Interplay of Water–Energy Security and Food Consumption Patterns towards Achieving Nutrition Security in Katsina State, North-Western Nigeria

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Abstract: Everyone has the right to secure water, energy, and food supplies. These essential resources are stressed in many countries. With the current population growth rate and urbanisation, especially in sub-Saharan Africa, there is a need for more food, water, and energy to sustain the increasing population. The aim of this study was to assess the inter-relationship among water and energy in various urban and rural households to support food and nutrition security. Considering the social-economic peculiarities of the region, a specific framework and questionnaire were developed for the study. A survey involving 1785 questionnaires was conducted. Urban and rural stratification methods were used in selecting settlements across the regions. The household’s nutritional status was measured in relation to protein-rich foods as well as vegetable and fruit consumption. In addition to the Person’s correlation coefficient, which was applied to measure the association between two categories of food consumption, the chi-squared test of interdependence to determine the effect of the urban–rural dichotomy on resource utilisation was calculated. The findings indicate a high risk of undernourishment associated with insufficient sources of water and energy, as well as inappropriate sanitation facilities, especially in rural communities.

Keywords: sustainable development; water sources; energy sources; energy crisis; scarcity; sanitation facilities; nutrition assessment; resource access; urban–rural dichotomy; urbanisation

1. Introduction

The water–energy–food nexus has been promoted as a theoretical tool for achieving sustainable development. The nexus perspective tackles the links connecting the essential resources of water, food, and energy [1–3]. These three resources have long been recognised as essential to human life and socio-economic progress. The nexus approach perspectives highlight the multiple inter-reliance among water, energy, and food security and the underlying natural resources. It also draws attention to the potential synergies and trade-offs, as well as complicit and efficient utilisation [4–9]. The future securities of water, energy, and food are of major global concern [10]. Major challenges are inaccessibility, rapidly growing global demand, resource constraints, disparity in regional availability, and variations in demand and supply. Population growth, urbanisation, climate change, economic growth, land use, and technological developments have been identified as major drivers of rapidly growing demand of water, energy, and food [2,8,10]. The demands for water, energy, and food have exceeded the available supplies in some regions of the world.
such as sub-Saharan Africa, characterised by poverty as well as rapid population and particularly urban growth [11–13].

Access to safe water and sanitation is a universal need and a basic human right. It is an essential element of human development and poverty alleviation and constitutes a necessary component of primary health care. Inadequate water and sanitation result in sickness and potentially death, as well as in higher health costs, lower workforce productivity, overall school enrolment decline, and low retention rates of schoolgirls [14,15].

The availability to good and sufficient water resources influences production and is a major criterion for the sustainable development of the agricultural sector in Nigeria. Although the country is rich in both surface and groundwater resources, it has been estimated that the total precipitation of 1062.336 km\(^3\)/y for the whole country is linked to an average total precipitation of 1150 mm/y. However, spatio-temporal variations in rainfall across different regions of the country indicate surplus in some regions and scarcity in other regions. This results in challenges for effectiveness in utilisation and productivity improvement in water-scarce regions [16].

The northern region of Nigeria, which comprises both arid and semi-arid belts, is an area characterised by little rainfall. The annual rainfall declines northwards to an average of less than 500 mm in a season of 60 days, with the upper and lower confidence limits being 635 and 389 mm, respectively [16]. Over the years, there has been evidences of prevalence of events of drought in the region with increasing pressure on available water resources and a requirement for better resource management [17]. The increasing desertification in the northern region is also attributed to the persistent deforestation of the savannah woodland and bushes having been converted into open agricultural land with no protection during the heavy rain downpours, leading to erosion and soil degradation [18].

Considering the fast-growing population in Nigeria, arable land is also required for food production and wood for energy generation, thus resulting in trees being cut down and leaving the fields open during the dry seasons when there are no crops on the field. This leads to erosion of the topsoil layer during heavy and frequent rain downpours [19]. Energy is a vital input for the socio-economic growth for any country. Despite the enormous endowments of renewable and non-renewable primary energy resources, Nigeria is still faced with many electricity challenges linked to generation, transmission, distribution, and marketing. This has hampered its economic development. The total installed capacity of power generation in Nigeria in August 2015 was 12,522 MW, but only 7141 MW were available [20]. According to the World Bank [21] in 2020, 85 million Nigerians do not have access to grid electricity. This corresponds to 43% percent of the country’s population and makes Nigeria the country with the greatest energy access deficit in the world. The lack of reliable power is a significant constraint for many communities in terms of socio-economic progress, resulting in an annual economic loss estimated at USD 26.2 billion (NGN 10.1 trillion), which is equivalent to about 2% of the GDP. The report further revealed that, Nigeria’s position is only 171 out of 190 countries in terms of obtaining electricity. Electricity access is seen as one of the major limitations for the private sector development. Water and energy are critical components of the food system as well. Energy type, price, and availability are key factors that influence growers and manufacturers [22].

At household level, water, energy, and food securities are described as states when people almost always have economic and/or physical access to safe and sufficient water, clean energy, and nutritious food, enabling healthy and productive lives. On the other hand, household water insecurity is defined as the inability to access and utilise safe, reliable, and sufficient corresponding resources for a healthy life and good well-being [23]. Low access to food has been identified as a major contributing factor to chronic under-nutrition, which has been estimated to negatively impact on 793 million individuals globally [24]. Ensuring accessibility and ability to afford adequate and modern forms of household energy is crucial for maintaining public and individual health and well-being. Yet, millions of households globally lack access to clean energy sources [25]. Therefore, the concepts of
water, energy and food securities include three key dimensions: availability, accessibility, and utilisation [26–29].

A single household has been identified as a unit of demand and is seen as the most appropriate component in influencing consumption practices [9]. Relevant to household resource use, a household comprises those who live and eat together. Household energy consumption is defined as the amount of energy spent on various household appliances, which include all energy type of use in the household [30]. In addition, household water consumption is characterised as the amount of water used for all usual household applications including drinking, food preparation, and bathing, as well as related household utility needs of the inhabitants [31]. Furthermore, the FAO [32] defined household food consumption as the entire sum of food available for consumption, which excludes the food taken outside except when prepared at home. Relevant to dietary diversity, household food consumption has been defined as the frequency of unique foods or categories of food consumed over a period of time, which has been considered as a measure to determine nutritional status [33]. A considerable proportion of water, energy, and food consumption in the municipalities can be ascribed to domestic use. For example, energy consumption at households in Nigeria and Burkina Faso account for approximately 65% and 75% of the overall consumption, respectively [34–36].

Many studies have assessed the relationship among water, energy, and food at the regional, national, and international levels. However, limited work has been undertaken on the interaction between water, energy, and food at the domestic level [9]. Individual constituents of the nexus have been examined in some research projects. Similarly, other studies [36–38] assessed individual elements such as water, energy, or food as a separate entity. Vieira et al. [37] evaluated the efficacy of household water utilisation. Furthermore, they linked household water efficiency and socio-demographic variables with each other. In addition, Ogwumike and Ozughalu [38] analysed household energy poverty and highlighted its implications for achieving sustainable development in Nigeria. They found that most Nigerian households did not have adequate access to clean energy sources. Moreover, Zouh et al. [34] evaluated the rural food security at household level in northern Pakistan. Their findings revealed that among some factors impacting on household food security, gender played a dominant role.

Effective and sustainable accessibility to safe and sufficient water, clean cooking energy, and healthy food is critical towards achieving sustainable development in any society [39–41]. According to the FAO [42], nutritious security can only be achieved when all people at all time have access to nutritious diets, comprising all vital nourishments and water, combined with sanitary environment and sufficient health services that guarantee a healthy and active life for all household members. Consequently, access to clean cooking fuels is paramount to a healthy and active life. Therefore, accessibility to these essential resources should be unbiased between urban and rural communities. Accessibility to water, energy, and food resources are driving forces in the urban–rural context. Their sources are basic commodities for both urban and rural communities in terms of household services [43–45]. The variability in household characteristics (family size, socio-economic variables, and seasonality) and appliances for water, energy, and food consumption patterns is enormous [46,47].

The main aim of this study is hence to examine the accessibility of water sources, cooking energy sources, and various food consumption patterns across the representative urban and rural households in Katsina state, north-western Nigeria. The objectives were to (a) explore the interplay of water–energy security and food consumption patterns towards achieving nutrition security; (b) examine effects of water and energy scarcities on nutrition and food security; (c) evaluate accessibility to various household food and consumption patterns; and (d) compare food consumption patterns related to accessibility to various sources of water and energy in urban and rural households. Given that 47% and 53% of the region’s approximate 8.6 million people (as of 2020) live in urban and rural areas, respectively, and that their water, energy, and food accessibility situation reflects that of
most of the urban and rural households of other sub-Saharan African regions, it is presumed that selecting Katsina state as a case study would make the findings also relevant to other regions, especially to those with similar socio-economic and ecological characteristics.

This research paper is structured as follows: Section 1 briefly introduces and reviews the scientific literature concerning the nexus at household scale. Section 2 describes the methodology, which consists of a full description of the materials and methods used to carry out the research, involving the study area description, conceptual framework, and selection of the surveyed communities; data collection; and statistical analysis. Section 3 is dedicated to the research findings, as well as the discussion of findings, which highlights the strong connection between water and energy security towards achieving nutrition and food security and lastly concludes the article.

2. Materials and Methods

2.1. Description of the Study Area

Katsina state is situated in the north-western part of Nigeria between latitude 11°08′ N and 13°22′, and longitude 6°52′ E and 9°20′ E, comprising an area of 23,938 km². This state has territorial boundaries with Kano and Jigawa states to the east, Kaduna state to the south, and Zamfara state to the west. The Republic of Niger is located to the north. The state is part of the large high plains of Hausa land [48].

Katsina is classified into two distinct climatic zones on the basis of seasonal variations and months: tropical continental and semi-arid continental. The state is characterised by a hot dry season between March and May, as well as a warm wet season between June and September. Generally, the annual rainfall figures diminish northwards. The extreme northern region of the state, which is categorised as Sahel Savannah zone, is an area characterised by low rainfall of between 501 and 700 mm. In the central region of Katsina state, which consists of the Sudan Savannah zone, the region is characterised by rainfall between 701 and 900 mm. The southern part of the state consists of the Guinea Savannah with rainfall above 900 mm (Figure 1). A less characteristic season is identified by decreasing rainfall and a gradual decrease in temperature during October and November. The months between December and February are characterised by a cold and dry (harmattan) season. The proportions of urban and rural populations within Katsina state were 47% and 53%, respectively, in 2019 [48].

2.2. Conceptual Framework

The study is based on an assessment of the interrelationships among the three household’s essential resources, which are water, energy, and food. A generic conceptual framework provides a basic overview of potential pathways through which water and energy securities can have an impact on food security (Figure 2).

Household water and energy access influence cooking practices and dietary choices. The lack of access to safe and sufficient water sources and clean cooking energy can potentially negatively impact dietary choices, cooking practices, and sanitation. It can result in skipping meals and reduced cooking times by switching to food types that are less water and fuel demanding. Generally, a few of the major food types consumed in developing countries can be completely digested unless cooked. Protein-rich foods such as meat and beans are more water and energy demanding. Thus, the protein intake can be reduced when alternative faster cooking food types are chosen, resulting in unbalanced and poor nutrition. Water and energy scarcity can therefore influence the quantity, quality, and the type of food consumed and digested, and could be a cause of reduced nutrition leading to poor health conditions.

Lack of access to improved water and energy sources may lead to switches to inferior water and energy sources. Water and energy source ladders were designed as hierarchical relationships between household location and economic prosperity. Thus, poor access to improved water and clean energy compels households to come down from superior to inferior sources of various sources of water and energy. Consequently, consumption
of insecure and inadequate water and increased air pollution leads to uncompromised health issues.

Figure 1. (a) Map of Africa showing Nigeria; and (b) map of the study area outlining the surveyed communities across the three isohyets.

Poor access to safe and sufficient water and clean energy sources may also lead to the reallocation of household resources from other productive activities and preparations for water and energy procurements. Water and energy scarcity may compel household members to spend less time on being productive, hence reducing income-earning activities. Insufficient income may be spent on water and fuel purchases rather than on nutritious food. Data on household consumption can be collected either by questionnaire administration or interviews consisting of retrospective questions, or by the use of a household diary where records on household consumption and expenditure on a daily basis are recorded. This diary method lessens the reliance on respondent’s memory. However, data acquisition using the dairy method is particularly suitable for developed regions of the world where keeping records is part of the daily routines. In rural communities, where a substantial fraction of the population is illiterate, the diary method is likely to fail. Hence, the authors administered a questionnaire (see the Supplementary Materials), and interviews were conducted where necessary.
Figure 2. Links between household water and energy access on one side and nutrition and poor health on the other side.

2.3. Research Design

This study was undertaken in Katsina state located in north-western Nigeria. A stratified and random sampling technique was employed. The state has been stratified into urban and rural areas as adopted from the Katsina State Urban and Regional Planning Board format [49]. Three settlements were selected from each stratum representing urban and rural areas in the study area as indicated in Figure 1b.

The sample size was determined according to Isreal [50] at a 95% confidence level for each investigated community, which resulted in a total of 1785 respondents. Data on the number of households located in the case study region were not available. Therefore, household numbers in each of the targeted sampling communities were estimated by using an average of six persons per household as a standard, which has been estimated and adopted by the state Primary Health Care Development Agency in its routine immunisation programmes [51]. Furthermore, estimates informed the sampling frame, and then streets and households were selected for the administration of questionnaires (see the Supplementary Materials) across the respective communities (Table 1).

Table 1. Questionnaire distribution across the study area.
The estimated population of the state in 2019 was about 8,613,100, out of which 47% (4,048,100) and 53% (4,565,000) were located in urban and rural areas, respectively.

2.4. Data Collection

Both primary and secondary data were utilised in this evaluation. The primary data were generated through the administration of structured and pre-tested questionnaires. The English version of the questionnaire was adapted and translated into Hausa, which is the main local language. The questionnaires were administered face-to-face by 16 field assistants, who are conversant with the local language and familiar to the respective sampling communities, in addition to receiving training in questionnaire administration. Furthermore, all conversations and interviews were performed using local languages. 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 [52].

2.5. Study Variable

The variable outputs of the study were household nutritional security related to households’ water security. Food consumption patterns (of mainly protein-containing food items, vegetables, and fruits) related to various water and energy sources across the respective households. To assess the nutritional security level, each household was asked about protein-containing foods (of mainly animal protein foods, which include meat, fish, and egg consumption) as well as vegetable and fruit consumption frequencies within a month using the Household Dietary Diversity Score for measuring household food access designed by Swindale et al. [53]. Questions related to the household nutritional status had three domain responses of either rare (consumption of one or twice per month), sometimes (consumption of 3 to 10 times per month), or often (consumption of more than 10 times per month) adopting the Household Food Insecurity Access Scale response [54]. In addition to questions related to nutrition, each household was also asked about household water and energy sources for cooking.

Water sources and sanitation facilities in the respective households were also classified as improved or unimproved sources adopting the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene classification [55]. In addition, and in line with the energy ladder concept promoted by World Health Organisation [56], energy sources were also classified as non-solid (clean) and solid (unclean) sources in this research.

2.6. Data Analysis

IBM SPSS (version 24) was selected to analyse data. To identify the proportion of household consumption for various food types as well as water and energy sources, descriptive statistics (percentages) were calculated. Person product moment correlations were applied to determine possible associations among protein-rich foods as well as vegetable and fruit consumption among the urban and rural dwellers. Chi-squared tests of independence were undertaken to determine whether food consumption as well as water and energy source usages at household level are dependent on location.

3. Results

3.1. Overview of Survey Findings

A total of 1785 households participated in the study; 1187 (66.5%) and 598 (33.5) of participants lived in urban and rural areas, respectively. Figure 3 reveals that 470 (39.6%) and 2 (0.3%) households often consume protein-rich foods in the surveyed communities of urban and rural strata, respectively. A total of 539 (45.4%) and 550 (92.0%) households in the urban and rural areas, respectively, rarely consume protein-rich foods. In addition, the study revealed that 546 urban and 59 rural households rarely consume vegetables and fruits, representing 46.0% and 9.9% in the areas, respectively. Furthermore, 158 (13.3%) and 191 (31.9%) households only sometimes consume vegetables and fruits in the corresponding
urban and rural areas in this order. The results revealed that 40.7% and 58.2 of households often consume vegetables and fruits in the urban and rural households, respectively.

![Figure 3](image_url)

**Figure 3.** Consumption pattern of protein-rich foods and vegetables/fruits in the respective urban and rural households.

Results from the study revealed that high consumption of vegetables and fruits in the rural stratum (in contrary to low intake of protein-rich foods) was due to the local production of the commonly edible leafy vegetables that are mostly consumed either fresh or after storage using traditional preservation methods such as dehydration and drying. The most common leafy vegetables produced and consumed in rural areas include *Moringa oleifera*, *Leptadenia hastate*, *Cassia tora* (previously *Senna tora*), *Spinach oleracea*, and *Rumex acetosa*.

Okro (also known as ochro), tomatoes, onion, pumpkin, eggplant, and cucumber were among the non-leafy vegetables that are mostly consumed, while plum (prune) desert date (*Balanites aegyptiaca*), Shea (*Vitellaria*), doum fruit (*Hyphaene thebaica*), African fan palm (*Barassus aethiopum*), jackalberry (*Diospyros mespiliformis*), sweet detar (*detarium senegalense*), and African locust bean (*Parkia biglobosa*) were local fruits consumed in addition to mango, cashew, and guava. In urban areas, bananas, orange, pineapples, apple, pawpaw, watermelon, and grapes constitute major fruits that are consumed in addition to those in rural areas. Furthermore, in urban areas, lettuce, carrots, green bean, cabbage, and avocado constitute major vegetables on top of vegetable types that are consumed in rural areas.

The chi-squared analyses for protein food consumption ($\chi^2 = 390.046, p = 0.00$) and vegetable/fruit consumption ($\chi^2 = 249.925, p = 0.01$) of the households indicated that the accessibility and utilisation of the various food types that constitute the nutritional standard of the household dietary pattern were statistically significant. To determine the strength and direction of association between protein-rich food and vegetable/fruit consumption, the Pearson product moment correlation (PPMC) $r$ was calculated. Concerning urban stratum, the Pearson’s $r$ data analysis indicated that there is a strong association ($r = 0.988$). On the other hand, a weak association was revealed in the rural stratum ($r = 0.146$). However, the $p$-value for both was less than 0.05, indicating significance of the measure of association.
3.2. Effect of Water and Energy Scarcities on Households’ Cooking Habits

Our findings uncovered households’ water and energy scarcities as the influencing factor determining the households’ nutritional and health status. The study conceptual framework (Figure 1) demonstrates the inter-linkages between water and energy scarcities and food security. Moreover, the study indicated that scarce water and energy supplies affected the pattern and preference of food consumption across the urban and rural households. Findings from the study on the consequences of water and energy scarcities were reduced cooking sessions and eating inadequately cooked foods. Foods rich in essential nutrients but which require more water and cooking fuels such as beans and cowpeas were avoided due to water and energy scarcities.

The study further revealed that 52.3% and 54.8% of the urban households responded that water and energy scarcities, respectively, affect the pattern and preference of food intake. The study further revealed that for the rural households, 76.2% and 42.1% responded that water and energy scarcities, respectively, affect the pattern and preference of food intake.

Table 2 indicates a variety of coping strategies adopted in the events of water and energy scarcities. There is a significant \( p < 0.005 \) difference between urban and rural strata in the strategies adopted. The table revealed that in an event of water scarcity, various coping strategies were adopted to save water and cooking fuels across the affected households; 29.2% and 31.9% of the households in the urban and rural households, respectively, cooked single meals, and 34.3% and 45.2% of the surveyed households in the urban and rural households, respectively, cooked composite meals. A composite meal is made up of many different food types such as lasagne. The table further revealed that 36.5% and 22.9% prepared meals with less water requirements in the urban and rural households, respectively, to save water in the households.

Table 2. Effects of water and energy scarcities on food consumption patterns and nutrition in the urban and rural households, respectively.

| Stratum  | Reason for Meal Cooked | Proportion of Type of Meal Cooked (%) |
|----------|------------------------|--------------------------------------|
|          |                        | Single Meals | Composite Meals | Cooked Meals That Require Less Water | Cooked Meals That Require Less Energy | Total |
| Urban    | Save water             | 29.2         | 34.3            | 36.5                                  | -                                      | 52.3  |
|          | Save cooking energy    | 31.1         | 32.9            | -                                     | 36.0                                   | 54.8  |
| Rural    | Save water             | 31.9         | 45.2            | 22.9                                  | -                                      | 76.2  |
|          | Save cooking energy    | 19.4         | 52.7            | -                                     | 27.9                                   | 42.1  |

Moreover, the findings show that similar coping strategies in an event of energy scarcity were adopted. Table 2 shows that 31.1% and 31.9% in the urban and rural households, respectively, cooked a single meal, 32.9% and 57.7% prepared composite meals, and 36.0 and 27.9% cooked meals that require less energy requirement to save on cooking fuels.

The findings revealed that more than 60% of respondents preferred cooked meals that require less water and energy including roots and tuber crops (such as potatoes, cassava (also known as manioc), cocoyam (also called dasheen), and yam (various species of the genus *Dioscorea*)). Furthermore, a disparity between urban and rural households exists, whereby a high proportion of Irish potato and yam are consumed in urban households, whereas cassava, sweet potato, and cocoyam are highly consumed in the rural counterparts. In addition, the food called fura (millet ball or millet porridge) was found to be widely prepared and consumed in the rural areas; it is a culturally popular meal requiring composite cooking (prepared from cereals, mostly millet, and commonly mixed with milk). This traditional food (often characterised as a drink as well) is rich in both carbohydrates and minerals, being seen as the most common food in rural communities. It is often consumed during every mealtime of the day.
3.3. Household Feeding Habits, Nutritional Disorder, and Poor Health Conditions

Data from local health clinics in the urban and rural communities revealed the following common prevalent nutritional disorders in children, respectively: kwashiorkor (23% and 42.7%), marasmus (12% and 26%), and rickets (3.2% and 4.6%). Although there were no empirical data available, the noticeable lack of nutritious foods in routine diets could be a principal factor in the nutrition disorders identified at the local health clinics. For instance, the prevalence of kwashiorkor among children, especially in the rural households, seems to be partly due to vitamin-deficient but carbohydrate-rich food such as fura.

3.4. Households’ Water Sources Related to Protein-Rich Food as Well as Vegetable and Fruit Consumption

Access to secure, sufficient, and dependable sources of household water supply is crucial. Table 3 shows different kinds of household water sources related to protein-rich food in the respective urban and rural communities. The data indicate a variety of water sources for domestic use in the study. The chi-squared analyses for access to various household water sources related to various food consumption patterns ($\chi^2 = 417.840$) across the urban and rural surveyed households indicated that there is a significant ($p < 0.005$) difference among the urban and rural dwellers.

Table 3. Frequency of protein-rich food related to household water sources in urban and rural areas.

| Water Source                | Urban Scenario | Rural Scenario |
|-----------------------------|----------------|----------------|
| Rare                        | Sometimes      | Often          | Rare                        | Sometimes      | Often          |
| Freq. %                     | Freq. %        | Freq. %        | Freq. %                    | Freq. %        | Freq. %        |
| Piped water into dwelling   | -              | 16             | 9.0                        | 17             | 3.6            | -              | -              | -              | -              |
| Piped water to yard         | 7              | 1.2            | 4.0                        | 27             | 5.7            | -              | -              | -              | -              |
| Private borehole            | 86             | 16.0           | 43.3                       | 315            | 67.0           | 59             | 10.7           | 22             | 47.8           |
| Public tap                  | 51             | 9.5            | 6.7                        | 3              | 0.6            | 20             | 3.6            | 16             | 34.8           |
| Protected dug well          | 118            | 21.9           | 2.1                        | -              | -              | 93             | 16.9           | 3              | 6.5            |
| Unprotected dug well        | 203            | 37.7           | 77                         | 43.3           | 86             | 18.3           | 167            | 30.4           | 3              |
| Water vendor                | 7              | 4.3            | 19.1                       | 8              | 1.7            | 144            | 26.2           | -              | -              |
| Surface water               | 539            | 100            | 178                        | 100            | 470            | 550            | 100            | 46             | 100            |

The study revealed that privately or publicly owned boreholes are found across the scenarios in the respective urban and rural strata. In urban strata, the overall use of boreholes witnessed an upward trend across the three scenarios, whereas the utilisation level of water vendor use as a source of household water supply fluctuated. An initial increase was followed by a rapid decrease across the scenarios. There was a drastic rise of urban household-owned private boreholes from 14.0% to 67.0% for households that occasionally and often consume protein-rich foods. Piped water to the yard had the lowest proportion (0.6%) of utilisation in the urban strata. Meanwhile, for the rural stratum, the utilisation level of public boreholes at various households increased significantly across the scenarios.

Table 4 shows the utilisation levels of different sources of household water supply in relation to vegetable and fruit consumption in the respective urban and rural areas.

Sources of domestic water supply related to vegetable and fruit consumption in urban areas follow the same pattern compared to those related to protein-rich food intake in the same area, whereas a disparity exists in rural areas. Water vendors and tanker trucks are major sources of water supply across the three scenarios in rural areas. Unlike the common scenario of protein-rich food consumption, where boreholes as improved sources of water supply are utilised, a variety of water sources are used by households that often consume vegetables and fruits. The lowest utilisation level of private boreholes was 0.3%, whereas
the level was 18.7% for public boreholes. An unprotected dug well was found to be at the highest level of utilisation for the often scenario at 19.8% of the rural stratum. High proportions (67.0% and 65.0%) of private boreholes (an improved water source) was found for the often scenario for protein-rich food as well as vegetable and fruit consumption, respectively, in the urban areas. In rural areas, the study revealed a similar trend in the respective rural areas, where the highest (100%) proportion of boreholes (50% of private borehole and 50% of public borehole usage) was found within the often scenario of protein-rich food intake.

### Table 4. Frequency of the intake of vegetables and fruits related to household water sources in urban and rural areas.

| Water Source                | Urban Scenario |                  | Rural Scenario |                  |
|-----------------------------|----------------|------------------|----------------|------------------|
|                             | Rare           | Sometimes       | Often          | Rare            | Sometimes       | Often          |
|                             | Freq. %        | Freq. %         | Freq. %        | Freq. %         | Freq. %         | Freq. %        |
| Piped water into dwelling   | -              | 1               | 0.6            | 32              | 6.6             | -              |
| Piped water to yard         | -              | 1               | 0.6            | 27              | 5.6             | -              |
| Public tap                  | 7              | 1.2             | 4              | 2.5             | -               | -              |
| Private borehole            | -              | 26              | 16.5           | 314             | 65.0            | -              |
| Public borehole             | 86             | 15.8            | 8              | 5.1             | 13              | 2.7            |
| Protected dug well          | 51             | 9.3             | 12             | 7.6             | -               | -              |
| Unprotected dug well        | 118            | 21.6            | 2              | 1.3             | 3               | 0.6            |
| Water vendor                | 210            | 38.5            | 70             | 44.3            | 86              | 17.8           |
| Surface water               | -              | -               | -              | -               | -               | -              |
| Tanker truck                | 74             | 13.6            | 34             | 21.5            | 8               | 1.7            |
| Total                       | 546            | 100             | 158            | 100             | 483             | 100            |

Furthermore, higher proportions of unimproved sources, including 37.7% and 38.5% of water vendors (usually equipped with a cart and small drum), and 21.9% and 21.6% of unprotected dug wells, were found for the rare scenario of protein-rich food and vegetable/fruit consumption, respectively, in urban areas. In rural communities, the study revealed similar trends of higher proportions of unimproved water source usage among various households that rarely consume protein-rich foods, vegetables, and fruits. Water vendors (30.4% and 50.8%), tanker trucks (26.2% and 27.1%), and unprotected dug wells (13.6% and 16.9%) were utilised as sources of household water supply for protein-rich food as well as vegetable and fruit consumptions, respectively.

### 3.5. Household Sanitation Facilities Related to Protein-Rich Food as Well as Vegetable and Fruit Consumption

Tables 5 and 6 demonstrate utilisation levels of various sanitation facilities in relation to protein-rich food and vegetable/fruit consumption, respectively, in the urban and rural areas. Sanitation facilities related to protein-rich food intake in urban areas follow similar patterns to those related to vegetable and fruit consumption in the same area, whereas a disparity exists in rural areas. Overall household sanitation facility use related to protein-rich food intake the study shows that there is a significant ($p < 0.005$) difference between urban and rural strata. Similarly, related to vegetable and fruit consumption, a significant difference in sanitation facilities between urban and rural households exists ($p < 0.005$).

The chi-squared analyses for access to various sanitation facilities related to various food consumption patterns ($\chi^2 = 594.259$) across the urban and rural surveyed households indicated that there is a significant ($p < 0.005$) difference among the urban and rural dwellers. Improved sanitation facilities including septic tanks and pit latrines with slabs were found across the three scenarios of protein-rich foods, vegetable consumption, and fruit consumption. However, pit latrines without slabs, which are categorised as an unimproved sanitation facility, were also found across the three scenarios in the urban communities. Table 6 shows a progressive increase of septic tanks from 0.9% for the rare...
scenario to 32.9% for the sometimes scenario and subsequently to 92.1% for the often scenario with respect to both vegetable and fruit consumption. In the case of protein-rich food intake, Table 5 illustrates a progressive increase of septic tank utilisation from 38.2% for the sometimes scenario to 92.3% for the often scenario, while for the rare scenario, no septic tank was found.

Table 5. Frequency of protein-rich food related to household sanitation facilities in urban and rural areas.

| Sanitation Facilities      | Urban Scenario |                     | Rural Scenario |                     |
|----------------------------|----------------|---------------------|----------------|---------------------|
|                            | Rare           | Sometimes           | Often          | Rare               | Sometimes          | Often          |
|                            | Freq. | %    | Freq. | %    | Freq. | %    | Freq. | %    | Freq. | %    | Freq. | %    |
| Septic tank                | -     | -    | 68   | 38.2 | 434   | 92.3 | -     | -    | -     | -    | 1     | 50.0 |
| Pit latrine with slab      | 319   | 59.1 | 90   | 50.6 | 24    | 5.1  | 89    | 16.2 | 46    | 100  | 1     | 50.0 |
| Pit latrine without slab   | 219   | 40.6 | 20   | 11.2 | 12    | 2.6  | 440   | 80.0 | -     | -    | -     | -    |
| No facility (open defecation) | 1     | 0.2  | -    | -    | -     | -    | 21    | 3.8  | -     | -    | -     | -    |
| Totals                     | 539   | 100  | 178  | 100  | 470   | 100  | 550   | 100  | 46    | 100  | 2     | 100  |

Table 6. Frequency of intake of vegetables and fruits related to household sanitation facilities in urban and rural areas.

| Water Source               | Urban Scenario |                     | Rural Scenario |                     |
|----------------------------|----------------|---------------------|----------------|---------------------|
|                            | Rare           | Sometimes           | Often          | Rare               | Sometimes          | Often          |
|                            | Freq. | %    | Freq. | %    | Freq. | %    | Freq. | %    | Freq. | %    | Freq. | %    |
| Septic tank                | 5     | 0.9  | 52   | 32.9 | 445   | 92.1 | -     | -    | -     | -    | 1     | 0.3  |
| Pit latrine with slab      | 320   | 58.6 | 87   | 55.1 | 26    | 5.4  | 7     | 11.9 | 23    | 12.0 | 106   | 30.5 |
| Pit latrine without slab   | 220   | 40.3 | 19   | 12.0 | 12    | 2.5  | 45    | 76.2 | 158   | 82.7 | 237   | 68.1 |
| No facility (open defecation) | 1     | 0.2  | -    | -    | -     | -    | 7     | 11.9 | 10    | 5.2  | 4     | 1.1  |
| Totals                     | 546   | 100  | 158  | 100  | 483   | 100  | 59    | 100  | 191   | 100  | 158   | 100  |

Table 5 shows a drastic decrease in utilisation pattern of pit latrines with and without slabs related to protein-rich food and vegetable/fruit consumptions across the three scenarios. A decrease of pit latrines with slabs and without slabs from 59.1% and 40.6% for the rare scenario to 5.1% and 2.6%, respectively, for the often scenario concerning protein-rich food consumption in urban areas was observed. Additionally, the respective decreases of pit latrines with and without slabs follow similar patterns in relation to vegetable and fruit consumptions. For the rare scenario, 58.8% and 40.3% of pit latrines with slabs and without slabs, respectively, were found. Regarding the often scenario, 5.4% and 2.5% of pit latrines with and without slabs, respectively, were recorded. These show a significant drop across the three scenarios in urban communities.

In rural communities, the utilisation of sanitation facilities related to protein-rich food intake follows different patterns to those related to vegetable/fruit consumption. Pit latrines with slabs (an improved facility) were found across the three scenarios of protein-rich food consumption. In relation to vegetable/fruit consumption, various types of sanitation facilities, which include pit latrine with slab, open defecation (no facility), and pit latrine without slab, have the highest level of utilisation across the three scenarios. In contrast, septic tanks were only found for the often scenario. In relation to protein consumption, different utilisation levels of sanitation facilities were found. There was a significant increase of pit latrines with slabs from 16.2% for the rare scenario to 100% for the sometimes scenario, while for the often scenario, the utilisation level of pit latrines with slabs dropped to 50%. In addition, 50% of septic tank utilisation was witnessed for the rare scenario of protein-rich food consumption. The highest proportion of unimproved sanitation household-level facilities was found for the rare scenario: 3.8% without sanitation facility (open defecation) and 40.6% of pit latrines without slabs.
3.6. Household Energy Sources Related to Protein-Rich Food as Well as Vegetable and Fruit Consumption

The chi-squared analyses for access to various household cooking fuels related to different food consumption patterns ($\chi^2 = 555.592$) across the urban and rural surveyed households indicated that there is a significant ($p < 0.005$) difference among the urban and rural dwellers. Tables 7 and 8 indicate a great variety of household energy utilisation across the three scenarios in the respective urban and rural strata. Overall, the utilisation of fuelwood witnessed a downward trend across the scenarios in urban stratum, whereas the utilisation level of cooking gas witnessed an upward trend from households that sometimes consume vegetables and fruits as well as protein-rich foods compared to the often scenarios. In relation to vegetable/fruit consumption, fuel wood utilisation was found to be 91.9%, 62.0%, and 15.9% for the rare, sometimes, and often scenarios, respectively. Similar trends were also found related to protein-rich food intake, where 92.0%, 65.2%, and 13.8% were recorded for the rare, sometimes, and often scenarios. In terms of cooking gas utilisation across the three scenarios, the highest level of utilisation (82.6%) was recorded for the often scenario, followed by 29.2% for the sometimes scenario. The findings also revealed that the majority of households in the rural stratum used fuel wood as a household energy source for cooking across the three scenarios of protein-rich food consumption; the highest level of utilisation (67.8%) was found for both the rare and often scenarios, and 65.4% was recorded for the sometimes scenario. Electricity and kerosene were utilised only in urban areas. Only 3.2% and 3.1% of households used electricity as a source of household energy for cooking concerning the often scenario in the urban stratum for protein-rich food and vegetable/fruit intakes, respectively. In addition, 0.6% and 0.4% of households that occasionally and often consume protein-rich food utilised kerosene as a source of cooking energy, respectively. Furthermore, dung was only utilised in rural areas, with the highest level of utilisation (11.9%) for the rare scenario, followed by 3.6% for the sometimes scenario concerning vegetable/fruit intake. Only 2.4% of dung utilisation was recorded for the rare scenario regarding protein-rich food consumption in rural areas.

Table 7. Frequency of protein-rich food intake related to urban and rural energy sources.

| Energy Source | Urban Scenario | Rural Scenario |
|---------------|----------------|----------------|
|               | Rare | Sometimes | Often | Rare | Sometimes | Often |
| Electricity   | -    | -         | 15    | 3.2  | -         | -     |
| Gas           | -    | -         | 52    | 29.2 | -         | -     |
| Kerosene      | -    | -         | 1     | 0.6  | -         | -     |
| Charcoal      | 25   | 4.6       | 8     | 4.5  | -         | -     |
| Sawdust       | 3    | 0.6       | 1     | 0.6  | -         | -     |
| Fuel wood     | 496  | 92.0      | 116   | 65.1 | 65        | 13.8  |
| Agricultural residue | 15 | 2.8 | - | - | - | - |
| Dung          | -    | -         | -     | -    | 165       | 30.0  |
| Total         | 539  | 100       | 178   | 100  | 470       | 100   |

Table 7 shows a slight decrease in charcoal utilisation across the scenarios in the urban stratum, whereas an upward trend of charcoal use was recorded in the rural stratum across the scenarios for protein-rich food consumption. Results within each stratum showed 4.6% and 1.6% for rare cases as well as 4.5% and 4.3% for the sometimes scenario in the urban and rural strata, respectively. Table 8 shows similar patterns among various households in relation to protein-rich food consumption and vegetable/fruit intake in the urban stratum, whereas a disparity exists among various households located in the rural stratum. Only 3.2% of charcoal utilisation was found for the often scenario consumption in rural areas.
Table 8. Intake of vegetables and fruits related to urban and rural energy sources.

| Energy Source   | Urban Scenario | Rural Scenario |
|-----------------|---------------|---------------|
|                 | Rare          | Sometimes     | Often         | Rare           | Sometimes     | Often         |
|                 | Freq. | % | Freq. | % | Freq. | % | Freq. | % | Freq. | % | Freq. | % | Freq. | % |
| Electricity     | -     | - | -     | - | 15   | 3.1 | -     | - | -     | - | -     | - | -     | - |
| Gas             | -     | - | 51    | 32.3 | 389  | 80.5 | -     | - | -     | - | -     | - | -     | - |
| Kerosene        | -     | 1 | 0.6   | 2 | 0.4  | - | -     | - | -     | - | -     | - | -     | - |
| Charcoal        | 26    | 4.8 | 7    | 4.4 | - | - | - | - | - | - | - | - | - | - |
| Sawdust         | 3     | 0.5 | 7    | 0.6 | - | - | - | - | 11 | 3.2 | - | - | - | - |
| Agricultural residue | 502  | 91.9 | 98   | 62.0 | 77  | 16.0 | 40 | 67.8 | 125 | 65.4 | 236 | 67.8 | - | - |
| Dung            | 15    | 2.7 | - | - | - | - | - | - | 77 | 11.9 | 12 | 20.3 | 6 | 31.4 |
| Total           | 456   | 100 | 158  | 100 | 483  | 100 | 59  | 100 | 191 | 100 | 158 | 100 |

A significant downward trend of dung use was witnessed for the rural stratum across the rare and sometimes scenarios for vegetable/fruit consumption. For the rare case, 11.9% was recorded, while 3.1% was found for the sometimes scenario. In addition, only 2.4% of dung utilisation was recorded for the rare scenario concerning protein-rich food intake.

The findings revealed an energy switch from fuelwood to either agricultural residue or dung in the study area as a result of reduced access to forest resources. This is the case as most forests in the study area are serving as camping sites for insurgent groups that kidnap people and lunch attacks on the local population.

In contrast to dung, only 0.5% and 0.6% of sawdust use was noted for the rare and sometimes scenarios, respectively, in the urban areas. The study shows that the overwhelming majority of households that rarely consume protein-rich foods utilise solid (unclean) cooking energy sources.

4. Discussion

Good nutrition is an essential component of a healthy and productive life [57,58]. Nahla et al. [57,59] proposed that with regard to availability, accessibility, utilisation, and stability of food, nutrition should also form an integral part of all pillars of food security. Various food types that are associated with rich protein content are associated with eminent beneficial effects. In addition to molecule transport, protein helps in building and repair of cells.

Jager et al. [60] indicated that for building and maintaining mass muscles, an overall daily protein intake of between 1.4 and 2.0 g/kg body weight is required. Additionally, vegetables and fruits are regarded as a best source of fibre, minerals, and nutrients. Fibre intake is linked to lower incidences of cardiovascular diseases and obesity. Minerals and vitamins supplied from vegetables and fruits to diets are sources of phytochemicals that serve as antioxidants and anti-inflammatory agents [60,61]. In addition, Noorwali et al. [62] attributed a substantial weight of global disease and mortality to a low intake of vegetables and fruits. Moreover, Micha [63] identified dietary intake as a major factor associated with mortality from various cardiovascular-related diseases. In order to achieve food security at a household level, the quality of food consumed has to be considered. This is determined by the nutritional value of the food, in addition to the physical availability of food items.

The type of cooking in relation to the corresponding nutrient release and the overall appeal of the food can never be over-emphasised [64,65]. From work conducted in the camps for internally displaced people, it was eminent that while cooking diminishes disease prevalence, improves nutrition, and enhances food taste, the fuel necessary for cooking the hard-to-cook food (usually maize and beans) is not easily within reach, and the task of obtaining fuel for cooking is placed on women and children [66]. Thus, the choice of women to under-cook meals to save water and cooking fuels leads to an increase in the threat of food-borne illnesses. Therefore, the increasing scarcity of water and cooking fuels...
are likely to lead to families consuming less nutritious or even under-cooked meals. These findings are coincided by those of Sola et al. [67,68], who noted that diminishing availability of cooking fuel affects nutrition security.

In line with the Household Food Insecurity Access Scale response based on the three scenarios of food consumption [54], there were 39.4% and 0.3% of households that were nutrition-secure in urban and rural areas, respectively. In comparison, more households were severely nutrition-insecure: 45.4% of the urban and 9.9% of the rural households. Significant differences between urban and rural communities related to their nutritional status were found. The findings support several studies [69–72], which found great disparity in the nutritional status between urban and rural residences in various low- and medium-income countries. Consumption patterns in urban households were characterised by a high frequency of availability concerning dairy products and meat intake, which is contrary to rural households. In addition, Walbel and Hohfeld [73–76] found that undernutrition continues to be a challenge in rural areas. They found that various socio-economic factors such as income, educational status, employment, location, and food prices are the main factors influencing undernutrition.

On the basis of the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation classification of water sources [55], the study showed a significant association between the food consumption pattern and various water sources across the strata. High proportions of improved sources were found at the often scenario for protein-rich food and vegetable/fruit consumption, respectively. The findings revealed strong relationships between nutrition and access to safe and sufficient water in the study area, which coincides with similar findings by Li et al. [77]. Their study indicated that improved water sources decreased child malnutrition. Furthermore, Mabhaudhi et al. [78] attributed inadequate poor nutrition to water scarcity in poor sub-Saharan rural communities. Additionally, Mbwana et al. [79] attributed distance to a household water source among the significant determinants of nutrition status in the Dodoma rural community of Tanzania.

Gao et al. [80] investigated the links among household water, dietary diversity, and nutrition status in poor rural households of central and western China. They found that access to unimproved water sources was connected to lower likelihood of achieving dietary diversity. In addition, water inaccessibility shapes nutritional intake well beyond the cleanliness of the corresponding physical environment via many other non-production pathways, which include preparation of food techniques and dietary diversity [81]. The majority of households that access groundwater through private boreholes are high-income earners living in urban areas. The capacity to drill private boreholes for household water supply is within the financial reach of such individuals [82]. The findings reveal that the majority of public boreholes are constructed by the state government, especially in rural communities. This could be attributed to the fact that most rural areas in the state are not linked up with piped water. Generally, the study revealed a high utilisation of various sources of groundwater, which is comparable to findings in other low-income regions of South-East Asia, where groundwater sources play a critical role as sources for drinking water [83].

This study compares well with findings by Waibel and Hohfeld [73], who found that poor sanitation practices among other factors are linked to under-nutrition in various rural households of Vietnam. Furthermore, the study was in line with the work of Spears and Haddad [84]. Their findings reveal strong relationships between nutrition and sanitation. They found that the overwhelming majority of stunted children (reduced in their growth development) in India were found in various households with no sanitation facilities (open defecation). Furthermore, Mahmud and Mbuya [85] linked poor sanitation to diarrhoea, which consequently leads to undernutrition and compromises child growth. Their nutritional status has a significant relationship with water, sanitation, and hygiene (also known as WASH) practices. Chattopadhyay et al. [86] revealed that open defecation and non-use of sanitary napkins (menstrual pads) were among the key predictors of stunting among the adolescence girls in eastern India. Therefore, proper sanitation and hygiene
can support good nutrition and reduce stunting in children and teenagers. Additionally, Zavala et al. [87] and Momberg [88] associated the nutritional status including stunting with access to water and sanitation facilities.

The strong link between food security and energy has been established by FAO [89]. The inaccessibility to enough and suitable energy sources for cooking may compel people to change their cooking and eating practices by shifting to foods that demand less energy and cooking time or by reducing the number of meals. In addition, a direct linkage between household cooking energy and food security is shown by Makungwa et al. [90]. They suggested that food security cannot be achieved without due consideration of availability and accessibility of cooking energy of vulnerable households. A high proportion of charcoal utilisation in the urban stratum coincides with studies conducted by Ajoa [91]. In comparison, Win et al. [92] revealed a higher level of charcoal utilisation in various developing countries for urban compared to rural areas.

This suggests that nutrition security cannot be achieved without access to clean energy sources [93]. Consequently, Amare et al. [94] found a link between unsuitable household cooking energy sources and malnutrition among children. They discovered that children in households with conventional (solid) cooking fuel types were more likely to be stunted compared to those with non-solid (cleaner) types. Furthermore, ensuring a provision of clean energy source is a prerequisite for reducing food insecurity for the overwhelming majority of the sub-Saharan African population [67].

5. Conclusions

The interrelationships between household food consumption patterns as well as water and energy security among urban and rural households were assessed. The proposed generic framework was successfully tested in Katsina state, northern Nigeria. The study revealed that scarcities of water and cooking energy resulted in changes in cooking habits, whereby households decided to cook composite meals contrary to single meals. Households also reduced their cooking sessions from the usual three meals per day to two, or sometimes only one meal per day. Foods with shorter cooking times were favoured to those that took longer to cook. This was due to firewood scarcity. This compromised the nutritional status of especially children.

The study further revealed that there is a clear dichotomy between urban and rural households on food consumption patterns as well as sanitation facilities and sources of water and energy. Protein-rich food consumption patterns were the strong determinants on the various sources of water and energy use. A high consumption of protein-rich foods was highly associated with the utilisation of improved water and clean energy sources in urban households. Similarly, a low consumption frequency of protein-rich foods in rural areas was strongly associated with a high utilisation level of unimproved sources of water and sanitation facilities and unclean (solid) energy. The findings show that those households that often consume protein-rich foods are associated with 66.7% of private boreholes, 92.3% of septic tanks as sanitation facilities, and 82.6% use of liquefied petroleum gas as a source of cooking energy with respect to urban households. In comparison, for rural communities, the findings show 30.4% of water vendor use, 80.0% of pit latrines without slabs, and 66.0% of fuel wood utilisation for households that rarely consume protein-rich foods. Overall, the questionnaire produced results that validated the study conceptual framework, revealing the effects of water and energy scarcities on food and nutritional security. This led to both poor nutrition and health.

6. Limitations and Future Research

The community census data including household numbers have not been published previously, but are available from the Katsina state office of the National Population Commission. Furthermore, household numbers in the communities were also estimated on the basis of data from the World Health Organisation for the study area. Consequently, the projections in our paper are limited by available support data.
A vast majority of the rural inhabitants in Katsina state are facing the ever-increasing threat of banditry, a type of organised crime that includes murder, rape, kidnapping, and cattle rustling. Therefore, these circumstances have limited access to more households as the security of our survey team could not be guaranteed.

Data collected on the households’ food security were only related to the nutritional status of mainly protein, vegetable, and fruit consumption and their associations with various households’ water–energy source utilisation level. Other elements of food security, which include availability, accessibility, and stability, could also have been more incorporated in the study. Therefore, future studies should take into account other elements of food security. Moreover, the research should be extended and continued to other low- and middle-income developing countries to evaluate the progress towards achieving sustainable food–energy–water security.

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