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Assessment of Critical Environmental Resource Security for Sustainable Development: Water-Energy-Food Linkages and SDGs Attainment in Katsina State, Nigeria

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Abstract **Case Studies**

Katsina State, located in the extreme northern part of Nigeria within semi-arid Sahelian belt, characterizes the multifaceted interaction between the three critical environmental resources; water, energy and food (WEF) security and the accomplishment of Sustainable Development Goals (SDGs). The study quantifies resource security within a Water-Energy-Food (WEF) nexus context to assess its direct consequences for significant SDGs in the region. Using a mixed-method approach, secondary data from national databases and conducted primary survey (n=400) across the three ecological zones were synthesized. Results reveal a significant level of WEF insecurity: 51% of households experience water scarcity for five months annually, 87% rely on traditional biomass for cooking and 74% face moderate to severe food insecurity. A substantial negative correlation ($r = -0.74$, $p<0.01$) was recorded between a composite WEF Insecurity Index and a localized SDG Progress Index (SDGs 2, 6, 7, 13). The analysis indicates that the unidirectional, sectoral policies exacerbate trade-offs, such as expanded irrigation increasing groundwater stress without clean energy for pumping. The study concludes that attaining SDGs targets in the state requires paradigm shift to quantify nexus-informed governance. The study proposed a Regional-Specific Nexus Security Index a tool for integrated planning, targeting synergistic interventions such as solar-powered irrigation and regenerative agriculture to pause the cycle of resource dearth and improve sustainable development.

Keywords: Water-Energy-Food Nexus, Resource Security, Sustainable Development Goals (SDGs), Katsina State, Northern Nigeria, Quantitative Assessment, Index Development.

1. Introduction

1.1. Background: The Interconnected Resources Challenge

The universal ambition towards achieving the 2030 Agenda for Sustainable Development has underscored the complex and often precarious relationships between water, energy, and food systems, which are fundamental to both human welfare and economic advancement. These resource

areas are not independent entities but are intricately connected through a network of mutual reliance. Water is indispensable for energy production and agriculture, energy is critical for water management and various agricultural and food processing activities, and food systems, in turn, rely on and impact water and energy resources throughout their entire lifecycle (Bazilian et al., 2011; Hoff, 2011). Consequently, a lack of recognition and effective management of these interconnections leads to conflicting policies, inefficient resource allocation, and the unintentional worsening of trade-offs, ultimately compromising sustainable development objectives (Liu et al., 2018; Simpson & Jewitt, 2019).

The governance challenges in Sub-Saharan Africa are particularly pronounced, given the region's concurrent experience of rapid population growth, severe climate change impacts, and low coverage of modern energy and water services. In response to these multifaceted issues, the Water-Energy-Food (WEF) nexus has emerged as a critical analytical and operational paradigm. This approach provides a systems-level perspective, enabling the identification of synergies, the management of trade-offs, and the promotion of integrated, cross-sectoral planning (Bazilian et al., 2011). As noted by Molefe, et al, (2023), the integration of the WEF nexus into policy development is not merely advantageous but "essential for ensuring long-term resource security and sustainability," particularly within developing economies characterized by heightened resource pressures and constrained institutional capacities.

Katsina State is an ideal case, where the interdependence among water, energy and food systems commands livelihood and progressive outcomes (Sani and Miklas, 2021; Sani and Miklas, 2022). With over 80% of its population engaged in rain-fed agriculture, the state is acutely sensitive to climate shocks, experiencing recurrent droughts, desertification and erratic rainfall patterns (FGN, UN, 2020). These environmental pressures converge with rapid population growth to strain already limited Water-Energy-Food resources, creating a nexus of insecurity that directly impedes progress toward SDGs 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action).

1.2. Nigeria's SDG Landscape: Fragmented Progress and Persistent Gaps

Nigeria, as the most populous nation in Africa with an estimated population surpassing 220 million, offers a particularly pertinent context for nexus analysis. The nation has formally endorsed the 2030 Agenda, as evidenced by its successive Voluntary National Reviews (VNRs), including the 2025 submission to the United Nations High-Level Political Forum (UN, 2025). This review detailed advancements in reinforcing institutional structures, aligning the national statistical system with the Sustainable Development Goals (SDGs), and implementing the Integrated National Financing Framework (INFF). However, the report also presented a stark assessment: of the 52 critical SDG performance indicators monitored by the Nigerian government, only 34.6 percent showed improvement, while 30.8 percent remained stagnant, and a significant 34.6 percent experienced regression (UN, 2025). Furthermore, the analysis indicated that the confluence of global crises, including the COVID-19 pandemic, escalating climate change, and geopolitical instability, has imposed profound socio-economic shocks that continue to hinder developmental progress.

The 2025 Voluntary National Review's emphasis on five priority SDGs—namely, SDG 3 (Good Health and Well-being), SDG 5 (Gender Equality), SDG 8 (Decent Work and Economic Growth), SDG 14 (Life Below Water), and SDG 17 (Partnerships for the Goals)—is noteworthy for its exclusions. Specifically, SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 7 (Affordable and Clean Energy) are conspicuously absent from the prioritized list. This is particularly significant given that these three goals represent some of the most consistently underperforming targets within Nigeria. Rather than an oversight, this omission underscores the magnitude of the challenges faced. The Sustainable Development Report 2025 continues to classify Nigeria's standing on these goals as "major challenges," with scant indication of significant

progress as the 2030 deadline looms (Sachs et al., 2025).

1.3. The Water-Energy-Food Nexus in Nigeria: A Framework for Diagnosis and Action

Researchers in Nigeria are increasingly employing the Water-Energy-Food (WEF) nexus framework to understand resource interdependencies and their governance consequences in light of persistent systemic issues. For instance, Ojo, et, al,. (2025) investigated the applicability of the nexus approach to Nigeria's climate policy development, highlighting potential advantages such as increased resource efficiency, greater resilience to climate change, and diminished environmental damage through integrated planning. Complementary research has examined the WEF nexus within specific Nigerian sectors. Adeleye, et, al, (2021) explored the connections between agricultural output, environmental deterioration, and energy consumption. Adeoti, et,al,. (2023) conducted a comprehensive review of sustainability issues affecting Nigeria's water infrastructure. Furthermore, Sani and Miklas, (2022) analyzed the uneven relationships among food, energy, and water security in the context of achieving sustainable development.

A recurring theme in the existing research is the significant fragmentation of governance structures in Nigeria. The current constitutional framework distributes resource management duties among various federal and state agencies, such as the Federal Ministries of Water Resources, Environment, Agriculture and Rural Development, and Power. However, the absence of formal mechanisms for inter-ministerial coordination results in a systematic erosion of policy coherence. Consequently, policies for water, energy, and agriculture are often developed independently, neglecting the crucial interconnections and mutual dependencies between these sectors. This isolated approach, as noted by Simpson and Jewitt (2019), perpetuates inefficiencies and entrenches unsustainable patterns of resource utilization.

While the Water-Energy-Food nexus perception is broadly recognized, a critical gap exists in translating its theoretical values into quantifiable, regional-specific metrics that guide policy in contexts like Northern Nigeria (Sani and Miklas, 2022). Existing governance often remains sectoral; water resource plans are drafted with minimal integration of energy or agricultural strategies, leading to policy incoherence and unintended trade-offs (ref). For instance, promoting farmer-led irrigation to boost food security (SDG 2) may deplete aquifers (undermining SDG 6) if not paired with efficient technologies and clean energy (SDG 6).

This research investigates how to quantitatively evaluate water, energy, and food resources using a nexus framework, thereby filling identified gap in current understanding and what is the quantifiable connection between this integrated resource security and SDG accomplishment in Katsina State? Our objectives are threefold: (1) to assess the existing state of Water-Energy-Food security using primary and secondary data sources; (2) to statistically examine the connections between Water-Energy-Food security indices and localized SDG indicators; and (3) to design and suggest a comprehensive - the Katsina Nexus Security Index (K-NSI) - for planning and policy. By grounding the nexus in empirical, local data, this study provides a model for evidence-based resource governance critical for sustainable development in arid and semi-arid regions.

2. Methodology: An Integrated (Mixed-Methods) Approach for Nexus Assessment

2.1. Study Area

Katsina State is situated (latitude 11°08'N to 13°22'N) in Nigeria's Sudan-Sahelian savanna region. It experiences a semi-arid climate, characterized by an average annual rainfall of 600mm in the southern parts, decreasing to 500mm in the north. The rainfall occurs within a single season, typically from May to September, and the area faces high evaporation rates. The economy is heavily reliant on agriculture, with millet, sorghum, and maize being the primary crops. The state is grappling with significant environmental issues such as desertification, deforestation, and the depletion of vital water sources like the Sabke and Gada dams.

2.2. Data Collection

In order to achieve the desired objective of the study a sequential descriptive mixed-methods approach was employed (Creswell & Plano Clark, 2017). Primary data on water (involved accessibility, quality and usage), energy (sources, cost and usage for cooking and productive purposes) and food security (production, sources, consumption frequency and coping strategies (using Household Food Insecurity Assess Scale – HFIAS)) were collected through field survey; the primary data were obtained through questionnaire administration. The secondary data which involved rainfall variability (NIMET, 2025), groundwater level (KTSWB, 2025), National grid coverage (KEDCO, 2025), crop yield and prices (NBS, 2025). Moreover, to gain a deeper understanding of governance challenges and provide context for the quantitative data, 15 semi-structured interviews were carried out. Participants included officials from the ministries of water resources, environment, agriculture, and the department of energy, alongside leaders of farmers' cooperatives.

A multi-stage stratified random sampling was used to select 400 households across four Local Government Areas (LGAs) within the three existing ecological belts in Katsina state (el-Tantawi, 2011). The sampled communities were: Jibia (frontline, desertification), Katsina (urban), Dutsin-Ma (agrarian), and Funtua (southern agro-zone). The designs of questionnaires and guides for interviews were in line with various standards covering sections on household characteristics and compositions as well as socioeconomic status (Angelen et al, 2011).

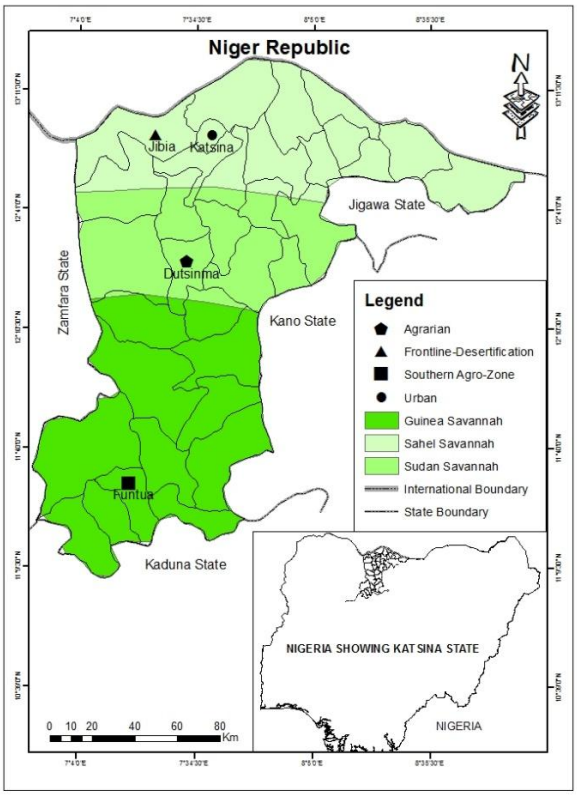

Figure 1.: Map of the study area showing sampled communities

2.3. Data Analysis

Primary and secondary data were analyzed using SPSS version 28 and R. Normalized security indices (ranging from 0-1) were developed for water, energy and food based on the assessments of availability, accessibility and stability. A composite Water-Energy-Food Insecurity Index (WEF-II) was calculated as the arithmetic mean of (1-WSI), (1-ESI) and (1-FSI). A localized index was developed, incorporating selected indicators relevant SDG 2, 6, 7, and 13.

Pearson Product-Moment Correlation (PPMC) and multiple linear regression were employed to evaluate associations between WEF indices and the SDG index. Spatial analysis of variance (ANOVA) was conducted across the investigated communities.

Thematic analysis of Key Informant Interview (KII) transcripts was conducted using NVivo 12 software to identify governance and institutional barriers.

Table 1: Summary of Data Sources and Analytical Variables

Nexus Domain	Main Quantitative Indicators	Data Source	Index Component
Water	Months of scarcity/year, distance to source (km), water use (l/p/day)	Survey, SWB	**Water Security Index (WSI)**
Energy	Primary cooking fuel, access to electricity (hours/day), energy expenditure share	Survey, NBS	**Energy Security Index (ESI)**
Food	HFIAS score, months of adequate provisioning, dietary diversity score	Survey, FAOSTAT	**Food Security Index (FSI)**
SDG Linkage	Proxy indicators (e.g., % children underweight, % using clean water)	Survey, State Reports	**SDG Progress Index**

3. Results

3.1. Quantified State of WEF Insecurity

The findings present a clear and challenging image of how resource limitations are intertwined throughout the state.

3.1.1. Water: The results revealed that 76% across the surveyed households experienced water scarcity for a duration exceeding six months annually. Water collection time averaged 43 minutes, surpassing the SDG 6 target of 30 minutes. Analysis of the groundwater levels indicated an annual decline of 0.4-1.2 metres in Jibia sampled community.

3.1.2. Energy: Energy poverty was pervasive, with 87% of the households depends on biomass fuels (firewood, charcoal and post-harvest waste) for

cooking. Grid electricity access was only limited to 42% of surveyed households, with an average supply of less than 4 hours per day. Energy expenditure constitute a substantial portion of the household income, an averaging of 21% monthly, primarily allocated to cooking and other accessories functions (including phone charging).

3.1.3. Food: Food insecurity was prevalent, affecting 74% of the investigated household at moderate or severe level (based on HFIAS) across the sampled communities. In addition, dietary diversity was also limited, characterized by the dominance of millet and sorghum. A statistically negative trend was observed in sorghum yields, declining by 13% over a two-year period, which correlate with reduced rainfall patterns ($r=0.65$, $p=0.005$).

3.2. WEF-SDG Connections: Statistical Indication

Statistical analysis confirmed strong linkage.

Analysis of the composite water-energy-food Insecurity Index (WEF-II) indicated a significant negative correlation with the localized Sustainable Development Goals (SDGs) progress index ($r= -0.73$, $p<0.01$). The study suggests that heightened integrated resource insecurity is strongly associated with diminished overall SDGs performance within the investigated communities.

Regression analysis identified the energy Insecurity Index as the most significant predictor of the Sustainable Development Goals Index (SDGI). The findings highlight the critical significance of energy access as primary leverage point for achieving systematic progress towards SDGs in the state.

Spatial analysis of variance (ANOVA) indicated significant disparities in resource security ($p<0.05$) and SDG performance across the surveyed communities. Jibia (frontline desertification), characterized by its frontline desertification, exhibited the highest Water-Energy-Food Insecurity Index (WEF-II) and the lowest scores. Conversely, Funtua (wetter south) experiencing a wetter climate, demonstrated relatively better performance, thereby highlighting intra-state vulnerability gradients.

Table 2: Correlation Matrix between Resource Security Indices and SDGs Progress Index

Index	Water Security (WSI)	Energy Security (ESI)	Food Security (FSI)	SDG Progress Index
WSI	1.00	0.58**	0.62**	0.70**
ESI	0.58**	1.00	0.49**	0.81**
FSI	0.62**	0.49**	1.00	0.65**
SDG Index	0.70**	0.81**	0.65**	1.00
WEF Insecurity Index	-0.85**	-0.90**	-0.78**	-0.72**

Index	Water Security (WSI)	Energy Security (ESI)	Food Security (FSI)	SDG Progress Index

** $p < 0.01$

3.3. Analysing the Governance Deficit: Findings from qualitative Data

Thematic analysis of Key Informant Interviews (KIIs) revealed a persistent "silo mentality." Officials admitted to operating with "different data and different targets." A water resource officer exemplified this, stating their focus was "water provision," not the downstream uses like irrigation or energy. This fragmentation helps explain why sectoral projects, even those well-intended; often fall short of delivering comprehensive benefits.

4. Discussion

4.1. Interpreting the nexus

The study corroborates the assertion that insecurity within the study area manifests as a nexus phenomenon, rather than series of discreet deficits. A robust correlation between energy poverty and diminished progress towards Sustainable Development Goals aligns with the prevailing global nexus literature (Amer and Kareem, 2025; Saidou and Lamia 2022; Utal, 2021, Sani and Miklas, 2021; Sani and Miklas, 2025, Aliyu, et, al., 2024), which identifies either one or the combined elements of the WEF as a critical towards achieving sustainable development. Amer and Kareem, 2025; Saidou and Lamia 2022 identifies that the dependence on biomass fuels perpetuates a negative feedback loop: time allocation to fuelwood collection diminishes agricultural productivity and incentivizes deforestation. Consequently, ecosystem services essentially for water regulation and climate resilience are compromised, thereby exacerbating food and water insecurity. This observation substantiates the "poverty-environmental trap" as theorized in the existing literature.

4.2 The Katsina Nexus Security Index (K-NSI)

To address this complex issue, the study proposed the Katsina Nexus Security Index (K-NSI). Building upon our existing diagnostic framework for water-energy-food insecurity, this index is designed as a strategic planning and monitoring instrument. It will be calculated annually at the local community level, utilizing a simplified set of key indicators (e.g., proportion of household having sustainable access to clean; energy; food, groundwater recharge rate among others). It finds vale in:

i. **Monitoring Progress**: Developing a singular, readily interpretable measure for evaluating the overall condition of combined resources.
ii. **Detecting synergistic relationship**: Directing investments toward interventions that yield the greatest return across multiple sectors. For instance, promoting drought-resistant crops, which simultaneously provide food, function as windbreaks to protect ecosystem and offer bio-energy benefits.
iii. **Trade-off Management**: Making it necessary to policymakers to evaluate, beforehand, the implication of a new irrigation initiative for local energy demand and the long-term sustainable use of groundwater.

4.3 Policy Implication and Future Direction: **The empirical data underscore the imperative for governance reform.**

The imperative to foster integrated resource management necessitates the establishment of a state-level nexus steering committee. This committee should be constituted with mandatory representation from key ministries, including those responsible for water, energy, agriculture, environment, and planning. The foundational objective of this body will be the formal adoption of the localized nexus framework, thereby initiating a coordinated approach to resource governance. This strategic integration aims to harmonize policies and practices across critical sectors, ensuring that interdependencies between water, energy, food, and environmental systems are proactively managed. By bringing together diverse ministerial perspectives, the committee will be well-positioned to develop and implement cohesive strategies that promote sustainable development and enhance resource security within the state. The adoption of the local nexus framework will serve as the crucial first step in operationalizing this integrated management approach, laying the groundwork for more effective and efficient resource utilization.

To address the multifaceted challenges faced by vulnerable communities, the implementation of nexus innovation pilot projects is critically important. These initiatives should be designed as integrated packages, demonstrating the synergistic benefits of combining different resource management strategies. For instance, a pilot project could involve the deployment of solar microgrids to provide a reliable and sustainable energy source for powering efficient drip irrigation systems. This irrigation infrastructure would then support community-managed vegetable gardens, thereby enhancing local food security. Furthermore, these integrated packages should incorporate agroforestry practices, which can contribute to soil health, biodiversity, and climate resilience, further strengthening the overall sustainability of the intervention. By focusing these pilot projects in the most vulnerable communities, the aim is to test and refine integrated nexus solutions in contexts where they can have the most significant positive impact, providing valuable lessons for broader scaling and replication.

The effective integration of the nexus framework into state-level development strategies requires its formal mainstreaming into both long-term development plans and annual budgetary allocations. This institutionalization ensures that the principles of interconnected resource management are not merely an addendum but a core component of policy and investment decisions. Consequently, all major development projects should be subjected to a mandatory "nexus impact assessment." This rigorous evaluation process is designed to systematically identify and quantify the potential synergies across water, energy, food, and environmental systems, thereby maximizing co-benefits. Equally important is the assessment's role in proactively identifying and mitigating potential trade-offs, ensuring that interventions in one sector do not inadvertently create undue burdens or negative consequences in others. By embedding this assessment requirement, the state can foster a more holistic and sustainable approach to development, optimizing resource utilization and promoting resilient socio-ecological systems.

5. Conclusion

This study presents a quantitative demonstration of the profound interlinkages between water, energy, and food security within Katsina State. The findings reveal that the integrated insecurity across these vital sectors acts as a significant impediment to achieving the Sustainable Development Goals (SDGs). A high correlation observed between the water-energy-food insecurity index and the SDG progress index empirically validates the inadequacy of conventional sectoral approaches to development. In response, the proposed local nexus framework offers a pragmatic methodology for transitioning from diagnostic analysis to integrated governance.

By systematically measuring and managing the water-energy-food nexus, policymakers in Katsina state and comparable regions are equipped with a tool to identify and leverage synergistic solutions.

This integrated approach facilitates more effective investment allocation and fosters the creation of a resilient foundation necessary for attaining the 2030 Agenda. Ultimately, the pathway to sustainable development in Northern Nigeria is intrinsically linked to the integrated governance of its most critical and vulnerable resource systems.

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