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Spatial Patterns and Socioeconomic Inequalities in Water Energy Food Access in Malawi

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Research Article

Keywords: Water–Energy–Food nexus: Socioeconomic inequalities, Spatial econometrics, Malawi (IHS5 2019–2020)

Posted Date: July 2nd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9874763/v1

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Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Discover Sustainability on September 26th, 2026. See the published version at https://doi.org/10.1007/s43621-026-04729-x.

Abstract

Household access to water, energy, and food (WEF) in Malawi remains uneven, and sector-by-sector analysis can miss overlapping deprivations. This study assesses combined WEF access and examines how socioeconomic and spatial inequalities structure these outcomes using Malawi IHS5 2019–2020 data. A household WEF Access Index (0–3) was constructed from improved water, electricity/modern energy, and food access indicators. Inequality was measured using the Gini coefficient and rich–poor ratios, while spatial dependence was analysed using Spatial Autoregressive (SAR) and Spatial Error Model (SEM) specifications and compared with Ordinary Least Squares (OLS). The study found that national mean WEF access was moderate (1.66/3), with high improved water access (96.5%) but low electricity access (11.0%) and modern cooking fuel use (19.6%). Energy services showed the greatest inequality, particularly electricity access (Gini = 0.890; rich–poor ratio 74:1). Formal spatial econometric results showed significant SAR spatial dependence for the composite WEF Access Index and electricity access, while SEM spatial error terms were not statistically significant. Wealth remained the dominant socioeconomic driver of access, urban districts had higher WEF outcomes, and Central and Southern regions remained disadvantaged relative to the Northern Region. These findings show that WEF access in Malawi is shaped by intersecting socioeconomic inequalities, regional disadvantage, and neighbouring-district spatial patterns, stressing the need for integrated district-level interventions that combine rural energy expansion, food-security support, and infrastructure planning.

1. Introduction

1.1 Background Information

Access to clean water, energy, and food is basic and essential for human well-being and development. However, billions of people continue to lack reliable access to these essential resources, particularly in low-income countries where poverty, infrastructure deficits, and climate-related shocks intensify household vulnerability (WHO & UNICEF, 2023; IEA, 2022). Many studies describe growing gaps in access to water, energy, and food, above all in regions sensitive to climate change (Simpson and Jewitt, 2019). This calls for an integrated approach to address the growth of water, energy, and food demands (Sušnik et al., 2026). The water–energy–food nexus reflects complex interdependencies and multidirectional interactions among resource systems (Kedir et al., 2022). The implementation of the Nexus approach facilitates the mitigation of resource insecurities and the enhancement of cross-sectoral coordination (Mooren et al., 2025; Okonkwo et al., 2023). Water-Energy-Food nexus plays a key role in the achievement of socio-ecological, socioeconomic sustainability, human and environmental well-being (Nhamo et al., 2025; Sušnik et al., 2026).

Across Africa, the interrelationship between water, energy, and food access is of critical importance. High dependence on rain-fed agriculture, limited electricity infrastructure, and climate-sensitive water systems increases exposure to droughts and floods, thereby intensifying resource insecurities (Machibula & Nungula, 2026). Climate shocks reduce crop harvests, weaken hydropower production and limit water availability at the household level (Mirzabaev et al., 2020). Yet, large disparities exist only 15% of countries have high WEF scores, 57% have moderate scores, and 28% have low scores (Nkiaka et al., 2023). The interlinked relationships and feedback mechanisms within the water–energy–food nexus play a critical role in determining household security across all three sectors (Ningi & Mullen, 2025). Understanding these connections is therefore vital for strategic planning, coordinated policy development, and effective governance of water, energy, and food systems. Ignoring these interdependencies can lead to fragmented interventions that may unintentionally worsen vulnerabilities in other resource areas(Ningi & Mullen, 2025).

Malawi experiences these interlinked resource challenges with intensity. The predominance of smallholder agriculture, reliance on biomass-based energy sources, and dependence on communal water contribute to heightened exposure to climate variability and seasonal shocks. Recent evidence indicates that approximately 67% of households have access

to basic drinking water services; however, substantial spatial inequalities persist. Access to basic water services is estimated at 63% in rural areas compared to approximately 87% in urban areas. Furthermore, nearly 37% of rural households report water collection times of thirty minutes or more, emphasizing persistent deficits in proximity, reliability, and household water security. (WHO/UNICEF JMP, 2023; UNICEF 2024).

Electricity access remains constrained, with approximately 23% of the population connected to electricity in 2024, and substantially lower access rates in rural areas relative to urban areas (World Bank, 2024). Persistent food insecurity exhibits pronounced seasonal variation, particularly among rural households facing limitations in dietary adequacy and increased reliance on coping strategies during lean periods. These conditions reflect the widespread nature of water, energy, and food access challenges in Malawi, shaped by spatial inequalities, poverty dynamics, and seasonal fluctuations. In addition to that, there is sectoral fragmentation of water, energy, and food analyses, resulting in limited understanding of the compounded insecurities experienced by households facing simultaneous resource constraints

Research on the water–energy–food (WEF) nexus in Malawi has largely been carried out in separate sectors, with most studies focusing on water access, energy use, or food security on their own (Adams, 2018; Mkomba, 2021; Sassi, M. 2023; Kang, Y., et al., 2019;Adeyemi et al., 2025). While a few studies have taken a nexus perspective, they are mostly based on regional or basin-level analyses and tend to focus on system-wide modelling, governance issues, or selected spatial overlaps (Mabhaudhi et al., 2019; Bhave et al., 2022; Zahedi et al., 2024). As a result, they do not fully reflect how water, energy, and food insecurities interact in everyday life at the household level, where people constantly make trade-offs and adjust their coping strategies. In addition, existing research provides a limited understanding of how these interconnections differ across socioeconomic groups, demographic characteristics, and locations. The use of spatial analytical approaches is also still limited, making it difficult to clearly identify areas where multiple forms of deprivation come together.

To address these gaps, this paper draws on data from the Malawi Integrated Household Survey 2019–2020 (IHS5), a nationally representative household survey, to:

1. analyse how water, energy, and food insecurities occur and interact at the household level, and how these patterns vary across socioeconomic and demographic groups; and
2. map the spatial distribution of multidimensional WEF deprivation using geospatial techniques to identify clusters and geographic disparities.

This study contributes to the WEF nexus literature in three ways. First, it develops a household-level WEF Access Index using nationally representative IHS5 data. Second, it quantifies socioeconomic inequality in WEF access using distributional measures such as the Gini coefficient, concentration index and rich–poor ratios. Third, it applies spatial econometric models to assess neighbouring-district dependence and district-level structural inequalities in WEF access. Together, these contributions provide policy-relevant evidence for integrated sustainability planning in Malawi.

2. Methodology

2.1 Study Area

This study was conducted in Malawi, with 28 districts grouped into the Northern, Central, and Southern administrative regions (NSO, 2019) as illustrated in Fig. 1. Malawi experiences a tropical climate with a rainy season from November to April, when farming activities intensify and water availability improves, and a dry season from May to October, when water scarcity is more common. The Southern region is densely populated and highly prone to dry spells and floods, whereas the Central region hosts the capital city and major economic activities, and the Northern region is sparsely populated but generally receives more reliable rainfall.

The analysis utilized data from all 28 districts covered in the Malawi Fifth Integrated Household Survey (IHS5) 2019–2020 (NSO & World Bank, 2021). For spatial consistency with national administrative boundaries, the four city councils of Blantyre, Lilongwe, Mzuzu, and Zomba were merged with their respective surrounding districts.

2.2 Data Gathering

This study used data from the Malawi Fifth Integrated Household Survey (IHS5) 2019–2020 conducted by the National Statistical Office of Malawi in collaboration with the World Bank (NSO & World Bank, 2021.. The survey collected detailed, nationally representative information on household characteristics, consumption, food security, water access, energy use, and housing conditions through face-to-face interviews using a structured questionnaire administered in all districts.

A two-stage sampling design was applied, with enumeration areas selected first, followed by households within each enumeration area. Survey weights provided in the IHS5 were applied to account for the sampling design and ensure national representativeness. The IHS5 dataset was selected for this study because it provides the most recent nationally representative and comprehensive data capturing socioeconomic and utility-access indicators across Malawi. Its standardized methodology and rigorous sampling framework make it appropriate for district-level comparative analysis.

Relevant variables on water access, electricity use, cooking fuels, food consumption, and household expenditure were extracted, harmonized, and prepared for statistical analysis.

Because this study relied exclusively on anonymized secondary data that are publicly available, no additional ethical approval was required. The original IHS5 data collection received ethical clearance from the relevant national authorities and adhered to international research standards (NSO & World Bank, 2021).

2.3 Variables

The primary outcome variable was a household-level Water–Energy–Food (WEF) Access Index constructed from three components: water access, energy access, and food access. Each component was coded as a binary indicator (1 = adequate access; 0 = inadequate access) using IHS5 definitions and internationally recognized classifications documented in the survey materials (NSO & World Bank, 2021). The WEF Access Index was calculated as the unweighted sum of the three binary components, producing a score ranging from 0 to 3, where higher values indicate better multidimensional access.

Water access was measured as the household's use of an improved drinking water source. Energy access was measured using (i) electricity access for lighting and (ii) modern cooking fuel use (LPG, electricity, biogas, or solar based). Food access was measured using the Food Consumption Score (FCS), constructed from household dietary frequency data in the IHS5.

Explanatory variables included wealth quintile, residence (urban/rural), region, season of interview, gender of household head, and district identifiers for spatial analysis. Table 1 summarizes all variables and their coding.

Table 1
Description and Classification of Variables Used in the Analysis

Category	Variable	Description
Primary Outcome Variable	WEF Access Index	Composite index (0–3) constructed as the unweighted sum of water access, energy access, and food access indicators.
WEF Component Indicators	Improved Water Access	Household uses an improved drinking water source (1 = yes, 0 = no).
	Electricity Access	Household has electricity for lighting (1 = yes, 0 = no).
	Modern Cooking Fuel	Household uses LPG, electricity, biogas or solar-based fuel (1 = yes, 0 = no).
	Food Consumption Score (FCS)	Continuous score based on weighted frequency of food group consumption (WFP methodology).
	Food Diversity	Number of food groups consumed within the reference period.
Derived Binary Outcomes	High WEF Access	WEF index above the sample median (1 = high access, 0 = low access).
	High Electricity Access	Electricity access above the sample median.
	High Modern Cooking Access	Modern cooking access above the sample median.
Explanatory Variables	Wealth Quintile	Household economic status based on consumption expenditure distribution.
	Residence	Urban or rural location.
	Region	Northern, Central or Southern region.
	Season	Rainy (lean) or post-harvest season.
	Gender of Household Head	Male- or female-headed household.
	District	District of residence (used in spatial models).
	Aggregated District Name	District classification after merging city councils with surrounding districts.
Survey Design Variable	Household Weight	Sampling weight provided in IHS5 to ensure national representativeness.

2.4 Theoretical Framework

This study draws on three complementary frameworks: the Water, Energy and Food Nexus Framework, the Sustainable Livelihoods Framework and Spatial Dependence Theory. These frameworks were selected because they collectively explain (i) interdependencies across resource systems, (ii) household-level socioeconomic determinants of access, and (iii) geographic clustering and spillover effects in WEF outcomes. Together, they provide the conceptual foundation for the econometric and spatial models introduced in Section 2.6.

2.4.1 WEF Nexus Framework

The Water–Energy–Food Nexus Framework conceptualizes water, energy and food systems as interdependent resource domains, where changes in one sector can generate consequences for the others (FAO, 2014;Shah, T. 2023, Endo et al., 2017; Simpson & Jewitt, 2019; Simpson et al., 2022; Rhouma, 2024; Yupanqui et al., 2025; Drobinski et al, 2025)

Water is essential for drinking, cooking, sanitation and agricultural production, and it also supports energy generation in Malawi because most electricity is produced from hydropower (World Bank, 2022). Energy is required for cooking, lighting, irrigation and food storage. Food security depends on reliable access to water and energy, which support crop production, processing and preservation (Botai et al., 2024; Ningi & Mullen, 2025). These examples illustrate key pathways through which water, energy and food systems interact at the household level. When any of the systems is weak, pressure increases on the others. Poor access to water can reduce agricultural productivity and increase the time required to collect water for domestic use. Limited access to energy can reduce irrigation capacity and food storage, which contributes to food insecurity (Sušnik et al., 2026). During food shortages, households often rely on biomass fuels for cooking because they are readily available, which can degrade natural resources and increase exposure to unsafe water sources (Ringler et al., 2013; Rasul & Sharma, 2016). The WEF Nexus Framework therefore supports understanding of integrated strategies that improve household wellbeing.

The relationship among the three components can be summarized as:

$$WEF_i = f(W_i, E_i, F_i)$$

1

where W_i, E_i and F_i represent household water, energy and food access for household i, respectively.

In Malawi, this framework aligns with the strong seasonal and regional variation in resource access. Households in the rainy season rely on natural water sources and have higher farming demands, while the post-harvest season is marked by better food availability but variable access to fuel and water. Differences in district infrastructure and environmental conditions illustrate how weaknesses in any part of the nexus shape the overall WEF outcomes observed in the country.

2.4.2 Sustainable Livelihoods Framework

The Sustainable Livelihoods Framework complements the WEF nexus by explaining how household assets and contextual conditions influence access to essential resources. The framework considers five forms of capital which include human, physical, natural, financial and social capital, all of which contribute to livelihood strategies and outcomes (Serrat, 2017). These capitals interact with wider economic, governance and policy environments to determine how households secure water, energy and food, and how they cope with shocks and constraints to their wellbeing (Rahman & Chen, 2019; Serrat, 2017).

The relationship can be expressed as:

$$WEF_i = g(HH_i, EN_i)$$

2

where HH_i captures household characteristics such as wealth, education, gender of household head and residence, and EN_i represents environmental and community conditions such as water systems, energy infrastructure and food markets.

These factors are shaped by wider structural conditions. In this study, the interaction of household assets with contextual factors is represented conceptually as follows:

$$HH_i, EN_i = k(P_i, R_i, C_i)$$

3

where P_i denotes poverty and economic status, R_i denotes regional context, and C_i captures climatic and policy environments. This expression is developed as part of this study to highlight how differences in socioeconomic and geographic conditions influence household access to water, energy and food.

This framing helps explain why wealthier households and those in urban areas tend to have better access to modern cooking fuels and electricity. In contrast, poorer households often depend on biomass fuels and experience seasonal shortages in food. It also explains why districts in Malawi with stronger infrastructure and market linkages generally show higher levels of WEF access.

2.4.3 Spatial Dependence Theory

Spatial Dependence Theory, developed within the field of spatial econometrics, posits that outcomes observed in one geographic area are influenced by conditions in neighboring areas due to the interconnected nature of social, economic, and environmental processes (Anselin, 1988). Access to water, energy, and food (WEF) resources does not occur in isolation within administrative boundaries. Districts that share similar environmental characteristics, infrastructure networks, market linkages, and exposure to climatic shocks are likely to exhibit comparable levels of WEF access. Consequently, inequalities in WEF access may cluster spatially, reflecting both local conditions and spillover effects from neighboring districts. Recent WEF nexus studies have similarly demonstrated substantial spatial heterogeneity and regional interdependence in resource security and resilience outcomes, highlighting the importance of accounting for spatial interactions when examining WEF systems (Li et al., 2025; Wang et al., 2025; Zhang et al., 2024). This theoretical perspective provides the rationale for applying spatial econometric models to investigate whether disparities in WEF access across Malawi are influenced by geographic spillovers and spatial clustering.

This spatial relationship can be written as:

$$y = \rho\, Wy + X\beta\ + \epsilon$$

4

where y represents the WEF access index, W is the spatial weights matrix, and ρ captures the level of spatial dependence in WEF outcomes across neighboring districts. X denotes the matrix of explanatory variables, β represents the associated coefficients, and ϵ is the error term capturing unobserved influences on WEF access.

Evidence from recent studies in sub–Saharan Africa shows strong spatial clustering in resource access and environmental vulnerability, with adjacent districts often facing similar service limitations (Kazembe, 2020). In Malawi, districts in the Southern region frequently show similar patterns of low electricity access, heavy reliance on biomass fuels, seasonal water challenges and lower food consumption scores. These shared challenges create spatial clusters of deprivation that must be recognized when analyzing WEF patterns.

2.5 Conceptual Framework

Structural and institutional conditions, including wealth, place of residence, regional context, distance to services, environmental constraints, gender of the household head, education, and governance and policy environments, create the broader context within which households secure essential resources (FAO, 2014; IEA, 2021; Nhamo et al., 2020). These structural and institutional factors influence the availability, affordability, quality and reliability of water systems, energy infrastructure and food markets, particularly in low-income settings such as Malawi (World Bank, 2018).

The conceptual framework presented in Fig. 2 was developed by the authors based on an extensive review of the WEF nexus literature, sustainable livelihoods theory, and spatial inequality research. It synthesizes established theoretical relationships rather than introducing a new theory. The framework integrates insights from prior studies to guide variable selection and modelling strategy in this study.

Household and gender factors add another important layer to the conceptual framework by shaping how households can obtain essential services. The burden of collecting water and firewood, which disproportionately falls on women and girls, limits their time for productive activities, education, and food preparation. This time, poverty directly affects access to improved water sources and modern cooking fuels while indirectly undermining household food security and nutrition. (UNICEF & WHO, 2023; Ho et al., 2021)

These household characteristics, therefore drive variation across the three WEF access dimensions. Water access reflects whether a household uses an improved water source and the amount of time spent collecting water. Energy access is measured using indicators of electricity connection status, use of modern cooking fuels such as LPG, and dependence on biomass fuels such as firewood. Food security is captured through food consumption patterns, dietary diversity, meal frequency, coping strategies and reported experiences of food shortages.

The WEF Access Index is a composite indicator constructed specifically for this study and is not intended as a standardized global index. It is based on internationally recognized and validated component measures, including improved drinking water definitions from the WHO/UNICEF Joint Monitoring Program (JMP), modern energy access criteria aligned with SDG7 standards, and food security measurement using the Food Consumption Score methodology. Composite approaches of this nature are widely used in multidimensional poverty and nexus research to capture overlapping deprivations across sectors (Endo et al., 2017; Simpson & Jewitt, 2019; Simpson et al., 2022; Yupanqui et al., 2025). The index, therefore reflects the degree of simultaneous household-level access to water, energy, and food services within a unified analytical framework. Spatial and seasonal conditions further shape variation in access to water, energy and food across Malawi. Seasonal differences in rainfall and interview timing influence water availability, agricultural production, energy use for cooking and food consumption patterns. Together, these spatial and temporal contexts contribute to differences in household WEF outcomes, which are captured in the WEF Access Index. The index is subsequently analyzed using spatial mapping, inequality measures and statistical modelling to identify patterns and determinants of WEF access across Malawi.

2.6 Econometric Modelling

The analysis proceeded in four stages. First, descriptive statistics were used to summarize national patterns of WEF access. Second, inequality measures, including the Gini coefficient, concentration index and rich–poor ratios, were used to assess socioeconomic disparities. Third, survey-weighted regression models were estimated to identify household-level determinants of WEF access. Finally, district-level spatial econometric models were used to assess whether WEF access outcomes were associated with neighbouring-district patterns after accounting for regional and urban structural differences. All household-level models applied IHS5 sampling weights following established guidance for complex surveys (Deaton, 1997; Heeringa, West & Berglund, 2017). The approach aligns with multidimensional welfare frameworks (Alkire & Foster, 2011), access modelling in water, energy and food systems (Pachauri & Spreng, 2011; Medina, 2021), and nexus studies emphasising inequality and spatial variation (Hanjra & Qureshi, 2010; Al-Saidi & Elagib, 2017; Simpson & Jewitt, 2019).

To assess whether water, energy and food access share common unobserved determinants, a multivariate logistic model was estimated, assuming the disturbance vector

$$\epsilon_{hd} = \left(\epsilon_{\text{Water}}, \epsilon_{\text{Energy}}, \epsilon_{\text{Food}}\right)'$$

5

follows a trivariate normal distribution. Significant cross-equation correlations ($p < 0.001$) indicated that WEF dimensions are interdependent, consistent with multidimensional access literature (Pachauri & Spreng, 2011; Conway et al., 2021; Pumain & Rozenblat, 2022).

Associations between household characteristics and continuous WEF access were estimated using the model:

$$\mathrm{WEF}_{ih} = \beta_0 + \beta_1 \mathrm{Wealth}_h + \beta_2 \mathrm{Urban}_h + \beta_3 \mathrm{Region}_h + \beta_4 \mathrm{Season}_h + \beta_5 \mathrm{GenderHead}_h + \epsilon_{ih}.$$

6

Wealth captures economic status via consumption quintiles; *Urban* distinguishes rural from urban areas; *Region* reflects structural differences across Northern, Central and Southern Malawi; *Season* differentiates the rainy and post-harvest periods; and *Gender Head* identifies female-headed households. Coefficients measure the average change in WEF access associated with each factor. Wald tests and VIF statistics were used to check joint significance and multicollinearity (Cameron & Miller, 2015).

Determinants of achieving above-median WEF access were examined using a survey-weighted logistic regression model, expressed as:

$$\Pr(Y_h = 1) = \mathrm{logit}^{-1}(\alpha + X_h\delta),$$

7

where $Y_h = 1$ indicates that household $h$attained an above-median level of combined WEF access. The vector X_h includes structural, household and contextual determinants of WEF access in Malawi consistent with recent nexus and access literature (Simpson & Jewitt, 2023; Mazenda & Nkwana, 2025; Mutanga et al., 2024). These determinants reflect socioeconomic status (wealth quintile, education of the household head), demographic and gendered labour roles (female-headed household and household size), spatial and infrastructural context (urban or rural residence, region, and distance to improved water sources), and temporal and environmental pressures (season of interview and district-level environmental constraints). Positive coefficients increase the likelihood of achieving high WEF access. Model specification was evaluated using Pregibon's link test to assess functional form adequacy (Pregibon, 1979), while marginal effects were estimated to improve interpretation of results (Bartus, 2005).

To test whether the wealth gradient varies by context, interaction models were estimated:

$$\mathrm{WEF}_{ih} = \gamma_0 + \gamma_1 \mathrm{Wealth}_h + \gamma_2 \mathrm{Context}_h + \gamma_3 (\mathrm{Wealth}_h \times \mathrm{Context}_h) + u_{ih}.$$

8

where $Wealth_h$captures socioeconomic status and $Context_h$represents moderating conditions including season, urban–rural residence, and region. The interaction term $\gamma_3$tests whether the effect of wealth strengthens or weakens under different contextual settings consistent with emerging WEF-nexus inequality literature (Mutanga et al., 2024; Mazenda & Nkwana, 2025). The disturbance term u_{ih}represents household-specific unobserved influences on WEF access, such as preferences or unmeasured resource constraints. Because households are clustered within districts, multilevel random-intercept models were additionally estimated:

$$WEF_{ihd} = \delta_0 + \delta_1 X_{ih} + u_d + \epsilon_{ihd}$$

9

where u_d is a district-level random effect reflecting unobserved environmental and infrastructural factors shared by households in the district d, and ϵ_{ihd} is an idiosyncratic household-level error. Intraclass Correlation Coefficients (ICCs) quantified the proportion of variance attributable to district clustering, while likelihood-ratio tests were used to assess the relevance of multilevel modelling (Snijders & Bosker, 2012).

To examine spatial dependence in district-level WEF access outcomes, household-level indicators were aggregated to the district level using IHS5 sampling weights and merged with the Malawi district shapefile. A row-standardised contiguity spatial weights matrix was constructed to define neighbouring districts based on shared boundaries. Baseline Ordinary Least Squares (OLS) models were first estimated using region and urban district status as covariates, followed by Moran's I tests on OLS residuals to assess residual spatial autocorrelation.

Spatial Autoregressive (SAR) and Spatial Error Model (SEM) specifications were then estimated using Generalized Spatial Two-Stage Least Squares (GS2SLS). The SAR model assessed whether WEF outcomes in a district were associated with outcomes in neighbouring districts:

$$y = \rho\, Wy + X\beta\ + \epsilon$$

10

where y represents the district-level WEF outcome, W is the row-standardised spatial weights matrix, ρ is the spatial lag parameter, X is a vector of covariates, and ϵ is the error term.

The SEM model assessed whether unobserved spatially correlated factors remained in the model errors:

$$y = X\beta\ + u, u = \lambda\, Wu + \epsilon$$

where λ captures spatial dependence in the error term. Model results were compared descriptively using OLS R^2 and spatial-model pseudo R^2, while the statistical significance of SAR and SEM spatial terms was used to assess spatial dependence.

Inequality in WEF access was further quantified to understand distributional differences across households. Three complementary measures were applied: Gini coefficient, the Concentration Index (CI), and the Theil GE (0) index, which decomposes inequality into within- and between-region components:

$$GE\left(0\right) = \frac{1}{N}\sum\nolimits_{i=1}^{N}\frac{y_i}{\mu}\ln\left(\frac{y_i}{\mu}\right),$$

11

where y_i denotes household WEF access and μ is the mean WEF level. Positive CI values indicate pro-rich inequality in access, aligned with recent African WEF-nexus findings showing persistent disparities by wealth and geography (Mutanga et al., 2024; Mazenda & Nkwana, 2025). To enable a unified evaluation of household conditions across the three resource dimensions, a composite WEF Access Index was constructed as the sum of standardized indicators for water, energy, and food access (Simpson & Jewitt, 2023):

$$\text{WEF Index} = \text{WaterAccess} + \text{EnergyAccess} + \text{FoodAccess},$$

12

providing a summary metric that reflects multidimensional access outcomes at the household level. Indicators were defined following international monitoring standards, including WHO/UNICEF JMP classifications for improved water and electricity access (WHO/UNICEF JMP, 2023), the SDG7 definition of modern cooking fuels (World Bank, 2022), and the Food Consumption Score recommended by the World Food Programme (WFP, 2022). The construction of the composite WEF access index aligns with recent multidimensional WEF nexus measurement approaches (Masuda et al., 2021; Mutenga et al., 2024). All models underwent diagnostic checks, including tests of functional form,

multicollinearity, district-level variance, spatial dependence and sampling robustness. These procedures confirmed stable estimates and strong internal validity consistent with the IHS5 survey design.

To visualize geographic disparities in WEF access, spatial maps were constructed for each dimension (water, energy and food), as well as for the composite WEF index. Seasonal and regional maps highlighted differences between rainy and post-harvest periods and across Malawi's districts, Together, these visualizations clearly demonstrate spatial inequalities and help prioritize areas for integrated WEF interventions.

3. Results

3.1 National WEF Access Profile

Table 2 shows that, nationally, households have a moderate level of WEF access, with a mean WEF Access Index of 1.66 on a 0–3 scale. A mean value of 1.66 on a 0–3 scale indicates that the average household has access to approximately two of the three WEF components, but simultaneous access to all three remains limited. Improved water access is high at 96.5%, and most households report access to modern lighting (96.6%). However, this largely reflects reliance on battery-powered torches and solar lamps rather than grid-based electricity, indicating limited access to reliable and higher-capacity energy services. Deeper energy deprivation is evident in cooking practices, as only 19.6% of households use modern cooking fuels, suggesting continued dependence on traditional biomass. Food access is also modest with an average Food Consumption Score of 45.4, indicating Food access is modest, with an average Food Consumption Score (FCS) of 45.4. Under WFP thresholds (poor < 28, borderline 28–42, acceptable > 42), this falls within the acceptable. Malawi achieves strong coverage in water and basic lighting, but access to modern cooking energy, electricity, and adequate food remains limited for a large share of the population.

Table 2
National-Level WEF Access Indicators (IHS5 2019–2020)

Indicator	National Average
Overall WEF Access Index (0–3 scale)	1.656
Improved Water Access	96.5%
Modern Cooking Fuel	19.6%
Electricity Access	11.0%
Modern Lighting	96.6%
Food Consumption Score	45.4

3.2 Sociodemographic Characteristics

Clear sociodemographic differences were observed across the WEF components, as shown in Table 3. Water access remains high across all groups, with statistically significant variation by wealth, residence, gender and region ($p < 0.05$). In contrast, electricity and modern cooking fuel access exhibit much stronger inequalities. Modern cooking access increases from 5% in the poorest wealth quintile to 47% in the richest, and electricity access rises from 1% to 37%, with both gradients highly significant ($p < 0.001$). Seasonal variation is limited for water and cooking fuel access, although electricity access is marginally higher in the post-harvest period ($p = 0.040$). Female-headed households have lower modern cooking use (14% vs 22%) and lower electricity access (7% vs 13%) compared to male-headed households (both $p < 0.001$). Urban households report much higher access to modern cooking (75% vs 9%) and electricity (46% vs 4%) than rural households, while rural households have relatively higher water access ($p < 0.05$). Regional variation is also

evident: modern cooking ranges from 16% in the Northern Region, 21% in the Central, to 19% in the Southern, and electricity access falls from 15% in the North, 8% in the Centre, to 12% in the South (all $p < 0.001$) (IHS5 2019–2020).

Food security exhibits the strongest socioeconomic gradient among all WEF indicators. Only 15% of households in the poorest quintile are food secure compared with 84% in the richest quintile ($p < 0.001$). Urban households experience substantially greater food security than their rural counterparts, with 81% and 45% food secure respectively ($p < 0.001$). Households headed by women are disproportionately disadvantaged, with 42% food secure compared to 55% among male-headed households ($p < 0.001$). Seasonal variation is modest, increasing from 49% food secure during the lean season to 53% post-harvest, although wealth-related inequalities remain evident throughout the year (interaction $p < 0.001$). Clear regional disparities are also present: food security is highest in the Northern Region (68%) and lowest in the Central Region (43%, $p < 0.001$).

Table 3
Socioeconomic Inequalities in WEF Components

Variable	%Water Access	P	% Modern Cooking	P	%Electricity	P	%Food Secure	P	N
Wealth Quintile									
Poorest (Q1)	98.4	< 0.001***	4.9	< 0.001***	0.5	< 0.001***	15.4	< 0.001***	2,051
Poor (Q2)	97.3		8.5		2.1		35.9		2,159
Middle (Q3)	96.7		12.1		4.1		52.4		2,274
Rich (Q4)	96.3		24.9		11.4		67.5		2,359
Richest (Q5)	93.9		47.4		37.0		83.9		2,591
Season × Wealth									
Lean Season	96.5	0.269	19.6	0.350	11.0	0.040*	48.9	< 0.001***	11,434
Poorest (Q1)	98.1		3.6		0.6		13.2		988
Poor (Q2)	97.0		8.1		2.0		31.8		942
Middle (Q3)	95.8		12.2		4.5		52.5		980
Rich (Q4)	96.0		28.6		13.4		68		982
Richest (Q5)	94.0		51.3		41.2		86.1		1,074
Post-harvest	96.5	0.269	19.6	0.350	11.0	0.040*	52.7	< 0.001***	11,434
Poorest (Q1)	98.6		6.2		0.4		17.5		1,063
Poor (Q2)	97.6		8.9		2.2		39.3		1,217
Middle (Q3)	97.4		12.0		3.8		52.4		1,293
Rich (Q4)	96.6		22.1		9.9		67.1		1,377
Richest (Q5)	93.8		44.6		33.9		82.4		1,517
Gender of Household Head									
Male	96.2	0.004	22.0	< 0.001***	12.7	< 0.001***	55.3	< 0.001***	7997

Notes: *Statistical significance: *** p < 0.001, ** p < 0.01, * p < 0.05. Sample represents households from Malawi IHS5 2019–2020. WEF access definitions: Improved water sources, modern cooking fuels, electricity access and food secure. All estimates weighed using household survey weights*

Variable	%Water Access	P	% Modern Cooking	P	%Electricity	P	%Food Secure	P	N
Female	97.3		14.4		7.4		41.5		3437
Residence									
Urban	90.2	< 0.001***	75.0	< 0.001***	45.6	< 0.001***	81.3	< 0.001***	2,092
Rural	97.8		8.8		4.3		45.2		9,342
Region									
Northern	95.2	< 0.001***	16.0	< 0.001***	14.6	< 0.001***	68	< 0.001***	2,176
Central	97.7		20.9		8.4		43.4		3,952
Southern	95.8		19.4		12.4		53.3		5,306

Notes: *Statistical significance: *** p < 0.001, ** p < 0.01, * p < 0.05. Sample represents households from Malawi IHS5 2019–2020. WEF access definitions: Improved water sources, modern cooking fuels, electricity access and food secure. All estimates weighed using household survey weights*

3.3 Socioeconomic Inequalities in WEF Access

Substantial inequality exists across the individual water, energy and food components of the WEF nexus in Malawi. Table 4 summarizes these disparities using the Gini coefficient, concentration index, and rich–poor access ratio to assess how unevenly services are distributed between socioeconomic groups. Higher Gini values and larger rich–poor ratios signal greater inequality, while a positive concentration index shows that access is concentrated among wealthier households.

Electricity access shows the highest level of inequality, with a Gini coefficient of 0.890 and a rich–poor ratio of seventy-four to one, indicating that reliable power remains largely unavailable for low-income households. Modern cooking fuel follows a similar pattern, with a Gini of 0.804 and a ratio of ten to one, reflecting continued dependence on traditional biomass among the poor. Food access is moderately unequal, with a Gini of 0.210 and a ratio of almost two to one, demonstrating the persistent burden of food insecurity. Water access is the most equitably distributed dimension, with a Gini of 0.035 and a ratio close to unity, suggesting high national coverage.

Table 4
Inequality in water, energy and food dimensions of the WEF nexus,

Dimension / Indicator	Gini Coefficient	Concentration Index	Rich–Poor Ratio
Overall WEF Access Index	0.227	0.124***	1.91 : 1
Electricity Access	0.890	0.567***	74 : 1
Modern Cooking Fuel	0.804	0.412***	10.25 : 1
Improved Water Access	0.035	–0.010***	0.95 : 1
Resource Burden Index	0.205	–0.050***	n.a.
Food Consumption Score (FCS)	0.210	n.a.	1.93 : 1
Food Diversity Score	0.133	n.a.	1.47 : 1
Food Expenditure (MWK/year)	0.339	n.a.	3.06 : 1
Food Insecurity (FIES)	n.a.	–0.161*	2.47 : 1 (Poor : Rich)
Coping Strategies (rCSI)	n.a.	–0.221*	3.44 : 1 (Poor : Rich)
Urban WEF Mean Score	n.a.	n.a.	2.45
Rural WEF Mean Score	n.a.	n.a.	1.50
Regional Theil (GE(0))	0.088	n.a.	n.a.
Seasonal Theil (GE(0))	0.088	n.a.	n.a.

Notes: *n.a. = not applicable. Significance levels: * p < 0.10, ** p < 0.05, *** p < 0.01. Food insecurity and rCSI ratios are expressed as Poor: Rich (deprivation measures). Positive concentration indices indicate pro-rich inequality, while negative values indicate pro-poor concentration*

Regional and seasonal inequalities are minimal, with Theil GE values close to zero. However, access remains significantly higher in urban areas compared to rural areas, consistent with spatial infrastructure patterns.

Table 5 reports clear socioeconomic and spatial disparities in the overall WEF Access Index in Malawi. Access increases steadily with household wealth, from 1.17 among the poorest quintile to 2.24 among the richest, indicating a strong inequality gradient. Urban households have significantly higher access (2.45) than rural households (1.50). Regional differences are evident, with the Northern Region showing the highest access (1.79), followed by the Southern (1.67) and Central Regions (1.60). Seasonal disparities are modest, with slightly lower access during the lean/rainy season (1.64) than in the post-harvest period (1.67). Gender differences are also observed: female-headed households record lower WEF access (1.51) compared to male-headed households (1.72).

Table 5
Socioeconomic and spatial variation in the Overall WEF Access Index [REF]

Characteristic	Category	Mean WEF Access Index
Wealth Quintile	Poorest (Q1)	1.17
	Poor (Q2)	1.41
	Middle (Q3)	1.59
	Rich (Q4)	1.87
	Richest (Q5)	2.24
Urban–Rural Residence	Rural	1.50
	Urban	2.45
Region	Northern	1.79
	Central	1.60
	Southern	1.67
Season	Lean/Rainy Season	1.64
	Post-Harvest/Dry Season	1.67
Household Head Gender	Female-headed	1.51
	Male-headed	1.72

3.4 Spatial Patterns of WEF Access

Figure 3 shows clear spatial variation in food security, with higher access concentrated in several northern districts and lower access observed across parts of the Southern Region.

3.5 Composite WEF Access

Figure 4 presents the composite WEF access index across Malawi's districts. The spatial pattern shows a distinct southward concentration of deprivation. Most districts in the Southern Region fall within the lowest composite access categories, indicating simultaneous deficits in water, energy and food services. In contrast, many Northern districts appear in the higher access categories, suggesting broader service coverage across the nexus.

Within the Central Region, composite access varies districts such as Ntcheu and Dedza fall into medium access classes, while Lilongwe and Dowa remain comparatively better positioned. Only a small number of districts elsewhere show high composite access, reflecting limited pockets of progress. Composite map highlights Central and Southern Malawi as priority areas, where overlapping and persistent nexus deprivations are concentrated geographically.

3.6 Seasonal Variations

Seasonal patterns are shown in Fig. 5. The Map indicates that water access improves after the harvest However, water access remains uneven across districts due to underlying structural inequalities.

Food access exhibits pronounced seasonal variation across districts, as illustrated in Fig. 6. During the lean season, much of the Southern Region records poor or middle food security, while the Northern Region consistently shows high or very high food access. After the harvest, conditions improve in many central and southern districts, with several moving

from poor to middle or high food access. Despite this seasonal recovery, districts such as Nsanje, Chikwawa, Balaka and Machinga continue to show low food security, indicating persistent vulnerability. The maps highlight a strong north–south divide and only partial seasonal improvement in the most food-insecure areas.

Figure 7 illustrates seasonal variation in energy access across districts. During the lean season, several districts in the Central and Southern regions display low or poor access, while parts of the Northern region maintain relatively high or very high access. In the post-harvest season, access improves slightly in some districts, particularly in the South, although many areas remain in the low-access category.

3.7 Econometric models

3.7.1 Determinants of WEF Access

Survey-weighted regression results in Table 6 show that wealth is the strongest determinant of WEF access in Malawi. Compared with the poorest households, richer groups record significantly higher electricity access, modern cooking fuel use, and food consumption, confirming a steep pro-rich inequality gradient across the nexus. Urban households achieve substantially better energy and food outcomes than rural households. Female-headed households report significantly lower WEF access, especially in food consumption, indicating persistent gender-related disadvantage in resource access.

Regional differences are present but smaller in magnitude. The Northern Region shows slightly better performance in energy access than the Central and Southern Regions. Seasonal variation is modest, with WEF access slightly higher post-harvest than during the lean season.

Table 6
Survey-Weighted OLS Estimates of the Determinants of WEF Nexus Outcomes

Predictor	WEF Access	Electricity Access	Modern Cooking	Food Score
Wealth: Poor	0.194(0.017)***	-0.002 (0.004)	0.014(0.008)*	5.651(0.356)***
Wealth: Middle	0.364 (0.018)***	0.011 (0.005)**	0.041 (0.009)***	9.821(0.386)***
Wealth: Rich	0.568 (0.019)***	0.049 (0.007)***	0.110 (0.010)***	15.098(0.443)***
Wealth: Richest	0.794 (0.021)***	0.236 (0.011)***	0.216 (0.013)***	25.654(0.545)***
Rural (vs Urban)	-0.681 (0.021)***	-0.322 (0.013)***	-0.581(0.013)***	-8.403(0.497)***
Central (vs North)	-0.024 (0.019)	-0.023(0.009)**	0.089(0.009)***	-4.621 (0.534)***
South (vs North)	0.014 (0.018)	0.013 (0.009)	0.072(0.009)***	-2.638 (0.524)***
Post-harvest (vs Rainy)	0.032 (0.012)**	-0.007 (0.005)	0.011 (0.007)*	0.676 (0.298)**
Female-headed	-0.113 (0.013)***	-0.020 (0.006)***	-0.024 (0.007)***	-3.735 (0.306)***

Note: *Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10. Results are from survey-weighted linear regressions using IHS5 sampling weights to ensure national representativeness*

3.8 Spatial Econometric Analysis of WEF Access Outcomes

Formal spatial econometric models were estimated to assess whether district-level WEF access outcomes were spatially dependent after accounting for regional and urban structural differences. The spatial models used a row-standardised district contiguity matrix and were compared with baseline OLS models.

Moran's I tests on the OLS residuals did not show statistically significant residual spatial autocorrelation for WEF access, electricity access, or modern cooking. However, the SAR models showed significant spatial dependence for the composite WEF Access Index and electricity access, while modern cooking showed marginal spatial dependence. In contrast, SEM spatial error terms were not statistically significant across the three outcomes. These results suggest that spatial dependence in WEF outcomes is better captured through neighbouring-district access patterns than through residual spatial error correlation.

3.8.1 Spatial Autoregressive Model Results

Table 7 presents the Spatial Autoregressive (SAR) model results. The SAR models provide evidence of spatial dependence in district-level WEF outcomes. For the composite WEF Access Index, the spatial lag coefficient was negative and statistically significant (ρ = −0.188, p = 0.017), indicating that district-level WEF access is associated with neighbouring-district patterns after controlling for region and urban status. Central and Southern districts had significantly lower WEF access than Northern districts, while urban districts had significantly higher access.

Electricity access showed the strongest spatial dependence. The spatial lag coefficient was large and statistically significant (ρ = −1.460, p = 0.001), suggesting strong spatial structuring in district-level electricity access. Central and Southern regions had lower electricity access than the Northern Region, while urban districts had significantly higher electricity access.

For modern cooking fuel access, the spatial lag coefficient was negative and marginally significant (ρ = −0.669, p = 0.062). This suggests weaker but still suggestive evidence of spatial dependence. Urban status remained a strong and statistically significant predictor of modern cooking fuel access, while regional differences were not statistically significant in the SAR specification

Table 7
Spatial Autoregressive Models of WEF Access Outcomes

Predictor	WEF Access β (SE)	Electricity Access β (SE)	Modern Cooking β (SE)
Spatial lag parameter, ρ	−0.188 (0.079)*	−1.460 (0.449)**	−0.669 (0.359)†
Central Region	−0.294 (0.069)***	−0.165 (0.041)***	−0.008 (0.042)
Southern Region	−0.195 (0.065)**	−0.093 (0.036)*	0.015 (0.041)
Urban district	0.302 (0.070)***	0.107 (0.040)**	0.209 (0.042)***
Constant	2.070 (0.128)***	0.320 (0.056)***	0.221 (0.055)***
Pseudo R^2	0.623	0.156	0.503
Wald test of spatial term, p-value	0.017	0.001	0.062

Notes: SAR models were estimated using GS2SLS with a row-standardised district contiguity matrix. Reference category: Northern Region and non-urban districts. Significance: *** p < 0.001, ** p < 0.01, * p < 0.05, † p < 0.10.

3.8.2 Spatial Error Model Results

Table 8 presents the Spatial Error Model (SEM) results. In contrast to the SAR models, the SEM specifications did not show statistically significant spatial error dependence. The spatial error terms were not significant for the composite WEF Access Index (λ = 0.188, p = 0.689), electricity access (λ = 0.144, p = 0.793), or modern cooking fuel access (λ = 0.080, p = 0.856). This suggests that, after accounting for region and urban status, the remaining unobserved spatial error correlation is limited.

The SEM results still show important structural differences. Central and Southern regions had significantly lower composite WEF access than the Northern Region. For electricity access, Central and Southern regions also remained significantly disadvantaged, while urban districts had higher electricity access. For modern cooking fuel access, urban status remained strongly significant, but regional differences were not statistically significant.

Table 8
Spatial Error Models of WEF Access Outcomes

Predictor	WEF Access β (SE)	Electricity Access β (SE)	Modern Cooking β (SE)
Spatial error parameter, λ	0.188 (0.469)	0.144 (0.548)	0.080 (0.437)
Central Region	−0.312 (0.069)***	−0.128 (0.048)**	−0.028 (0.038)
Southern Region	−0.223 (0.064)***	−0.100 (0.045)*	−0.011 (0.035)
Urban district	0.297 (0.077)***	0.129 (0.045)**	0.220 (0.045)***
Constant	1.792 (0.055)***	0.176 (0.038)***	0.134 (0.030)***
Pseudo R^2	0.555	0.373	0.481
Wald test of spatial term, p-value	0.689	0.793	0.856

Notes: SEM models were estimated using GS2SLS with a row-standardised district contiguity matrix. Reference category: Northern Region and non-urban districts. Significance: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

3.9 Model Comparison: Non-Spatial and Spatial Econometric Models

Table 9 compares the OLS, SAR, and SEM models. The results indicate that the SAR specification provides the most useful spatial evidence for the composite WEF Access Index and electricity access, as the spatial lag terms are statistically significant for both outcomes. For modern cooking, the SAR spatial term is marginally significant at the 10% level. In contrast, the SEM spatial error terms are not statistically significant across all outcomes, suggesting that residual spatial error dependence is limited once region and urban status are included.

The model comparison indicates that spatial dependence is better captured through spatially lagged district outcomes, particularly for the composite WEF Access Index and electricity access. This suggests that neighbouring-district conditions and shared infrastructure environments may influence access patterns, whereas unobserved residual spatial error correlation appears less important.

Table 9
Comparison of Non-Spatial and Spatial Econometric Models for WEF Access Outcomes

Model comparison item	WEF Access	Electricity Access	Modern Cooking
OLS R^2	0.555	0.373	0.481
SAR Pseudo R^2	0.623	0.156	0.503
SAR spatial term, ρ	−0.188	−0.460	−0.669
SAR p-value	0.017	0.001	0.062
SEM Pseudo R^2	0.555	0.373	0.481
SEM spatial error, λ	0.188	0.144	0.080
SEM p-value	0.689	0.793	0.856

Notes: OLS reports conventional R^2. SAR and SEM models use GS2SLS with a row-standardised contiguity matrix. Spatial-model pseudo R^2 values are descriptive and not directly comparable with OLS R^2.

4. Discussion

This study provides new evidence on the spatial and socioeconomic inequalities shaping household access to water, energy and food in Malawi. Although improved water access is relatively high nationally, the combined WEF Access Index reveals that many households still face overlapping deprivations, especially in energy and food access. This confirms the concern raised in WEF nexus literature that analysing water, energy and food separately can miss how resource insecurities interact at household level (Endo et al., 2017; Nhamo et al., 2025). Similar patterns of uneven progress in basic services have also been reported across low-income and sub-Saharan African settings, where poverty, infrastructure deficits and climate sensitivity continue to constrain household wellbeing (FAO, 2014; WHO & UNICEF, 2023).

Energy access emerged as the most unequal dimension of the nexus. Electricity access and modern cooking fuel use remain concentrated among wealthier and urban households, while poorer and rural households continue to depend heavily on traditional biomass fuels. This pattern is consistent with Zalengera et al. (2014), who documented the persistence of biomass dependence in Malawi, and with IEA (2022), which highlights the continued limitations of electricity access in many low-income settings. In this study, the extremely high rich–poor ratio for electricity access suggests that energy deprivation remains the binding constraint within Malawi's WEF nexus, supporting Munyanyi's (2025) argument that energy poverty is central to broader resource insecurity.

The strong wealth gradient observed across WEF outcomes shows that household economic capacity remains a major determinant of access. Wealthier households are better positioned to afford electricity connections, modern cooking fuels, diverse diets and coping mechanisms during seasonal stress. This is consistent with Benson et al. (2005), who linked poverty to food insecurity in Malawi, and with Ntodwa and Chirwa (2025), who show that welfare inequalities remain spatially and economically patterned. The results therefore suggest that WEF access should be understood not only as a service-availability issue, but also as a question of household capability and affordability.

Urban districts had consistently better WEF outcomes than non-urban districts, particularly for electricity and modern cooking fuel access. This reflects the stronger infrastructure base, market access and service connectivity available in urban areas. World Bank (2022) similarly notes that infrastructure and service access often remain uneven between urban and rural populations. In Malawi, these urban advantages mean that national averages can conceal the depth of rural deprivation, especially where energy systems, transport networks and food markets remain weak (Nhamo et al., 2025).

Gender-related inequalities also remain important. Female-headed households had lower WEF access in several dimensions, reflecting wider gendered constraints in income, employment and household responsibilities. The burden is not only economic, but also time-related, since women and girls often carry responsibility for water and firewood collection. These gendered responsibilities can restrict opportunities for education, paid work and food preparation, reinforcing the structural and sociocultural pathways through which WEF inequality is reproduced (Nhamo et al., 2025).

The spatial results show that WEF access is geographically structured. Central and Southern districts remained disadvantaged relative to the Northern Region, reflecting differences in infrastructure, land pressure, market access and exposure to climatic risks. This pattern is consistent with Ntodwa and Chirwa (2025), who describe spatial poverty clustering in Malawi. The formal spatial econometric results refine this interpretation: SAR models showed significant spatial dependence for the composite WEF Access Index and electricity access, while modern cooking showed marginal spatial dependence. However, SEM spatial error terms were not statistically significant, suggesting that residual spatial error correlation is limited once regional and urban structural factors are included. This means the spatial process is better understood as neighbouring-district access patterns rather than unexplained residual clustering, aligning with wider WEF nexus arguments on spatial interlinkages in resource systems (Simpson & Jewitt, 2019; Mirzabaev et al., 2020).

Seasonality also shapes WEF access, especially through food availability and household resource burdens. Food consumption and some energy-related outcomes improved modestly in the post-harvest period, while water access remained comparatively stable. This reflects Malawi's reliance on rain-fed agriculture, where food stocks, household income and coping strategies vary across the agricultural calendar. Mabhaudhi et al. (2019) similarly emphasises the seasonal sensitivity of food and resource systems in southern Africa, while NSO (2020) provides the survey context showing how household welfare indicators vary across time and location.

The persistence of water collection burdens despite high reported improved water access deserves attention. Improved source classification does not fully capture reliability, distance, functionality or time costs. Phiri et al. (2023) and Truslove et al. (2019) show that rural water systems may be classified as improved while still facing functionality and reliability constraints. This means that water access should not be assessed by source type alone; service quality, proximity and reliability are equally important, especially because collection burdens are often gendered.

From a nexus perspective, the findings demonstrate that water, energy and food access are interconnected through household capabilities, infrastructure systems and spatial context. Hoff (2011) and Daher and Mohtar (2015) argue that WEF systems must be understood as interdependent rather than isolated sectors. In this study, poorer rural households face overlapping constraints across energy, food and water burdens, while wealthier and urban households are better positioned to secure all three resources. The neighbouring-district patterns observed in the SAR models further suggest that district-level infrastructure gaps and regional inequalities shape household resource access beyond individual household characteristics (Endo et al., 2017).

Improving WEF access in Malawi requires integrated strategies that address socioeconomic inequality, spatial disadvantage and infrastructure gaps together. Rural energy expansion should be a priority because electricity and modern cooking fuel access are the most unequal dimensions of the nexus. Food-security interventions should be geographically targeted to vulnerable districts, especially in Central and Southern Malawi, while water policy should move beyond improved-source coverage to include reliability, distance and functionality. As argued in the WEF nexus literature, coordinated interventions across water, energy and food systems are more likely to produce equitable and sustainable outcomes than isolated sectoral programmes (Mabhaudhi et al., 2019; Simpson & Jewitt, 2019; Nhamo et al., 2025).

5. Policy Implications

The findings highlight the need for integrated and equity-focused policies to improve water, energy and food access in Malawi. Energy access should be the immediate priority, as electricity showed the greatest inequality, with a Gini coefficient of 0.890 and a rich–poor access ratio of 74:1. Rural electrification, decentralised renewable energy systems, affordable clean cooking technologies, targeted subsidies and innovative financing could help expand access among low-income and rural households.

The spatial results also show that WEF access is geographically uneven, with Central and Southern districts facing persistent disadvantage. Policy responses should therefore move beyond uniform national interventions and prioritise districts with overlapping water, energy and food deficits. Since SAR results suggest neighbouring-district patterns in WEF and electricity access, district-level planning should be coordinated across adjacent areas rather than implemented in isolation.

The interconnections between water, energy and food further show that sector-specific interventions are unlikely to fully address multidimensional deprivation. Stronger coordination among institutions responsible for energy, water, agriculture, local government and social protection would support more integrated resource planning.

Finally, the WEF Access Index provides a practical tool for identifying vulnerable households and districts. Integrating similar indicators into national and district planning frameworks could improve evidence-based decision-making and support progress towards Zero Hunger (SDG 2), Clean Water and Sanitation (SDG 6), Affordable and Clean Energy (SDG 7), and Reduced Inequalities (SDG 10).

6. Conclusion

This study contributes to understanding WEF access inequalities in Malawi by showing that household access to water, energy and food is shaped by intersecting socioeconomic and spatial disadvantages. Although improved water access was high, the composite WEF Access Index remained moderate, reflecting persistent deficits in electricity, modern cooking fuel and food access. Energy access was the most unequal dimension, with electricity showing the widest rich–poor gap. Wealth was the strongest determinant of WEF access, while urban districts had better outcomes, and Central and Southern districts remained disadvantaged relative to the Northern Region.

The formal spatial econometric analysis further showed that WEF access is geographically structured. SAR models identified significant neighbouring-district dependence for the composite WEF Access Index and electricity access, while modern cooking showed marginal spatial dependence. In contrast, SEM spatial error terms were not statistically significant, suggesting that residual spatial correlation is limited once regional and urban structural factors are considered. This indicates that WEF inequalities are driven by both household socioeconomic conditions and district-level service environments.

These findings show that there is a need for integrated, equity-focused and geographically targeted policy responses. Rural electricity expansion and clean cooking technologies should be prioritised, alongside improvements in water-system reliability and year-round food-security support. The study is limited by its cross-sectional design and reliance on self-reported household data. Future research should use longitudinal data and more detailed spatial, climate and infrastructure indicators to examine how WEF inequalities evolve and whether improvements in one district generate benefits for neighbouring areas.

Declarations

Author contributions

C.M. and F.M.B. conceived and designed the study. F.M.B. and C.M. curated the data. C.M., F.M.B., and M.M. conducted the formal analysis. F.M.B., C.M., and M.K. developed the methodology. J.N.C. supervised the study. C.M. and M.M. prepared the visualizations. F.M.B. and C.M. wrote the original draft of the manuscript. C.M., F.M.B., M.M., M.K., and H.C reviewed and edited the manuscript. All authors read and approved the final manuscript.

Acknowledgements

The authors would like to thank the National Statistical Office of Malawi for making the Integrated Household Survey (IHS5) data publicly available. The views expressed in this article are those of the authors and do not necessarily reflect those of any affiliated institutions.

Clinical Trial Number

Clinical trial number: not applicable.

Ethics Approval and Consent to Participate

Not applicable. This study is based on secondary analysis of anonymized data from the Malawi Fifth Integrated Household Survey (IHS5) 2019–2020 conducted by the National Statistical Office of Malawi. The dataset is publicly available and contains no personally identifiable information.

Consent for Publication

Not applicable.

Data Availability

The data that support the findings of this study are publicly available from the World Bank Microdata Library. The Malawi Fifth Integrated Household Survey (IHS5) 2019–2020 dataset can be accessed at https://microdata.worldbank.org/index.php/catalog/3818 subject to the data provider’s terms and conditions. All data used in this study were obtained from publicly available secondary sources.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Competing Interests

The authors declare that they have no competing interests.

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Figures

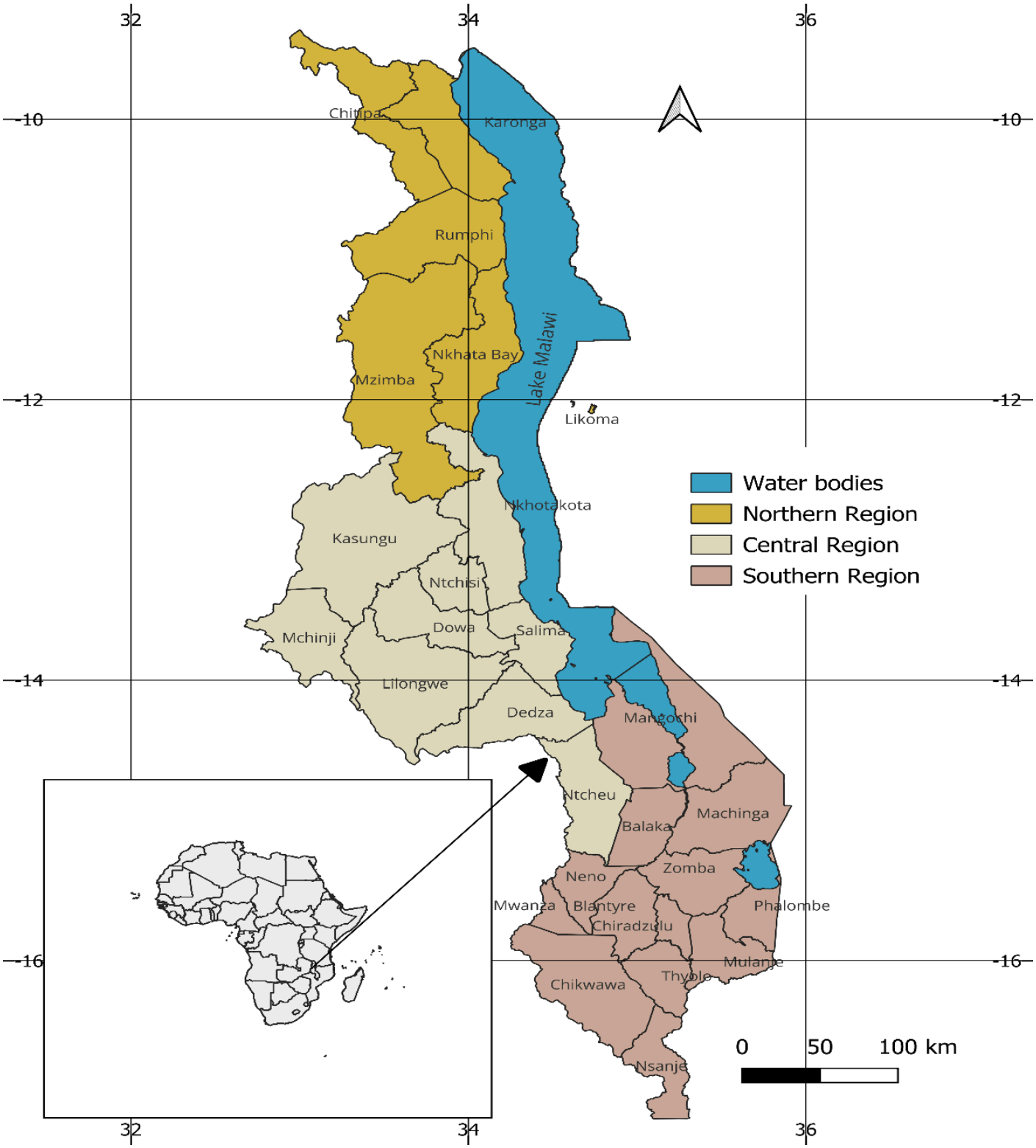


Figure 1

Map of Malawi showing the 28 administrative districts included in the study.

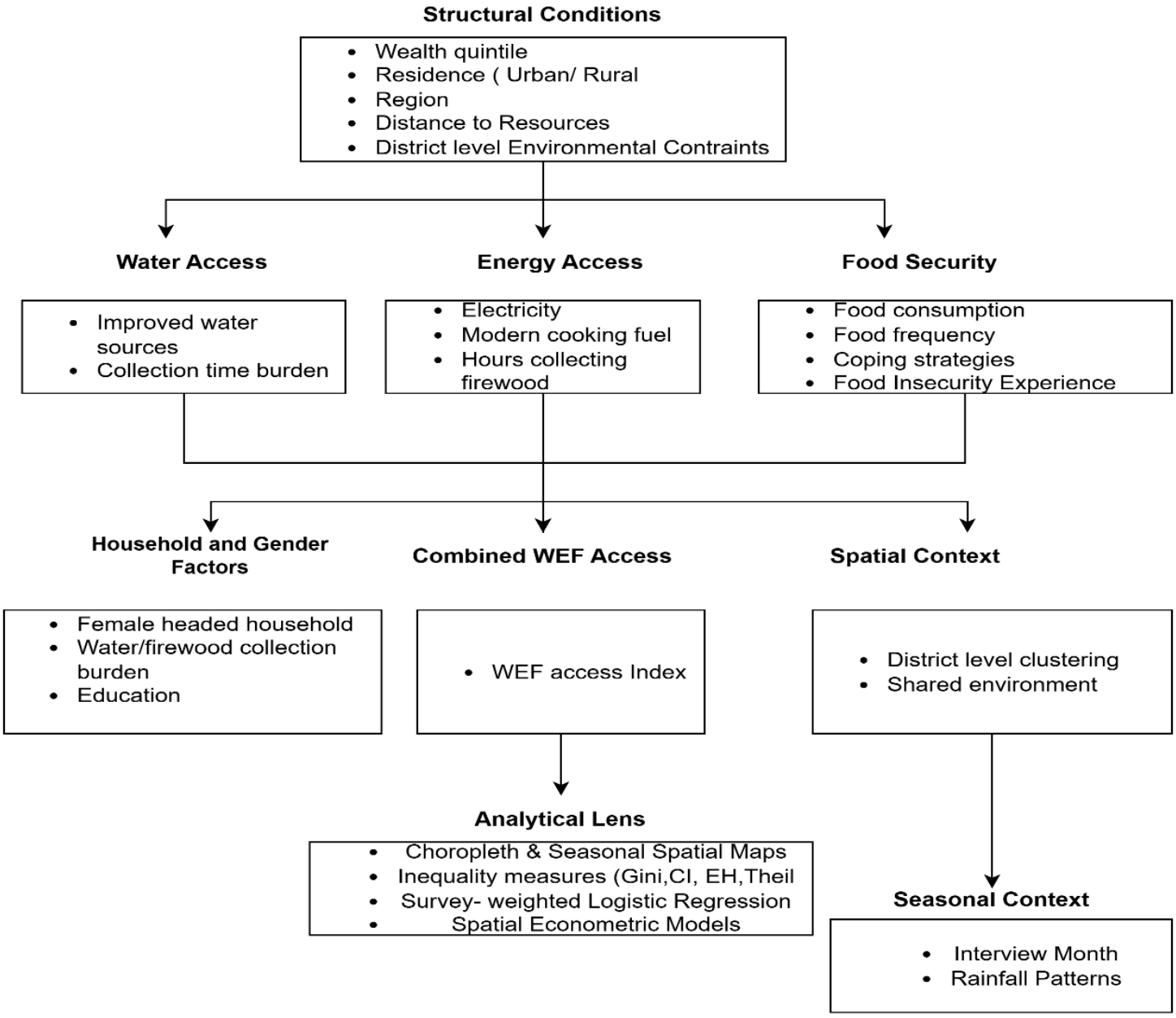


Figure 2

Conceptual framework of determinants and pathways shaping household WEF access

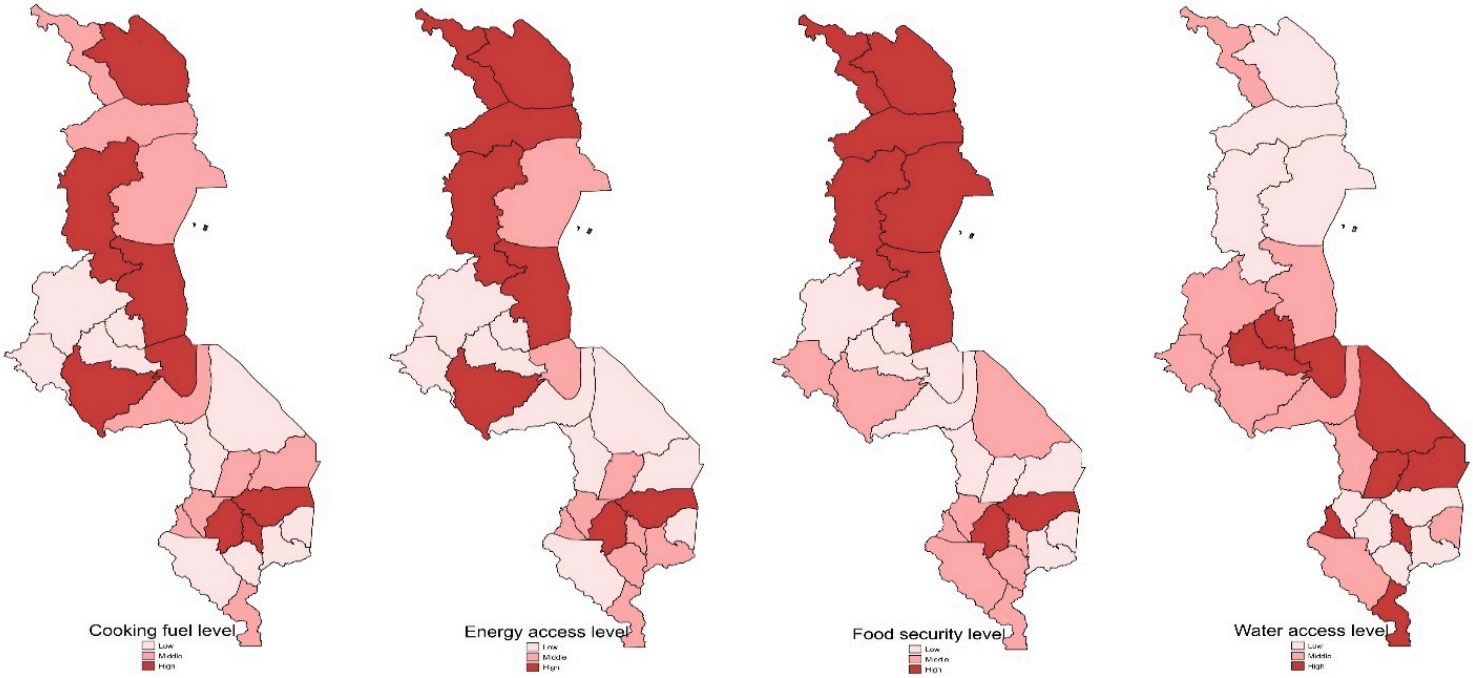


Figure 3

Spatial Patterns of WEF Access

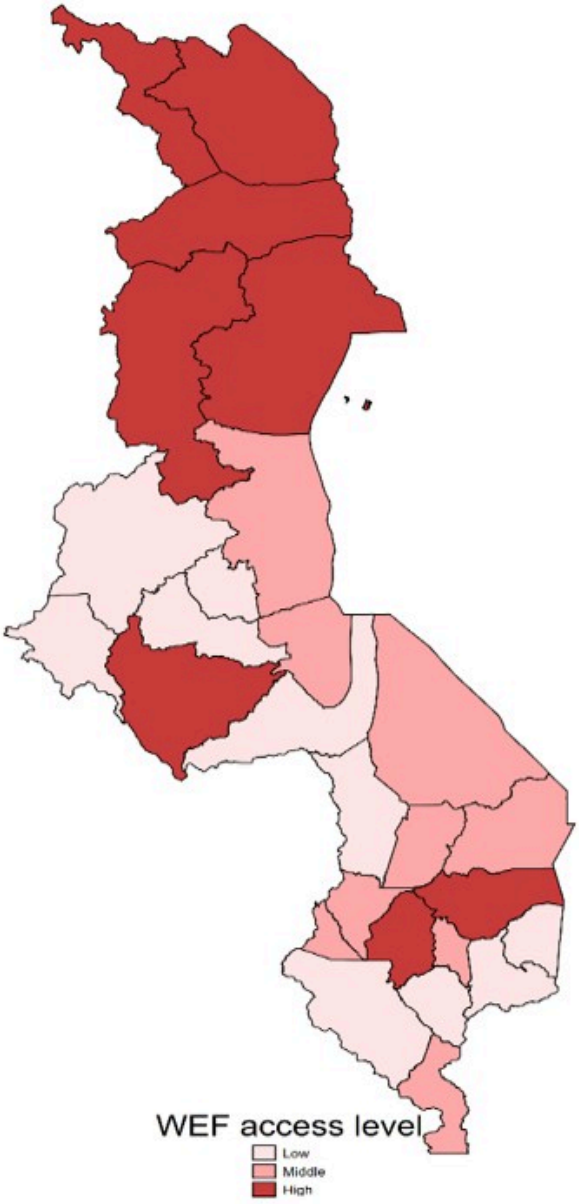


Figure 4

Spatial Patterns of Composite WEF Access

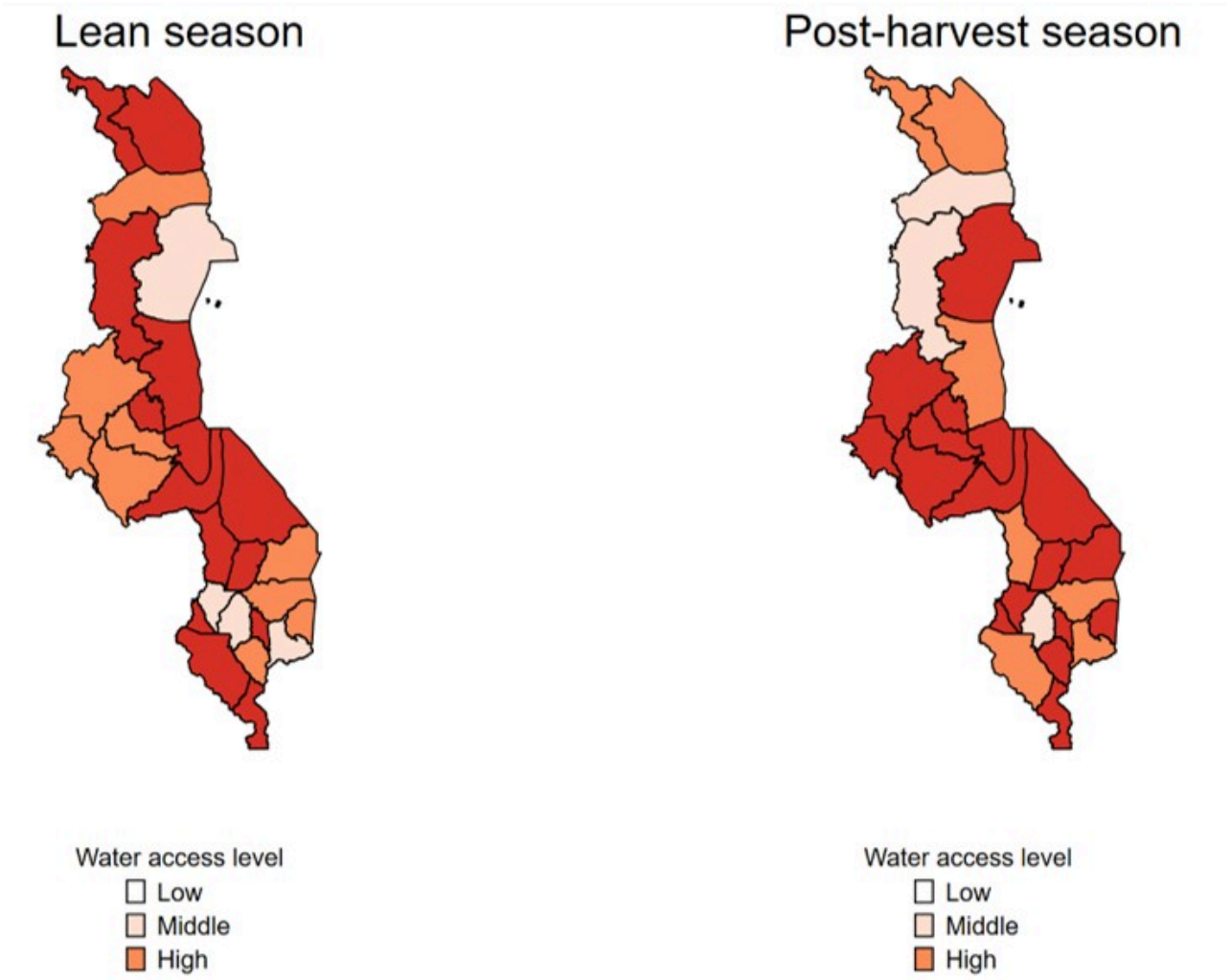


Figure 5

Water access level

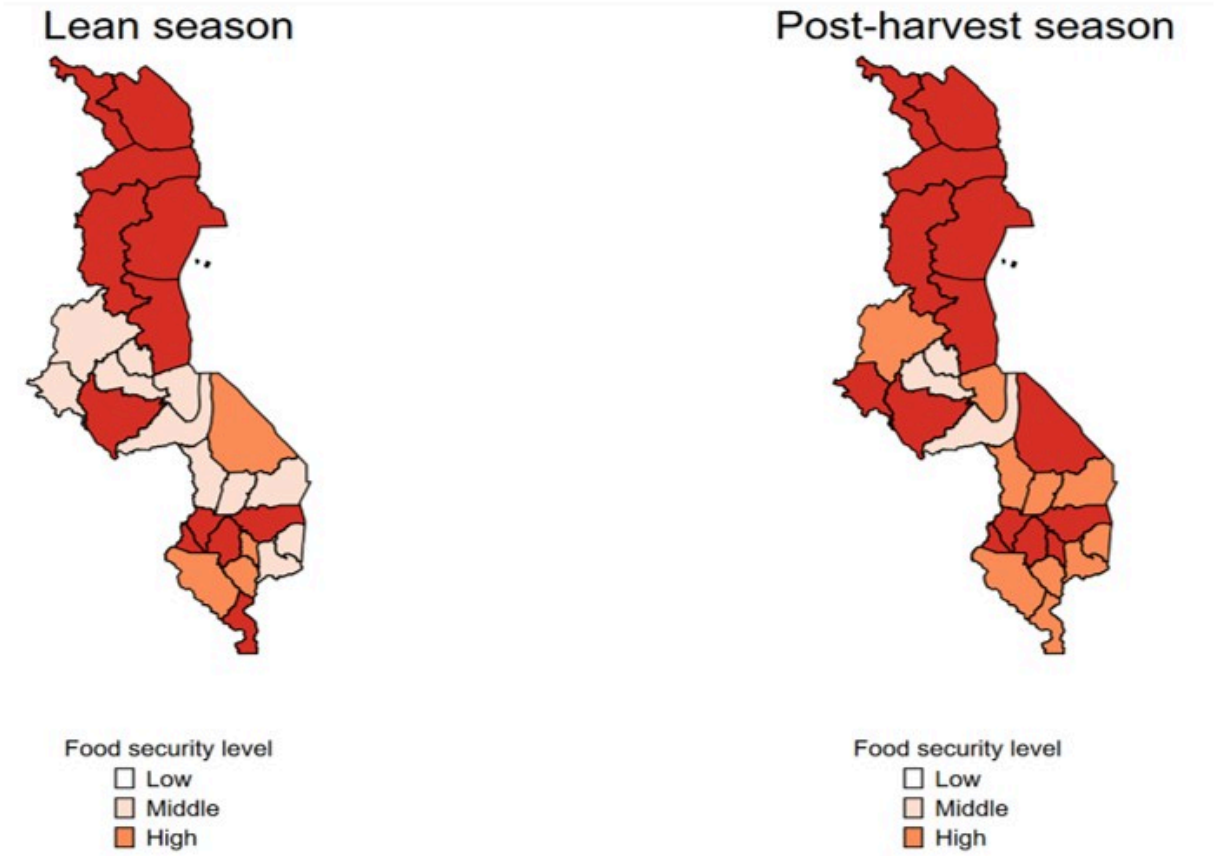


Figure 6

Food security Level

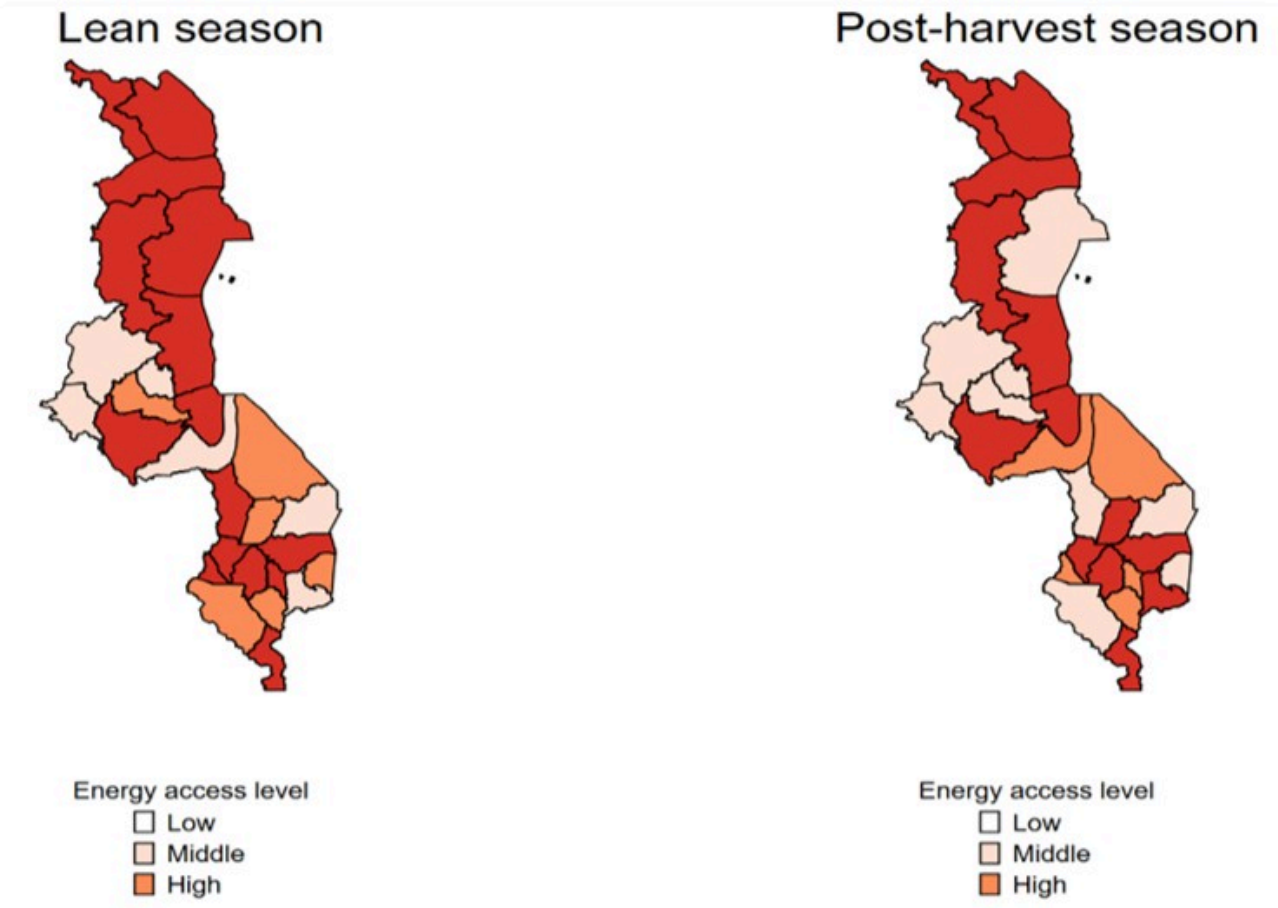


Figure 7

Energy access Level