



RESEARCH ARTICLE

Assessing Fire Weather Risk in Nigeria Using the Fire Weather Index (FWI) Derived from MERRA2 Reanalysis Data

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Abstract

Nigeria is particularly susceptible to the impacts of climate change, experiencing heightened thermal stress and frequent wildfires, especially during its dry seasons. A recent study investigated the country's fire weather conditions and associated risks. This research utilized the Fire Weather Index (FWI) system and MERRA2 data to assess temperature patterns and fire hazard across Nigeria, aiming to gain a deeper understanding of fire weather dynamics and regional vulnerability. Examining data for 1990, 2000, 2010, 2020 & 2024, the study revealed FWI values ranging from a minimum of 0.7 to a maximum of 76.2, with an overall average of 29.8. Temporal analysis of the mean FWI values indicated significant fluctuations: In 1990, the average was 29.1, signifying a very high risk. By 2000, this escalated to 34.6, categorizing it as Extreme. Subsequent years, such as 2010 (27.2) and 2020 (27.8), continued to show very high risk levels. Regional variations were also pronounced: The Northern zone consistently exhibited Extreme risk levels, with Borno State recording the highest value at 57.0. The Middle Belt region experienced a mix of very high and extreme conditions, peaking in Plateau State at 33.9. In contrast, Southern Nigeria generally registered lower risks, ranging from Low to High, with Bayelsa State showing the lowest recorded FWI at 2.0. These findings are crucial for developing effective early warning systems, informing sustainable land management strategies, and formulating robust climate adaptation plans. Such measures are vital for mitigating the growing threats of extreme heat and recurrent wildfires across the nation.

ARTICLE HISTORY

Received: 9 February 2026

Accepted: 17 April 2026

Published: 14 May 2026

KEYWORDS

Nigeria, Fire Weather Index (FWI), MERRA2, Thermal Stress, Wildfires, Climate Change,

Citation: Menegbo, E. M., Jackson, K. P. & Samuel, A.D. (2026). Assessing Fire Weather Risk in Nigeria Using the Fire Weather Index (FWI) Derived from MERRA2 Reanalysis Data. *Journal of Geomatics and Environmental Research*, 9(1), Pp 31-42

1. INTRODUCTION

Nigeria, situated in West Africa, features a wide variety of climate types, from the dry northern regions of the Sahel to the humid tropical rainforests in the south. This diverse geography, combined with a fast-growing population and a climate heavily influenced by the Inter-Tropical Convergence Zone (ITCZ), makes the nation particularly susceptible to harsh weather events and the effects of climate change. Among these impacts, rising temperatures that lead to increase heat-related strain, and the increasing occurrence and severity of wildfires, present significant environmental, economic, and social difficulties.

Wildfires, which are often started by human activity or worsened by natural conditions like extended dry periods and high temperatures, can devastate agricultural lands, destroy buildings and infrastructure, harm natural ecosystems, and contribute to air pollution with serious health risks for the public. In this context, "heat flux" simply means the transfer of heat from the Earth's surface into the atmosphere, largely driven by sunlight and air temperature. A high rate of heat flux causes plants and soil to dry out more quickly, which in turn increases how easily fuel burns and boosts the overall fire danger. However, comprehensive, direct measurements of heat flux components are rare, especially in regions like Nigeria. Therefore,

alternative measures, such as surface air temperature, serve as crucial indicators for understanding the thermal conditions that set the stage for fire events.

Accurately and promptly assessing fire risk is essential for effective disaster prevention and management. Older methods often depend on localized observations, which are not sufficient for monitoring fire danger across an entire country. The Fire Weather Index (FWI) system, developed by the Canadian Forest Service, is a well-known and commonly used method worldwide for figuring out fire risk. It uses daily weather readings like temperature, relative humidity, wind speed, and precipitation. The FWI system offers a range of indicators that reveal the moisture levels of various combustible materials and the potential for a fire to spread.

Globally, the presence of reanalysis datasets, which integrate observational data with numerical weather prediction models, offers a significant advantage for conducting detailed, long-term climate studies, especially in areas where ground-based observations are limited (Gelaro *et al.*, 2017). One such dataset is MERRA2 (Modern-Era Retrospective analysis for Research and Applications, Version 2), developed by NASA's Global Modeling and Assimilation Office (GMAO). It provides a consistent history of atmospheric and land surface conditions spanning several decades. Its worldwide reach and relatively detail in both space and time make it well-suited for evaluating fire weather conditions in regions with scarce data, such as Nigeria.

Despite the common occurrence of wildfires in Nigeria and increasing heat, there is a clear absence of a comprehensive, nationwide assessment of fire weather. This is particularly true for studies using robust scientific methods like the Fire Weather Index (FWI) system, especially when informed by reanalysis data. This research aims to address this gap by systematically examining thermal conditions and their contribution to fire risk across Nigeria, utilizing the FWI system calculated from MERRA2 reanalysis data.

Research Objectives

This study has the following specific objectives:

- I. Calculating the temporal (decadal) variations of FWI across Nigeria using MERRA-2 reanalysis data from 1990, 2000, 2010, 2020, and 2024.
- II. To analyze the spatial and temporal (decadal) variations of FWI across different climatic zones of Nigeria from 1990 to 2024

Climate Change and Its Impacts in Nigeria.

Nigeria is currently undergoing significant changes in its climate. These transformations are characterized by a rise in temperatures, shifts in rainfall patterns, and a more frequent occurrence of severe weather events. Across the country, consistently higher temperatures have been observed, resulting in longer dry periods and an increased rate of water evaporating from the ground and plants. These alterations create heat-related difficulties for human populations, farm animals, and crops. They also exacerbate drought conditions and contribute to the drying out of landscapes, making these areas more susceptible to fires. Research has highlighted that Nigeria's Sahelian and Guinea Savanna regions are particularly vulnerable to these climatic shifts, which directly impact agricultural output and water availability.

Wildfires in Nigeria: Causes and Impacts.

Wildfires represent a recurring environmental threat in Nigeria, particularly common during the dry season, which typically spans from November to March. While some of these blazes occur naturally, the vast majority are human-induced. These often originate from agricultural practices, such as burning vegetation to clear land or rejuvenate grazing areas, as well as hunting activities, uncontrolled waste burning, and accidental ignitions. The repercussions are extensive, including the destruction of farms and forests, a decline in natural life, deterioration of soil, air pollution that contributes to respiratory illnesses, and substantial financial losses. Despite their widespread occurrence, thorough, data-driven evaluations of wildfire risk across the entire nation remain limited, often depending on localized findings or anecdotal accounts.

The Fire Weather Index (FWI) System.

The FWI system is a sophisticated, internationally recognized framework that integrates meteorological observations to assess fire danger (Van Wagner, 1987). It comprises six standard components:

- I. Fine Fuel Moisture Code (FFMC): Represents the moisture content of fine fuels (e.g., cured grasses, litter) and their flammability. Highly responsive to daily temperature, relative humidity, and precipitation.

- II. Duff Moisture Code (DMC): Represents the moisture content of moderately deep organic layers (e.g., duff, medium-sized woody fuels). Slower to respond to daily weather changes than FFMC.
- III. Drought Code (DC): Represents the moisture content of deep, compact organic layers and larger fuels. Responds very slowly to weather changes, reflecting long-term drought effects.
- IV. Initial Spread Index (ISI): Combines FFMC and wind speed to estimate the potential rate of fire spread.
- V. Buildup Index (BUI): Combines DMC and DC to represent the total amount of fuel available for combustion.
- VI. Fire Weather Index (FWI): Combines ISI and BUI to provide a numerical rating of fire intensity potential.

The Fire Weather Index (FWI) system has been widely adopted and proven effective across the globe, in diverse environments ranging from temperate woodlands to tropical zones. Although initially created for northern coniferous forests, its fundamental principles concerning fuel moisture and fire propagation are broadly relevant. However, adjustments to specific thresholds may be necessary for native vegetation and ecological settings. Its application in West Africa, particularly Nigeria, remains largely unexplored, hampered by a lack of consistent, long-term data.

Remote Sensing and Reanalysis Data for Fire Weather Assessment.

Satellite observation has profoundly changed environmental monitoring, offering crucial information for identifying fires (such as products from MODIS and VIIRS) and charting land cover (as seen in studies like Hansen *et al.*, 2013). Nevertheless, determining fire danger levels relies on meteorological information. Unfortunately, weather stations on the ground are frequently scarce and inconsistently placed across much of Nigeria, leading to significant gaps in data.

Fortunately, reanalysis datasets, like MERRA2, overcome these challenges. They achieve this by integrating a wide range of past observations (from satellites, ground sensors, and aircraft) with advanced atmospheric models. This process generates a comprehensive and consistent global record of atmospheric and land surface conditions over both space and time (Gelaro *et al.*, 2017). MERRA2 offers daily or even sub-daily information for the key components needed for the Fire Weather Index (such as temperature, relative humidity, rainfall, and wind speed) worldwide. This makes it a dependable resource for analyzing past fire weather patterns in areas where direct local measurements are scarce. Other research has successfully employed reanalysis data for determining FWI values and evaluating fire risk in different global regions, thereby proving its usefulness and trustworthiness (San-Miguel-Ayanz *et al.*, 2013).

Linkage between Heat Flux (Thermal Conditions) and Fire Weather

The movement of heat within the environment, specifically the direct transfer of heat from the surface to the air (sensible heat flux) and the heat removed via evaporation (latent heat flux), is fundamentally important in determining the moisture levels of combustible materials. Elevated temperatures, often a direct result of increased sensible heat flux, promote greater evapotranspiration, leading to drier vegetation. These drying impacts are directly reflected in key components of the Fire Weather Index (FWI) system, namely the Fine Fuel Moisture Code (FFMC), Drought Moisture Code (DMC), and Drought Code (DC). Indeed, prolonged periods of warmth, even without immediate ignition, significantly prepare the landscape for fire by diminishing the moisture content within potential fuels. Consequently, analyzing temperature trends and their relationship with FWI components offers an indirect but effective method for comprehending how thermal conditions influence fire potential. For this study, surface air temperature (T2M) will serve as our primary indicator of the thermal stress driving the desiccation of fuels.

2. MATERIALS AND METHODS

This section outlines the data sources, the computational procedures for the FWI system, and the analytical methods employed to assess thermal conditions and fire risk in Nigeria.

The Study Area

Nigeria, located in West Africa, spans approximately 923,768 square kilometers, roughly situated between latitudes 4°N and 14°N and longitudes 2°E and 15°E. The country experiences two main climate periods: a wet season, generally from April to October, and a dry season, from November to March. However, the precise timing and length of these seasons differ considerably from the southern parts to the northern regions. Nigeria is home to several distinct natural environments: Mangrove Swamps, Tropical Rainforest,

Guinea Savanna, Sudan Savanna, and Sahel Savanna. Each of these zones boasts its own unique plant life, which influences how easily vegetation ignites and the typical patterns of wildfires. A clear shift in climate can be observed across the nation. The southern areas enjoy a tropical rainforest climate, marked by substantial rainfall and humidity throughout the year. As one travels north, the climate gradually changes to a tropical savanna, encompassing the Guinea and Sudan savannah regions. This area features a distinct wet season (roughly May to October) followed by a long and intense dry period (approximately November to April). The very northern parts fall within the semi-arid Sahel region. This progression of climates directly shapes the kinds of plants that thrive, which then act as material for fires. As a result, the dense forests in the south are less prone to burning. Conversely, the central and northern savannas, primarily covered by grasses and scattered woodlands, dry out extensively during the dry season, making them highly susceptible to fire.

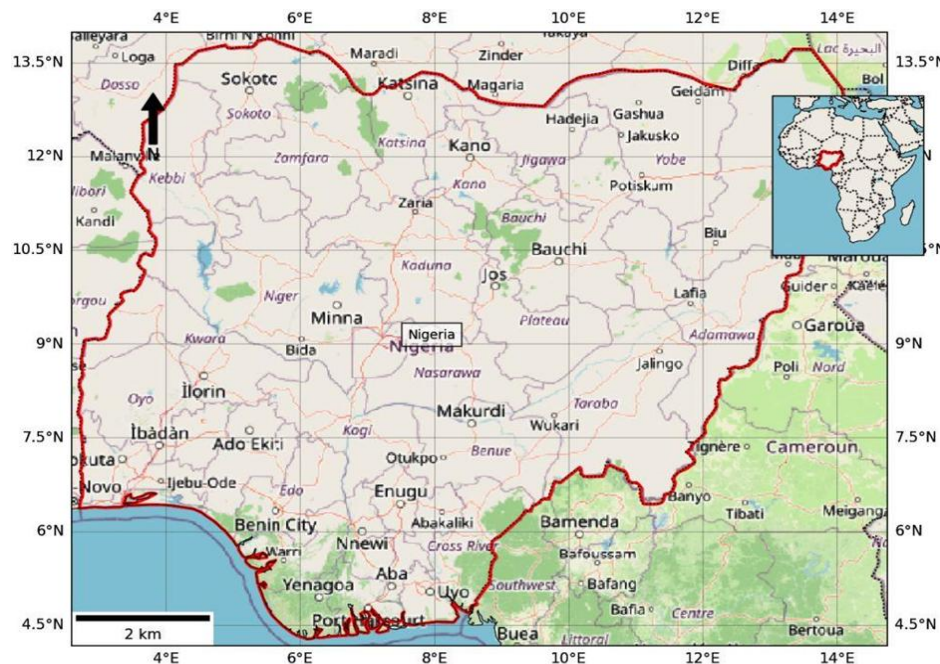


Figure 1. Map of Nigeria. Source: OSM (2026)

Data Sources

MERRA2 Reanalysis Data: For this study, we relied on data from the MERRA-2 project, which is generated by NASA's Global Modeling and Assimilation Office (GMAO). This dataset was our main source for all atmospheric and weather-related information. The specific variables gathered included:

- I. 2-meter Air Temperature (T2M): For calculating FWI components directly and as a proxy for thermal conditions/heat flux.
- II. 2-meter Relative Humidity (RH): Essential for FFMC calculation.
- III. Total Precipitation (TP): Used for all moisture codes (FFMC, DMC, DC).
- IV. 10-meter Wind Speed (WS10M): Used for ISI calculation.

The information utilized was obtained from the Google Earth Engine platform, exhibiting its original spatial resolution (around 0.5° latitude by 0.625° longitude) and a daily frequency. An extensive historical duration, spanning from January 1, 1990, to December 31, 2024, was then analyzed to identify long-term trends and year-to-year differences. The MERRA2 dataset was chosen due to its consistent quality, global coverage, and incorporation of various observational measurements, making it well-suited for extended climate research, especially in regions with scarce data. However, certain limitations are acknowledged, such as its broad spatial detail, which might not fully capture localized atmospheric events, and any inherent inaccuracies within the model itself.

Method for Data Processing and FWI Calculation

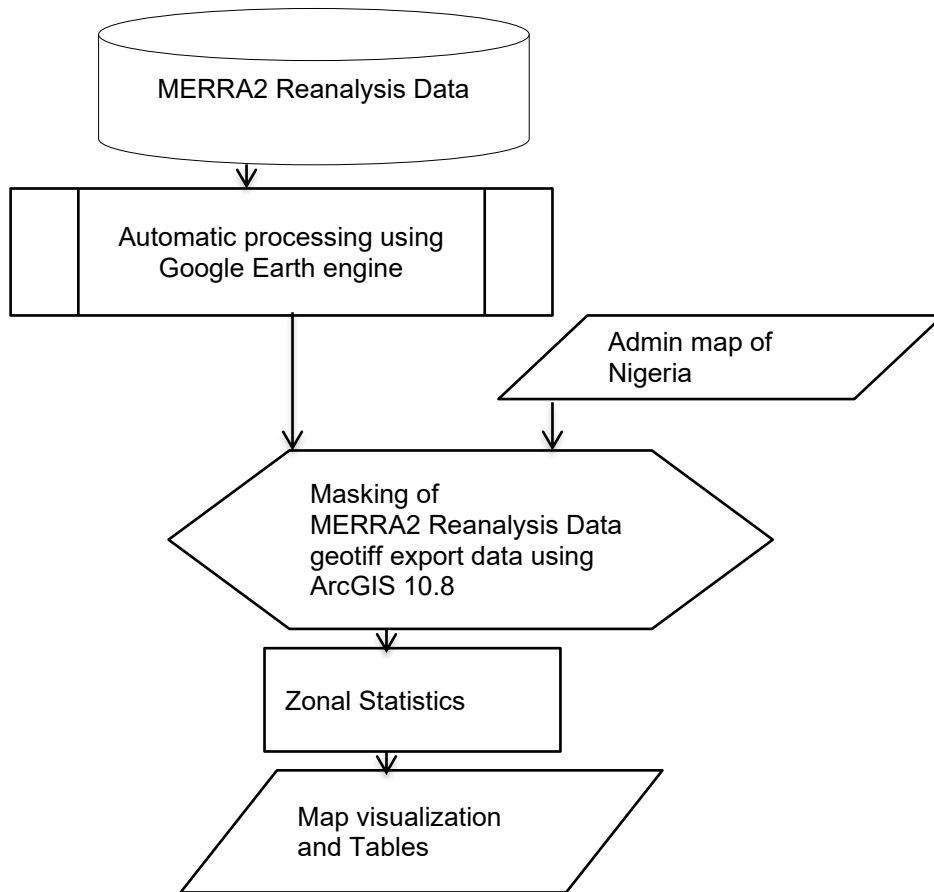


Figure 2. A flowchart illustrating the Fire Weather Index (FWI) methodology workflow Nigeria. Source: Authors (2026)

We analysed the MERRA-2 data for Nigeria using Google Earth Engine and ArcGIS 10.8, performing daily calculations for every individual grid cell. The equations for the Fire Weather Index (FWI) system were then applied repeatedly, day by day, across the entire study period. These computations drew upon established algorithms, programmed in JavaScript within Google Earth Engine, and followed the standard procedures outlined by the Canadian Forestry Service. To account for an initial adjustment or 'spin-up' period, the starting values for the moisture indicators were set based on the region's typical climatic conditions.

Spatio-temporal Analysis

The resulting daily FWI grids were analyzed to understand fire weather risk patterns:

- I. Temporal Analysis: Monthly and seasonal mean FWI values were calculated for the entire country to highlight the Temporal (decadal) variations of fire risk.
- II. Spatial Analysis: Maps of long-term mean FWI were generated to identify geographical hotspots of high fire danger.
- III. Risk Classification: FWI values were categorized into standard danger classes (Low: 0-5, Moderate: 6-11, High: 12-20, Very High: 21-30, Extreme: >30) to facilitate interpretation and comparison.

3 RESULTS AND DISCUSSION

Spatial and temporal (decadal) variations of FWI

The temporal analysis of the nationwide average FWI reveals a decadal pattern, as shown in Figure 3 - 8 and Tables 1 and 2.

Table 1. Summary of Results

	1990	2000	2010	2020	2024	1990-2024
MIN	0.0	0.0	0.0	3.2	3.4	0.7
MAX	85.1	84.3	72.3	67.5	69.3	76.2
MEAN	29.1	34.6	27.2	27.8	32.6	29.8

Table 2. Average values of FWI over Nigeria from 1990 to 2024

States	Min	Max	Mean
Abia	5.5	7.8	6.6
Adamawa	21.0	44.1	31.3
Akwa Ibom	2.7	2.7	2.7
Anambra	6.9	8.9	7.9
Bauchi	34.4	45.2	41.7
Bayelsa	0.7	3.3	2.0
Benue	12.8	21.3	16.5
Borno	44.0	72.1	57.0
Cross River	4.3	9.4	6.6
Delta	4.1	6.6	5.3
Ebonyi	10.2	10.2	10.2
Edo	5.2	10.0	7.7
Ekiti	12.3	16.2	14.3
Enugu	9.9	9.9	9.9
Federal Capital Territory	17.3	19.5	18.3
Gombe	30.7	47.4	39.5
Imo	5.6	5.6	5.6
Jigawa	40.3	59.3	48.7
Kaduna	21.5	39.8	30.8
Kano	37.9	41.1	39.2
Katsina	40.1	57.8	50.3
Kebbi	31.1	47.1	38.5
Kogi	11.3	19.0	15.8
Kwara	15.3	26.5	21.1
Lagos	3.8	3.8	3.8
Nassarawa	17.9	29.7	24.4
Niger	17.9	33.1	25.0
Ogun	3.3	5.5	4.4
Ondo	3.2	7.2	4.6
Osun	4.1	9.9	7.0
Oyo	9.3	20.9	13.7
Plateau	29.2	38.4	33.9
Rivers	3.2	3.3	3.2
Sokoto	42.2	58.4	52.8
Taraba	12.3	28.9	19.9
Yobe	48.3	63.7	55.7
Zamfara	34.8	53.7	44.7

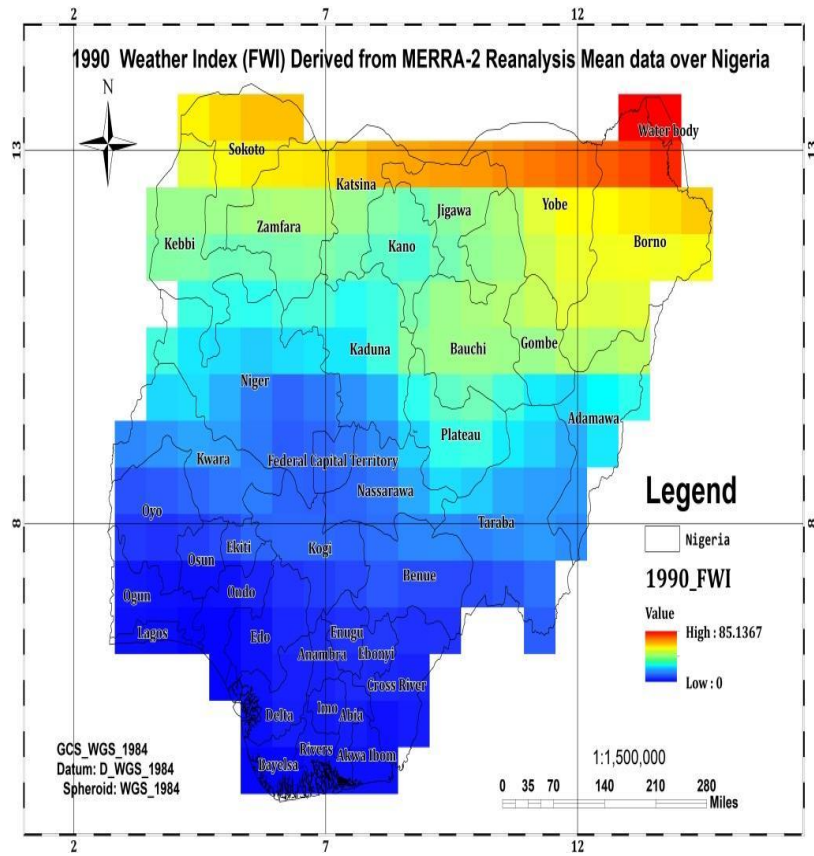


Figure 3. A map showing the 1990 Fire Weather Index (FWI) Spatial distributions over Nigeria

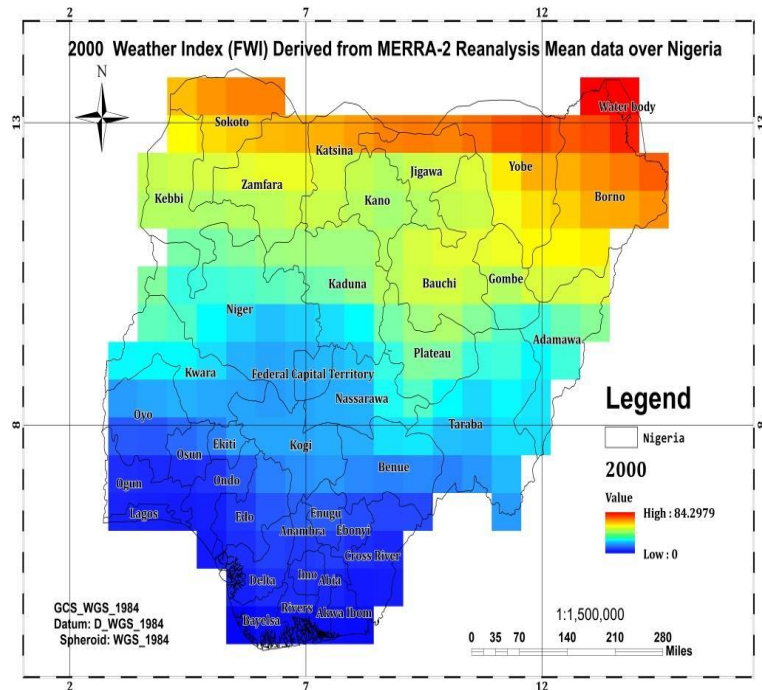


Figure 4. A map showing 2000 Fire Weather Index (FWI) Spatial distributions over Nigeria

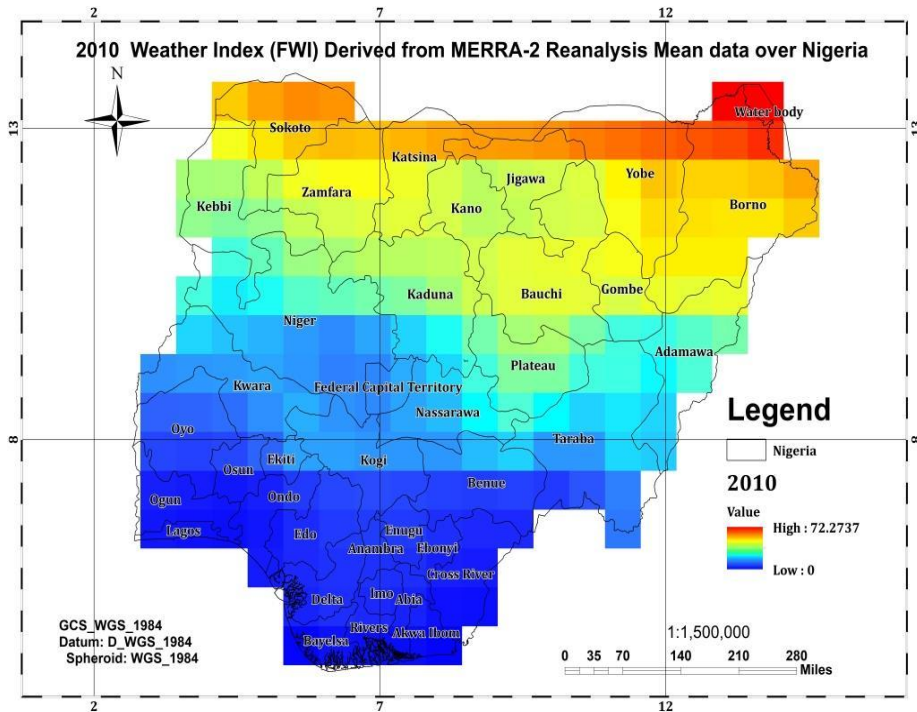


Figure 5. A map showing 2010 Fire Weather Index (FWI) Spatial distributions over Nigeria

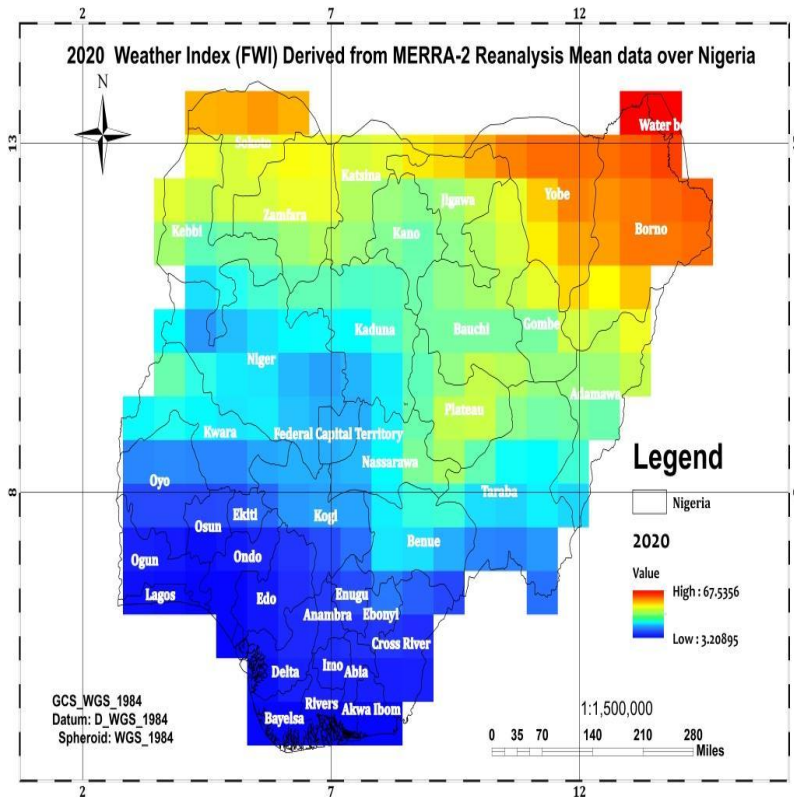


Figure 6. A map showing the 2020 Fire Weather Index (FWI) Spatial distributions over Nigeria

During Nigeria's wet season, from May to October, the potential for fire is generally quite low, owing to abundant rainfall and high humidity. However, a significant increase starts in November, coinciding with the beginning of the Harmattan season. The danger reaches its peak in January and February, with fire risk readings across the country frequently escalating into the "High" to "Very High" categories. This heightened

risk is driven by a combination of factors: almost no rainfall, very low air moisture (often dropping below 20% in the north), warm daytime temperatures, and steady winds. Together, these conditions rapidly dry out savanna grasses and other light vegetation. The fire danger then begins to lessen around March and April as a weather front known as the Intertropical Discontinuity (ITD) moves northward, ushering in more humidity and the season's first rains. This distinct annual pattern clearly demonstrates that the dry Harmattan season is the most critical period for fire hazards throughout Nigeria.

Spatial Distribution of Fire Risk

The spatial distribution of fire weather risk shows a clear and significant north-south gradient (Figure 2). An analysis of fire weather index (FWI) data collected between 1990 and 2024 (as presented in Figures 3-8 and Tables 1-2) reveals several key findings. The lowest FWI value observed during this period was 0.7, while the highest recorded reached 76.2, with the overall average standing at 29.8. Looking at the average FWI values in Nigeria over successive decades, there have been notable shifts.

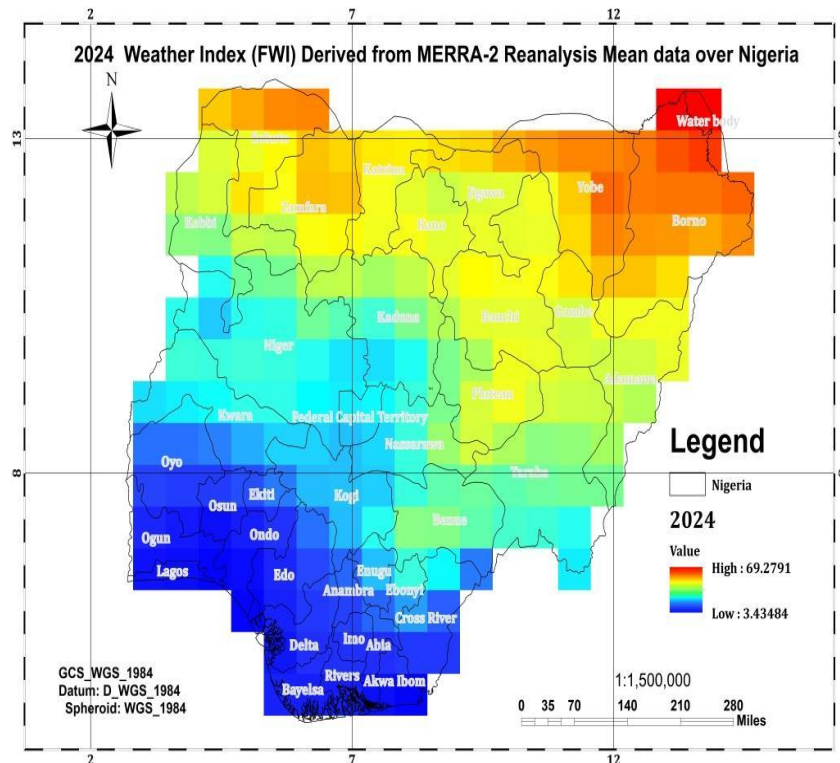


Figure 7. A map showing the 2024 Fire Weather Index (FWI) Spatial distributions over Nigeria

Levels were classified as mean in 1990 (29.1), escalated to extreme in 2000 (34.6), and returned to very high in both 2010 (27.2) and 2020 (27.8). Geographically, the northern states consistently exhibited extreme FWI levels across the board, with Borno State registering the peak at 57.0. The middle belt region experienced a combination of very high and extreme classifications, with Plateau State recording its highest value at 33.9. In contrast, Nigeria's southern states showed FWI values that spanned from low to high, with Bayelsa State noting the lowest figure at 2.0.

Northern Nigeria's Sudan Savanna and Sahel regions face the most significant fire risk. States like Borno, Yobe, Jigawa, Katsina, Sokoto, and Kebbi regularly show "Very High" to "Extreme" fire danger during the dry season. This situation arises from the area's climate, which includes a prolonged and severe dry period, coupled with its vegetation, primarily made up of annual grasses that completely dry out, providing a vast and continuous supply of easily flammable material.

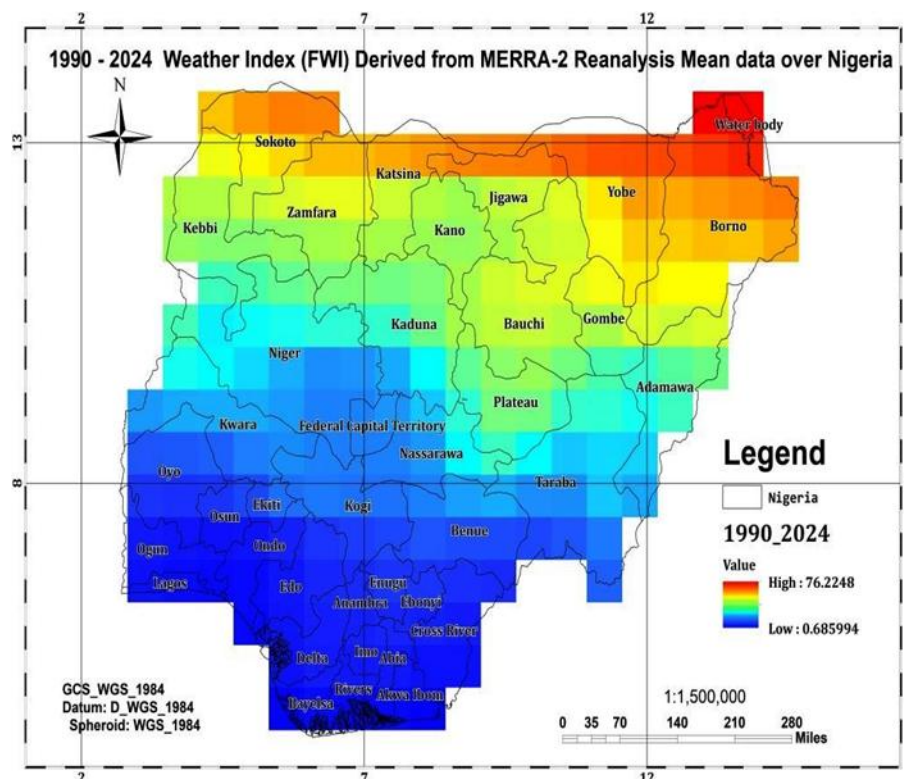


Figure 8. A map of the 1990 to 2024 Fire Weather Index (FWI) Spatial distributions over Nigeria

Northern Nigeria's Sudan Savanna and Sahel regions face the most significant fire risk. States like Borno, Yobe, Jigawa, Katsina, Sokoto, and Kebbi regularly show "Very High" to "Extreme" fire danger during the dry season. This situation arises from the area's climate, which includes a prolonged and severe dry period, coupled with its vegetation, primarily made up of annual grasses that completely dry out, providing a vast and continuous supply of easily flammable material.

Moving south, the Guinea Savanna region, often referred to as the "Middle Belt" (including areas such as Niger, Kwara, Benue, Taraba, and the Federal Capital Territory), experiences a "High" to "Very High" risk. This zone acts as a transitional area, with a somewhat shorter dry spell than the northern regions, but still possesses ample flammable grasses and open woodland vegetation.

The southern Tropical Rainforest zone, including the Niger Delta and coastal states such as Lagos, Rivers, Bayelsa, and Cross River, exhibits the least likelihood of fire occurrence. Consistent high humidity and plentiful rainfall throughout the year prevent vegetation from drying out sufficiently to support large-scale blazes. However, even here, fire risk can climb to "Moderate" levels during particularly intense dry periods. This indicates that fires are not impossible, especially in cleared agricultural land and damaged forest areas.

Implications for Fire Management

The findings from this study provide a scientific foundation for a proactive national fire management strategy. The FWI-based risk maps can be used for:

- I. **Early Warning Systems:** Daily FWI forecasts can provide several days of lead time for fire agencies and the public to prepare for high-risk conditions.
- II. **Strategic Resource Allocation:** During the peak season, firefighting resources (personnel, equipment) can be pre-positioned in the identified high-risk zones in the northern and central regions.
- III. **Policy and Public Awareness:** The risk maps can guide policies on controlled burning periods for agriculture and inform public awareness campaigns to prevent accidental ignitions during high-danger days.

Limitations and Future Work

While this study is thorough, it does have several limitations. Firstly, the MERRA-2 data provides a broad overview (with a resolution of approximately 50-60 kilometers), which means it may not fully capture local weather differences influenced by specific land features or small, intense weather systems. Secondly, the Fire Weather Index (FWI) relies exclusively on weather conditions. It does not incorporate other critical factors that contribute to the overall danger of fires, such as the type and amount of flammable materials, sources of ignition (like human activity or lightning), or the terrain itself.

Future research should focus on:

- I. **Downscaling:** Employing statistical or dynamical downscaling techniques to produce higher-resolution fire weather risk maps.
- II. **Integrated Fire Risk Modeling:** Combining the FWI with satellite-derived data on land cover, vegetation condition (NDVI), and human activity (population density, road networks) to create a more holistic fire risk model.
- III. **Validation:** Systematically validating the FWI outputs against observed fire activity using satellite active fire products (MODIS) to fine-tune the index for Nigerian conditions.

4 CONCLUSION AND RECOMMENDATIONS

This study successfully applied the Canadian Fire Weather Index (FWI) system, using MERRA-2 reanalysis data, to conduct the first comprehensive, nationwide evaluation of fire weather risk in Nigeria. The findings clearly indicate a strong seasonal pattern, with fire danger reaching its peak during the December to March Harmattan season. Furthermore, a distinct geographical trend was observed, showing the highest risk in the northern savanna environments and the lowest in the southern rainforests.

This methodology provides a robust, scientifically credible, and economical approach for assessing fire danger, which is particularly valuable for a region with limited on-the-ground meteorological infrastructure. The insights from this research offer crucial information for Nigeria's Federal Fire Service, the National Emergency Management Agency (NEMA), and state-level environmental protection bodies. Integrating the FWI as an operational tool can significantly improve Nigeria's capabilities in wildfire preparedness, prevention, and response, ultimately helping to safeguard its precious natural environments and secure the livelihoods of its communities.

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