate-induced environmental stress thus accelerating wetland degradation. A Traditional Authority from Diang village supported this assertion and noted that, "*Slash-and-burn farming along the Lom River strips away the trees that protect the banks. Worse, when water levels drop during the dry season, some fishermen use harmful chemicals in low-water pools, killing young fish and polluting domestic water for downstream villages."*

Field results revealed that hydrological stress has directly compromises domestic water security, with 54.66% of households reporting a drop in water tables, seasonal stream drying, and water contamination. The number of plants and animal species has declined due to prolonged dryness. A significant majority (54%) of households experience habitat fragmentation caused by the combined effects of agricultural land expansion and intensive seasonal hunting of animals and bird species. Also, 52.66% of respondents reported suffering from forest canopy disruption and the loss of commercial NTFPs. Unregulated timber logging have removes economically vital species such as moabi (*Baillonella toxisperma*) and wild mango (*Irvingia gabonensis*), undermining long-term household income from gatherable goods. Commenting on this, a Local Pharmacopoeia Practitioner in Yanda village noted ‘*'about 75% of our NTFPs such as moabi, wild mango, and okro are now gathered for commercial traders targeting urban markets in Bertoua and Ngoundere while young raffia leaves and medicinal roots are essential local medicines, intense harvesting and bushfires prevent these plants from regenerating."*

About 48.66% of respondents cited high levels use of chemical in fishing and juvenile mortality. During periods of extreme low river flow, fishermen occasionally deploy harmful chemical substances in isolated water pools to maximize

catches, causing mass juvenile fish mortality and contamination of domestic water sources. Interview results with the local leader of Moabi Village noted that *"Small-scale sand, clay, and kaolin digging alongside informal gold panning along wetland borders causes riverbanks to collapse. The open excavation pits disrupt natural drainage lines and fill our clear streams with mud and sediment."* Using fieldwork data, analysis was done to establish the existing relationship between climate variability (rainfall and temperature) and the prices of wetland ecosystem provisioning services (Bush mango, Eru, Njangsa, Fresh cassava, Bitter kola, Hard charcoal, plantains and Porcupine) using the Pearson Product Moment Correlation Analysis and the results were presented on Table 5.

The Pearson Product Moment Correlation results presented on Table 5 on the relationship between climate variable and wetland services indicated strong positive relationships between rainfall, temperature and the prices of most wetland services. Based on rainfall amount, the result indicated that a significant positive correlations were observed with bush mango (r=0.663, p=0.037), Eru (r=0.679, p=0.021), fresh cassava (r=0.670, p=0.030), bitter kola (r=.663, p=0.007), and porcupine (r=0.709, p=0.001).

***Table 5.*** *Correlations Analysis of climate variability and wetland provisioning services.*

| | | Rainfall | Temperature | Bush Mango | Eru | Njangsa | Fresh Cassava | Bitter Kola | Hard Charcoal | Plaintains | Porcupine |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Rainfall | Pearson Correlation | 1 | 0.732 | 0.663 | 0.679 | 0.679 | 0.670 | 0.663 | 0.652 | 0.660 | 0.709 |
| | Sig. (2-tailed) | | 0.268 | 0.037 | 0.021 | 0.321 | 0.030 | 0.007 | 0.348 | 0.340 | 0.001 |
| | N | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Average Temperature | Pearson Correlation | 0.732 | | 0.730 | 0.726 | 0.718 | 0.723 | 0.730 | 0.749 | 0.741 | 0.855 |
| | Sig. (2-tailed) | 0.732 | 1 | 0.020 | 0.274 | 0.012 | 0.027 | 0.270 | 0.031 | 0.009 | 0.005 |
| | N | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

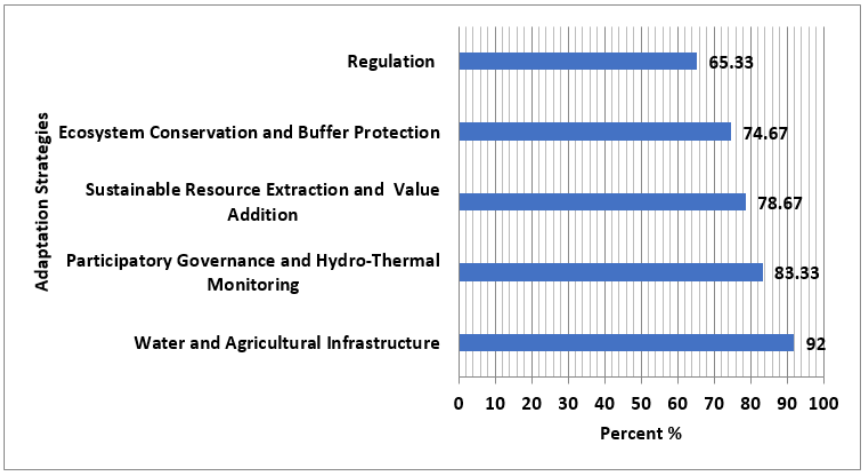
**. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed).
Source: Fieldwork, 2026.

However, the relationship with Njangsa (r=0.679, p=0.321), Hard charcoal (r=0.652, p=0.348), and plantains (r=.0660, p=0.340) were not statistically significant. Based on temperature, the result noted a significant positive correlations occurred with bush mango (r=0.730, p=0.020), Njangsa (r=0.718, p=0.012), fresh cassava (r=0.723, p=0.027), Hard charcoal (r=0.749, p=0.031), plantains (r=0.741, p=0.009), and porcupine (r=0.835, p=0.005). The relationship with eru (r=0.726, p=0.274), and bitter kola (r=0.730, p=0.270) were not significant. Overall, the results suggest that increase in rainfall and temperature tends to be associated with increases in the prices of several ecosystem provisioning services. Climate variability appears to influence the market prices of wetland products, with temperature showing particularly strong relationships. The strongest observed relationship is between temperature and porcupine price (r=0.835), while rainfall also has a strong relationship with porcupine price (r=0.709). This suggests that climatic conditions may affect the availability, harvesting, supply and consequently prices of these ecosystem provisioning services. These findings align with wider research across the Congo Basin which shows how climate variability operates as a key amplifier of wildlife scarcity and price instability [43, 44]. During periods of adverse weather or low crop productivity, rural households frequently resort to bush meat hunting as a socio-economic coping mechanism or safety net to offset farm failure [45].

## 4.4. Stakeholders Adaptation Strategies

To address these compounding vulnerabilities, household perceived adaptation strategies for stakeholders (Figure 11) revealed overwhelming community demand for water and agricultural adaptation infrastructure (92%), participatory governance and hydro-thermal monitoring (83.33%), sustainable resource extraction and value addition (78.67%), ecosystem conservation and 50-meter non-clearing riparian buffer zones (74.67%), and the regulation of artisanal mining and chemical fishing (65.33%). As seen on Figure 11, water and agricultural adaptation infrastructure received overall endorsement as households practice floodplain agriculture and depend directly

on natural streams for domestic water, severe rainfall volatility during dry-season months. Respondents recognize that top-down environmental prohibitions are ineffective when enforced without local consultation and customary backing. Hence, establishing CWMCs and installing localized river staff gauges if implemented could allowed traditional quarter heads to enforce customary bylaws while generating actionable hydro-climatic data to inform municipal development planning of wetlands. Households also reportedly favour introducing community-managed nurseries for Raphia sp and other wetland species and specialized processing equipment for NTFPs, such as moabi oil extraction and basketry. For the respondents, processing raw materials locally yields higher economic returns per harvested unit, reducing the physical volume of biomass that must be extracted to sustain household income.




Source: Fieldwork, 2026.

***Figure 11.*** *Perceived household Adaptation Strategies.*

Three-quarters of respondents' support enforcing designated 50-meter non-clearing riparian buffer zones along the Lom River axis and restricting slash-and-burn clearing in hydromorphic cores. These conservation measures are recognized as essential for preserving the natural capacity of floodplains to store water, filter pollutants, and attenuate downstream flood risks. Riparian zones play a paramount role in regulating channel stability, intercepting agricultural runoff, and attenuating flood pulses [46]. The regulation of artisanal mining and chemical fishing recorded the lowest relative endorsement among the respondents. There were hesitant toward strict regulatory bans unless viable alternative livelihoods are provided by stakeholders. As [47, 48] observed, strict conservation enforcement or abrupt regulatory bans frequently fail in low-income rural settings where resource-extractive activities serve as primary economic safety nets. Furthermore, institutional capacity showed that households strongly prefer decentralized, community-rooted governance over central state bureaucracies. Although, implementation support is highest for the Diang Municipal Council (90%), Local Traditional Councils (85.33%), Quarter Heads (81.33%), and Local Women and Youth Cooperatives (76.67%), compared to sector-specific state ministries like MINFOF (61.33%), MINEPIA (45.33%), or MINMIDT (36.67%), sustaining wetland-dependent livelihoods however requires institutionalizing CWMCs, deploying solar-powered irrigation and rainwater harvesting, formalizing local NTFP processing, and embedding community-led conservation laws directly into the municipal PCD.

## 5. Conclusion and Policy Recommendations

The study revealed that climate variability has important implications for wetland provisioning ecosystem services in Diang Sub-Division. The observed warming tendency and considerable variability in annual and seasonal rainfall influence the availability and reliability of wetland resources, particularly freshwater, fish, agricultural resources, fuelwood, timber, fibre and medicinal plants. These services make significant contributions to household food security, income, domestic needs, traditional healthcare and income generation across the study area. However, the sustainability of these services is increasingly challenged by the interaction between climatic variability and human pressures, including timber exploitation, slash-and-burn agriculture, hunting, fishing and small-scale mineral extraction. The spatial differences in resource dependence have further proven that the costs of climate variability are not uniform, but depend on the particular provisioning services on which individual communities rely. Therefore, maintaining the ecological integrity of the wetlands

is essential for sustaining their contribution to livelihoods under changing climatic conditions.

To safeguard and protect wetland ecosystem provisioning services integrity and enhance community livelihood resilience in the Diang Sub-Division, an integrated policy and governance framework must be institutionalized across municipal and community levels by key stakeholders. Firstly, local authorities should establish and strictly enforce 50-meter non-clearing riparian buffer zones along the Lom River axis and its primary tributaries to stabilize riverbanks, control soil erosion, and prevent channel siltation driven by slash-and-burn agricultural clearing. Secondly, key government related delegation of ministries resource charged with effective coordination and governance should be formalized by establishing CWMCs and embedding them directly into the municipal PCD. This includes empowering local councils and community leaders to enforce customary bylaws alongside municipal mandates. Thirdly, direct extraction pressure on fragile biomes must be mitigated by promoting value addition for NTFPs which could increase household revenue per harvested unit. Finally, local adaptive capacity should be strengthened by deploying decentralized infrastructure, including solar-powered irrigation, rainwater harvesting systems, and river staff gauges for participatory hydro-thermal monitoring to alleviate acute dry-season water stress.

## Abbreviations

| | |
|---|---|
| AEWA | African Eurasian Migratory Waterbird Agreement |
| AFB | Adaptation Fund Board |
| AU | African Union |
| CV | Coefficient of Variation |
| CWMCs | Community Wetland Management Committees |
| CHIPS | Classification and Typology of Cameroonian Wetland Systems |
| FIS | Freshwater Information System |
| ha | Hectares |
| IPCC | Intergovernmental Panel on Climate Change |
| MEA | Millennium Ecosystem Assessment |
| MINFOF | Ministry of Forestry and Wildlife |
| MINEPIA | Ministry of Livestock, Fisheries and Animal Industries |
| MINMIDT | Ministry of Mines, Industry and Technological Development |
| MINEE | Ministry of Water Resources and Energy |
| MINEPDED | Ministry of Environment, Protection of Nature and Sustainable Development |
| NASA | National Aeronautics and Space Administration |
| NTFPs | Non-Timber Forest Products |
| NGOs | None Governmental Organizations |
| PES | Payment for Ecosystem Services |
| CDP | Communal Development Plan |
| POWER | Prediction of Worldwide Energy Resources |
| SES | Socio-Ecological Systems |
| SDGs | Sustainable Development Goals |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| WWAP | World Water Assessment Programme |

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**Baba Adamu:** Conceptualization, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Writing – original draft

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## Conflicts of Interest

The authors declare no conflicts of interest.

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