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Application of geospatial technology and decision model in the development of improved food security index

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Most developing countries are currently experiencing a severe food security crisis. A good policy to mitigate food insecurity is dependent on accurate assessment. Therefore, an improved assessment of food situation is important in implementing food security measures. Existing food security assessments are limited in integrating localized variables, often needing more context-specific information. This study proposes a new food security index (Hybrid Food Security Index-HFSI), the Nigerian state was used as a case study. Data used include; food consumption, poverty levels, variability in food prices, inflation, climate variability data and the status of road infrastructure. The study also integrated a hybrid Multi-criteria Criteria Decision Model (MCDM) and geo-spatial technology. The geo-spatial presentation of food security across Nigeria shows that food security is generally better in the Southern part of the country than in the Northern region. Broadly, indicators' performance primarily improves from the country's North to South, which suggests that Northern states tend to be less food secure than Southern states. According to the Fuzzy-DEMATEL-ANP model, the Poverty level indicator significantly impacts the food security situation in all focused states, as it received the highest priority weight of 0.1487. The study recommends intensifying poverty alleviation programs to improve food security, and women's development programs should be prioritized. This study provides policymakers and stakeholders with evidence-based assessments to address food security challenges in Nigeria.

Keywords Food Security, Sub-Saharan Africa, Geospatial assessment, Multi-criteria Modelling

Access to adequate, safe, affordable, and nutritious food is a fundamental human right[1]. The Food and Agriculture Organization (FAO) defines *food security* as having access to enough safe and nutritious food that satisfies dietary needs and preferences for a healthy and active life. A food-secure status per FAO definition has led to transdisciplinary research and interventions addressing intertwined food security issues such as inadequate calorie intake, food preferences, and lack of access to sufficient food. Further, this has stressed the importance of routinely assessing the status of food security at all levels (country, regional and global) to ensure citizens' nutritional requirements are met. At country levels, this has furthered the development of national food security metrics and indicators[2]. An accurate, evidence-based assessment of food security status is crucial for identifying population sub-groups needing assistance, enabling informed policy-making, targeted interventions, implementation and monitoring[3].

Numerous studies have examined food security in Africa in response to the urgent need to combat hunger. For instance[3], evaluated the impact of drought, food security policies, and climate change on irrigation schemes in Sudan, while[4] used geo-spatial technology to investigate the effects of climate variability and extreme weather on food insecurity and agriculture-based livelihoods in Ghana. At a regional level[5], evaluated the food security situation in West African countries using a combination of tools and a unique approach. Various factors have been identified as contributing to food security challenges in Africa, including the limited mechanization of African farm systems[6], droughts linked to climate change that cause significant losses in crop production and

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increased food prices, all compounded by the COVID-19 pandemic[7]. A plethora of recommendations for addressing food security have also been made from these and other studies. However, implementing a unified action plan for the entire region, e.g., West/sub-Saharan Africa, may need to be more practical and effective due to differences in each country's agricultural sector practises and priorities. Additionally, pooling resources at a regional level could face several bottlenecks due to differing country-specific priorities for achieving sustained food security.

Notably, at the country level, food security is influenced by government policies at different levels (national, state, and local). One of the key recommendations for achieving food security, based on the in-depth study conducted by[8] on research priorities and gaps in food security in several developing countries, is the need to harmonize interventions and efforts at all levels of government: macro (national/state) and micro (household and individual) levels. With specific reference to Nigeria, and besides the authors' experiential knowledge of the governance framework and political dynamics in Nigeria, this study focuses on a state-level assessment of food security due in part to their strategic position, leverage and political will to implement localized transformational policies that can ensure a food-secure nation. Focusing on assessing food security parameters at the state level in Nigeria could enable evidence-based deployment of resources to address food security challenges impacting the micro-level (household and individual) via local government administration, thus promoting the national food security agenda. This approach has been validated and guided by previous studies in a similar context[9,10].

Moreover, previous studies in this research work have primarily focused on only one dimension of food security, such as food availability[11,12], food utilization[13,14], or food accessibility[15,16]. Meanwhile, food stability and the impacts of climate change, all critical aspects of food security, should be assessed/reported[8]. Innovative policy mechanisms that can achieve sustainability and developmental goals cost-effectively, especially in developing countries such as Nigeria, should be inclusive, encapsulating various dimensions of food security[8,17,18]. In this study, multiple dimensions of food security and a critical evaluation of interactions between these dimensions are prioritized to address knowledge gaps and contribute towards holistic, evidence-based policy formulation and interventions/strategies. Including climatic variabilities as an additional dimension, as captured in this study, will further enhance knowledge on how climate change affects food security in a focus state-level context.

The Global Food Security Index (GFSI) is a composite indicator measuring food affordability, availability, quality, and safety[18] for tracking food security progress; it is programmed globally. While state-level information on food security metrics is advocated, current data used to classify the GFSI are sourced from organizations such as the World Bank and FAO, which only provide information (averages) at the national level. This makes it challenging to assess food security at a state level (sub-national); this is the focus of the current study. Like most countries, Nigeria has high variability in climate, culture, region, and socioeconomic conditions across the states. Therefore, an everyday national context is limited and cannot address the variability across the states. Modifications to the GFSI and FAO food security indicators thus become necessary using available local data sources at the state level. Hence, the identification of the food security indicators and their distribution across Nigerian states becomes critical, and by integrating geo-spatial technology to analyze food security data in Nigerian states, this study enables comparisons of composite values and spatially-mapped visualization of food security parameters, improving planning and monitoring of adaptation strategies at the subnational level.

Previous studies have acknowledged the need to investigate food security (index) and have approached it in various ways. For instance, Chen et al.[19] reassessed the GFSI and proposed a method to reduce subjective weight assignment[20]. assessed the status of rural women's food security in one of Nigeria's states using multi-stage random sampling. In a similar study[21], investigated the food security index in Bangladesh and the impact of food support from the government on the FSI. Another study for the African context was focused on.

Sub-Saharan African (SSA) nations to explore the relationship between food security and nutrition, circular economy, innovation, and climate change[22]. To achieve food sovereignty in SSA, a study explored African governments' role in pursuing policies that support food security or food sovereignty. A study in Ethiopia developed a composite FSI that considers the dimensionality of availability, accessibility, usage and stability[23]. Generally, despite numerous studies on food security, there is scarce literature on the development of robust FSI[19,23]; this study is therefore essential to add to the body of literature to enhance FSI. In addition, even though recent studies have established the fact that climate change has a profound impact on food security in Africa generally[24] and in Nigeria in particular[25], it is imperative to integrate the climate change variability impact on the food security index model, however, to the best of the authors' knowledge, no study has integrated climate change variable in the development of FSI as done in this study. This study therefore finds application at regional, state and local level contextual applications, in cognizance to peculiarity of factors that are rarely captured at global projection of food security.

The novelty of this study lies in developing the Hybrid Food Security Index (HFSI) with context-specific variables, implemented at the state level, using multiple food security dimensions with a decision support system in a geo-spatial environment. A hybrid multi-criteria decision-making (MCDM) model is embedded in the geo-spatial technology to assess food security indicators and determine the HFSI. The MCDM model uses a set of matrices to analyze the relationship between indicators of an event, determine their influence, and assign priority-based weights to each indicator. This modelling approach has been effective in assessing risk for events that depend on indicators such as flood[26], erosion[27], and groundwater pollution[28]. Its flexibility and ease of implementation with geo-spatial technology make it advantageous[26,27]. Finally, the HFSI in this study considered women's employment, which is crucial in the development of the food security index for developing countries. Integration of the above-mentioned local context variable makes the food security index dynamic and crucial to capture local, national and regional food security situations. As done in this study, the integration of the local variables in the modelling of food security ensures a realistic model and such ideology can be applied to any other region or study condition. The approach can be easily applied or transferred to various regions, providing the additional advantage of contextualized food security evaluation. This study further assessed the interactions between different dimensions of food security, which is especially relevant for the focused context. Overall, this approach is thus new and considered suitable for state-level assessment of the food security situation; a case study of Nigeria is illustrated in the study. This study aims to provide a new contextualized and integrated approach to food security assessment; the overall objective is to develop an improved food security index by integrating local contextualized food security scenarios using geo-spatial technology and multi-criteria decision support tools, the case of the Nigeria state is used as an application of the hybrid food security model.

In the manuscript structure, the study area and data sources are discussed in Materials and Methods. The construct of the four dimensions of food security indicators was captured in Sect. 2.3, and the criteria for developing the four dimensions of security: food affordability, availability, utilization and stability were detailed in the section. The analyses and the method for estimating food stability indicators were stated in Sect. 2.4. The application of the decision tool was highlighted in Sect. 2.5, "Integration of Indicators and Determination of HFSI", while the details for of coupling of the MCDM and GIS were done in Sect. 2.6. The result of the study and discussion is stated in Sect. 3, and the interaction between the food security indicators was also discussed. The HFSI was introduced in Sect. 3.6. The last part of the manuscript outlines the conclusion and policy recommendation, as well as the limitations and further research of the study.

Materials and methods

Study area

Nigeria's population is currently about 200 million people and a significant proportion of the populace experiencing an acute food insecurity crisis. Nigeria has an estimated 923,769 square kilometres landmass and five distinct vegetation zones with varying climates. The country is made up of 36 states and 6 geopolitical zones, with the capital city, the Federal Capital Territory (FCT), located in the centre of the country (see Fig. 1).

Data collection sources

Secondary data and complementary information on various factors such as food consumption (as a share of household expenditure), poverty levels, percentage share in education through research and development, variability in food prices, inflation, and status of road infrastructure in Nigerian states, were extracted from the National Bureau of Statistics website (NBS). Temperature and rainfall data were collated from the World Bank climate change portal. The Nigeria Demographic and Health Survey Report 2018 from the National Population Commission provided data on access to drinking water, employment of women in different states,

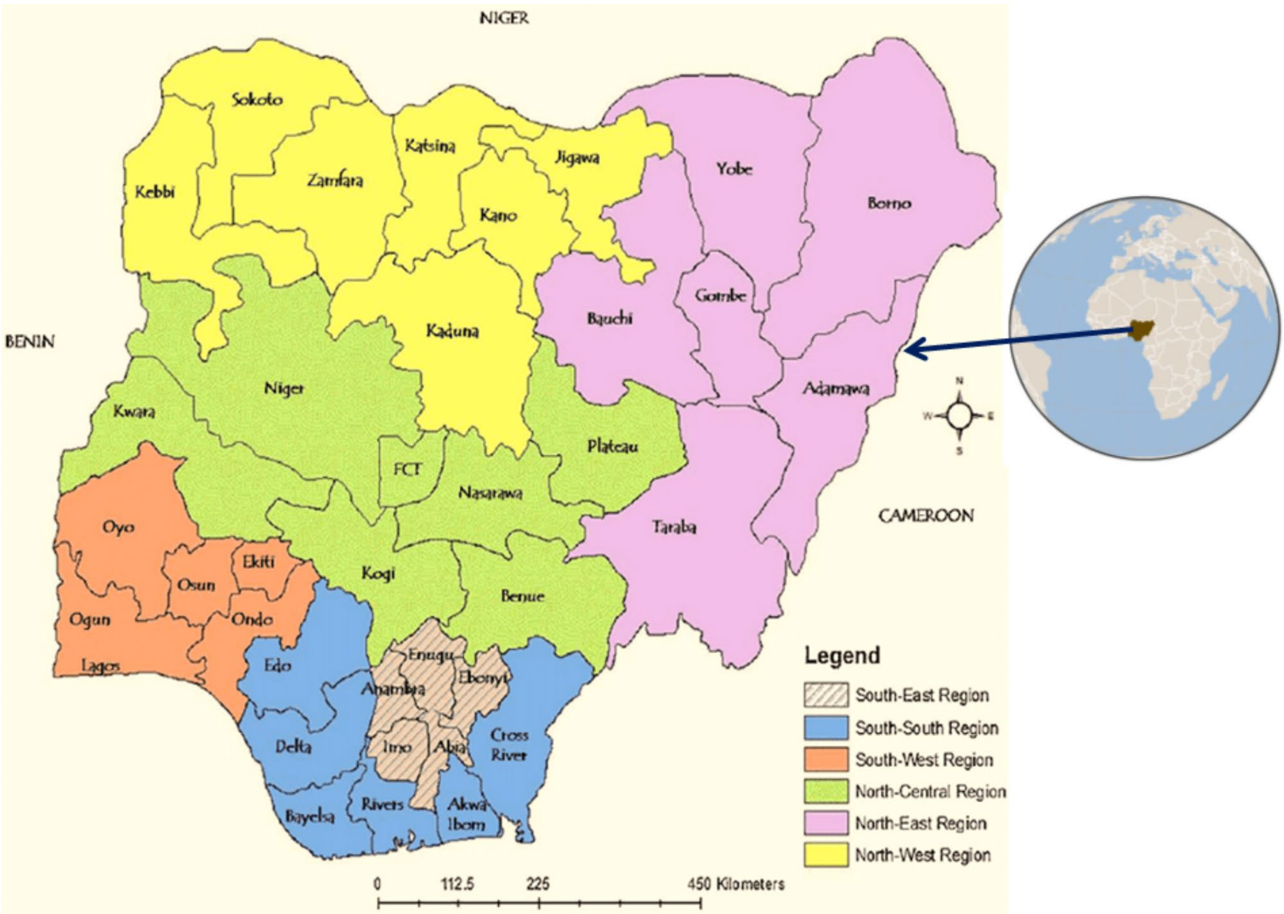

Fig. 1. Map of Nigeria showing the six geopolitical zones and 36 states – focus of current study. Source:[28]

and sanitation. The survey was conducted with support from international partners such as the World Health Organization (WHO), the United States Agency for International Development (USAID), the Bill and Melinda Gates Foundation (BMGF), and the United Nations Population Fund (UNFPA), ensuring its reliability. Figure 1 was obtained from GIS map from previous research work[28], while Figs. 2, 3, 4, 5, 6, 7, 8, 9 and 10 was generated from ArcGIS software version 10.1,

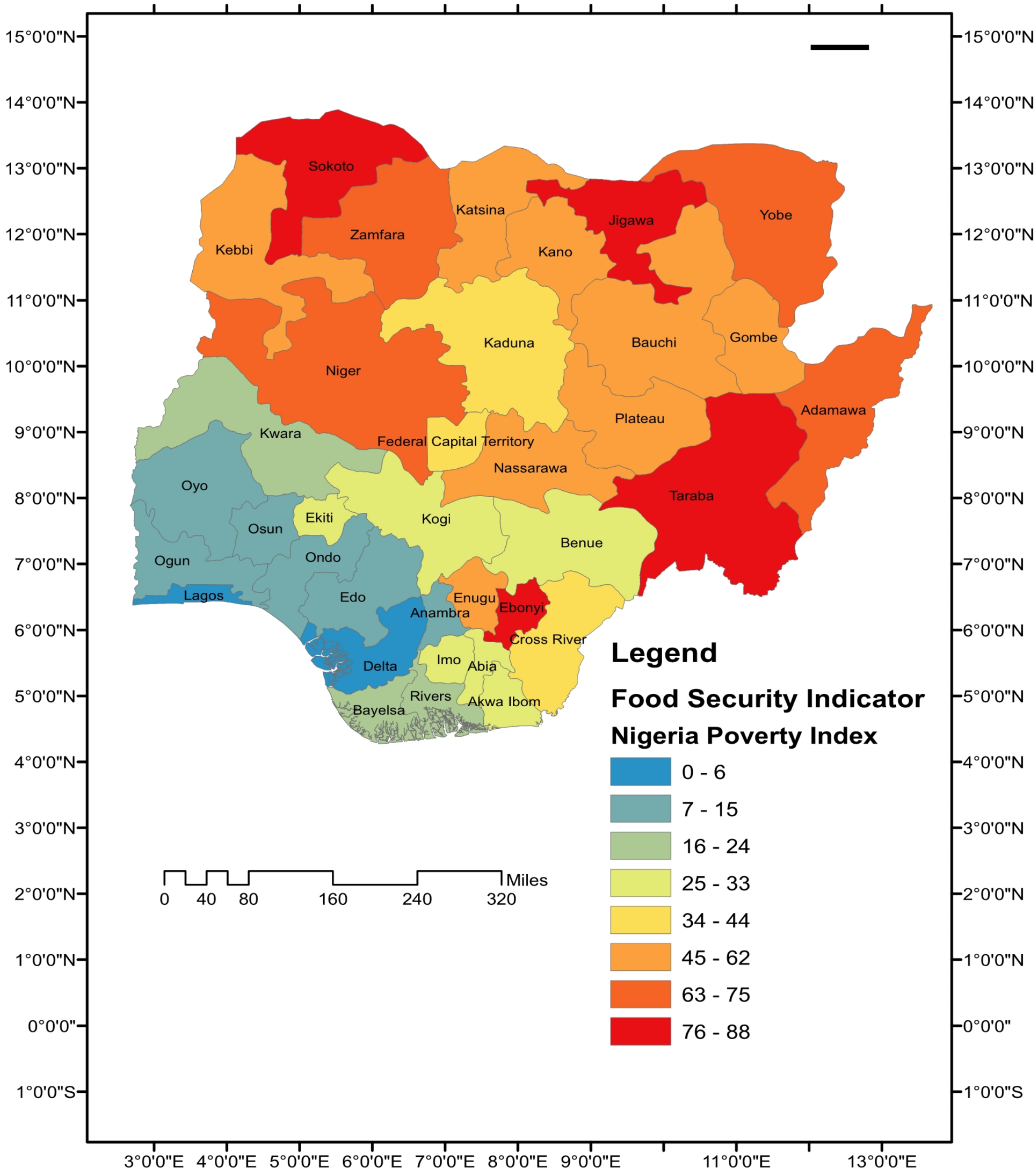

Fig. 2. Poverty index of Nigerian States (With the exception of Bornu State).

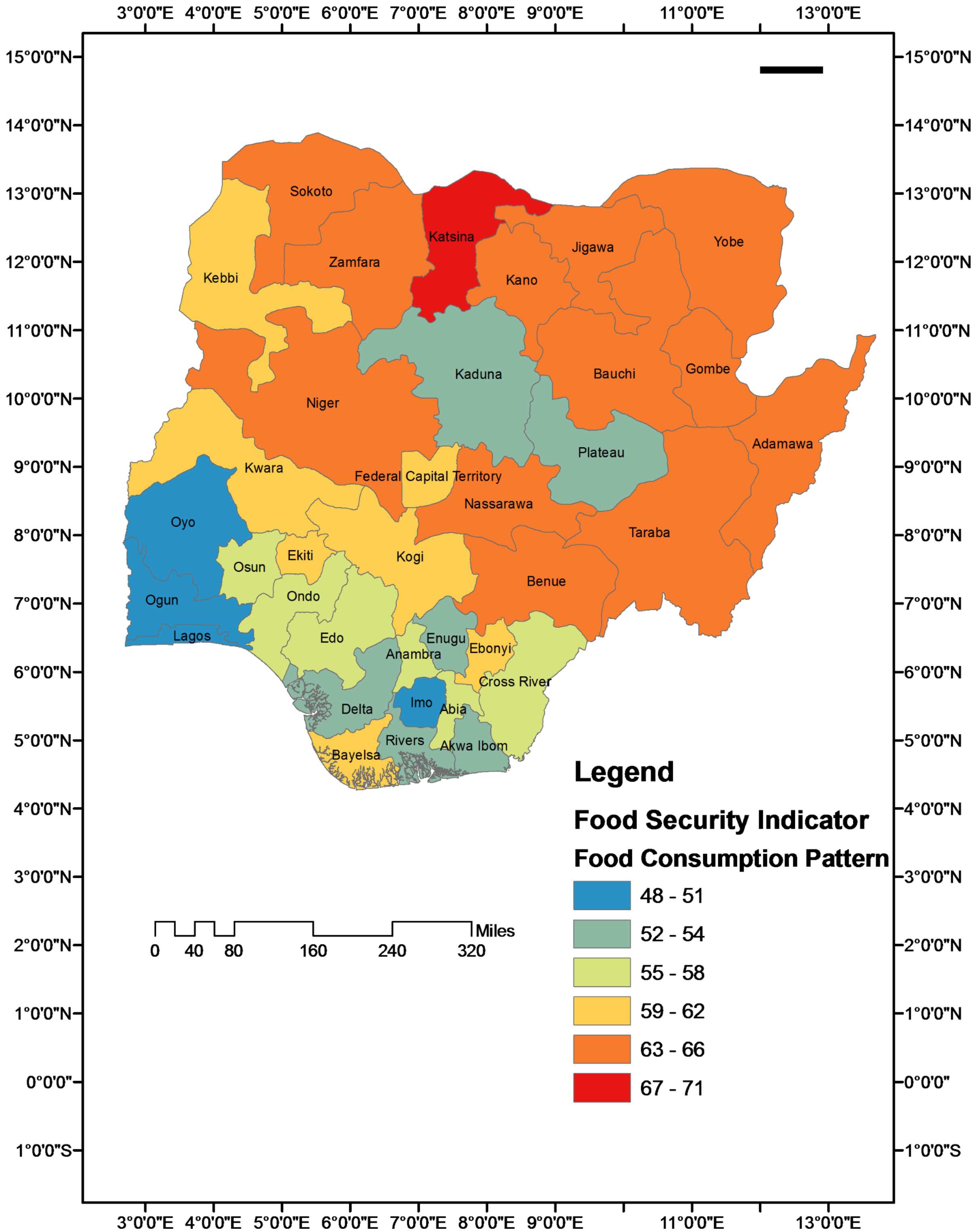

Fig. 3. Nigeria food consumption pattern.

Construct of food security indicators

Existing indicators for food security assessment have been criticized for not considering evolving salient and representative factors. Previous studies have shown these indicators' limitations[29,28]. For example, the GFSI, which has been used since 2012 to assess food security in 100 countries, is based on three dimensions: Affordability, Availability, and Quality and Safety; with 28 indicators, the GFSI is limited in the application/integration of subnational contexts such as climate change, women employability in developing FSI[30]. found that the GFSI had shortcomings that could have been improved to get reliable results over a short period. In

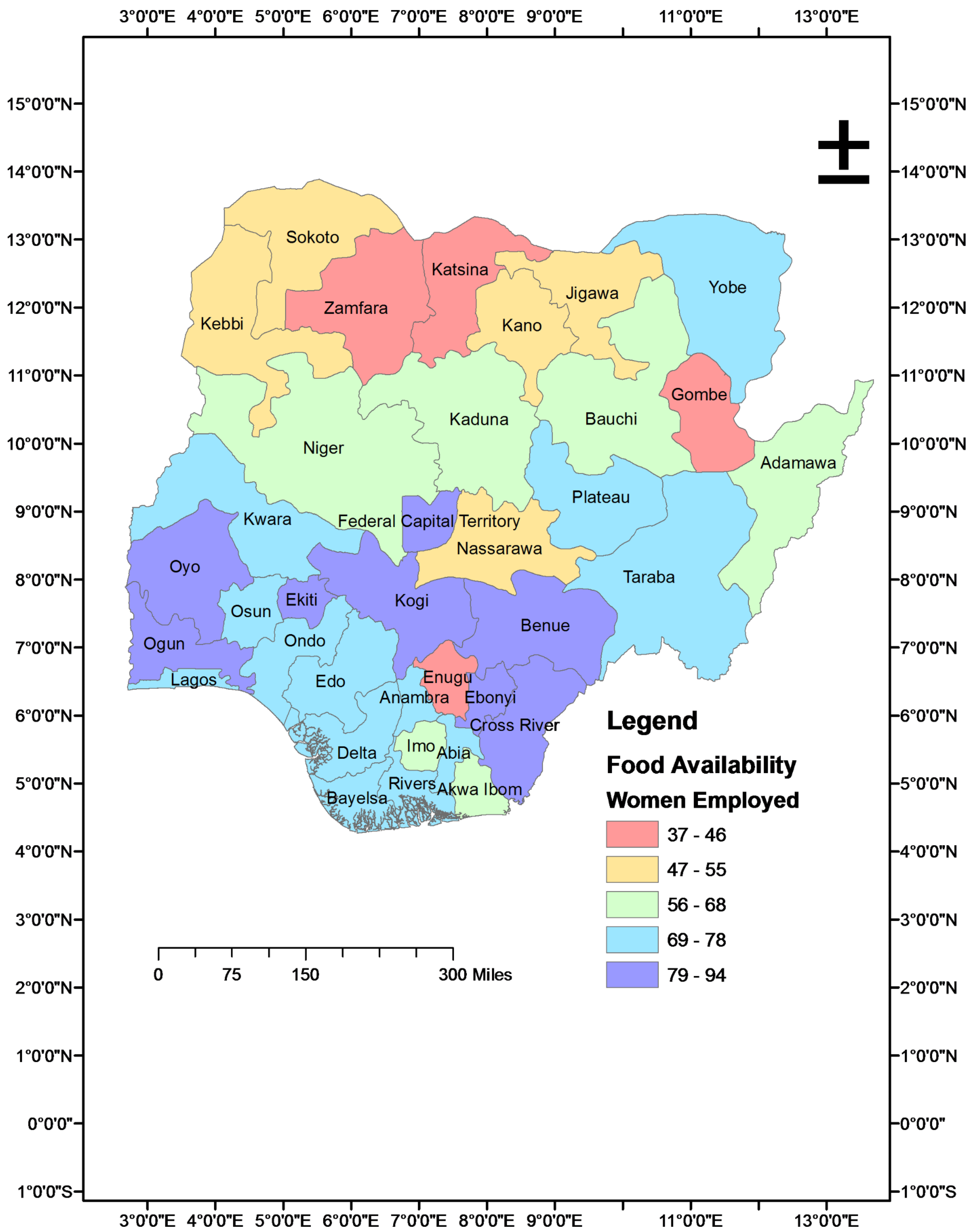

Fig. 4. Women employed across the various Nigerian states.

their study, the Food Security Index (FSI) proposed by the FAO was considered more reliable. However, FAO has 19 complex indicators to which is difficulty to apply or measure food security, because of data availability in developing countries. Therefore, a modified or hybrid version of the two indices (GFSI and FSI), such as the Hybrid Food Security Index (HFSI) proposed in this study, that is context-sensitive, becomes necessary to assess food security better. This aligns with recommendations made in a previous study[31]. Appendix A1 contains figures of other geospatial data. The HFSI developed in this study combines the strengths of two indices and considers the peculiarities of the study area, available data, and representative context-specific food security

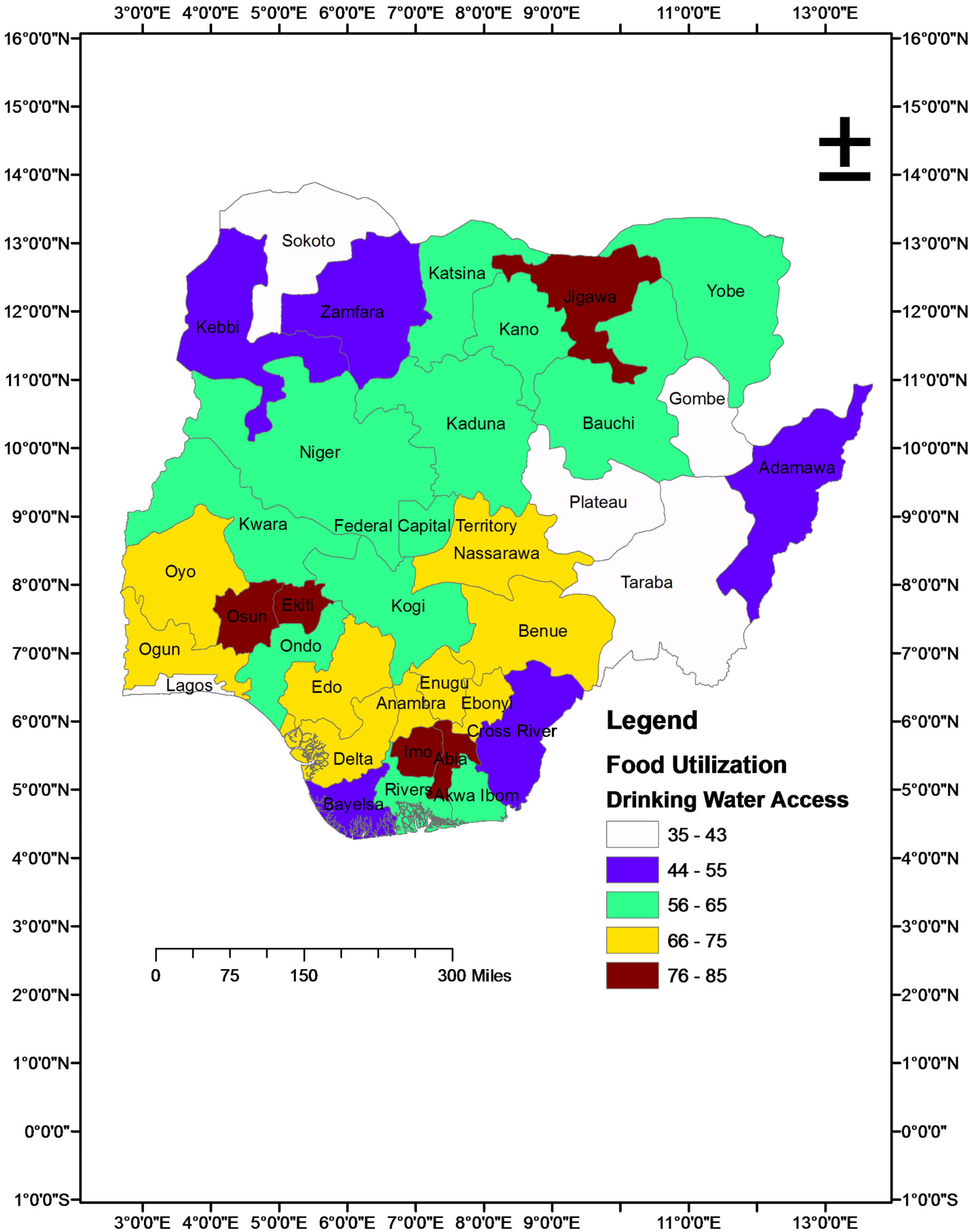

Fig. 5. Access to improved drinking water in Nigerian states.

issues in the focused area. The HFSI is based on the four FAO dimensions of food security: Food affordability, Food availability, Food Stability, and Food utilization. Each dimension is explained briefly.

Food affordability

The factors contributing to food insecurity in developing countries are strongly linked to poverty, making food unaffordable for many people. When there is a food shortage or an increase in demand and prices, only those with higher purchasing power can afford to buy food, while those with weaker purchasing power may go hungry

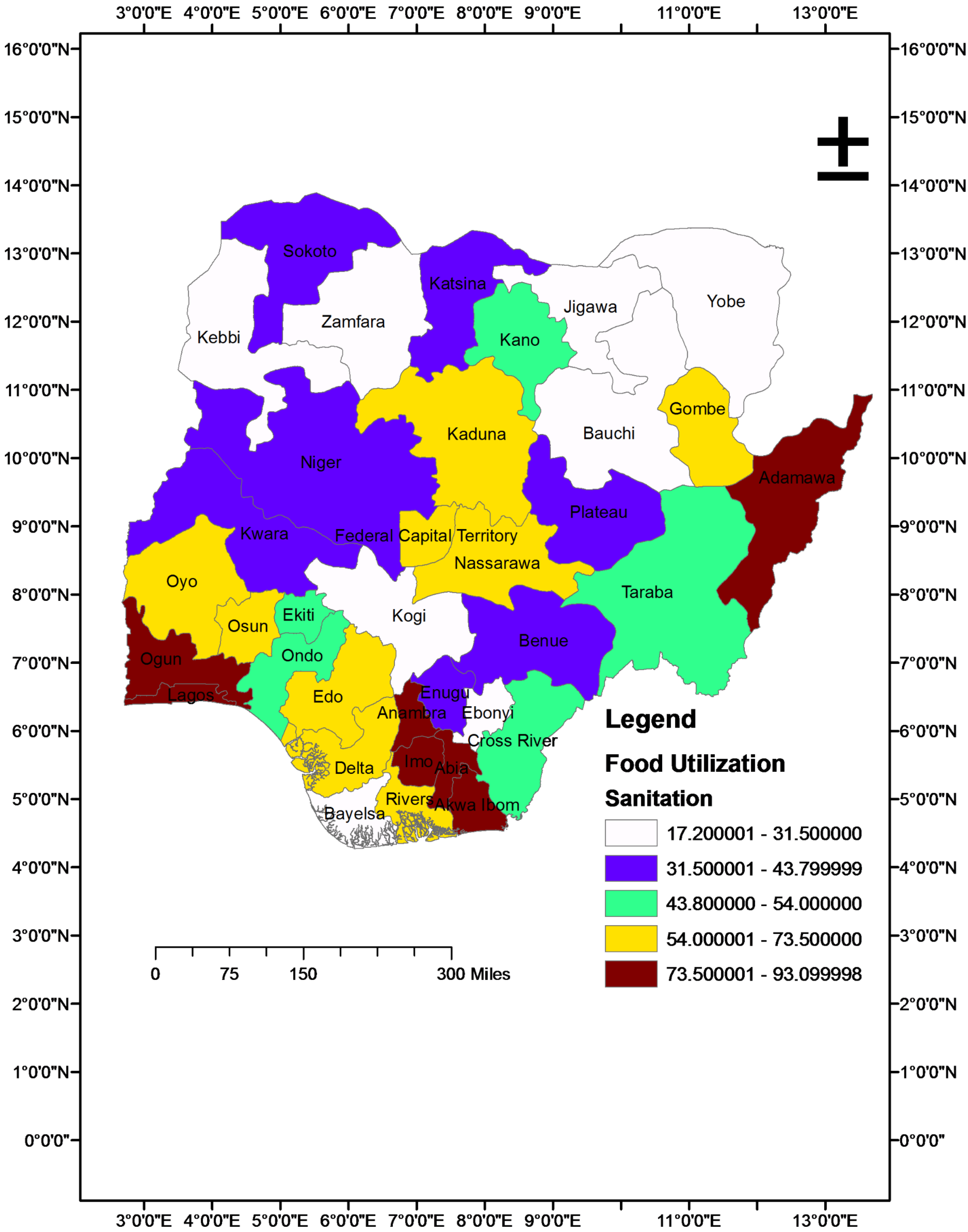

Fig. 6. Access to improved sanitation in Nigerian states.

or have to settle for less nutritious options. This aligns with the findings of[7], who emphasized that more than simply having enough food available is needed to guarantee it can be accessed, obtained and consumed. Despite reports of food loss and waste, poverty remains a significant obstacle for many in developing countries regarding accessing or securing available food. In this study, food affordability is thus represented by two sub-indicators: the proportion of the population below the global poverty line (i.e., poverty levels) and food consumption level as a share of household expenditure (i.e., reflecting household food purchasing power).

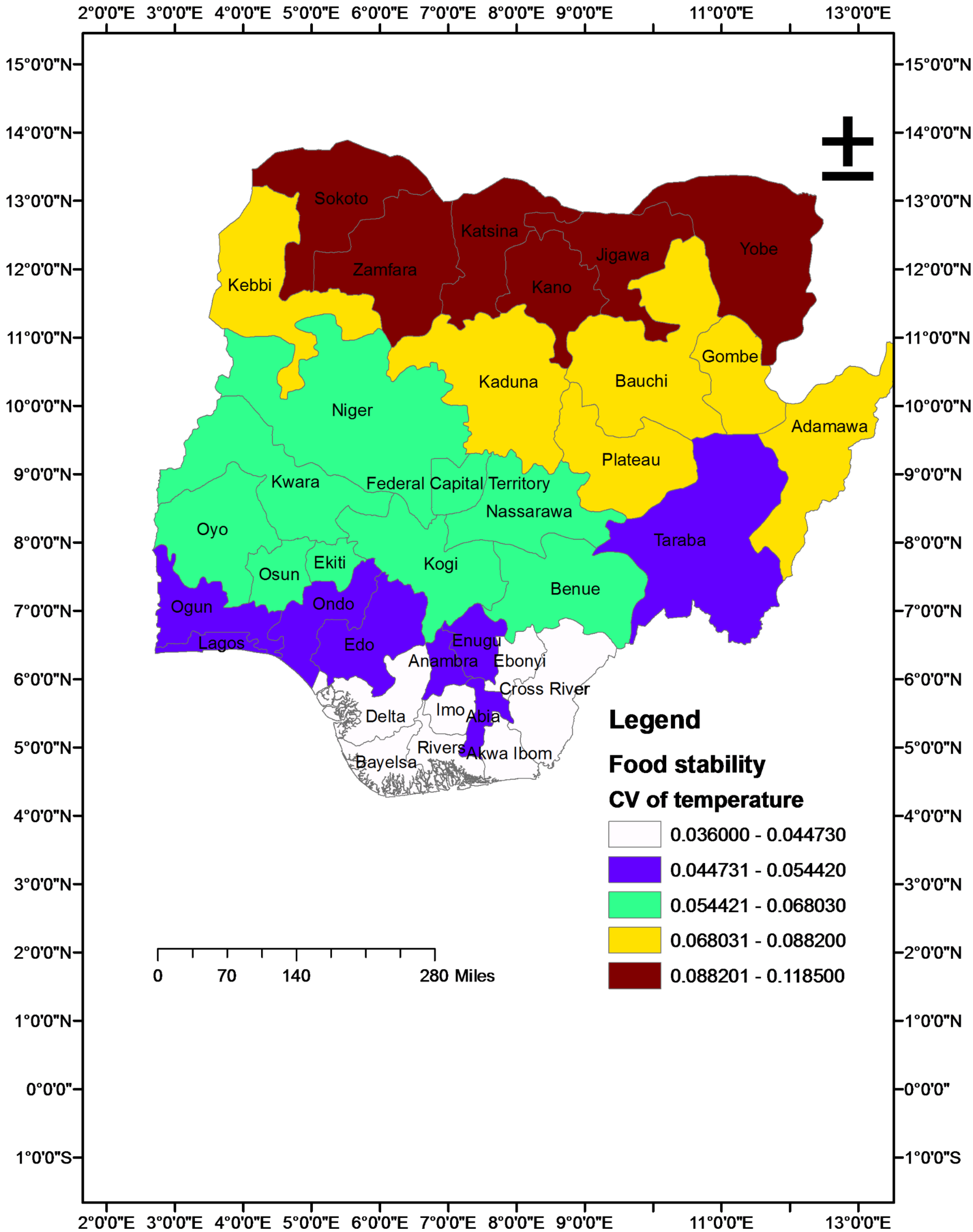

Fig. 7. Temperature variation assessment for various states in Nigeria.

Food availability

Food availability refers to the amount and quality of food produced (domestically or imported), supplied and distributed[5]. Thus, the state of the road network (i.e., road infrastructure) plays a critical role in ensuring access to available food. A well-maintained road network enables farmers to transport and sell their agricultural produce from remote rural areas to urban centres. Conversely, as in many developing countries, a poorly maintained road network can lead to increased transportation costs and, in some cases, prevent the conveyance of agricultural produce entirely. These consequently result in food loss, spoilage and waste. Therefore, this study considers road

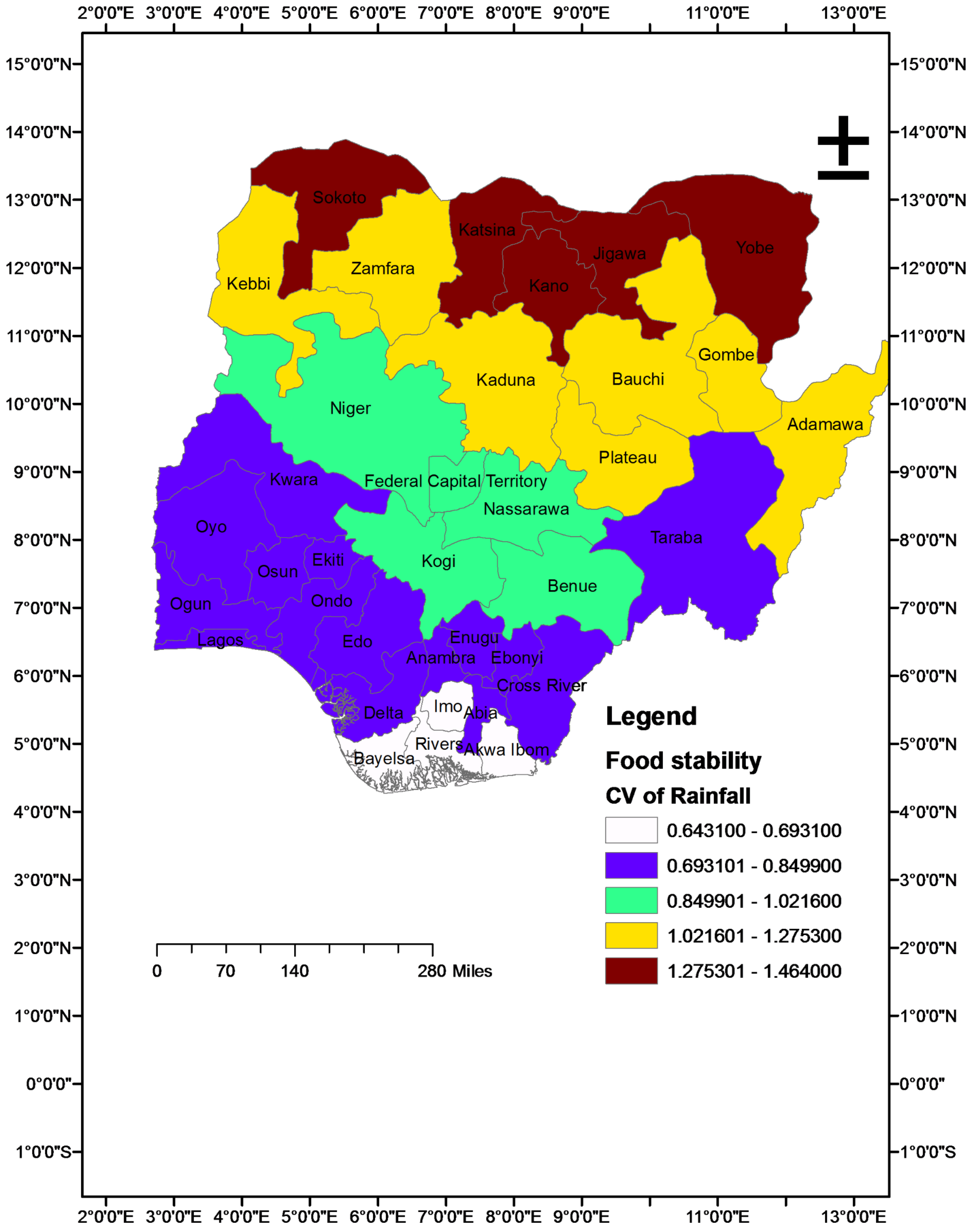

Fig. 8. Rainfall variation assessment for various states in Nigeria.

infrastructure as an essential food availability indicator, as highlighted by road crash data in various states, which sheds light on the challenges faced in the conveyance of agricultural produce.

Research shows that in sub-Saharan Africa, women account for 70–80% of household food production, while in Asia, they account for 65%, and in Latin America and the Caribbean, 45%[32]. Various studies have demonstrated women's significant contribution to food security in Nigeria. For example[33], found that while men primarily contribute to economic accessibility to food, women contribute more to sustainable access to food in the Southwest region of Nigeria. Additionally[34], emphasized that women in West African countries

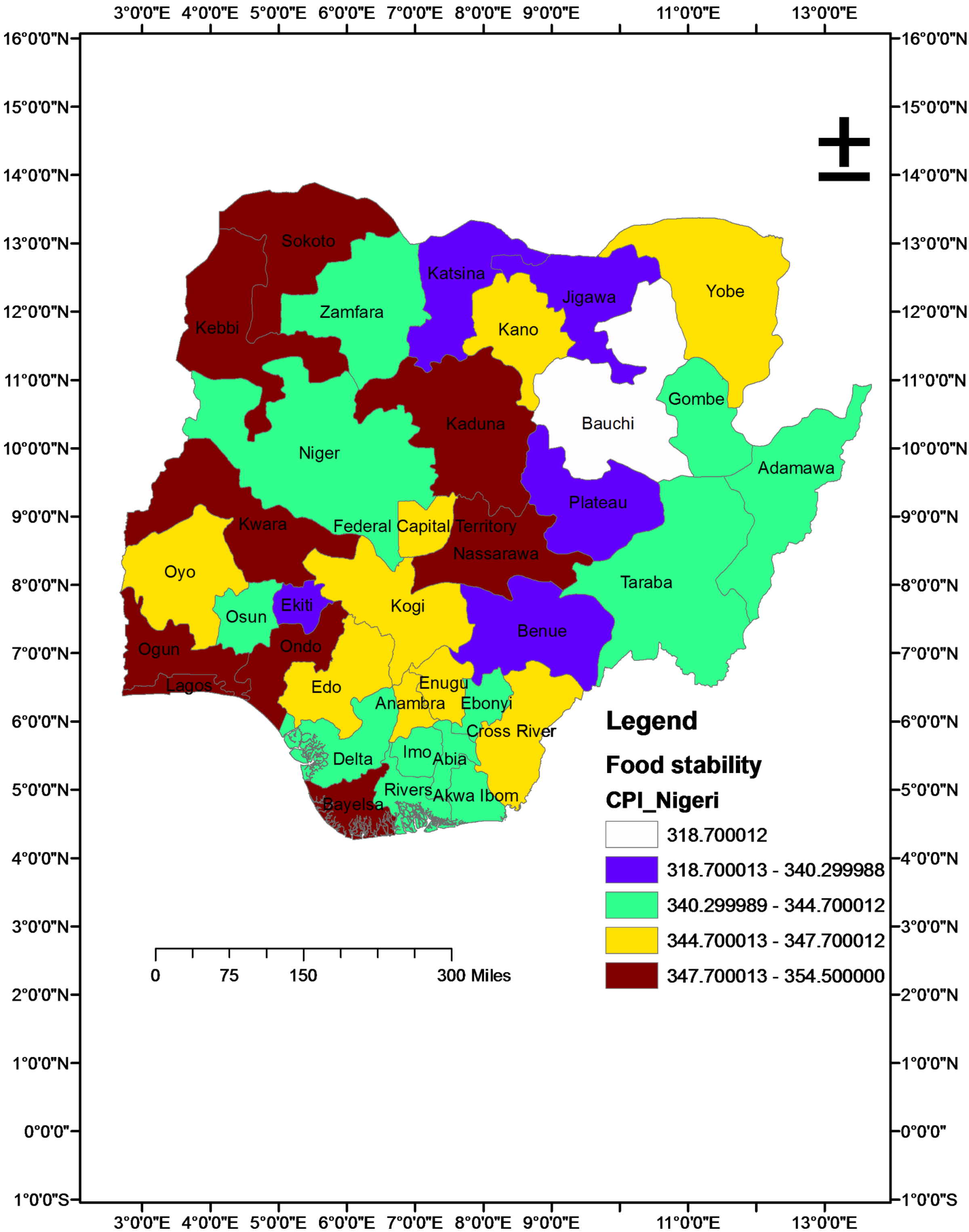

Fig. 9. Food Price variation assessment for various states in Nigeria.

play a crucial role in food security, from production to distribution and nutrition. Despite their critical roles, their contributions to food security have yet to be fully recognized or documented; this indicates that women's employment status significantly impacts food security in Africa more than in other regions. Unfortunately, the GFSI and FAO index fails to capture this sub-indicator under food availability in food security, particularly as it applies to Africa. This study recognizes the importance of women's involvement in food security and thus factors this in the HFSI. Another critical factor in food availability is the average amount of protein consumed. However,

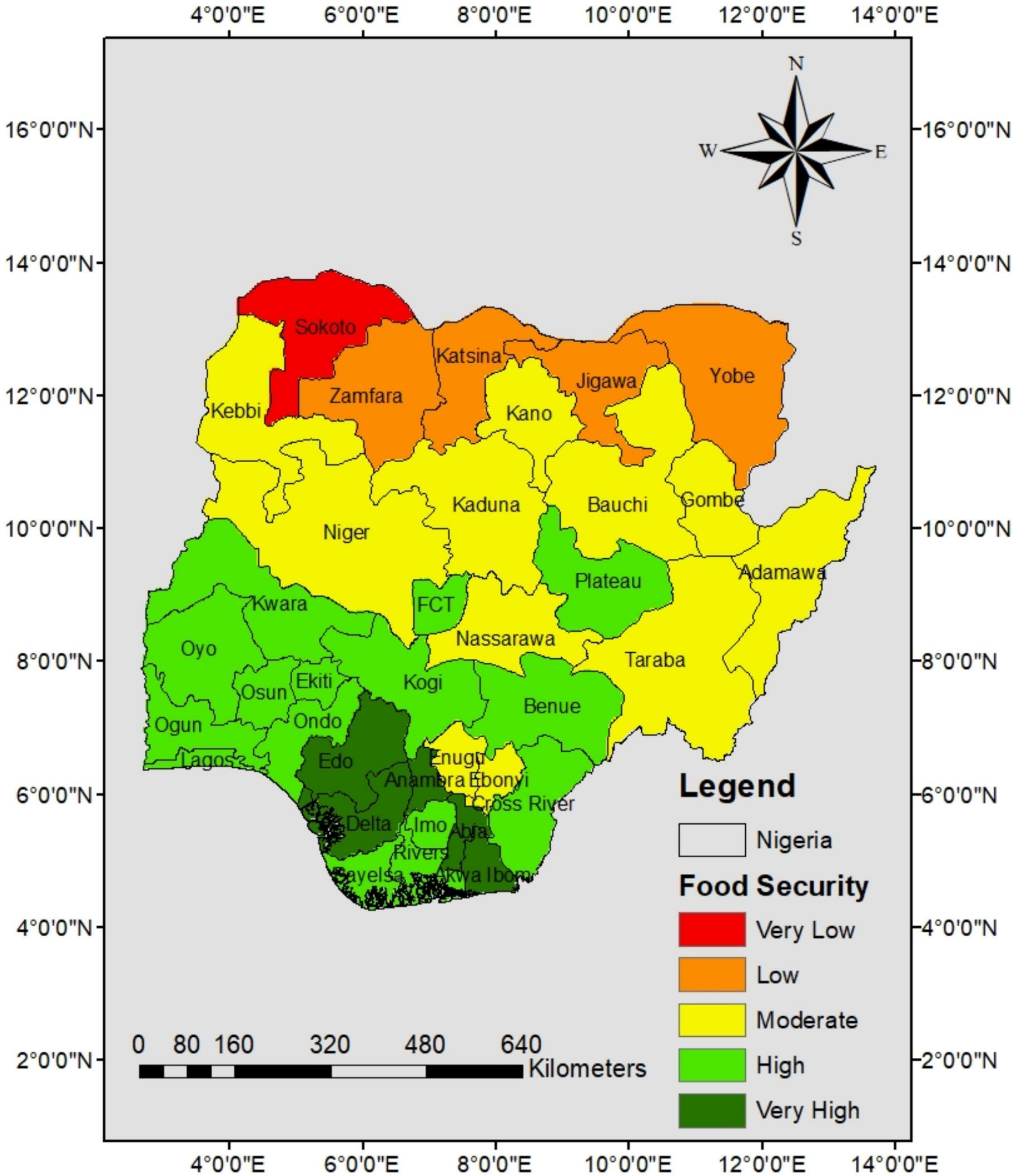

Fig. 10. Hybrid Food Security Index for various states in Nigeria.

this can be challenging to measure in most developing countries. Nonetheless, the data on consumption expenditures for protein-rich foods used in this study provides some insight into this factor.

Food utilization

The term "utilization" reflects how households and individuals prepare and handle food safely and use the food that is available to them; this captures important factors: nutrient bioavailability, whether they have access to clean water and proper sanitation (i.e., water availability, sanitation), nutrition security, feeding practices and food safety[5]. In this study, two representative indicators of food utilization are used (based on data availability): the percentage of the population with access to clean drinking water and the percentage of the population with access to proper sanitation.

Food stability
Food stability pertains to the affordability, availability, and accessibility of food, which can be affected by various factors, including socioeconomic and environmental issues. For instance, climate change and environmental problems may result in an unstable food supply, while social unrest, such as war and economic problems, can cause food prices to rise. In this study, climate variability is considered an environmental factor since rain-fed agriculture is still the primary method of farming in most developing countries and the study area. The variability of rainfall and temperature can significantly impact food production. Hence, these were factored into this study. Moreover, other socioeconomic factors that can lead to food insecurity are considered through their impact on food prices and inflation. Table 1 shows the food security dimensions, the sub-indicators for each dimension, indicators in the previous food security indices, and those constituting the HFSI.

Analyses and estimation of food stability indicators

Estimation of climate change indicator
To quantify food stability, climate change indicator, rainfall and temperature variabilities were used to reflect the impact on food production. 30-year (1990 to 2020) rainfall (and temperature) data of various Nigerian states were analysed using the coefficient of variation (CV) to measure the deviation from the average amount of rainfall. I.e., CV is the ratio of the standard deviation (SD_i) of rainfall amount to the rainfall mean for the various states. Higher CV values indicate a wider level of dispersion around the mean. Previous studies have used SD_i (Eq. 1) to examine variability and predictability of climate[35,36].

$$SD_i = \sqrt{\frac{(x - x_m)^2}{n-1}} \tag{1}$$

Where x is the monthly rainfall data and temperature, x_m is the mean annual precipitation and temperature for the period under study, n is the number of data.

$$CV_i = \frac{SD_i}{Mean\ \ (x_m)} \tag{2}$$

The CV values assigned to each Nigerian state represent the amount of variation in the climate data from the average. Hence, higher CV values indicate more variability in rainfall, which can impact water resources and temperature in that state. These values can be used as proxy indicators of climate change, and higher values may indicate greater vulnerability to drought and increased costs of food production over time.

Estimation of food price variability and inflation
To determine fluctuations in food prices and inflation, the Consumer Price Index (CPI) is often employed as a gauge. The Nigeria Bureau of Statistics provided data for the year 2020, and the CPI was calculated using Eq. (3) of the Laspeyres formula.

$$\text{Laspeyres formula} = \frac{\sum(Observation\ Price\ *\ Base\ Quantity)}{\sum(Base\ Price\ *\ Base\ Quantity} \tag{3}$$

Indicators	Sub-indicators	FAO Index	GFS Index	Hybrid FSI
Affordability	Food consumption as a share of household expenditure	Indicator not available	Indicator and sub-indicator available	Indicator captured from GFS index
	Proportion of population under global poverty line	Indicator not available	Indicator and sub-indicator available	Indicator captured from GFS index
Availability	Road Infrastructure	Indicator and sub-indicator available	Indicator and sub-indicator available	Indicator not captured from both FAO and GFS index
	Women employability	Indicator available, sub-indicator not available	Indicator available, sub-indicator not available	Indicators
	Average Protein Supply gr/capita/day	Indicator and sub-indicator available	Indicator available, sub-indicator not available	Indicator captured from FAO and GFS index
Food Utilization	Percentage of population with access to improved drinking water source	Indicator and sub-indicator available	Indicator and sub-indicator not available	Indicator captured from FAO index
	Percentage of population with access to sanitation facilities	Indicator and sub-indicator available	Indicator and sub-indicator not available	Indicator captured from FAO index
Food stability	Climate change variability	Indicator available, sub-indicator not available	Indicator and, sub-indicator not available	Captured as research priority gap in Farrukh et al., (2020)
	Variability in food price and inflation	Indicator and sub-indicator available	Indicator and, sub-indicator not available	Captured as per capita food supply variability in FAO index

Table 1. Previous and current-study food security indices.

In order to assess the relationship between different food security indicators, we conducted a correlation analysis using the Pearson method, which is represented by Eq. (4).

$$r = \frac{n\sum\left(x_i - x_m\right)\left(y_i - y_m\right)}{\sqrt{\sum\left(x_i - x_m\right)^2\sum\left(y_i - y_m\right)^2}} \tag{4}$$

Where r is the correlation coefficient, x_i = values of the x variables of indicators in a sample x_m = mean values of the x variables of indicators ; y_i = values of the y variables of indicators in a sample; y_m = mean values of the y variables of indicators

Integration of indicators and determination of HFSI

To determine the HFSI, a hybrid MCDM model and geospatial technology were combined to harmonize all food security indicators. The hybrid MCDM model involved three phases: the Fuzzy method, Decision-Making Trial and Evaluation and Laboratory (DEMATEL) method, and the analytic network process (ANP) method, the Fuzzy-DEMATEL-ANP model was applied in this study. This approach was previously used by[30] to assess flood risk, for detailed information on the application of the hybrid MCDM model, readers are referred to previous publication by the author and various authors[26,2728,30]. The input data for the model comprise a set of pairwise decision matrices obtained from questionnaires administered to food security experts. Fuzzy triple numbers $\left(l_{ij}^k,\ m_{ij}^k,\ u_{ij}^k\right)$ were adopted as the mode of data input for the questionnaires based on the scale shown in Table 2.

Phase one: the fuzzy method

The first step in the fuzzy method consists of aggregating the experts' pairwise comparison matrix components to create the fuzzy decision matrix with Eq. (5).

$$\bar{D}_{ij} = \left(\bar{l}_{ij},\ \bar{m}_{ij},\ \bar{u}_{ij}\right)\ \begin{cases} \bar{l}_{ij} = \frac{1}{n}\sum_{k=1}^{n} l_{ij}^k \\ \bar{m}_{ij} = \frac{1}{n}\sum_{k=1}^{n} m_{ij}^k \\ \bar{u}_{ij} = \frac{1}{n}\sum_{k=1}^{n} u_{ij}^k \end{cases} \tag{5}$$

where *k* represents the *k*th expert (*k* = 1, 2, …, *n*), $\bar{D}_{ij}$ represent the elements that make up the fuzzy decision matrix, $\bar{D}$. The final step is the defuzzification of $\bar{D}_{ij}$ using Eq. (6) to obtain crisp values that represent elements of the initial decision matrix, D_{ij}.

$$D_{ij} = \frac{\bar{l}_{ij} + 4\bar{m}_{ij} + \bar{u}_{ij}}{6} \tag{6}$$

Hence the final product of the fuzzy method which is the initial decision matrix, *D* can be written as Eq. (7).

$$D = \begin{bmatrix} D_{11} & D_{12} & \cdots & D_{1n} \\ D_{21} & D_{22} & \cdots & D_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ D_{n1} & D_{n2} & \cdots & D_{nn} \end{bmatrix}_{n\times n} \tag{7}$$

Where n denotes the number of indicators.

Phase two: the DEMATEL method

The DEMATEL method starts with the decision matrix from the fuzzy method. The first step is to normalize the matrix T to get another matrix $\bar{T}$ using Eq. (8).

Fuzzy numbers $\left(l_{ij}^k,\ m_{ij}^k,\ u_{ij}^k\right)$	Linguistic values
(0, 0, 0.25)	No influence
(0, 0.25, 0.5)	Very low
(0.25, 0.5, 0.75)	Low
(0.5, 0.75, 1.0)	High
(0.75, 1.0, 1.0)	Very high

Table 2. Fuzzy numbers and corresponding linguistic values[37].

$$\bar{T}_{ij} = D_{ij}/\bar{\lambda}; \quad \bar{\lambda} = 1/\max_{1\leq i\leq n}\left(\sum\nolimits_{j=1}^{n} D_{ij}\right) \tag{8}$$

The last step is to calculate the total relationship matrix T based on the normalized matrix $\bar{T}$. The T matrix shows the direct and indirect relationships between the indicators, and this is determined using Eq. 9.

$$T_{ij} = \bar{T}_{ij} \times \left(I - \bar{T}_{ij}\right)^{-1} \tag{9}$$

Where I is an Identity matrix.

The final product of the DEMATEL method, i.e., the total relationship matrix, can then be written as Eq. 10.

$$T = \begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1n} \\ T_{21} & T_{22} & \cdots & T_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ T_{n1} & T_{n2} & \cdots & T_{nn} \end{bmatrix}_{n\times n} \tag{10}$$

Phase three: the ANP method

The ANP method follows a process similar to phase two. It takes the output of the DEMATEL method as its input and begins by determining an unweighted super-matrix, $\bar{W}$ from the matrix $\tilde{T}$. To determine $\bar{W}$, an α-cut threshold is defined by experts to filter out the minor influences in T. Here, $\bar{W}_{ij} = 0$ when $T_{ij} < \propto$ and $\bar{W}_{ij} = T$, then $T_{ij} \geqslant \propto$. Where $\bar{W}_{ij}$ is an element of the unweighted super-matrix.

The next step entails the normalization of $\bar{W}$ to obtain the weighted super-matrix, W. Here, the elements of the matrix W are defined by Eq. (11).

$$W_{ij} = \bar{W}_{ij}/\bar{C}_i \tag{11}$$

Where W_{ij} is an element of the weighted super-matrix and $\bar{C}_i$ is defined as the sum of elements of the matrix $\bar{W}$ by columns given mathematically as

$$\bar{C}_i = \sum_{i=1}^{n} \bar{W}_{ij} \tag{12}$$

Hence the weighted super-matrix W can be written as Eq. (13):

$$W = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ W_{n1} & W_{n2} & \cdots & W_{nn} \end{bmatrix}_{n\times n} \tag{13}$$

To determine the individual weights of indicators using the ANP method, the final step involves obtaining a limit super-matrix. This is done by multiplying the weighted super-matrix by itself multiple times, i.e., the weighted super-matrix is raised to limiting powers until the super-matrix converges into a stable long-term super-matrix which represents the weight of the indicators. Mathematically, this can be represented as $\lim_{k\to\infty} = W^k$, where W denotes the limit super matrix and k denotes any number.

Coupling the MCDM model with geospatial techniques

This study used a combination of MCDM and geospatial techniques to calculate the HFSI, employing a weighted linear combination method within a GIS environment. The weighted linear combination method as implemented in this study can be expressed mathematically as

$$HFSI = \sum_{i=1}^{n} W_i M_i \tag{14}$$

Where HFSI is the food security index, W_i is the Fuzzy-DEMATEL-ANP determined weight of each indicator and M_i is the map component of each indicator as delineated in the GIS environment. In order to obtain M_i, this study used the fuzzy membership technique to standardize the initial delineated maps of the indicators. This ensured that the harmonization of the indicators was consistent. Two fuzzy membership classes, "MS Small" and "Large," were used for this purpose.

Result and discussion

Food security affordability assessment

The affordability dimension of food security was evaluated by analysing the percentage of the population living below the global poverty line and the food consumption as a share of household expenditure in each state.

Poverty index

The study measured poverty levels based on consumption expenditures instead of income, similar to previous studies. Figure 2 depicts the geospatial map of the poverty index of Nigerian states (excluding Bornu State due to the ongoing crisis, which made it difficult to assess the state's poverty index), revealing significant differences in poverty levels throughout the country. This implies that each state has different policies and approaches to eradicating poverty that must be coordinated at the federal level, resulting in significant gaps in poverty levels across Nigeria. The four states with the highest poverty indices, ranging from 76 to 88, are Sokoto, Jigawa, Taraba, and Ebonyi, with 87.73, 87.02, 87.72, and 79.76, respectively. Three of these states are in the Northern region, while Ebonyi state is in the Southern region. Lagos and Delta states have the lowest poverty indices in the 0 to 6 class. Lagos state is known as the nation's industrial hub, while Delta state is known for its oil exploration and wealth. These activities in these regions likely contribute to high economic growth. Analysis by geo-political zone revealed that the Southwest region states (Oyo, Ogun, Osun, Ondo and Lagos) generally have a better poverty index, with most falling between categories 7 to 15, except for Lagos and Ekiti States, which fall within categories 0 to 6 and 25 to 33. However, poverty is a major issue in the North-west region, with the highest poverty indexes found in Sokoto and Jigawa states. Three states fall between 45 and 62 indexes, and one falls within the 63 to 75 index range. Kaduna state, on the other hand, has the best poverty index in the region. The Northeastern states have the lowest performance index, with several states falling under the high poverty index category in the region. With numerous displacement camps and prolonged terrorism, Bornu State likely has the highest poverty index in Nigeria. The poverty index in the North Central states (Niger, Kwara, FCT, Kogi, Nasarawa, Plateau, and Benue) is comparatively better than that of the North-east and North-west regions. Additionally, the poverty index in the Southeast and South-South regions is better than in the North-Central states. Across Nigeria, poverty levels decreased from North to South, possibly due to differences in (political, environmental and economic) interventions.

Food insecurity and Poverty are related[11]. Table 3, "Correlations among all food security indicators", indicates that there is a correlation between Poverty and climate change. Policy measures by the state government on food

		CV Temp	CV Rainfall	Water & Sanitation	Variation in Food Price	Improved Water Access	Women employed	Road Infrastructure	Protein Food	Poverty Index	Food Consumption
CV Temp	Pearson Correlation	1	0.984**	−0.419*	−0.224	−0.368*	−0.625**	0.066	−0.319	0.657**	0.629**
	Sig. (2-tailed)		0.000	0.011	0.190	0.027	0.000	0.701	0.058	0.000	0.000
	N	36	36	36	36	36	36	36	36	36	36
CV Rainfall	Pearson Correlation	0.984**	1	−0.417*	−0.243	−0.385*	−0.627**	0.072	−0.311	0.687**	0.625**
	Sig. (2-tailed)	0.000		0.011	0.154	0.021	0.000	0.676	0.065	0.000	0.000
	N	36	36	36	36	36	36	36	36	36	36
Water Sanitation	Pearson Correlation	−0.419*	−0.417*	1	0.221	0.281	0.152	0.233	0.275	−0.256	−0.469**
	Sig. (2-tailed)	0.011	0.011		0.196	0.096	0.377	0.171	0.105	0.131	0.004
	N	36	36	36	36	36	36	36	36	36	36
Variation in Food Price	Pearson Correlation	−0.224	−0.243	0.221	1	−0.149	0.106	0.257	−0.084	−0.253	−0.290
	Sig. (2-tailed)	0.190	0.154	0.196		0.387	0.537	0.130	0.628	0.137	0.086
	N	36	36	36	36	36	36	36	36	36	36
Improved Water Access	Pearson Correlation	−0.368*	−0.385*	0.281	−0.149	1	0.314	0.025	0.275	−0.444**	−0.293
	Sig. (2-tailed)	0.027	0.021	0.096	0.387		0.062	0.884	0.105	0.007	0.083
	N	36	36	36	36	36	36	36	36	36	36
Women Employed	Pearson Correlation	−0.625**	−0.627**	0.152	0.106	0.314	1	0.198	0.088	−0.551**	−0.424**
	Sig. (2-tailed)	0.000	0.000	0.377	0.537	0.062		0.247	0.609	0.001	0.010
	N	36	36	36	36	36	36	36	36	36	36
Road Infrastructure	Pearson Correlation	0.066	0.072	0.233	0.257	0.025	0.198	1	−0.298	−0.047	−0.098
	Sig. (2-tailed)	0.701	0.676	0.171	0.130	0.884	0.247		0.078	0.785	0.568
	N	36	36	36	36	36	36	36	36	36	36
Protein Food	Pearson Correlation	−0.319	−0.311	0.275	−0.084	0.275	0.088	−0.298	1	−0.264	−0.168
	Sig. (2-tailed)	0.058	0.065	0.105	0.628	0.105	0.609	0.078		0.120	0.326
	N	36	36	36	36	36	36	36	36	36	36
Poverty Index	Pearson Correlation	0.657**	0.687**	−0.256	−0.253	−0.444**	−0.551**	−0.047	−0.264	1	0.587**
	Sig. (2-tailed)	0.000	0.000	0.131	0.137	0.007	0.001	0.785	0.120		0.000
	N	36	36	36	36	36	36	36	36	36	36
Food Consumption	Pearson Correlation	0.629**	0.625**	−0.469**	−0.290	−0.293	−0.424**	−0.098	−0.168	0.587**	1
	Sig. (2-tailed)	0.000	0.000	0.004	0.086	0.083	0.010	0.568	0.326	0.000	
	N	36	36	36	36	36	36	36	36	36	36

Table 3. Correlations among all food security indicators. ** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

policy centred on applying sustainable agro-ecology practices are crucial, especially for the areas more hit by climate change. It is also essential that policies that integrate technology, innovative and resilient agricultural practices are introduced to farmers at all levels[3,4,11]. In recognition of the insecurity situation, the various states should adopt state-level security measures that ensure farmers can embark on agriculture without fear or intimidation.

Food consumption pattern
The food consumption patterns in a state reflect the demand for food and non-food items. The percentage of household expenditure spent on food, i.e., food consumption as a share of household expenditure, is a crucial affordability indicator in food security assessments, as reflected in the GSFI assessment tool. In a typical developing country like Nigeria, food items comprise a higher proportion of household spending (hence a higher consumption pattern) than non-food items. Further, consumption patterns can vary across a country, as shown in Fig. 3; which illustrates spatial variability in food consumption patterns across the states and regions in Nigeria.

From Fig. 3, Kastina state has the highest food consumption rate of 71%. The Northeastern states have a food consumption pattern that falls in the second-class range of 63 to 66%. Northwestern states, except Kebbi and Kaduna, have a high value on food consumption patterns similar to those in the Northeastern region. Kebbi and Kaduna have improved values of 59% and 54%, respectively. In the North Central region, some states have improved food consumption patterns, such as Plateau, FCT, Kwara, and Kogi, while others are in the same class as the Northeastern states. The food consumption pattern analyses show that the Southwest states had the best performance. Three of the six Southwest states were identified as the best in the index. Following them were the states in the South-South and then the Southeast. A similarity was observed between the food consumption pattern and poverty index assessment. The trend improved from the country's Northern part to the Southern part. These two indicators could be utilized as a research tool to identify states that require attention to advocate intensified efforts towards improved food-security policy changes.

Food availability assessment

Food security availability assessment was evaluated by assessing road infrastructure, expenditure on protein sources and women's employment, using the food availability sub-indicators itemized in Table 1. The proxy data used in this study for these sub-indicators, i.e., percentage protein content (based on four main categories of proteins: fish and seafood, meat, poultry and poultry products, and milk and milk products) and road crashes in each Nigerian state, are provided in Supplementary Information (S1). Per road infrastructure indicators, several Nigerian states have reported high numbers of road crashes, with some exceeding 100. This suggests that the country's transportation system and road network are weak and inadequate. As a result, the transportation of agricultural products across the country may be impacted. Analyses of protein supply assessment reveal that each state in Nigeria has varying expenditures on protein sources. States near the coast, such as Bayelsa, Delta, and Cross River, spent more on fish and seafood, while landlocked states like Yobe, Jigawa, and Taraba spent less on protein sources. However, some states with significant rivers also spent more on fish and seafood. Regarding meat protein sources, Bauchi, Edo, and Delta spent the most on meat at 11.5%, 7.6%, and 6.8%, respectively. Interestingly, Rivers State, which is coastal, spent less on fish and seafood and more on meat. For poultry and poultry products, Abia and Akwa Ibom spent the most at 16.2% and 16.1%, respectively. Anambra State had the highest expenditure on milk and milk products at 5.5%. Overall, Abia, Akwa Ibom, Bayelsa, Delta, and Edo have the highest expenditure on protein sources in decreasing order of percentage expenditure: 28.7%, 26.6%, 19.8%, 18.6%, and 18.3%, respectively. A key implication from this is that the location of a state impacts protein source availability.

Finally, women's employment varies across Nigerian states, as shown in Fig. 4. Cross River State has the most employed women, while Zamfara, Kastina, Gombe, and Enugu have the lowest. According to regional assessments, the Southern states have the most employed women overall. A study by[33] found a positive correlation between income-generating women and attaining household food security. Therefore, it is crucial to acknowledge the importance of promoting women's employment for sustainable household food security in Nigerian states. The findings here implied that policies for women's empowerment in all sectors should be prioritized, especially for the states that recorded low-employed women; this is imperative to bridge the poverty gap. Also, each state government should develop a workable solution and implement measures to enhance the food distribution network[21]. The policy recommendation of[38] on the need to increase women's human capital, income generation and health are viable policies that state governments should embark on and ensure that the impact of banditry is neutralized[33]; this will enhance food security conditions, especially in the northern states of Nigeria.

Food utilization assessment

The percentage of the population with access to improved drinking water and sanitation was used to evaluate food utilization. Figure 5 displays the percentage of the population with access to drinking water, while Fig. 6 illustrates access to improved sanitation across Nigerian states.

Figure 5 indicates that the states with the highest access rates to clean drinking water - between 76% and 85% - are Jigawa, Osun, Ekiti, Imo, and Abia. It is noteworthy that Jigawa is the only northern state in this group, while the other four are in the South. This explains why northern Nigeria tends to experience more frequent outbreaks of waterborne illnesses. For example, there have been cholera outbreaks in 22 different states and the Federal Capital Territory of Abuja, resulting in the deaths of at least 653 Nigerians (2021 cholera statistics). Unfortunately, the lack of access to safe drinking water across the country has also contributed to the spread of other diseases. A similar reflection regarding access to improved sanitation is mirrored, as shown in Fig. 6.

Inadequate sanitation is a common problem in the northern states, likely due to water scarcity. On the other hand, most states along the coastlines have improved sanitation, except Bayelsa State, which falls under the lowest category despite being situated in a coastal area. Nigeria has lower access to WASH services than other countries in the region. The World Bank reports that 57 million Nigerians still lack access to improved water, while 130 million people use unsanitary sanitation facilities. Research conducted by the Water and Sanitation Program of the World Bank shows that poor sanitation alone costs the country approximately N455 billion (US$2 billion) annually, resulting in significant socioeconomic impacts. All these have implications for food utilization and food security across the Nigerian States. Policy measures suggested here are the importance and the urgency of the government (especially highly affected states) to build a database of areas suffering from severe water scarcity and poor sanitation. Specialized programs, policies, and support should be extended to them. The government agenda should include the development of irrigation schemes, the optimized use of water, and the provision of resilient behavioural training[3].

Food stability assessment

The food stability dimension assessment was based on analyzing the impact of changes in climate factors (temperature and rainfall) and food prices over a certain period.

The climate change impact due to temperature variability

The coefficient of variation (CV), which statistically indicates the deviations of data points from the mean, was employed to determine the temperature variability across different states in Nigeria. High CV values indicate more temperature variability, which can negatively impact food production and cause food insecurity. Figure 7 presents the temperature CV assessment for each Nigerian state.

According to Fig. 7, the Northern region has the highest CV temperature values, with Kebbi, Sokoto, Katsina, Jigawa, and Yobe being the states with the highest values. Conversely, the states located in the extreme South, such as Delta, Rivers, Akwa Ibom, Imo, Bayelsa, Cross River, and Ebonyi, have the lowest CV temperature values. This pattern indicates a natural process of temperature changes, with a distinct decrease in CV temperature values from the country's Northern to Southern region. This finding suggests that the northern regions experience higher mean temperature variability while the southern regions have less variation. Hence, it is crucial to consider the spatial location of each state when developing policies and critical infrastructures to address the effects of temperature variability on food production and security. For example, to enhance food security in the northern regions, it is crucial to prioritize interventions such as research on developing temperature-resistant crop varieties and implementing adaptation strategies to mitigate temperature changes' impact on crop growth and yield.

The climate change impact due to rainfall variability

Rain-fed agriculture, predominant in developing countries, is significantly impacted by unpredictable rainfall. The impact of this has resulted in the uneven and unreliable distribution of rainfall in various states in Nigeria, as shown in Fig. 8, illustrating a trend similar to the CV temperature results discussed. Five states in the extreme north had the highest CV values, except for Zamfara state. Yobe state received the highest rainfall CV value of 1.464034, followed by Jigawa with 1.406246. Seven states, including Kebbi, Zamfara, Kano, Kaduna, Bauchi, Gombe, and Adamawa, fall into the second category with a CV value of 1.0216 to 1.2753. The third and fourth categories have four and fifteen states, respectively. The states with the lowest CV of rainfall, similar to CV temperature, are located in the extreme South, including Rivers, Akwa Ibom, Imo, and Bayelsa States. This study's findings on the variation of climatic factors in Nigeria's states indicate that CV for temperature and rainfall reduced from the Northern to the Southern region. This contrasts with another study conducted in Ghana, which reported that temperatures increase while rainfall decreases in different ecological zones[36]. These findings emphasize the importance of agricultural reforms that consider climate change's impact on food production. The reforms will aim to develop smart agricultural practices such as drought-resilient seedlings, application of organic fertilizer, enhanced integrated soil-crop-water management system, precision agriculture, smart agricultural systems and technology[34]. There should be concerted efforts to context-tailored policies to mitigate climate change's adverse effects on the agricultural sector[22,24,39].

Food price variability and inflation

Food price variability and inflation across different states were analysed using the Consumer Price Index (CPI), which measures the average change in the prices of goods and services over time. Figure 9 illustrates the variation in CPI across the states in the study.

Interaction between the food security indicators

Correlation analysis, which determines how strongly two variables are related, was conducted in this study to evaluate the interactions between food security indicators. Table 3 presents results revealing the correlation between the food security indicators across all 36 states and the FCT.

Table 3 shows a direct correlation between the poverty index and CV Temp ($r = 0.657$; $p = 0.000$) and between the poverty index and CV rainfall ($r = 0.687$; $p = 0.000$). This indicates a relationship between the poverty index and the two climatic variables of rainfall and temperature. This is consistent with a study that found compelling evidence of the negative impact of climate variability on impoverished rural communities in Nigeria[3,24,25,40,33]. The poverty index of Nigerian states is correlated with climate variability. As the climate varies from north to south, agricultural production is negatively impacted. The rural poor, who rely heavily on rain-fed agriculture and may need access to improved crop varieties, are hit the hardest. This poses a significant challenge for the country.

Food consumption tends to increase in response to changes in climatic variables such as temperature and rainfall. This positive relationship means higher temperatures and greater rainfall often consume more food. However, the correlation between the temperature variability and improved water access is negative and weak (r= -0.368; p=0.027), as is the correlation between the variability of rainfall and improved water access (r= -0.385; p=0.021). This suggests that a slight reduction in access to improved water may occur with increased temperature and rainfall variability.

The correlation analyses show no notable relationship between food price variabilities and expenditure on protein consumption and other indicators in different states. However, the analysis revealed an important finding: a strong correlation exists between women's employment across the various states and the poverty index (r= -0.551; p=0.001) and food consumption patterns (r= -0.424; p=0.010). This suggests that as the number of employed women in a state increase, there is a decrease in poverty levels and household food insecurity. This highlights the significance of women's empowerment in combating food insecurity in the country.

Hybrid food security index

Fuzzy-DEMATEL-ANP based weights of food security indicators

The hybrid MCDM model was used in this study to determine the individual specific weighting of ten food security indicators, as listed in Table 4.

According to the Fuzzy-DEMATEL-ANP model, the Poverty level indicator significantly impacts the food security situation in all focussed states, as it received the highest priority weight of 0.1487. The following most influential indicators, in descending order, are Food Consumption (0.1382), Food Price Variability and Inflation (0.1328), Protein Supply (0.1176), and Climate Change Variability (0.1091). Access to Sanitation Facilities has the least impact (0.0751), followed by Women's Employability (0.0869), Access to Drinking Water (0.0957), and Road Infrastructure (0.0960). According to the weightings of various indicators, the food affordability dimension is the most critical factor in addressing food security issues in Nigeria. This is consistent with a study conducted by[33], which revealed that COVID-19 restrictions caused households in Nigeria to lose income, leading to increased food insecurity and limited nutritional options.

GIS-MCDM food security spatial modelling

Food security indicators were adjusted using the weighted linear combination method in the GIS modelling environment. Normalised maps for each indicator, obtained employing the WLC method, were categorised into "MS Small" or "Large" fuzzy membership classes. Poverty, food consumption, road infrastructure, temperature and rainfall variability, and food price variability were classified as "MS Small". In contrast, women's employability, protein supply, access to drinking water, and sanitation were classified as "Large." The combined contribution of temperature and rainfall variability indicators determined climate change variation. To create the Climate Change Variation indicator's normalised map component, both temperature and rainfall variability indicators map components were normalised and then overlaid using the fuzzy overlay tool. Subsequently, all indicators (C1 – C9) were harmonised to obtain the hybrid food security index (HFSI) and the spatial map of the country. Finally, the HFSI-spatial map was classified into five categories: "Very Low," "Low," "Moderate," "High," and "Very High", as shown in Fig. 10.

Figure 10 shows that food security is generally better in the Southern part of the country compared to the Northern region. Most of the states in the North have Very Low to Moderate food security levels, while most states in the South have Moderate to Very High food security levels. These findings are consistent with previous research conducted by[35], which reported that 84.9% of households in northern Nigeria struggle with food poverty[36]. studies supported this trend, having observed that the most vulnerable and food-insecure households are located in the North-West and North-East regions of the country.

A closer inspection of Fig. 10 reveals that Sokoto state has the lowest food security index of 30.11% and is the only state in the country classified under a Very Low food security rating. Five Northern states are classified as having Low food security ratings, including Zamfara (32.37%), Jigawa (36.31%), Kastina (37.14%), and Yobe (38.83%). The poor performance of these states can be attributed to high poverty rates and variations in climate change. Poverty is also a constraining factor for improved food security in Benue state, as noted by[41]. In addition, high poverty rates in the North have increased banditry, terrorism, and kidnapping activities, adversely affecting

Food security dimensions	Food security indicators	Weight (fuzzy scale/percentage)
Affordability	Food consumption (C_1)	0.1382/13.82%
	Poverty levels (C_2)	0.1487/14.87%
Availability	Road infrastructure (C_3)	0.0960/9.60%
	Women employability (C_4)	0.0869/8.69%
	Protein supply (C_5)	0.1176/11.76%
Utilization	Access to drinking water (C_6)	0.0957/9.57%
	Access to improved sanitation (C_7)	0.0751/7.51%
Stability	Climate change variability (C_8)	0.1091/10.91%
	Food price variability and inflation (C_9)	0.1328/13.28%

Table 4. Relative weights of food security indicators based on the fuzzy-DEMATEL- ANP method.

the availability, affordability, and accessibility of food items in Borno State[32]. Similarly[33], established that these issues also affect Kastina state.

In contrast, the southern parts of Nigeria performed better in terms of food security ratings than the northern parts. Abia State has the highest food security performance (78.59%) and is classified as a Very High food security state. Four other states, Akwa Ibom (77.26%), Delta (75.29%), Edo (73.45%), and Anambra (73.24%), were also classified as Very high food security states. However, Enugu (49.55%) and Ebonyi (49.71%) were classified as Moderate food security states. This is consistent with[42], which found that 61.1% of households in Enugu were vulnerable to food insecurity[35]. observed that only 30% of households in three LGAs of Enugu state were food secure. Also[9], , reported a 54.3% rating of food insecurity in other areas of Enugu state. This poor performance of Enugu state compared to other states in the region could be due to a low rate of employed women in the state, the lowest in the region. The high poverty rate in Ebonyi state, the highest in the region, is believed to be the main factor contributing to the state's current situation; this aligns with the findings from previous studies on the poverty levels of households in various states[36,41,32,33].

Validation of the hybrid food security index-HFSI model

Validation of the model proposed here is crucial; it entails a comprehensive process that confirms that the HFSI Model is accurate and reflects the actual food security situation. Several validation mechanisms abound in literature, such as metrics like Mean Absolute Error (MAE), Sensitivity Analysis, and Correlation and Causality. This study uses correlation analysis; HungerMap data from the World Food Program was used to validate the HFSI Model[43]. The HungerMap^{live} tracks core indicators of acute hunger in real-time using the outcome level 1 indicators in the Integrated Food Security Phase Classification (IPC) Framework. The Summary of food security and related metrics for Nigeria, published April 2023, was used for the correlation analysis. The HFSI and HungerMap data are shown in the appendix. The result of the correlation analysis is shown in Table 5. The result indicates a correlation value of 0.764, generally, a correlation of 0.7 to 1 are indicative of a strong correlation, hence it can be inferred that the HFSI model strongly predicts food security situation. Commonly, access to food security data at the state level in most developing countries remains a significant challenge; hence, informed policy implementation becomes unattainable; this challenge also impacts the ability to validate the FAO and GSF index since they exist at the national level; this further indicates the importance of this study.

Conclusion and policy implications

This study proposes a novel hybrid food security index (HFSI) that considers context-specific information to present a more representative assessment of food security using the Nigeria case scenario. The HFSI included rarely assessed food security dimensions, such as food stability, measured via several indicators harmonized via the GIS-based Fuzzy-DEMATEL-ANP model to generate a spatial map illustrating the food security rating across the states in Nigeria. The study reveals a disparity in food security levels in each state and geo-political zones of Nigeria. Broadly, indicators performance primarily improves from the country's North to South, which suggests that Northern states tend to be less food secure than Southern states. High poverty level and climatic variability in Northern Nigeria, which are critical indicators of the food affordability and stability dimensions, were identified as the primary reasons for the poor food security rating. While food security rating improves from the Northern to the Southern region, with most Southern states performing better than the Northern states, there is still cause for concern in both Enugu and Ebonyi states. The significance of these results and policy suggests the need for aggressive yet targeted and pro-rata poverty alleviation interventions in food-insecure states. Understanding the performance of the indicators in each state provides an opportunity for tailored interventions. It is advocated here that a state-level food policy that considers the peculiarity of the food production and distribution network will be imperative. For example, in Ebonyi state, as with the Northern states, poverty alleviation programs should be intensified to improve food security. In Enugu state, however, women's development programs may be more appropriate to plug inefficiencies hampering household food security. The COVID-19 outbreak brought to recall the impact of disruption in food distribution, a policy document that ensures reduced dependence on foreign foods, with a comparative advantage in the local food production, should be prioritized. Smart agricultural technology that considers and strives to mitigate the limiting impacts of natural hazards should be adopted.

Limitations and future outlook

Data availability is a critical challenge in most developing countries; this usually affects modelling. This study would have benefited from more data (indicators); however, due to the inability to access more data, this study

Poverty_Index	HungerMapData
1	0.764**
	0.000
36	36
0.764**	1
0.000	
36	36

Table 5. Correlations analysis between HFSI and HungerMap data. **Correlation is significant at the 0.01 level (2-tailed).

is limited in the final output. Out of the 36 states in Nigeria, 35 states and the federal capital territory (FCT) were investigated. Borno state, located at the extreme, was exempted; this is connected to the insecurity in the region. This study applied MCDM in the geospatial environment; despite the strength and ease of using MCDM in decision-making, it is usually based on the perception of experts, which can be subjective. In addition, as recognized by various researchers in the development of FSI, measuring the FSI is presumed to mean "to estimate," which implies that the output is an approximation. Therefore, this study attempts to map the FSI using appropriate indicators deemed fit through literature and experts' opinions. While the Fuzzy-DEMATEL-ANP assigned the second lowest influence weight to Women's Employability, the correlational analysis between employed women across the states with poverty index and food consumption pattern suggests that women's employability might be more significant in promoting food security. Women's employability in attaining food security should be investigated further. In line with other recent research work on the impact of climate change on food security, it is suggested that further research on the impact of climatic factors on food security at subnational levels be conducted. Further research on the new indicators peculiar to various states and locals that impact food security and the interactions of the indicators is needed. The food security projections for developing countries with old and new indicators will be essential in developing resilient strategies.

Data availability
Data from this research is available through request from the corresponding author.

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Author contributions

This work was carried out in collaboration between all the authors. Authors ECC and CCO designed the study, ECC and CCO collected the data. OODA, OOO, CEO and ECC analyzed the data, wrote the protocol. OODA, ECC and CCO wrote the first draft of the manuscript, and edited the manuscript. All authors read and approved the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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