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# Impact of climate variability on water resources management in Mbengwi Municipality, Momo Division, Cameroon

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## Abstract

The study analyzes the impact of climate variability on water resource management in Mbengwi Municipality, Cameroon, employing descriptive research designs with 76 respondents sampled systematically. Data was gathered through structured questionnaires and observations, supplemented by secondary sources. Key findings indicate that global warming is perceived as high by 69.1%, leading to increased seasonal unpredictability (46.9%) and more frequent natural disasters (40.0%). Analysis of rainfall and SPI data for 1981–2023 indicates high inter-annual variability, with only a weak long-term drying tendency and more frequent dry conditions in recent years. Land-cover results for 1980, 2002, and 2025 show expansion of built-up areas and arable land, alongside a decline in woodland and grazing land. A significant reduction in water availability, affecting 52.6% of respondents, was reported, and reveals concerns about surface water, with 86.8% noting stream and river drying, and 85.5% indicating severe reductions in water availability. Challenges include unpredictable rainfall (69.7%) and increased water demand (72.4%). Despite existing practices such as rainwater harvesting (90.8% effectiveness), obstacles like funding shortfalls (76.3%) and weak governance (60.5%) hinder improvement. Community participation was deemed moderate (51.3%) with some impact. The study emphasizes the need for integrating traditional knowledge and modern technologies for resilient water management.

***Keywords:*** Cameroon; Climate Variability; Mbengwi Municipality; Momo Division; Water

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## 1. Introduction

Water resources, agriculture, forestry, fisheries, human settlements, and health (Kushawaha et al., 2021) are among the socioeconomic sectors negatively affected by climate variability in many parts of the world (Upadhyay, 2020). The productivity, diversity, and functions of many ecosystems and livelihoods around the world are predicted to change (Muluneh, 2021) as these variations spread across regions and affect human and natural systems separately or in conjunction with other determinants (Pörtner et al., 2022; Parmesan et al., 2022). Since most African economies rely more on climate-sensitive activities (Pereira, 2017), many operate near environmental and climatic tolerance levels (Droogers et al., 2009), and their capacity to adapt may be constrained by institutional, technical, and financial constraints (Tol et al., 2004), this is predicted to have a significant impact on their economies (Praveen and Sharma, 2019). As demonstrated by the effects of current climate variability and weather extremes, such as droughts and floods, typhoons and storm surges, issues with water supplies, heat waves, disease vectors, and the like. Africa is already at risk from climate variability and extremes (Codjoe and Atiglo, 2020; Wright et al., 2024), which, in turn, affect natural resources, food security, and economic performance (Tofu et al., 2023), all of which are critical to the livelihoods of the vast majority of the impoverished.

Cameroon is especially susceptible to the effects of climate variability because of its varied climatic zones, which range from the humid south to the Sahelian north (Awazi et al., 2023). With longer dry seasons and heavy rainfall during the wet season causing floods, rainfall patterns have grown more erratic (Vondou et al., 2021; Njouenwet et al., 2022). Water availability issues for home and agricultural uses have been made worse by Cameroon's climate variability (Fonjong and Zama, 2023). The government has responded by implementing measures to enhance water management through the creation of infrastructure and policy frameworks (Tantoh and McKay, 2020). However, inadequate resources and unequal distribution impede efforts to alleviate water shortage, resulting in more severe water stress in some areas (Akinyetun and Ogunbodede, 2023). Because of this discrepancy, some places may have sufficient access to water, while others are severely low on it.

Rainfall is a major source of water resources for the primarily agricultural Northwest Region of Cameroon (Sedrique and Nfor, 2021). Unpredictable rainfall brought on by climate change has an impact on the amount of water available for home and agricultural use (Fonjong and Zama, 2023). Water shortage during dry spells is exacerbated by issues in the region, including deforestation, inadequate water infrastructure, and unsustainable farming practices (Pemunta, 2013; Tume, 2021). In tackling today's issues, traditional water management techniques such as community-managed water sources have gotten little attention (Tantoh and McKay, 2020; Beyonyi and Ile, 2023). To guarantee sustainable water usage, it is imperative to combine technology improvements with local knowledge, which drives the need for contemporary water management techniques (Obiorah et al., 2025). This method acknowledges the importance of both contemporary technologies and conventional methods for managing water resources fairly and efficiently.

Climate variability is significantly affecting Mbengwi Municipality, Momo Division, Cameroon. The backbone of the local economy, agriculture, has been disrupted by changes in rainfall patterns. The Division relies on rainfall, rivers, and small streams for water, but climate variability has decreased water flow, especially during the dry season. This has heightened the need for improved water management systems, particularly in rural areas with limited access to clean water. Land degradation and deforestation have also depleted water catchment areas, making water resource management in Mbengwi Municipality more challenging (Tamasang, 2025). The growing population in the Municipality further strains the limited water supplies, with water shortages becoming more apparent in recent years. Residents depend on nearby springs and streams, but their reliability has decreased due to reduced rainfall. Consequently, many people face frequent water shortages during the dry season and are compelled to rely on contaminated sources. Given the increasing demand and fluctuating water availability, Mbengwi Municipality urgently requires a robust water management system, as current measures are inadequate. In response, non-governmental organizations and local government agencies have initiated projects aimed at improving access to clean water and managing existing water resources more sustainably.

Climate variability is an increasing concern in Mbengwi Municipality, Momo Division, Cameroon. Over recent decades, changes in rainfall patterns, rising temperatures, and the frequency of extreme weather events have become more evident. However, limited empirical data and analysis specific to Mbengwi Municipality hinder a comprehensive understanding of the extent and characteristics of climate variability. This lack of information poses challenges for developing suitable adaptation strategies. Understanding the trends and patterns of climate variability in Mbengwi Municipality is crucial for anticipating future conditions and designing effective interventions for water and agricultural resource management. Although climate variability and water stress have been studied in Cameroon and other parts of Africa, empirical evidence specific to Mbengwi Municipality remains limited. Few studies have combined long-term rainfall analysis, SPI, land-cover change, and household-level evidence on water access and management practices in the same case study. This study addresses that gap by linking climatic trends, land-cover dynamics, and community responses in one local framework. Consequently, this study investigated the impact of climate variability on water resources management in Mbengwi Municipality, Momo Division, Cameroon. Specifically, (i) the study analyzed the trends and patterns of climate variability in Mbengwi Municipality over the past few decades, (ii) assessed the impacts of climate variability on water resources management, and (iii) evaluated the existing water resources management practices in Mbengwi Municipality and their effectiveness in addressing climate-related challenges.

## 2. Materials and methods

### 2.1. Study area

Mbengwi Municipality in Momo Division of the Northwest Region of Cameroon is the divisional capital. Situated in Cameroon's northern region of the Pan-African fold belt, the Mbengwi Municipality is between longitudes 9°57’ and 10°06’ East of the Greenwich meridian and latitudes 6°06’ and 5°58’ North of the equator (Mbassa et al., 2020) (Figure 1), with a surface area of 147000 $m^2$ (Njualem, 2023) and a population of 9734 inhabitants (National Community Driven Development Programme (PNDP) 2012). This Municipality is in western Cameroon's transitional area between the grassland and forest regions (Njualem, 2023). The dry season and the rainy season are the two distinct seasons that define its primarily tropical climate (Awazi et al., 2019). The rainy season, which lasts from March to mid-October, is when most rainfall occurs; however, this pattern has been extremely erratic in recent decades (Awazi et al., 2019). The long-term average yearly temperature is 30°C (Njualem, 2023). The Mbengwi Municipality receives 1450 mm of rainfall on average per year (Awazi et al., 2019). The savannah grassland predominates in vegetation, and the topography might be characterized as rolling (Awazi et al., 2019). Mbengwi Municipality relies on rainfall, rivers, and small streams for water, but climate variability has reduced water flow, especially during the dry season. This Municipality is perfect for the study because of the numerous springs that cascade down the highlands and create water catchments that can be used to manage water resources.

### 2.2. Research design

This study used a descriptive cross-sectional household survey combined with secondary analysis of rainfall data and land-cover data for Mbengwi Municipality. The household survey was conducted from January to June 2025. Quantitative data from the survey were analyzed together with rainfall records and land-cover information to examine climate variability, its effects on water resources, and local management responses.

### 2.3. Study population

The study population was made up of the total population of inhabitants in the Mbengwi Municipality. According to information obtained from the Mbengwi Municipal Council Development Plan (PNDP, 2012), there are approximately 9,734 inhabitants in the Municipality. This population is settled in the twenty-nine villages that make up Mbengwi Municipality.

## 2.4. Sample size and sampling technique

A total of 76 respondents were included in the household survey. The final sample size was determined by field feasibility, including time, access, and resource constraints, and was distributed across the selected communities to ensure coverage of the study area. A multistage sampling approach was used. Four communities were selected as strata, and households within each stratum were listed and assigned codes. Nineteen households were then selected from each stratum at regular intervals after a random starting point. Where a selected household was unavailable or declined participation, the next eligible household was approached.

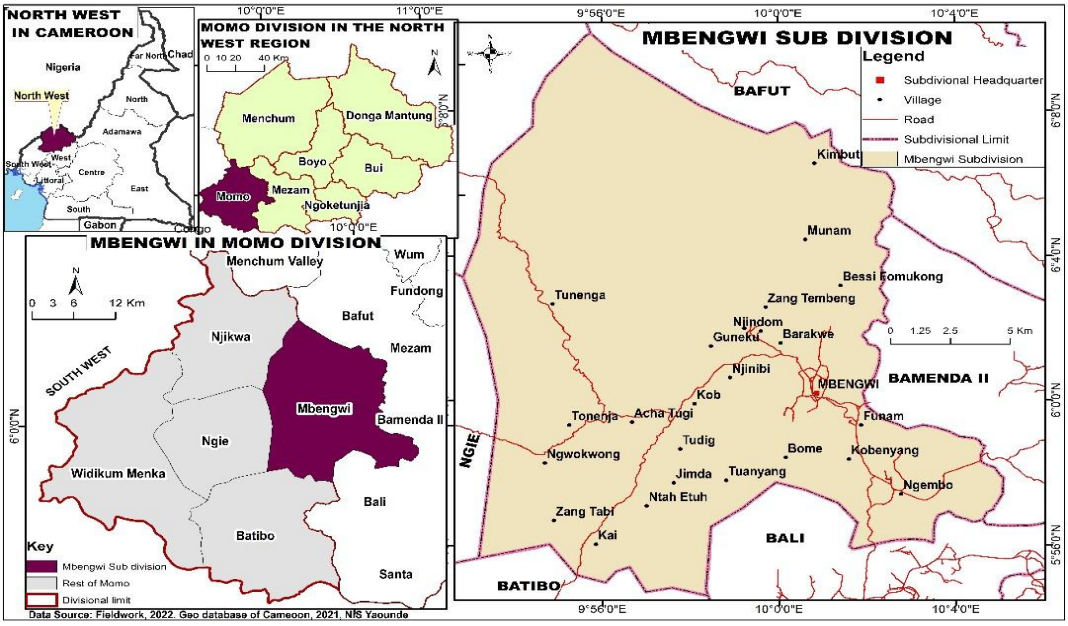



**Figure 1.** Location of the Mbengwi Municipality (Source: The Authors, 2025)

## 2.5. Data sources

Both primary and secondary sources of data were used. Structured questions and observation were used for primary data collection. The questionnaire was divided into five parts. The first part of the questionnaire focused on the respondent's socio-demographic information, the second part focused on water resources inventory, the third part focused on trends and patterns of climate variability, the fourth part focused on impacts of climate variability on water resources management, and the fifth part focused on water resources management practices in addressing climate-related challenges. Research articles, reports, reviews, theses, and online sources were among the many published and unpublished works that provided secondary data for the study. The Northwest Regional Meteorological Service provided the rainfall statistics. The mean monthly rainfall from 1981 to 2023 served as the dataset.

## 2.6. Data collection

Before starting primary data collection, the researchers were able to familiarize themselves with the study site using a pre-field survey. Structured questions and observational techniques were used for data collection. The researchers observed firsthand how Mbengwi Municipality's water resources management methods are affected by climate variability, as well as trends and patterns of climate variability in the Municipality. As a source of primary data, photos were taken using cameras and smartphones.

## 2.7. Data analysis

Data from the questionnaire was analyzed by using Microsoft Excel 13, after being checked for accuracy, consistency, and completeness. Descriptive statistics were used to calculate the frequencies and percentages, and the results were displayed in tables and charts.

Rainfall data consisted of monthly rainfall totals for 1981-2023 obtained from the Bamenda station, which is usually used to represent the Regional Meteorological Station that serves the Mbengwi Municipality in the Northwest Region of Cameroon. This station tracks temperature and precipitation patterns during the rainy (April–November) and dry (November–April) seasons of the tropical environment. The dataset used for analysis was complete for the study period. SPI was computed at an 8-month timescale to reflect rainfall conditions across the main rainy season period from March to October. In the same vein, the Standardized Precipitation Index (SPI) was calculated (Table 1). The SPI is a tool which was developed primarily for defining and monitoring drought. It allows an analyst to determine the rarity of a drought at a given time scale (temporal resolution) of interest for any rainfall station with historic data.

**Table 1.** Standardized Precipitation Index Classification (SPIC)

| SPI Value | Category | Probability (%) | Frequency in 100 years | Severity of event |
|---|---|---|---|---|
| >2.00 | Extreme wet | 2.3 | 100 | 1 in 1 year |
| 1.5 to 1.99 | Severely wet | 4.4 | 70 | 1 in 1.1 years |
| 1.00 to 1.49 | Moderately wet | 9.2 | 50 | 1 in 1.3 years |
| 0 to 0.99 | Mildly Wet | 34.1 | 45 | 1 in 1.5 years |
| -0.1 to -0.99 | Mild dryness | 34.1 | 33 | 1 in 3 years |
| -1.00 to -1.49 | Moderate dryness | 9.2 | 10 | 1 in 10 years |
| -1.50 to -1.99 | Severe dryness | 4.4 | 5 | 1 in 20 years |
| <-2 | Extreme dryness | 2.3 | 2.5 | 1 in 50 years |

*Source: World Meteorological Organisation (2012)*

The probability of the recurrence of drought and wetness events is based on the standardized precipitation (SPI). It categorizes events from extreme wet (>2.00) to extreme dryness (<-2.00), showing how frequently each condition is likely to occur over 100 years. Mild wetness and mild dryness are the most frequent, each with 34.1% probability, occurring every 1.5 to 3 years. In contrast, extreme events (both wet and dry) are rare, each with just 2.3% probability and expected once every 50 years. This highlights the rare extreme conditions compared to more moderate fluctuations. It can also be used to determine periods of anomalously wet events. Conceptually, SPI is the number of standard deviations by which the precipitation values recorded for a location would differ from the mean over certain periods. In statistical terms, the SPI is equivalent to the Z-score.

$$Z - \text{score} = x - \frac{\mu}{\delta} \quad \text{(McKee et al., 1993)}$$

Where:

Z-score expresses the x score's distance from the mean (μ) in standard deviation (δ) units.

Statistically, the SPI is based on the cumulative probability of a given rainfall event occurring at a station. SPI was used to assess the occurrence of drought incidents. All anomaly graphs generated from the data were fitted with trend lines and linear equations. The trend lines indicate an increase or decrease in the elements under study. Consistency and relationships between these climates, land cover change and water resources were analyzed systematically. All inter-annual and seasonal variations were treated as anomalies to establish trends, illustrated in graphs, fitted with $R^2$ and linear equations to show variations in each climatic element.

Other measures of central tendencies for these weather elements included Standard Deviation (σ), Variance and Coefficient of Variation (CV), calculated as:

$$\sigma = \frac{\sqrt{\Sigma(Y - \bar{Y})}^2}{N}$$

$$CV = \sigma * \frac{100}{\bar{Y}}$$

Where: $\bar{Y}$ = mean

N = sample size

From these analyses, tables were generated to summarize climatic characteristics. The drought vulnerability for this study is assessed by reconstructing historical occurrences on an 8-month time scale, beginning from March (onset of first rains), and ending in October (end of wet season). This time scale is the wet season, where water is more available, and most agricultural ventures are rain-fed. Detailed scenarios were presented where the frequency of droughts was assessed on an annual basis. Typical dry season months (November, December, January, and February) were not used in assessing SPI for this study because these are normal drought season months. This drought season is one where agriculture and water resources, as well as other components of the natural and human environments, are most vulnerable to weather conditions due to water scarcity. Anomalies were calculated for all climatic elements analyzed for this study.

Anomalies are calculated thus:

$$\frac{\text{Mean}}{\mu} * 100$$

For cartographic data analysis, shapefiles of the administrative limits of Cameroon were obtained from the National Institute of Cartography (NIC) and the National Institute of Statistics (NIS) in Yaounde, which constitute part of the Geo database of Cameroon for 2024. The shapefiles were displayed in ArcGIS 10.8 for further analysis. The administrative limits shapefiles, including national, regional, divisional, and subdivisional limits, were all used to produce the location map. A polygonal shapefile of the Mbengwi Municipality was extracted for further usage, especially the clipping of the satellite images for processing.

Three Satellite images of different years (1980, 2002 and 2025) were downloaded from the United States Geological Survey (USGS) Earth Explorer Copernicus Data Hub of the European Union. The images were processed to portray the spatio-temporal dynamics (changes in land use over time) of the study area. However, only the built-up area was necessary to visualize the trends and patterns of urban expansion and land use.

The Images of the chosen years were imported into Erda's Imagine 2013, where preprocessing (layer-stacking and image enhancement) was done, and the images were imported into ArcGIS 10.8. Interactive Supervised Image Classification (Maximum Likelihood) was adopted for the processing of the image to generate a raster format depicting the designed land cover/land uses. The raster format was converted to vector format before the extraction and symbolization of the built-up area to produce the urban evolution maps.

**Table 2.** Source of Satellite Images

| Image date | Sensor | Date | Resolution | Bands | Path | Cloud Cover |
|---|---|---|---|---|---|---|
| 12/02/1980 | LT03 | 12/04/2025 | 60m | 4 | 187/057 | 10% |
| 08/02/2002 | Lat 7 ETM+ | 13/04/2025 | 30m | 8 | 187/057 | 1% |
| 21/01/2025 | Landsat 9 | 15/03/2025 | 15 & 30m | 13 | | 1.3% |

*Sources: Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Instrument, Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), Sentinel 2A Multi-Spectral Instrument*

Another satellite image that was used for the work was a Google Earth image; the last update dates to 18th December 2024. This image was downloaded using the software Universal Map Downloader 9.30 and imported into ArcGIS 10.8; The image permitted the digitization of the water resources, especially the enhancement of the hydrographical network, which was also generated automatically from an Advanced Spaceborne Radiometer (ASTER) image downloaded still from USGS Earth Explorer for the study.

## 3. Results

This study investigates how climate variability affects water resources management in Mbengwi Municipality and finds practical adaptation techniques to support sustainability and resilience. It focuses on three core objectives: analyzing historical trends and patterns of climate variability, assessing the impacts of climate variability on water resources management, and assessing the existing water resources management practices in responding to climate-related challenges.

### 3.1. Trends and patterns of climate variability in Mbengwi Municipality over the past few decades

Trends and patterns of climate variability in Mbengwi **M**unicipality over the past few decades were examined by looking at access to pipe water, sources of water, dependable water structures, spring sources used for drinking water, rainfall analysis for water resources in the Municipality, inter-annual rainfall variability, rainfall anomaly trend for Mbengwi Municipality (1981-2023), Standardized Precipitation Index (SPI) variability, decadal rainfall variability, trends and patterns of climate variability, changes in rainfall patterns, impact of temperature changes, causes of climate variability and land cover/land use analysis.

#### *3.1.1. Access to Piped Water*

To examine access to pipe water, respondents were asked to give a score from 1 to 4 in respect to which score best described the situation under investigation, as shown in Table 3. Results reveal that most of the respondents, 51 or 67.1%, have less than 50% piped water coverage. The results indicate that only 10 or 13.2% of respondents have access to 50–70% pipe water coverage and 70-90% pipe water coverage, respectively. Findings indicate that 5 or 6.6% of respondents have near-complete access to 90–100% to piped water, underscoring the urgent need for water distribution system investment and infrastructure development throughout the Mbengwi Municipality.

**Table 3.** Percentage of population having access to piped water

| Population | Frequency | Percentage |
|---|---|---|
| Less than 50% | 51 | 67.1 |
| 50-70% | 10 | 13.2 |
| 70-90% | 10 | 13.2 |
| 90-100% | 5 | 6.6 |
| Total | 76 | 100.0 |

*Source: Field survey (2025)*

#### *3.1.2. Sources of water*

To examine the sources of water in Mbengwi Municipality, respondents were given “yes” or “no” options to choose from a list of water sources in the Municipality, as shown in Figure 2. Results indicate that most respondents, 31 or 40.8%, rely on groundwater. Findings further indicate that 25 or 32.9% of respondents rely on spring. This was followed by those who rely on surface water, 17 or 22.4% of all respondents, and 3 or 3.9% rely on rainwater harvesting. Although this reliance poses questions regarding water quality, sustainability, and susceptibility to climate-related disturbances, it also shows how the community has adapted to limited formal water infrastructure by using natural water sources.

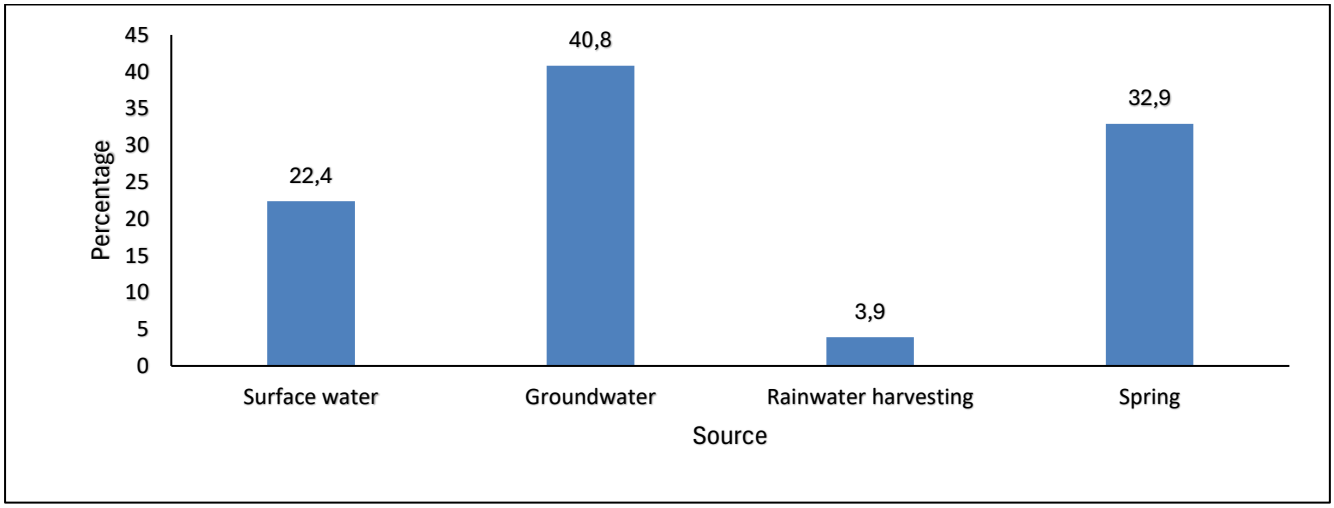



**Figure 2.** Source of water in Mbengwi Municipality (Source: Field Survey, 2025)

### *3.1.3. Dependable water structures*

Results in table 4 show that most respondents, 65 or 85.5%, said yes for Wells and 11 respondents or 14.5% said no. Findings revealed that respondents who said yes to boreholes were 51 or 67.1%, and 25 or 32.9% said no. It can be inferred from the table that 47 respondents, or 61.8%, said yes for public taps and 29 or 38.2%, said no for private taps; 46 respondents, or 60.5%, said yes and 30 or 39.5%, said no. These findings suggest that due to the impact of climate variability on water resources in the Municipality, residents depend on different water structures as a management strategy.

**Table 4.** Dependable water structures

| Structures | Yes | | No | |
|---|---|---|---|---|
| | Frequency | Percentage | Frequency | Percentage |
| Public taps | 47 | 61.8 | 29 | 38.2 |
| Private taps | 46 | 60.5 | 30 | 39.5 |
| Wells | 65 | 85.5 | 11 | 14.5 |
| Boreholes | 51 | 67.1 | 25 | 32.9 |

*Source: Field Survey (2025)*

### *3.1.4. Spring sources used for drinking water*

The study examined the number of available springs used for drinking water, and respondents were asked to score from 1 to 4 as shown in Figure 3. Results indicate that most respondents, 42 or 55%, stated that they have access to 5-10 springs. Findings revealed that respondents who stated 10-15 springs were 20 or 26%, and those who said less than 15 were 11 or 15%, while respondents who stated none were 3 or 4%. This suggests that the Municipality is characterized by the availability of springs, and these natural water supplies are threatened by climatic variability.

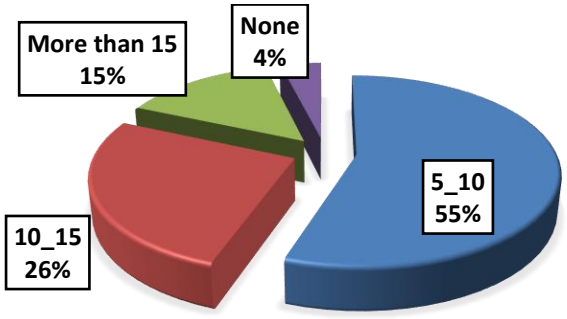



**Figure 3.** Number of springs used for drinking water (source: field survey, 2025)

### *3.1.5. Rainfall analysis for water resources in Mbengwi Municipality*

A clear pattern of wet and dry seasons may be seen in the monthly distribution of rainfall over the course of the year (Figure 4). Rainfall is low in January and February, starts to increase in March, and then gradually increases in April and May. June marks the beginning of the rainy season, which peaks sharply in July with more than 400 mm of rain falling. High rainfall is also experienced in August and September, albeit marginally less than in July, suggesting a prolonged period of intense precipitation. As the dry season returns in October, rainfall starts to decrease and then drastically decreases in November and December. There is only one main rainy season, as indicated by the data's unimodal rainfall pattern. This unimodal seasonal pattern helps explain the strong dependence of households on springs, wells, and rainwater harvesting, as well as the dry-season water shortages reported in the survey.

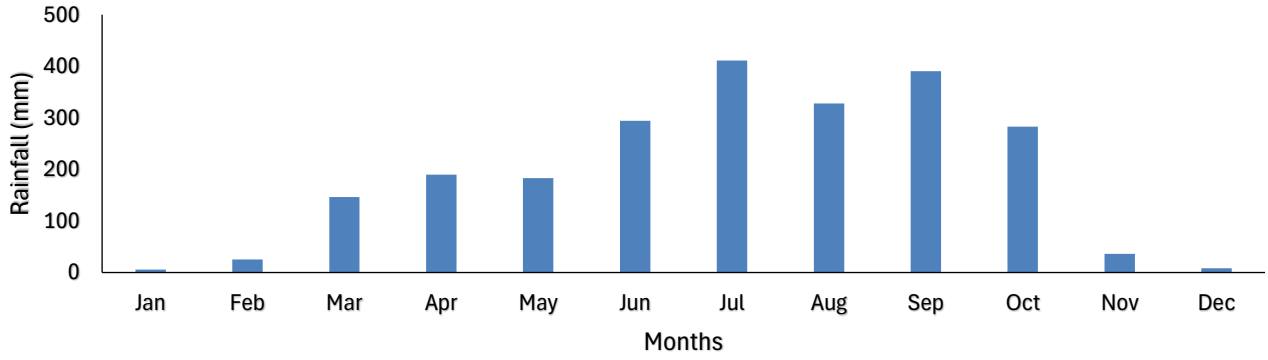



**Figure 4.** Monthly Rainfall Distribution Chart for Mbengwi Municipality (mm) (Source: Northwest Regional Meteorological Service, 2023)

### *3.1.6. Inter-annual rainfall variability*

Plotting rainfall values in millimetres (mm) on the vertical axis and years on the horizontal axis, the line graph illustrates the annual rainfall trend from 1981 to 2023 (Figure 5). The data points exhibit notable inter-annual variability and connect to a fluctuating line. Vertical arrow bars are used to indicate the range or degree of uncertainty in each year's data. The rainfall readings primarily fluctuate between 170 and 210 mm, indicating that while there are variations from year to year, the range is quite small. The equation $y = -0.2279x + 199.744$ yields a linear trend line with a negative slope and an $R^2$ value of 0.0645, which is displayed on the chart. Although the low $R^2$ value suggests that this trend only accounts for a small portion of the variation in the data, it does show a very slight declining trend in yearly rainfall over the studied time. Planning for water resources,

agriculture, and climate adaptation initiatives is all hampered by this type of fluctuation since it can result in both surplus and deficit rainfall periods.

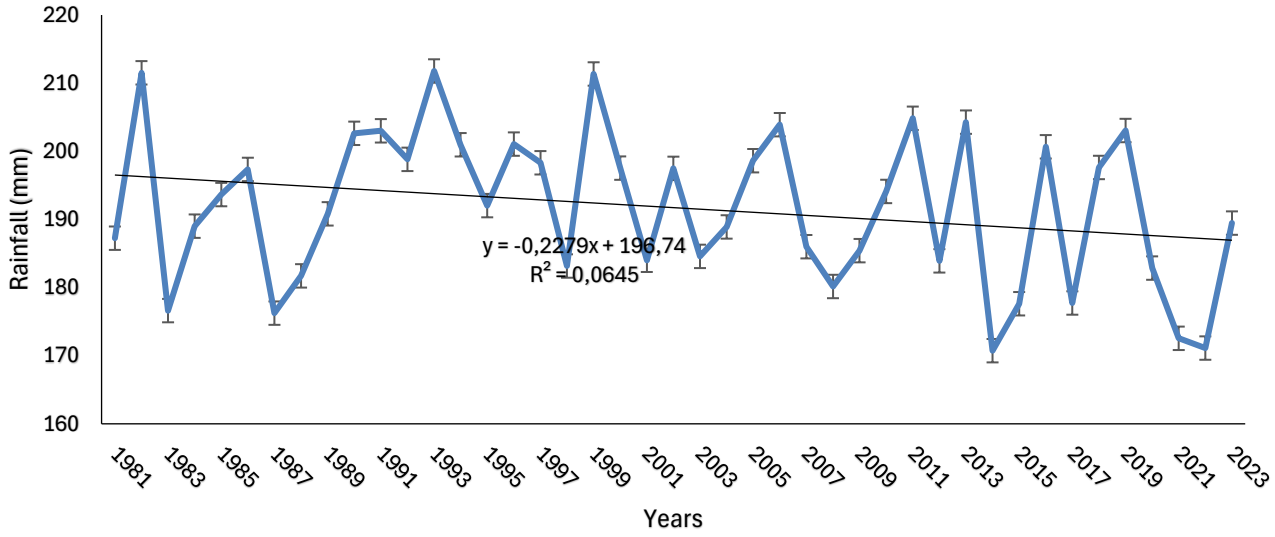



**Figure 5.** Annual rainfall trend for Mbengwi Municipality (1981–2023) Source: Northwest Regional Meteorological Service (2023)

### *3.1.7. Rainfall anomaly trend for Mbengwi Municipality (1981-2023)*

Additionally, there are both positive and negative annual variations from the long-term average rainfall. Negative deviations indicate that a certain year's annual rainfall was less than average (Figure 6).

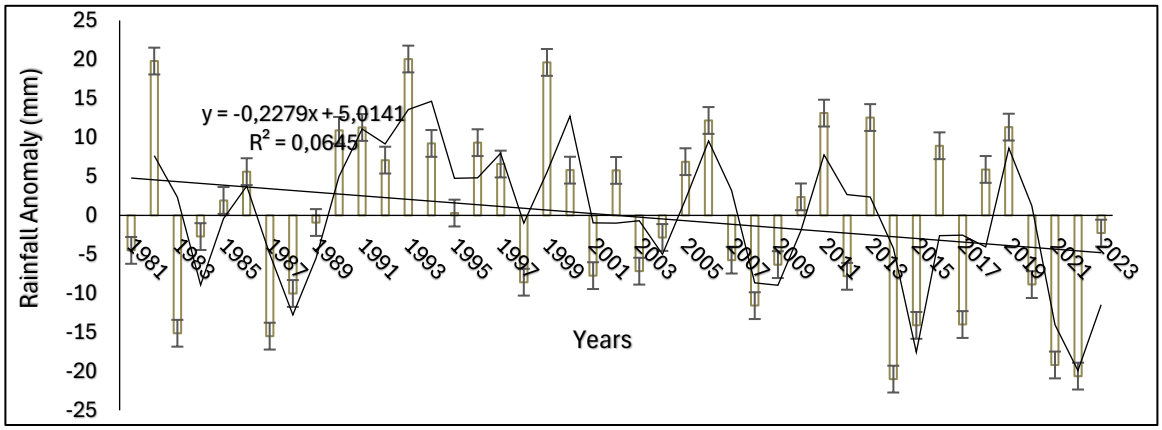



**Figure 6.** Rainfall Anomaly Trend for Mbengwi Municipality (1981-2023) Source: Generated from Northwest Regional Meteorological Service's Data (1981-2023)

Rainfall over average is represented by positive values, and below normal years are indicated by negative values. There is no discernible pattern in the line joining the data points, which shows significant inter-annual fluctuation. A tiny decline in rainfall anomalies over time is indicated by the graph's linear trend line, which has a slight negative slope. The low R2 value (0.0645), however, indicates that this trend is not statistically significant and that many variances are caused by other factors. Positive and negative anomalies coexist in the early years, but negative anomalies are more common in recent decades, which may indicate a change towards drier conditions. The slight declining trend could nevertheless indicate regional changes in rainfall patterns or slow climate change. The need

for enhanced climate monitoring and flexible water management techniques to manage effects on local livelihoods, agriculture, and water resources is highlighted by this modest drop and significant unpredictability.

### *3.1.8. Standardized Precipitation Index (SPI) variability*

SPI results show notable year-to-year variability, with some recent periods appearing drier than earlier ones. However, the SPI analysis in this study is descriptive and should be interpreted with caution. The SPI from 1981 to 2023 is displayed in Figure 7, which illustrates how wet and dry circumstances change over time. Both wet and dry extremes are seen in the data, which demonstrates notable year-to-year variations. The trend line ($y = -0.0202x + 0.4444$) shows a slight downward tendency in SPI. However, the low R2 value (0.0645) indicates that this trend explains only a small part of the variability. Some recent years appear drier than earlier ones, but the long-term pattern should be interpreted cautiously. These findings support the need for continued monitoring and careful water resources planning.

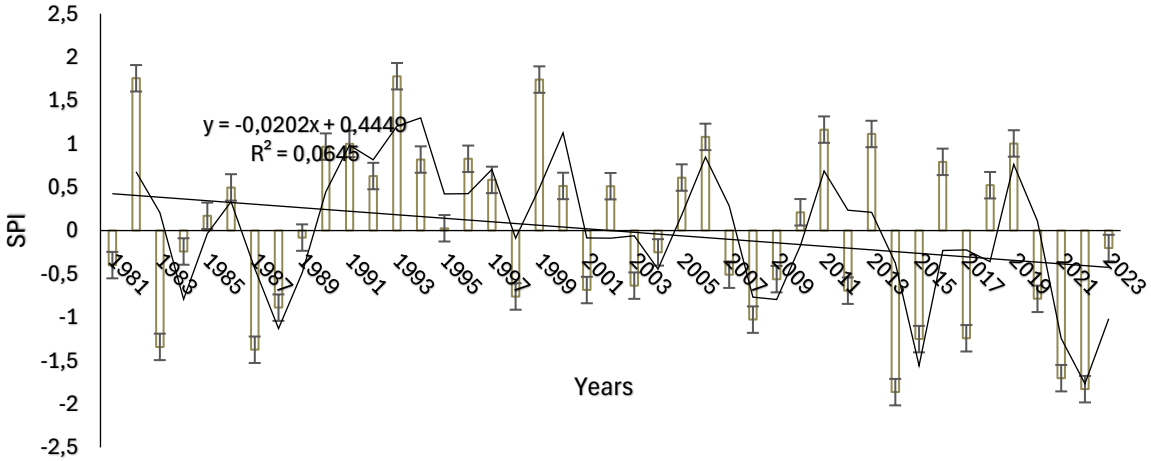



**Figure 7.** Overall SPI Trend for Mbengwi Municipality (1981–2023) Source: Generated from Northwest Regional Meteorological Service's Data (1981-2023)

### *3.1.9. Decadal rainfall variability*

The SPI trends for the years 1981–1991, 1992–2002, 2003–2012, and 2013–2023 are displayed in Figures 8, 9, 10, and 11.

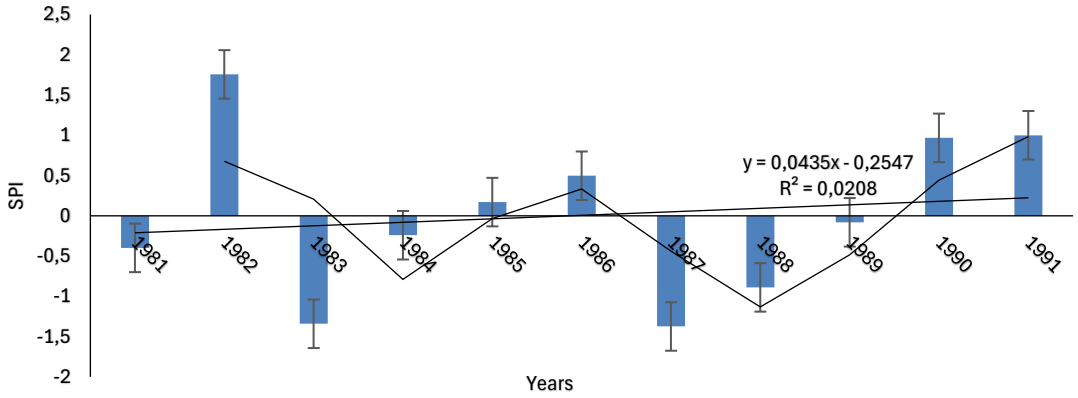



**Figure 8.** Decadal Trends in SPI for Mbengwi Municipality (1981–1991) Source: Generated from Northwest Regional Meteorological Service's Data (1981-1991)

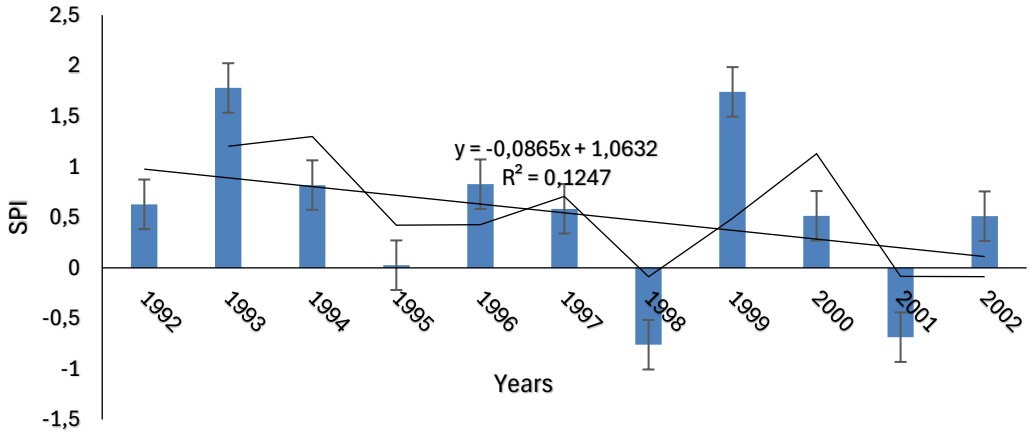



**Figure 9.** Decadal Trends in SPI for Mbengwi Municipality (1992–2002) Source: Generated from Northwest Regional Meteorological Service's Data (1992-2002)

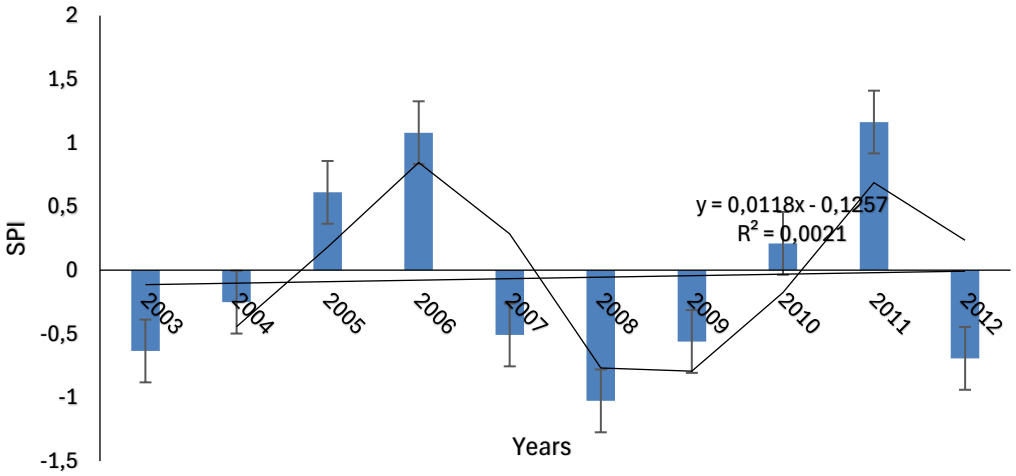



**Figure 10.** Decadal Trends in SPI for Mbengwi Municipality (2003–2012) Source: Generated from Northwest Regional Meteorological Service's Data (2003-2012)

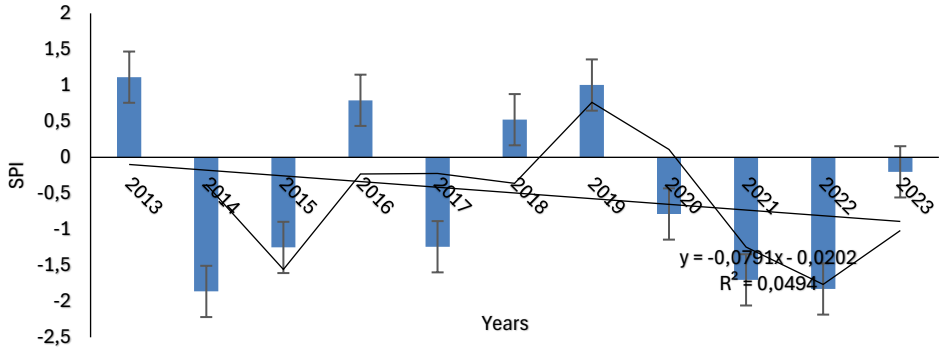



**Figure 11.** Decadal Trends in SPI for Mbengwi Municipality (2013–2023) Source: Generated from Northwest Regional Meteorological Service's Data (1981-2023)

The SPI values for the first two periods (1981–1991, 1992–2002) exhibit very mild swings. Whereas the 1992–2002 period shows a more chaotic pattern, a small negative trend ($R^2$ = 0.1247) indicates a transition towards drier conditions. The 1981–1991 period shows a slight positive trend ($R^2$ = 0.208), indicating typically damp conditions. The SPI graph for the years 2003–2012 is flat (R2 = 0.0021), indicating no change and mostly dry rainfall. The final 2013–2023 graphic shows a distinct decreasing trend (R2 = 0.494), indicating notable drought years with a high frequency of negative SPI values, particularly in recent years. This graph shows a progressive trend of increasing dryness over time, consistent with both the increasing frequency of dry weather and broader patterns of climate change. Differences in the consistency of the observed patterns are reflected in the R2 values across the times.

### *3.1.10. Summary of decadal mean annual rainfall characteristics for Mbengwi (1981–2023)*

With a mean of 189.21 mm and a constant coefficient variation of 5.56%, rainfall varied over the decades (Table 5). With the maximum rainfall (197.86 mm) and a positive MSPI of 0.54 (indicating favourable moisture conditions), the 1992–2002 period was described as slightly wet. On the other hand, the most recent decade (2013–2023) indicated mild dryness with a decrease in rainfall (186.15 mm) and an MSPI of -0.49. Notably, there was a general downward tendency in rainfall throughout the study period, even if it rose between 1981 and 1991 and between 2003 and 2012. All eras were categorized as "Reliable" in terms of data quality, notwithstanding fluctuations, indicating trustworthy readings for climatological evaluations.

**Table 5.** Summary of rainfall characteristics for Mbengwi Municipality (1981-2023)

| Decade | MRF (mm) | SD | CV (%) | MSPI | SPIC | Reliability | Trend |
|---|---|---|---|---|---|---|---|
| **1981-1991** | **181.8** | **11.27** | **5.87** | **0.01** | **Mildly wet** | **Reliable** | **Increase** |
| 1992-2002 | 197.86 | 9.16 | 4.63 | 0.54 | Mildly wet | Reliable | Decrease |
| 2003-2012 | 191.04 | 8.79 | 4.6 | -0.06 | Mild dryness | Reliable | Increase |
| 2013-2023 | 186.15 | 13.31 | 7.15 | -0.49 | Mild dryness | Reliable | Decrease |
| Mean | 189.21 | 10.63 | 5.56 | 0.00 | Mildly wet | Reliable | Decrease |

*Source: Field Survey (2023)*

*Note: MRF = mean rainfall; SD = standard deviation; CV = coefficient of variation; MSPI = mean SPI; SPIC = SPI class; mm = millimetre*

### *3.1.11. Trends and patterns of climate variability*

Trends and patterns of climate variability were examined, and respondents were asked to score from 1 to 3, as shown in Table 6. Results indicate that most respondents, 53 or 69.7%, scored high for gradual warming of the local climate, 22 or 28.9% scored medium, and 1 or 1.3% scored low. Furthermore, increased unpredictability in seasonal change was 35 or 46.1% for high and medium, respectively, while low was 6 or 7.9% for trends and patterns of climate variability in the Municipality. The findings indicate that for more frequent natural disasters, 31 or 40.8% said low, and 23 or 30.3% said medium, while 22 or 28.9% said high for trends in climate variability. This suggests that although natural disasters do occur in the Municipality, they are not common.

**Table 6.** Trends in Climate Variability

| Trends | High | | Medium | | Low | |
|---|---|---|---|---|---|---|
| | **Frequency** | **Percentage** | **Frequency** | **Percentage** | **Frequency** | **Percentage** |
| Gradual warming of the local climate | 53 | 69.7 | 22 | 28.9 | 1 | 1.3 |
| Increased unpredictability in seasonal change | 35 | 46.1 | 35 | 46.1 | 6 | 7.9 |
| More frequent natural disasters | 22 | 28.9 | 23 | 30.3 | 31 | 40.8 |

*Source: Field Survey (2025)*

### *3.1.12. Changes in rainfall patterns*

Changes in rainfall patterns for the Municipality were examined, and respondents were to decide on an option of "yes" or "no" as shown in Table 7. Results revealed Significant changes in Mbengwi Municipality's rainfall patterns, and most respondents, 40 or 52.6%, said yes for increased rainfall with consistent patterns, and 36 or 47.4% said no. Furthermore, the table showed that 52 or 68.4% said yes to decreased rainfall with more prolonged dry periods, and 24 or 31.6% said no. Most respondents, 57 or 75%, said yes for unpredictable rainfall patterns with irregular distribution, and 24 or 31.6% said no. No noticeable change in rainfall patterns, 58 or 76.3% for no and 18 or 23.7% for yes. This suggests that the agricultural output and water security of the Municipality are directly threatened by these changes in precipitation patterns.

**Table 7.** Changes in rainfall patterns over the years

| Rainfall Patterns | Yes | | No | |
|---|---|---|---|---|
| | Frequency | Percentage | Frequency | Percentage |
| Increased rainfall with consistent patterns | 40 | 52.6 | 36 | 47.4 |
| Decreased rainfall with more prolonged dry periods | 52 | 68.4 | 24 | 31.6 |
| Unpredictable rainfall patterns with irregular distribution | 57 | 75.0 | 19 | 25.0 |
| No noticeable change in rainfall patterns | 18 | 23.7 | 58 | 76.3 |

*Source: Field Survey (2025)*

### *3.1.13. Impact of temperature changes*

Residents of Mbengwi Municipality have faced certain difficulties because of temperature fluctuations (Table 8). Most respondents, 61 or 80.3%, said yes for prolonged heat waves, and 15 or 19.7% said no. Furthermore, 43 or 56.6% said yes for a colder-than-usual season, while 33 or 43.4% said no. The findings indicate that 54 or 71.1% said yes to sudden fluctuations between hot and cold temperatures, while 22 or 28.9% said no. This suggests that temperature variations in the Municipality may have a significant effect on water quantity and quality. Respondents who said no significant impact observed 59 or 77.6%, and those who said no were 17 or 22.4%.

**Table 8.** Impacts of temperature changes

| Temperature changes | Yes | | No | |
|---|---|---|---|---|
| | Frequency | Percentage | Frequency | Percentage |
| Prolonged heat waves | 61 | 80.3 | 15 | 19.7 |
| Colder-than-usual seasons | 43 | 56.6 | 33 | 43.4 |
| Sudden fluctuations between hot and cold temperatures | 54 | 71.1 | 22 | 28.9 |
| No significant impact observed | 17 | 22.4 | 59 | 77.6 |

*Source: Field Survey (2025)*

### *3.1.14. Causes of climate variability*

The causes of climate variability in the Municipality were examined, and respondents were expected to give a score from 1 to 4, as seen in Figure 12. Results indicate that most respondents, 37 or 48.7%, stated both natural phenomena and human activities, 30 or 39.5% stated human activities, 5 or 6.6% stated natural phenomena, and 4 or 5.3% said they are not sure. This suggests that this knowledge is essential for creating suitable adaptation and mitigation plans that consider both natural and man-made influences.

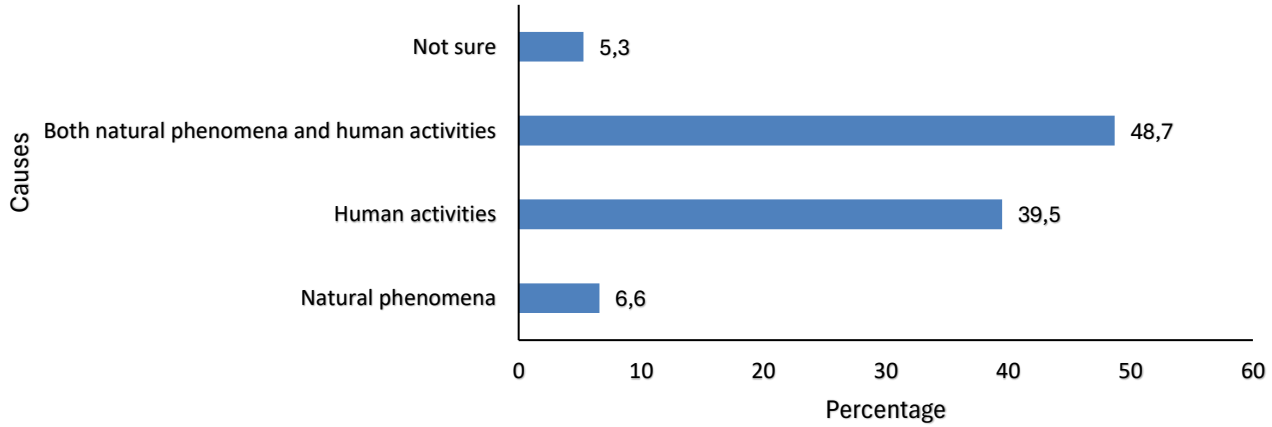



**Figure 12.** Causes of Climate Variability (Source, Field Survey, 2025)

### *3.1.15. Land cover/use analysis*

Land cover/land use changes in Mbengwi Municipality were examined with the use of data from 1980-2025 in surface area, as indicated in Table 9. Results revealed that build-up areas have increased from 6.0ha in 1980 to 14.33ha in 2025. The table further shows that arable land increased from 58.32ha in 1980 to 90.73ha in 2025. Agroforestry decreased from 113.78ha in 1980 to 109.08ha in 2025, and woodland decreased from 25.06ha in 1980 to 20.37ha in 2025, while grazing land decreased from 186.02ha in 1980 to 154.67ha in 2025. This suggests that these shifts may result in environmental problems like deforestation and land degradation, highlighting the necessity of sustainable management techniques and balanced land use planning.

**Table 9.** Categories of land cover/use in Mbengwi Municipality (1980-2025) in surface area

| Land cover/use | Area (Ha) | | | | | |
|---|---|---|---|---|---|---|
| | 1980 | 1980 (%) | 2002 | 2002 (%) | 2025 | 2025 (%) |
| Built-up area | 6.0 | 1.54 | 8.99 | 2.31 | 14.33 | 3.68 |
| Arable land | 58.32 | 14.99 | 83.1 | 21.35 | 90.73 | 23.31 |
| Agroforestry | 113.78 | 29.24 | 103.1 | 26.49 | 109.08 | 28.03 |
| Woodland | 25.06 | 6.44 | 23.51 | 6.04 | 20.37 | 5.23 |
| Grazing land | 186.02 | 47.80 | 170.48 | 43.80 | 154.67 | 39.74 |
| Total | 389.18 | 100 | 389.18 | 100 | 389.18 | 100 |

*Source: Field Survey (2025)*

#### 3.1.15.1. *Land cover map of 1980 in the Mbengwi Municipality*

The classified maps were checked against available reference information and visual interpretation of the imagery to confirm the plausibility of major land-cover classes. The 1980 land-cover map shows the spatial distribution of built-up areas, arable land, agroforestry, woodland, and grazing land in Mbengwi Municipality. Grazing land and agroforestry were the dominant classes, while built-up areas remained limited (Figure 13)

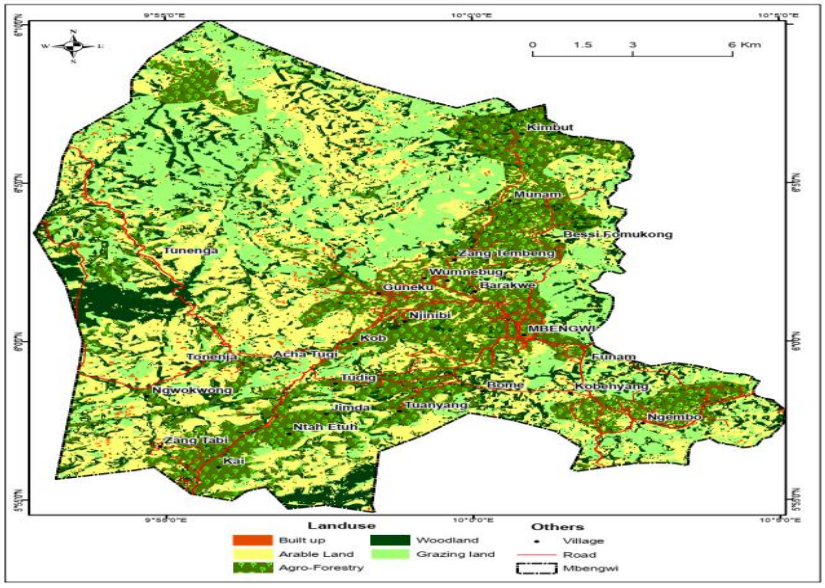



**Figure 13.** Land Cover Map of 1980 in the Mbengwi Municipality
Source: Author's Creation from Fieldwork and Landsat 9 Imagery from January 2025

3.1.15.2. *Land cover map of 2002 in the Mbengwi Municipality*

The 2002 land-cover map indicates continued dominance of agroforestry and grazing land, together with expansion of arable land and built-up areas in parts of the Municipality (Figure 14).

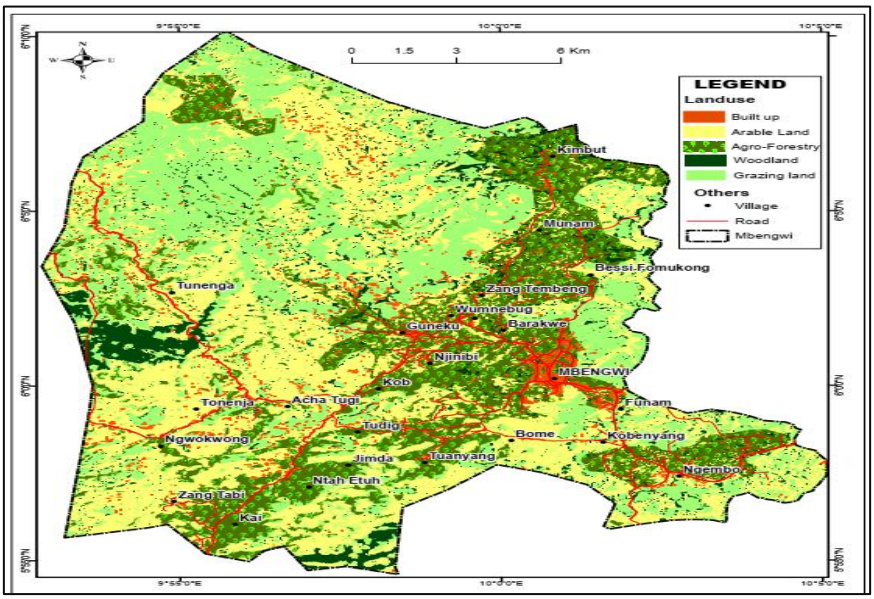



**Figure 14.** Land cover map of 2002 in the Mbengwi Municipality
(Source: Author's creation from fieldwork and landsat 9 imagery from January 2025)

3.1.15.3. *Land cover map of 2025 in the Mbengwi Municipality*

The 2025 land-cover map shows further expansion of built-up areas and arable land, together with a continued reduction in woodland and grazing land. These changes are consistent with increasing pressure on land and water resources in the Municipality (Figure 15).

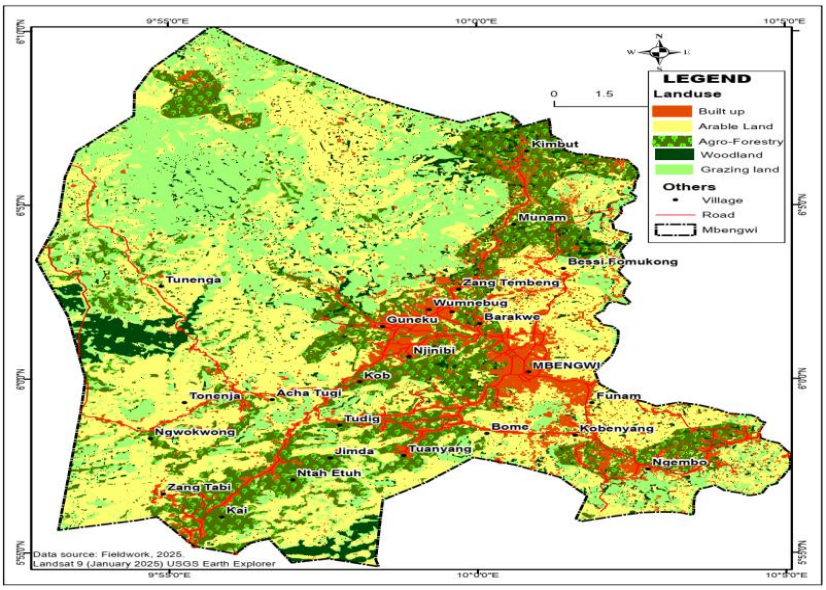



**Figure 15.** Land cover map of 2025 in the Mbengwi Municipality (Source: Author's creation from fieldwork and landsat 9 imagery from January 2025)

*3.1.16. Changes in land cover/use (1980-2025) in surface area*

Table 10 illustrates the changes in land cover/use surface area in Mbengwi Municipality from 1980 to 2025, providing a clear and insightful overview of land use dynamics over time. Notably, arable land shows the most significant increase (+32.41 ha), reflecting growing agricultural expansion, while grazing land experiences the greatest decline (–31.35 ha), indicating a shift in land use priorities or degradation. Built-up areas also show steady growth due to urbanization.

**Table 10.** Changes in Land Cover/Use Surface Area (1980-2025)

| Land cover/use | Changes (Ha) | | |
|---|---|---|---|
| | 1980-2002 | 2002-2025 | 1980-2025 |
| Built-up area | 2.99 | 5.34 | 8.33 |
| Arable land | 24.78 | 7.63 | 32.41 |
| Agroforestry | -10.68 | 5.98 | -4.7 |
| Woodland | -1.55 | -3.14 | -4.69 |
| Grazing land | -15.54 | -15.81 | -31.35 |

*Source: Field Survey (2025)*

*3.1.17. Incidence of climate variability and land cover on water resources*

The impact of climate variability and land cover on water resources management was examined, and respondents were asked to rate it on a scale of 1 to 3, as shown in Table 11. Results indicate that, consistently, water availability is decreasing: 51 (67.1%) said high, 25 (32.9%) said medium, and (0%) recorded no score.

Furthermore, findings show that 42 (55.3%) said it was medium for occasional water shortages during certain seasons, 31 (40.8%) said it was high, and 3 (3.9%) said it was low. No major changes in water availability, 36 (47.4%) said medium, 27 (35.5%) said low, and 13 (17.1%) said high. Most respondents, 47 (64.5%), said low for an increase in water availability; 24 (31.6%) said medium, and 3(3.9%) said high. This pattern points to a systematic deterioration of water supplies that needs immediate attention.

**Table 11.** Trends in Water Availability Due to Climate Variability

| Water trends | High | | Medium | | Low | |
|---|---|---|---|---|---|---|
| | F | % | F | % | F | % |
| Consistently decreasing water availability | 51 | 67.1 | 25 | 32.9 | 0 | 0 |
| Occasional water shortages during certain seasons | 31 | 40.8 | 42 | 55.3 | 3 | 3.9 |
| No major change in water availability | 13 | 17.1 | 36 | 47.4 | 27 | 35.5 |
| Increased water availability | 3 | 3.9 | 24 | 31.6 | 49 | 64.5 |

*Source: Field Survey (2025)*

## 3.2. Impact of climate variability on water resources management

To attain this objective, the study examined the seasonality of springs and streams, the effects of climate variability on water availability, the significant impact of climate variability on surface water resources, the significant challenges of climate variability for water resources management, and the primary challenge of climate variability for water resources management in the Municipality.

### *3.2.1. Seasonality of springs and Streams*

Respondents were asked to give a score from 1 to 4 on the seasonality of springs and streams in the Municipality as presented in Figure 16. Most respondents, 32(42.1%), said 10 to 15 for the seasonality of springs and streams; 30 (35.5%) stated 5 to 10; 5 (14.5%) mentioned 15 to 20; and 4 (7.9%) identified with more than 20 Municipalities. Though their seasonality makes them susceptible to climatic fluctuations and may make them unreliable during protracted dry spells, the fact that seasonal springs and streams are so common suggests that natural water drainage systems are functioning well.

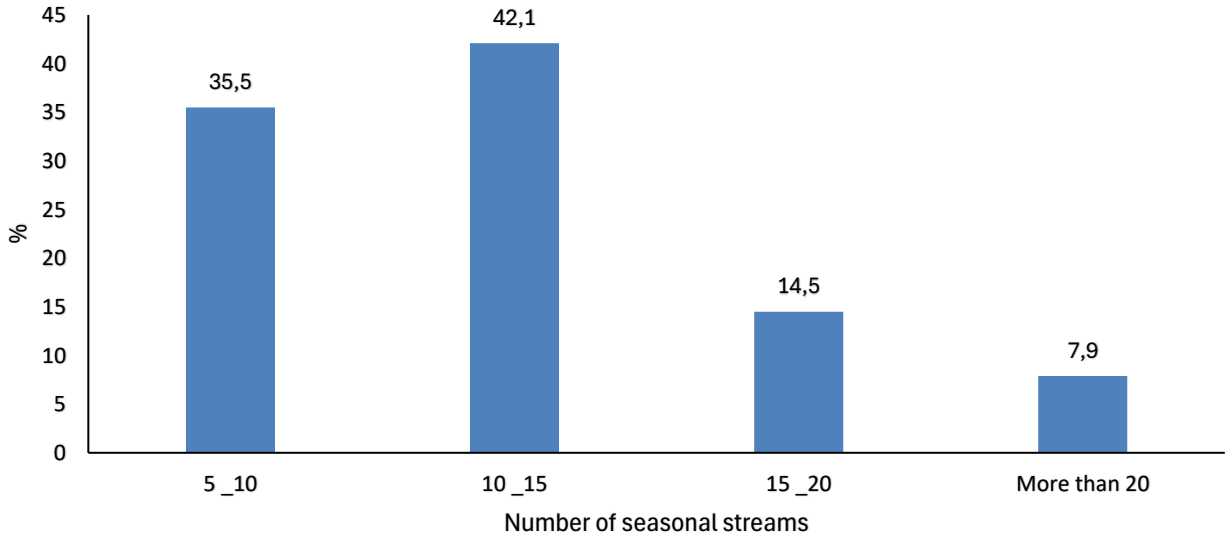



**Figure 16.** Seasonality of Springs and Streams in Mbengwi Municipality (Source: Field Survey, 2025)

### *3.2.2. Effects of climate variability on water availability*

To achieve this goal, respondents were asked to rate the effects of climate variability on water availability in the Mbengwi Municipality on a scale of 1 to 4, as indicated in Table 12. Results revealed that most respondents, 40 (52.6%), reported a significant reduction in water availability, followed by those who reported a moderate reduction, 34 (44.7%), and those who reported an increase, 2 (2.6%). This suggests that because surface water resources such as rivers, lakes, and streams are directly exposed to variations in temperature and precipitation, they are especially susceptible to climate variability.

**Table 12.** Effects of climate variability on water availability

| Effect of Climate Variability on Water Availability | Frequency | Percentage |
|---|---|---|
| Significant reduction in water availability | 40 | 52.6 |
| Moderate reduction in water availability | 34 | 44.7 |
| Increased water availability | 2 | 2.6 |
| Total | 76 | 100.0 |

*Source: Field Survey (2025)*

### *3.2.3. Effects of climate variability on surface water resources*

Table 13 shows that most respondents, 66 (86.8%), said yes to the drying up of streams and rivers, and 10 (13.2%) said no. Furthermore, 39 (51.3%) said yes to the increase in flooding, and 37 (48.7%) said no. Findings indicate that 53 (69.7%) respondents said yes to reduced water quality, and 23 (30.3%) said no. Most respondents, 65 or 85.5%, said yes for severe reduction in water availability, and 11 or 14.5% said no. Most respondents, 55 (72.4%), said no to a moderate reduction in surface water, and 21 (27.6%) said yes. This implies that when changes do occur, they are typically severe rather than mild, underscoring the severity of surface water system disruptions brought in by climate variability.

**Table 13.** Impacts of climate variability on surface water resources

| Changes | Yes | | No | |
|---|---|---|---|---|
| | F | % | F | % |
| Drying up of streams and rivers | 66 | 86.8 | 10 | 13.2 |
| Increased flooding | 39 | 51.3 | 37 | 48.7 |
| Reduced water quality | 53 | 69.7 | 23 | 30.3 |
| Severe reduction in water availability | 65 | 85.5 | 11 | 14.5 |
| Moderate reduction | 26 | 27.6 | 55 | 72.4 |

*Source: Field survey (2025)*

### *3.2.4. Challenges of climate variability in water resources management*

Respondents were asked to rate the challenges posed by climate variability to water resources management on a scale of 1 to 3 (Table 14). Most respondents, 53 or 69.7%, said it was high due to unpredictable rainfall patterns, followed by 20 or 26.3% who said medium, and 3 or 3.9% who said low. Furthermore, 39 (51.3%) said medium for extended drought periods, followed by 20 (26.3%) who said low and 17 (22.4%) who said high. Results show that 55 (72.4%) said it was high for increased water demand, followed by 19 (25%) who said it was medium, and 2 (2.6%) who said it was low. Findings revealed that 49 (64.5%) said medium for reduced groundwater recharge, 14 (18.4%) said low, and 13 (17.1%) said high. This suggests that to create sustainable adaptation strategies that address both direct and indirect climate implications, these extended impacts need to be thoroughly assessed.

**Table 14.** Challenges of climate variability for water resource management

| Challenges | High | | Medium | | Low | |
|---|---|---|---|---|---|---|
| | F | % | F | % | F | % |
| Unpredictable rainfall patterns | 53 | 69.7 | 20 | 26.3 | 3 | 3.9 |
| Extended drought periods | 17 | 22.4 | 39 | 51.3 | 20 | 26.3 |
| Increased water demand | 55 | 72.4 | 19 | 25.0 | 2 | 2.6 |
| Reduced groundwater recharge | 13 | 17.1 | 49 | 64.5 | 14 | 18.4 |

*Source: Field Survey (2025)*

### *3.2.5. Primary challenge of climate variability in water resources management*

Table 15 indicates that the primary challenge of climate variability in water resources management was identified, with most respondents (72, 94.7%) saying yes to reduced water levels in rivers and lakes, and 4 (5.3%) saying no. Results show that 54 (71.1%) said yes to increased frequency of droughts and dry spells, and 22 (28.9%) said no. Furthermore, 58 (76.3%) said they had difficulty predicting water availability, and 18 (23.7%) said they did not. For increased water pollution, 43 (56.6%) said yes and 33 (43.4%) said no. This suggests that climate variability has a cascading effect on water resources management.

**Table 15.** Primary challenge of climate variability in water resources management

| Impacts | Yes | | No | |
|---|---|---|---|---|
| | F | % | F | % |
| Reduced water levels in rivers and lakes | 72 | 94.7 | 4 | 5.3 |
| Increased frequency of droughts and dry spells | 54 | 71.1 | 22 | 28.9 |
| Difficulty predicting water availability | 58 | 76.3 | 18 | 23.7 |
| Increased water pollution | 43 | 56.6 | 33 | 43.4 |

*Source: Field Survey (2025)*

## 3.3. Existing water resources management practices in Mbengwi Municipality

This objective was achieved by examining the most widely implemented water resources management practices, the main obstacles to implementing them effectively, and the role of community participation in water resources management.

### *3.3.1. Most implemented water resources management practice*

Table 16 shows that most respondents (69, 90.8%) said rainwater harvesting is the most effective, while 7 (9.2%) said it is not effective. Results show that 27 (35.5%) said it was effective and not effective for the construction of dams and reservoirs, respectively, while 22 (28.9%) said it was not applicable. Findings indicate that 60 (78.9%) said it is effective for drilling boreholes and Wells, 14 (18.4%) said it is not effective, and 2 (2.6%) said it is not applicable. Results revealed that 43 (56.6%) said it is effective for the conservation of agricultural techniques, 27 (35.5%) said it is not effective, and 6 (7.9%) said it is not applicable.

**Table 16.** Most implemented water resources management practice

| Strategies | Effective | | Not Effective | | Not Applicable | |
|---|---|---|---|---|---|---|
| | F | % | F | % | F | % |
| Rainwater harvesting | 69 | 90.8 | 7 | 9.2 | 0 | 0 |
| Construction of dams and reservoirs | 27 | 35.5 | 27 | 35.5 | 22 | 28.9 |
| Drilling boreholes and wells | 60 | 78.9 | 14 | 18.4 | 2 | 2.6 |
| Conservation agriculture techniques | 43 | 56.6 | 27 | 35.5 | 6 | 7.9 |

*Source: Field Survey (2025)*

### *3.3.2. Obstacles to implementing effective water resources management*

Table 17 on the main obstacles to implementing effective water resources management practices indicates that most respondents, 58 (76.3%), said high for lack of funding, 14 (18.4%) said medium and 4 (5.3%) said low. The table further states that 39 respondents (51.3%) rated the infrastructure as high, 36 (47.4%) rated it medium, and 1 (1.3%) rated it low. For poor water governance, 46 (60.5%) of respondents said high, and 25 or 32.9% said medium, while 5 (6.6%) said low. For weak policy enforcement, 37 (48.7%) of respondents said medium, 34 or 44.7% said high, and 5 (6.6%) said low. Limited community awareness: 33 (43.4%) of respondents said medium, 22 (28.9%) said low, and 21 (27.6%) said high. Limited community participation, 28 (36.8%) of respondents said high and medium, respectively, while 20 (26.3%) said low. It can be inferred from the table that unpredictable climate patterns: 47 (61.8%) of respondents said medium, 16 (21.1%) said high, and 13(17.1%) said low.

**Table 17.** Obstacles to implementing effective water resources management

| Obstacles | High | | Medium | | Low | |
|---|---|---|---|---|---|---|
| | F | % | F | % | F | % |
| Lack of funding | 58 | 76.3 | 14 | 18.4 | 4 | 5.3 |
| Weak infrastructure | 39 | 51.3 | 36 | 47.4 | 1 | 1.3 |
| Poor water governance | 46 | 60.5 | 25 | 32.9 | 5 | 6.6 |
| Weak policy enforcement | 34 | 44.7 | 37 | 48.7 | 5 | 6.6 |
| Limited community awareness | 26 | 27.6 | 33 | 43.4 | 22 | 28.9 |
| Limited community participation | 28 | 36.8 | 28 | 36.8 | 20 | 26.3 |
| Unpredictable climate patterns | 16 | 21.1 | 47 | 61.8 | 13 | 17.1 |

*Source: Field Survey (2025)*

### *3.3.3. Role of community participation in water resources management*

Respondents were asked to give a score from 1 to 4 regarding the correct response on the role of community participation in water resources management in Table 18. Results indicate that most respondents, 39 (51.3%), reported moderate participation with some impact. Respondents who stated critical and highly impactful, 30 (39.5%) for community participation. Those who reported minimal participation and minimal impact accounted for 6 (7.9%), while respondents who reported no involvement accounted for 1 (1.3%) of community participation in water resources management.

**Table 18.** Role of community participation in water resources management in Mbengwi Municipality

| Roles | Frequency | Percentage |
|---|---|---|
| Critical and highly impactful | 30 | 39.5 |
| Moderate participation with some impact | 39 | 51.3 |
| Minimal participation and minimal impact | 6 | 7.9 |
| No community involvement | 1 | 1.3 |
| Total | 76 | 100.0 |

*Source: Field Survey (2025)*

## 4. Discussion

This study examined the impact of climate variability on water resources management in the Mbengwi Municipality of the Momo Division in the Northwest Region of Cameroon. Specifically, the study analyzed trends and patterns of climate variability in Mbengwi Municipality over the past few decades; assessed the

impact of climate variability on water resources management; and evaluated existing water resources management practices.

Findings on trends and patterns of climate variability in Mbengwi Municipality revealed that global warming of the local climate was (69.1%) high; increased unpredictability in seasonal change was (46.9%) for both high and medium; and more frequent natural disasters were (40.0%) low. This implies that the climate variability of Mbengwi Municipality follows global trends observed in Sub-Saharan Africa, with local characteristics that significantly affect water supplies. These results are consistent with the IPCC predictions that temperatures in West Africa would increase by 1.5–4°C by 2100 (Warren et al., 2024). This supports a study by Nkiaka et al. (2017) in the Sudano-Sahel region that evaluated global reanalysis datasets as input for hydrological modelling; the Congo Basin shows similar warming trends, according to their research.

Results on the impact of climate variability on water resources management in Mbengwi Municipality reveal that (42.1%) said 10 to 15 for the seasonality of springs and streams in the Municipality. These results are consistent with those of Patterson et al. (2022), who used a functional flows technique to study the anticipated effects of temperature and precipitation variability on streamflow patterns. According to their findings, climate variability modifies the seasonality of spring and streams by producing earlier snowmelt and longer, drier summers, which lead to earlier and higher peak spring flows and lower summer and fall flows. Aquatic ecosystems, human-use water supplies, and the general stability of water systems may all be impacted by this change in the historical timing of water availability.

The effects of climate variability on water availability in Mbengwi Municipality show that 52.6% reported a significant reduction. These findings support the water and climate change studies conducted by ECA et al. (2020). According to their research, climate variability affects water supply by increasing the frequency of extreme weather events such as droughts and floods and by altering precipitation patterns, resulting in erratic water supplies. While rising sea levels can lead to saltwater intrusion into freshwater sources in coastal areas, higher temperatures can boost evaporation (Ray and Tikuye, 2025). These alterations jeopardize human access to clean, safe water, disrupt ecosystems, and affect hydropower and agriculture.

Results on the effects of climate variability on surface water resources in Mbengwi Municipality reveal that (86.8%) said yes for drying up of streams and rivers, (51.3%) said yes for an increase in flooding, (69.7%) said yes for reduced water quality, (85.5%) said yes for severe reduction in water availability, and (72.4%) said no for moderate reduction in surface water. These results are like those of the study by Ray and Tikuye (2025), which found that surface water resources are affected by climatic variability through hydrological changes, including altered river flow and increased droughts, which reduce water availability. Additionally, extreme weather can cause flooding, damage infrastructure, and contaminate water systems, while thermal pollution and algal blooms are examples of how it degrades water quality (Ray and Tikuye, 2025).

Challenges of climate variability for water resources management in Mbengwi Municipality include: (69.7%) rated it high due to unpredictable rainfall patterns, (51.3%) rated it medium due to extended drought periods, (72.4%) rated it high due to increased water demand, and (64.5%) rated it medium due to reduced groundwater recharge. The management of water resources is hampered by climate variability, which increases flooding and water scarcity, degrades water quality, damages infrastructure, and fosters resource rivalry (Ray and Tikuye, 2025). Changes in precipitation and evaporation patterns, decreased snowpack, rising sea levels that cause saltwater intrusion, and increased demand from expanding populations and agriculture are key issues that strain the capacity to provide a reliable and clean water supply (Salcedo et al., 2025). Improving water governance, investing in resilient infrastructure, integrating climate adaptation into water policies, and encouraging conservation initiatives are all necessary to address these problems.

The primary challenges of climate variability for water resources management in Mbengwi Municipality are: (94.7%) reported reduced water levels in rivers and lakes, (71.1%) reported increased frequency of droughts, (76.3%) reported difficulty predicting water availability, and (56.6%) reported increased water pollution. Unpredictable precipitation patterns, which lead to more severe droughts and floods; increased evaporation from rising temperatures; and threats to water quality from problems such as saltwater intrusion

and contamination are the main challenges of climate variability for the management of water resources (EPA, 2016). Due to supply disruptions, rising demand, infrastructure damage, and difficult-to-balance competing demands for diminishing and unreliable resources, these issues put pressure on water security (EPA, 2016).

Results on existing water resources management practices in Mbengwi Municipality show that rainwater harvesting, at (90.8%), is the most effective practice implemented in the Municipality. For the construction of dams and reservoirs, (35.5%) said it was effective, and (35.5%) said it was not effective as water resource management practice in the Municipality. Drilling of boreholes and wells, (78.9%) said it is effective as a water resource management practice in the municipality. Communities currently manage their water resources using nonstructural strategies, such as conservation and water-efficient farming, and structural strategies, such as constructing dams and reservoirs (Moniruzzaman et al., 2026). To guarantee fair access and sustainable use, community-led strategies that include local knowledge through involvement, awareness campaigns, and capacity building are also essential (Moniruzzaman et al., 2026). These methods are often part of a more comprehensive framework that considers the implications of climate change, water allocation, and water quality.

Findings on the main obstacles to implementing effective water resources management practices in Mbengwi Municipality indicate that (76.3%) said high for lack of funding, (51.3%) said high for weak infrastructure, for poor water governance, (60.5%) said high, weak policy enforcement, (48.7%) said medium, Limited community awareness, (43.4%) said medium, limited community participation, (36.8%) said high and unpredictable climate patterns, (61.8%) said medium. Inadequate financial and human resources, outdated infrastructure, and poor governance, which often result from fragmented institutions and a lack of coordination, are barriers to the efficient management of water resources (Adom and Simatele, 2024). Unpredictable weather patterns, such as droughts and floods driven by climate change, exacerbate these problems, while population growth increases demand and pollution places additional strain on resources (Adom and Simatele, 2024). Inadequate data, political meddling, and trouble reaching stakeholder consensus are other obstacles (Adom and Simatele, 2024).

Results on the role of community participation in water resources management in Mbengwi Municipality reveal that (51.3%) stated moderate participation with some impact, and critical and highly impactful, (39.5%). To ensure that projects align with local requirements, promote justice and sustainability, and foster a sense of ownership and responsibility, community engagement is essential to managing water resources (Ali and Kamraju, 2024). Involving local stakeholders in decision-making increases the acceptance, support, and long-term success of projects (Ali and Kamraju, 2024). Greater infrastructure, more equitable access, greater water quality, and the encouragement of water-saving techniques can all result from this involvement.

## 5. Limitations

This study has some limitations that should be considered when interpreting the findings. First, the household survey included 76 respondents, and the final sample size was partly shaped by field feasibility and resource constraints. The survey therefore provides useful local evidence, but its statistical precision is less precise than that of a larger sample. Second, the rainfall analysis was based on available monthly records and a descriptive SPI approach, and no additional formal trend test was applied in this study.

The reported long-term trends in rainfall and SPI should therefore be interpreted cautiously. Third, although the landcover analysis provides a useful picture of change over time, no formal accuracy assessment was included, and the mapped classes should be read as indicative of broad landcover dynamics rather than exact measured boundaries.

## 6. Conclusion

Climate variability has emerged as a key environmental factor that may be affecting local rainfall conditions and water availability in the Mbengwi Municipality. Temperature trends, the slow warming of the local climate, and sharp changes in precipitation patterns are three important aspects of climate variability that significantly affect local environmental conditions. Seasonality has become much less predictable. The community exhibits a thorough grasp of the causes of climate variability, including the role of both natural and human-caused

influences. This degree of understanding suggests environmental literacy, which offers a solid basis for attempts to mitigate and adapt to climate change. Rainwater collection is the most successful strategy, and community-based management practices show the highest levels of performance. Because rainwater collection is so successful and decentralized, community-controlled methods might be especially appropriate for climate-vulnerable regions. Building these communal assets while removing structural obstacles that impede efficient water resources management is the key to increased water security. The most promising route to climate-resilient water resource management in the region is the combination of traditional knowledge systems with suitable modern technologies, backed by better governance and sufficient funding.

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