Food-energy-water security in sub-Saharan Africa: Quantitative and spatial assessments using an indicator-based approach

Abstract

The challenge of achieving food, energy and water (FEW) security is greatest in sub-Saharan Africa (SSA) where millions of people lack access to electricity, reliable drinking water and one in four people are undernourished. To develop targeted policies, it is necessary to identify at-risk countries and the spatial patterns of FEW insecurity in the region. However, country and sub-regional level assessments of FEW security have received scant attention. In this study, we carried out quantitative and spatial assessments of FEW security in SSA using the Pardee Rand FEW Index. Results show that 41 countries in SSA are FEW insecure, with Burundi being the most affected country while the West African sub-region seems to have many FEW insecure countries. Spatial analysis of FEW security reveals the presence of spatial patterns in the distribution of FEW insecurity in SSA suggesting that a sub-regional approach may be used to tackle this challenge. However, literature review shows that this has to be approached with caution given that different contextual factors such as socio-economic and governance conditions may influence FEW security within countries. Our analyses imply that any policy response designed to enhance FEW security needs to address both socio-economic, governance and other contextual factors within countries.

Keywords: food security, energy security; water security; FEW security nexus; quantitative and spatial analysis; sustainable development goals

1. Introduction

Achieving global food, energy and water (FEW) security in a changing climate is one of the greatest challenges facing humanity in the 21st century (Gain et al., 2016). Around the world, over 821 million people are undernourished and 151 million children are stunted (WHO, 2018). Between 2015 and 2018, approximately 1.3 billion people lacked access to electricity while 3 billion were unable to secure clean fuel for cooking (Alstone et al., 2015; Ritchie and Roser, 2018). Hundreds of millions of people continue to face severe water insecurity around the world (Gain et al., 2016). In sub-Saharan Africa (SSA) over 319 million people lack access to reliable drinking water , with about 695 million people lacking access to improved sanitation facilities (Kanyerere et al., 2018). Although SSA is endowed with sufficient energy resources capable of meeting domestic demand, access to modern energy services including electricity has remained limited, with over 620 million people lacking access to electricity while about 730 million rely on traditional biomass for cooking (Ouedraogo, 2017).

Amidst existing challenges, new initiatives such as the Food-Energy-Water security nexus are being developed and/or operationalized globally to contribute efforts towards achieving nexus resource security which is crucial for sustainable development (Howells et al., 2013). The Sustainable Development Goals (SDGs) are used as a road map or guiding framework to attain this objective (le Blanc 2015). The SDGs, launched in 2015, target important issues that are central to FEW security nexus. These are: “zero hunger” (SDG 2); “clean water and sanitation” (SDG 6); and “affordable and clean energy” (SDG 7). Addressing food, energy and water security using the nexus approach is necessary due to increased stress on these resources as a result of rapid population growth, changing consumption patterns, economic growth, competition for land resources and climate change (Abulibdeh and Zaidan, 2020). However, efforts to achieve SDGs 2, 6 and 7 are increasingly undermined by limited understanding of the current state of FEW security particularly access and availability, as well as limited knowledge of how countries threatened by FEW shortages can develop contextually-appropriate and nationally-owned FEW-related policies and interventions. Despite the importance of FEW assessments in advancing knowledge on FEW security issues, no study (to our knowledge) has sought to investigate the regional and spatial dimensions of FEW security in SSA.

This paper fills an important gap in the FEW security literature by quantitatively and spatially analysing the state of FEW security across SSA in ways that clearly reveal how access and availability of FEW resources vary across countries using an indicator-based approach. The study addresses three objectives, which are to: 1) identify countries and sub-regions in SSA that are at low and high risk of FEW insecurity; 2) assess the spatial patterns in FEW insecurity; and (3) provide an overview of the local drivers of FEW insecurity as well as important needs-based approaches for spurring achievement of FEW security. In achieving these objectives, this paper provides new insights on the extent of FEW insecurity across countries and sub-regions in SSA and reveals sub-regions where commonalities and differences exist in terms of FEW shortages. Quantitative and spatial assessments of FEW security is important because FEW are increasingly interlinked on spatial scales by resource constraints, environmental constraints, technology, markets and speculation, trade, demand and supply, trends in agricultural commodity and energy prices (Ringler et al., 2013). Quantitative and spatial assessments are equally important for taking decisions relating to the transfer of nexus resources from areas of abundance to areas facing scarcity (Cansino-Loeza et al., 2020). Findings from the study have implications for FEW-related cross-sectoral policy development and implementation in SSA. The study is in line with recent calls for quantitative and spatial assessments of FEW security at national and regional scales (Hameed et al., 2019; Mohammadpour et al., 2019) and provides evidence on the ways in which researchers can enhance FEW security analysis beyond SSA.

2. Understanding food – energy – water (FEW) security

The concept of FEW security encapsulates concerns for food security, energy security and water security. Food security is when all people, always have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. Energy security is access to reliable and affordable energy for cooking, heating, lighting, communications and productive uses. Water security relates to the availability of, and access to sufficient and good quality water for human and ecosystem use. Although the FEW security concept has gained considerable attention in recent times, a universally acceptable framing of the concept is lacking (Zhang and Vesselinov, 2017). The interdisciplinary dimension of the FEW concept itself, as well as the challenges and opportunities that a linked-FEW security presents, may be the reason for this. In this study, we conceptualise FEW security as the availability of and access to: sufficient, safe and nutritious food to meet the dietary needs and food preferences for an active and healthy life; clean, reliable and affordable energy; and safe drinking water and sanitation.

Conceptualising FEW security this way offers a lens with which to understand the interdependencies between food, energy and water (Markantonis et al., 2019). To explain the interdependencies in a simple form: food can be used to produce energy, energy is needed to produce food, water is needed to grow food, while food transports (virtual) water, often using energy; water is often needed to generate energy, energy is needed to supply water, particularly to areas far away from the water source. Changes to any one of food, energy or water can affect the remaining two across a range of scales (Hoffmann et al., 2017). Previous empirical studies have used this interlinked FEW idea to reveal how interventions, such as river basin management and climate adaptation in the water sector, cross-cut energy, water and food policy issues, including advancing the utility of FEW as a tool for addressing wider socio-ecological and economic concerns (Keskinen et al., 2015; Momblanch et al., 2019). Using the FEW concept to inform analysis of trade-offs in decision-making on programs involving different sectors and stakeholders can spur resource use efficiency while at the same time helping to adapt policies and institutional arrangements to sustainable development ideals (Markantonis et al., 2019).

FEW security is context-specific, and as such previous researchers (e.g. Mohammdpour et al., 2019; Abulibdeh and Zaidan, 2020) have viewed it in terms of its spatial scale (local, national, regional or global); and other researchers (e.g. Momblanch et al., 2019;) in terms of its temporal scale (past and present conditions vs likely future conditions). Similarly, methodological differences (qualitative and quantitative) and data availability define how FEW security is approached/studied (Wichelns, 2017; Mohammadpour et al., 2019), including how specific in-country FEW-related problems and policy issues are assessed (Bieber et al., 2018).

Knowledge of FEW interlinkages is growing timidly amongst policy makers and development actors in SSA, and an increasing number of case studies demonstrate how this knowledge is used to address a wide range of regional FEW-related concerns (Bieber et al., 2018; Yang et al., 2018; Allam and Eltahir, 2019; Sahle et al., 2019). For example, Yang et al. (2018) used ‘knowledge of FEW interlinkages’ to assess the impact of climate and anthropogenic changes on the water, energy, food and ecosystems services in the Niger River Basin, revealing that accounting for FEW security goals in dam development can help to mitigate the negative impacts of climate change on water, energy and food resources across the basin. Sahle et al. (2019) applied the FEW security concept in the Omo-Gibe River Basin in Ethiopia and revealed that enhanced water management was key to achieving FEW security. The FEW idea has equally been used to demonstrate the vulnerability of energy infrastructure in Ghana, highlighting a need to diversify the energy sector, optimize investment in energy and water infrastructure, and strengthen agricultural intensification to achieve FEW security (Bieber et al., 2018). It has also been applied to show how win-win FEW outcomes may reinforce cooperation between riparian countries in transboundary basin management in the Blue Nile (Allam and Eltahir, 2019). Other studies have identified food, energy and water security as crucial to achieving sustainable development goals in the region (e.g. Gill et al., 2019). Although case study research focusing on FEW security is growing, little has been done to date to identify and spatially map countries and sub-regions in SSA that are at risk of FEW insecurity, including to understand why FEW insecurity persists and how to address the issue.

3. Methods

3.1. Brief information on sub-Saharan Africa

This study covers the entire sub-Saharan Africa and countries are grouped into different sub-regions following the approach used by the African Development Bank (AfDB). These sub-regions include: i) Economic and Monetary Community of Central Africa (CEMAC), ii) Economic Community of West African States (ECOWAS), iii) East Africa Community (EAC) and iv) Southern African Development Community (SADC). In total, the different sub-regions consist of 48 countries (Somalia is not included in this study due to data limitations). A full list of countries that make up each sub-region is available in Appendix A.

Figure 1: Map of SSA showing countries and different sub-regions. Notes on country codes are available in Appendix A.

In grouping these countries into different economic sub-regions, we have no intention to violate or reintroduce any geopolitical boundaries or suggest countries should join any sub-regional block. However, the existing sub-regional blocks have helped to harmonize investment incentives, standards, technical regulations, as well as policies relating to transportation, infrastructure and as such has enhanced intra-Africa trade (Kagochi and Durmaz, 2018). The basic demographic and economic indicators of the different economic sub-regions are shown in Table 1.

Rainfall in SSA is highly variable both spatially and temporally, and mostly controlled by the latitudinal migration of the intertropical convergence zone (Nkiaka et al., 2017a). As agriculture in SSA is predominantly rain-fed, rainfall constitutes a critical factor for (and accounts for) about 95% of overall crop production (Calzadilla et al., 2013; Serdeczny et al., 2017). Water resources are equally very variable both in space and time as a result of rainfall variability. Hydropower is the main source of electricity in SSA supplying more than 50% of total electricity consumption in the region (Conway et al., 2017). Rainfall, therefore, plays a critical role in food, energy and water security in SSA.

>>>>>>>>>>>>>>>>>>>>>>>>>**Insert Table 1 here**>>>>>>>>>>>>>>>>>>

3.2. The Pardee Rand Water-Energy-Food Index

This study utilised indicator scores collated from the Pardee Rand Food – Energy – Water (PR-FEW) Index database to assess the state of FEW insecurity in SSA. The PR-FEW Index is a quantitative model of FEW scores developed by the Rand Corporation (Willis et al., 2016). The database covers country scores of food, energy and water resources, depicting the FEW status and providing a benchmark for a composite computation of FEW index per country. Two sub-indicators are used as proxy to describe FEW security: availability and accessibility. Availability is the extent to which a population has adequate FEW resources to meet its needs, while accessibility describes the distribution of FEW resources across a given population.

Under the food sub-index, ‘availability’ measures if food supply in a country is sufficient to meet basic nutritional requirements while ‘accessibility’ demonstrates the extent to which a given population has access to diverse diets that meet its nutritional needs. Energy availability measures if a country's electricity infrastructure meets the energy needs of individuals and accessibility is used to measure if individuals have access to modern forms of energy for residential uses such as electricity, heating and cooking. Water availability is the amount of water that is used relative to amount needed to support basic domestic activities (cooking, eating and sanitation) and accessibility is described as access to improved drinking water and sanitation (Willis et al., 2016). These sub-indices (across each FEW resource) are integrated using an unweighted, geometric mean as shown in equation 1.

$$\text{FEW Index} = \sqrt[3]{(\text{Food sub index})\text{X}(\text{Energy sub index})\text{X}(\text{Water sub index})} \qquad (1)$$

To ensure that the PR-FEW Index is not influenced by any sub-index scale, all indicators are normalised and scaled from 0 to 1, where 1 is the most favourable score (suggesting conditions of FEW security) and 0 is the least favourable. Details on the development and calculation of the PR-FEW Index and sub-indices are available in Willis et al. (2016) and Abbott et al. (2017). The PR-FEW Index and sub-indices scores for all countries in SSA were obtained from the Pardee Rand online database[1]. The PR-FEW Index has been used in many studies (Abbott et al., 2017; Hameed et al., 2019; Abulibdeh and Zaidan, 2020). We chose the Pardee Rand FEW Index database and scores because: (1) they were recently published (i.e. within the last 5 years), (2) they capture data on food, energy and water availability and accessibility (3) they cover all countries in our study region (except Somalia) and (4) the index tool is easily accessible and has remained active (accessed last in September 2020).

The data extracted from the Pardee Rand online database was imported into a data processing tool to plot graphs that provide a visualisation of FEW variations across countries and sub-regions. To demonstrate how FEW varies spatially, FEW index scores were exported into ArcGIS 10.4.

[1]See https://www.prgs.edu/pardee-initiative/food-energy-water.html. A detailed overview of the methodology and indicators is available in the PR technical documentation: https://www.rand.org/pubs/tools/TL165.html. The FEW Index interactive tool is available here: https://www.prgs.edu/pardee-initiative/food-energy-water/interactive-index.html

Previous studies have adopted a similar approach to depict the spatial distribution of FEW resources (e.g. Mohammadpour et al., 2019). We also conducted a desk review of existing FEW studies in SSA to identify factors/local drivers reinforcing FEW insecurity and approaches to address them. We consider countries with a PR-FEW index and sub-index score of 0.50 or above as those on a path to achieving FEW security while those with a score below 0.50 are considered as FEW insecure (i.e. lagging behind).

3.3. Study limitations

The PR-FEW Index offers many advantages (e.g. provision of data on FEW availability), yet it has been criticised for not capturing impacts of socio-ecological shocks/stresses, and for ignoring potential future changes in availability and accessibility of FEW resources (Venghaus and Dieken, 2019). Since the publication of the PR-FEW Index in 2016, many countries in SSA have made progress on FEW security for their citizens. For example, more than 1000 MW of electricity from hydropower have been commissioned in SSA since 2016 (IHA, 2019) and other renewable energy projects (wind and solar) have equally been operationalised. Since 2017, food insecurity has been reversed (to some extent) in some countries, such as South Africa (Mabhaudhi et al., 2019), due to changes in FEW governance, better policies and improved access to land and water resources. These recent developments are not capture in the PR-FEW Index.

The PR-FEW Index provides information only at the national scale, masking FEW security situation at sub-national level (Mohammadpour et al., 2019). Based on this limitation, our results reflect only FEW conditions at the national and sub-regional levels. In spite of these limitations, the PR-FEW Index remains a useful tool for carrying out comparative analyses of FEW (in)security across countries and sub-regions (Willis et al., 2016; Abbott et al., 2017). We equally acknowledge that the number of factors reinforcing FEW insecurity and approaches to address this insecurity are in SSA are not exhaustive as some important factors may have been inadvertently left out.

4. FEW resource conditions and spatial variations

4.1. FEW security outlook in SSA

Six of the 47 SSA countries (i.e. 13%) in this study recorded PR-FEW Index scores of 0.50 and above. These are: Gabon (CEMAC, Fig. 2A), Botswana, Mauritius, Namibia, South Africa and Eswatini (SADC, Fig. 2D). We found that no country in the EAC (Fig. 2B) and ECOWAS (Fig. 2C) regions achieved an overall FEW Index score above 0.50.

Figure 2: Pardee Rand Index and sub-indices for CEMAC (panel A), EAC (panel B), ECOWAS (panel C) and SADC (panel D)

In considering national scores for individual FEW elements, we observed that eight countries (17%) recorded food sub-index score above 0.50 – these are Djibouti and Sudan (EAC, Fig. 2B), Guinea Bissau (ECOWAS, Fig. 2C) and Botswana, Mauritius, South Africa, Eswatini and Zimbabwe (SADC, Fig. 2D). Eleven countries (23%) recorded energy sub-index score above 0.50: Equatorial Guinea and Gabon (CEMAC, Fig. 2A), Djibouti and Seychelles (EAC, Fig. 2B), Cabo Verde and Senegal (ECOWAS, Fig. 2C) and Botswana, Mauritius, Namibia, South Africa and Eswatini (SADC, Fig. 2D). Eleven countries (23%) also recorded a water sub-index score above 0.50: Equatorial Guinea and Gabon (CEMAC, Fig. 2A), Cote d'Ivoire and Gambia (ECOWAS, Fig. 2C) and Botswana, Mauritius, Namibia, South Africa, Eswatini, Zambia and Zimbabwe (SADC, Fig. 2D). Furthermore, we found that no country in the CEMAC region recorded a food security sub-index above 0.50 while all countries in the EAC region scored below 0.50 for water security sub-index. Overall, the PR-FEW Index scores for more than 87% of the countries are less than 0.50, with Burundi having the lowest score for both PR-FEW Index and sub-indices. Table 2 shows the full ranking of countries based on the PR-FEW Index and sub-indices scores.

>>>>>>>>>>>>>>>>>>>>>>>**Insert Table 2 here**>>>>>>>>>>>>>>>>>>

4.2. Spatial variations in food, energy, and water across SSA

Based on the PR-FEW Index and sub-indices scores, we observed substantial FEW variations (as well as similarities in FEW availability and access) across countries and sub-regions in SSA (see Fig. 3A-D). CEMAC and SADC sub-regions show similarities in their FEW security status, depicted by PR-FEW Index scores of 0.24 - 0.68; whereas EAC and ECOWAS sub-regions show similar FEW status (scores here range from 0.19 - 0.45). Although considerable FEW variations exist across CEMAC and SADC countries, no substantial variations were recorded across countries in the EAC and ECOWAS sub-regions (Fig. 3A).

The food security sub-index scores reveal similarities in food security status across the CEMAC and ECOWAS sub-regions (scores for both regions range from 0.36 - 0.50); although the FEW variations among countries in these sub-regions is weak. Similarly, we observed that the EAC and SADC sub-regions display similar food security sub-index scores (ranging from 0.26 - 0.60). Despite this, substantial variations exist among countries within these sub-regions (Fig. 3B).

Further, EAC and SADC sub-regions show similar energy sub-index with scores ranging from 0.13 - 0.85; however, there are substantial variations among countries in the sub-regions (Fig. 3C). The energy security sub-index scores show similarities in energy security status across the CEMAC and ECOWAS sub-regions (scores range from 0.15 – 0.72).

CEMAC and SADC display similar water security status (the water sub-index scores range from 0.24 – 0.75) with strong variations existing among countries in the sub-regions. There are equally strong variations in the water sub-index among ECOWAS countries while EAC countries show weak variations. EAC countries also have low water sub-index scores compared to the rest of the sub-regions (Fig. 3D). PR-FEW Index scores indicate that countries within the same sub-region display the widest variations in energy sub-index scores in comparison to countries across sub-regions; the food security sub-index scores reveal that among countries in the same sub-region there are wide spatial variations in availability and access.

Figure 3: Regional variations in FEW resources based on Pardee Rand Index and sub-indices: FEWI (panel A), FI (panel B), EI (panel C) and WI (panel D) (FEWI: Food, Energy and Water Index; FI: Food Index; EI: Energy Index; WI: Water Index)

In trying to pin down the spatial distribution of FEW resources across SSA, our analysis of the PR-Index scores reveal that countries in the SADC sub-region have relatively similar spatial FEW distribution patterns (Fig. 4A). Two countries in the CEMAC sub-region, three in EAC, four in ECOWAS and five in the SADC share similar spatial FEW distribution patterns (Fig. 4B). Countries in the SADC sub-region display the highest energy security sub-index scores compared to other SSA countries except for Malawi, Madagascar and Mozambique. Countries in the CEMAC, EAC and ECOWAS sub-regions have similar spatial energy distribution patterns as shown in the energy security sub-index score (Fig. 4C), except for Burundi with the lowest energy security. Higher energy security sub-index scores were observed for Djibouti and Senegal in the EAC and ECOWAS sub-regions respectively and Gabon and DR Congo in the CEMAC sub-region. Most countries in the EAC sub-region have similar spatial water distribution patterns (their water security sub-index scores are relatively low). Four CEMAC, Six ECOWAS and three SADC countries have similar spatial water distribution patterns (see Fig. 4D). Malawi recorded the lowest water sub-index score in the SADC sub-region.

Figure 4: Spatial distribution of FEW insecurity based on Pardee Rand FEW Index (A), Food Index (B), Energy Index (C) and Water Index (D)

4.3. Countries and Sub-regions at low and high risk of FEW insecurity

Quantitative assessment of FEW resources suggest that countries and sub-regions seem to perform differently in terms of FEW availability and accessibility and apparently operate at different levels of FEW insecurity risks. Focusing on food insecurity, we observed that the CEMAC sub-region is relatively at high risk: countries here have the lowest food sub-index scores which portray them as having the worst case of food insecurity. Across all countries, Chad (CEMAC), Burundi (EAC), Guinea (ECOWAS) and Zambia (SADC) seem to be worst-off in terms of food insecurity risks. This finding corroborates the results from past studies (e.g. Ware and Kramer, 2019), which identified Burundi, Chad and Zambia among the top ten most food insecure countries in the world, with Burundi topping the list.

Further analysis reveal that the ECOWAS sub-region faces the highest level of energy insecurity (the sub-region has the lowest energy sub-index scores); whereas the EAC and SADC sub-regions are relatively the most energy secured. Across SSA countries, Chad and Central Africa Republic (CEMAC), Burundi (EAC), Liberia, Niger and Sierra Leon (ECOWAS) and Malawi and Madagascar are the least energy secured countries. In terms of water security, the EAC sub-region faces the highest risk of water insecurity. Comparison across countries reveal that Chad (CEMAC), Burundi and Eritrea (EAC), Cabo Verde and Niger (ECOWAS) and Lesotho and Malawi (SADC) face the highest risk of water insecurity. Taking together, Burundi recorded the lowest scores across all the PR-FEW Index and sub-indices, suggesting that the country is the most at-risk country in SSA.

5. Factors reinforcing FEW insecurity in SSA and approaches to address them

5.1. FEW insecurity factors

Our review of a wide range of scientific literature and policy documents suggests that several factors and practices reinforce FEW insecurity in SSA. First, most projects aimed at addressing food, energy and water insecurity as a nexus often focus on regional (Conway et al., 2017) or national scales (Imasiku and Ntagwirumugara, 2020). Such top-down approaches often relegate some critical needs at the local level where communities, households, institutions and small businesses face the real challenges of simultaneously meeting their food, energy and water needs (Terrapon-Pfaff et al., 2018; Gebreyes et al., 2020). Second, most countries in SSA are classified as Least Developing Countries (LDC) reflecting low economic growth, weak institutions, poor planning and management capacities which may limit the ability of a country to achieve resource security (van Ginkel et al., 2019). It has been argued that developed infrastructure such as transport, irrigation, water, energy and information and communication technology are critical for achieving SDGs including WEF security (Le Blanc, 2015). Other studies have also highlighted the importance of enhanced socio-economic conditions for achieving FEW security nexus in SSA.

Other reasons are related to climate change, increasing trends in land degradation, desertification, water scarcity, rapid population growth and the unsustainable exploitation of FEW resources (UNCCD, 2019; Ware and Kramer, 2019). In addition, a recent study has reported that the construction of large-scale dams for hydropower and irrigation schemes may instead lead to negative social transformation and disintegration of communities due to the loss of farming and grazing land, without alternative livelihood options - thereby reinforcing FEW insecurity (Gebreyes et al., 2020). These findings suggest that implementaion of large-scale dams may be the decision of top-level (external) authorities who lack an understanding of local and community needs, circumstances and insitituional arrangements. Therefore, to maximise the value of limited resources towards addressing FEW insecurity, it is improtant that a bottom-up approach is adopted to co-develop context-specific alternative FEW security scenarios and solutions with different community and national stakeholders. In the food sub-sector, food insecurity in SSA may be attributed to many factors such as post-harvest losses due to the absence of infrastructure including storage facilities, farm-to-market roads to evacuate agricultural products to market centres, irrigation facilities, fertiliser (Calzadilla et al., 2013; Sheahan and Barrett, 2017; Nkiaka and Lovett, 2019). Food insecurity in SSA may also be attributed to climate related events such as flood and droughts (Twongyirwe et al., 2019; Ware and Kramer, 2019), climate change and large-scale land acquisition from small-holder farmers and lack of incentives to stimulate increased agricultural production in SSA (Yengoh and Armah, 2015; Giller, 2020). Analysing survey data from 5,299 households, Niles and Salerno (2018) found that 71% of households in Africa, South Asia and Latin America reported that they experienced climatic shocks, and this was correlated with food insecurity as such households were 1.73 times more likely to have reported that they were food insecure (at least one month in a year). The study further discovered that while climate shocks influence food insecurity, access to and use of fertilisers, pesticides, veterinary medicines, and reliable household assets moderate the impact of climate variability on food insecurity. This suggests that amid poverty, access to and use of these resources could help farmers adapt to climate shocks and help them to reduce the impact of climate variability on food production and insecurity. Food security could further be enhanced if smallholder farmers exploit crop genetic diversity as this strategy could increase the production of food in SSA (Njeru, 2013).

Other contextual factors also account for FEW insecurity in the different sub-regions. For example, food insecurity in the CEMAC sub-region is attributed to recurrent conflicts, lack of economic and political reforms in the agriculture and food security sector and lack of sub-regional integration. (FAO, 2015; UNDP, 2017). In the ECOWAS sub-region, food insecurity has been partly attributed to poor market reforms (Moseley et al., 2010). These factors suggest that governance has a key role to play in achieving food security in Africa.

Energy insecurity is mostly due to widespread under developed energy systems (Ouedraogo, 2017) and high electricity cost (the cost of electricity in most SSA countries is more than double that of other developing countries) (Eberhard and Shkaratan, 2012). Energy insecurity in SSA can also be due to recurrent droughts in some regions as a result of rainfall deficits triggering water scarcity which reduces the output capacity of hydropower dams (Conway et al., 2017). According to International Energy Agency (IEA) urbanisation and population growth with a lack of proportional investment in the energy sector is also another factor undermining energy security in SSA (IEA, 2019). Although renewable energy diversification is an essential precursor for energy security and sustainability (Akrofi, 2021), a lack of efficient and economically sustainable power systems, coupled with costly infrastructure investments currently constrain the penetration of those resources in the electricity mix in SSA (Pistelli, 2020). Energy insecurity pushes many households in SSA to rely on unsafe sources of energy including open fires for cooking, and lighting, with severe health implications such as acute respiratory infections and lung cancer (Boateng et al., 2020).

Water insecurity may be attributed to different factors such as limited technical and institutional capacity, lack of adequate investment in the water sector, weak governance, absence of legislative and environmental regulations and lack of hydro-meteorological data for monitoring water resources across different countries (Gain et al., 2016; Nkiaka et al., 2017b; Yomo et al., 2019). In urban areas, most of the water supply is derived from rural landscapes, hence an increase in unplanned development and poor land management practices in rural catchments have substantially increased water scarcity and pollution. This has in turn contributed to reducing water availability and increasing delivery costs in urban areas (TNC, 2016). Groundwater exploitation to reduce water insecurity is constraint by services needed to support its development including energy, drilling and pumping equipment, physical access, limited financial resources and institutional support (Cobbing 2020). Contextual factors reinforcing water insecurity in EAC sub-region are mostly due to unfavourable climatic conditions characterized by rainfall variability and prolonged droughts (McNally et al., 2019; Thomas et al., 2019).

Overall, we find that there are generic and contextual factors that account for FEW insecurity in SSA with sub-regions having different peculiarities, highlighting the fact that a one-size-fits-all approach to addressing FEW insecurity may not be successful.

5.2. Approaches to address FEW insecurity in SSA

To date sectoral approaches to resources management have often resulted in an imbalance and uneven resource allocation, utilisation and distribution in SSA. As such, it is necessary to identify priority areas across FEW interrelated resources systems where intervention may benefit all the three sectors at the same time (Mabhaudhi et al., 2019). At the same time, efforts should be made by stakeholders to integrate environmental concerns and climate change adaptation into such policy decision making processes (Babu et al., 2018; Onyutha, 2018). It has equally been suggested that harmonising institutions and policies, enhancing governance as well as setting targets and indicators to direct, monitor and evaluate FEW security in both rural and urban areas may enhance FEW security (Nhamo et al., 2018). Other studies have suggested that for projects such as dam construction for hydropower and irrigation to be beneficial to the communities, bottom-up approaches must be adopted to address the needs of local communities by ensuring democratic decision making and accountability (Terrapon-Pfaff et al., 2018). Below, we outline approaches for addressing insecurity concerns related to each component of the FEW nexus.

5.2.1. Food security

To address food insecurity in SSA, the African Union Commission (AUC) has put in place a Comprehensive Africa Agriculture Development Programme (CAADP) (Mabhaudhi et al., 2019). Given the importance of food distribution in achieving food security, the CAADP suggests that improving rural infrastructure and market access will be critical for reducing food insecurity (Mabhaudhi et al., 2019). Other studies have suggested that reducing post-harvest losses will also contributed to reduce food insecurity in SSA (Sheahan and Barrett, 2017). Considering that 95% of agriculture in SSA is rain-fed, it is equally suggested that increasing small-holder irrigation can potentially reduce food insecurity in SSA (Xie et al., 2014; Mabhaudhi et al., 2019). However, due to the sensitivity of surface water to rainfall variability, using groundwater for irrigation may resolve the problem of water scarcity in food production (Cobbing and Hiller, 2019). This could be achieved by using solar photovoltaic pumps for groundwater abstraction (Schmitter et al., 2018). Other studies have proposed the adoption of climate information services (Akwango et al., 2017), conservation agricultural practices, introducing new crop varieties, choice of cropping system and sowing date, introducing agrobiodiversity, genetic improvement, sustainable intensification, and market monitoring (Waha et al., 2013; Thierfelder et al., 2014). It is hoped that implementing some of these proposals may potentially reduce food insecurity in SSA.

5.2.2. Energy security

According to IEA (2019), plans towards achieving energy security in SSA may begin by liberalizing access to electricity and clean cooking fuel. In the face of climate change impact on hydropower in SSA, countries with low scores for energy security such as Chad and Burundi may intensify the adoption of renewables (e.g. wind and solar energies) to meet local energy demands (Sweerts et al., 2019). Promoting/implementing energy and climate policies (with special attention on decarbonising power supply) can spur the adoption of hybrid mixes of variable renewable power sources - solar, wind and hydropower (Sterl et al., 2018). For instance, a recent study has shown that 60% of electricity demand in West Africa can be met with complementary renewable of which roughly half would be solar and wind power and the other half hydropower (Sterl et al., 2020). Arguably, to achieve energy security through renewables, countries may have to demonstrate policy commitment by putting in place clear targets and concrete plans to catalyse private sector investment in renewable energy projects and increase investor confidence through financial de-risking measures (Kazimierczuk, 2019; Sweerts et al., 2019). Similarly, developing climate services for the energy sector will be crucial for developing the renewable energy sector in SSA (Sterl et al., 2018). In addition, creating regional power pools will equally be play an important role in achieving energy security (Conway et al., 2017; Sterl et al., 2020). For example, energy security in the Southern Africa sub-region has largely been attributed to the creation of Southern African power pool which led to the putting in place of a sub-regional energy protocol and a regional energy access strategic action plan (Stiles et al., 2015).

5.2.3. Water security

Achieving water security in SSA may being by addressing water governance which is still at its infancy stage. Considering much of the water supply to urban areas in SSA is captured in rural areas, protecting rural catchments has the potential to improve urban water security and enhance rural livelihoods (TNC, 2016; Asibey et al., 2019). To achieve this, efforts are required to understand and to influence the behaviour of water users and other stakeholders (Okumah et al., 2019) as well as their willingness to support policies aimed at sustainable water resource management (Okumah et al., 2020). Similarly, exploitation of groundwater resources may reduce water insecurity in both urban and rural areas (Cobbing and Hiller, 2019). Although the success of this option is not guaranteed (due to the complex factors influencing resource exploitation, access and use), it could improve availability and access (Okumah et al., 2019). Ultimately, a combination of strategies – including regulations, increasing investment in the water sector, technical capacity building in the water sector, enhancing data acquisition, adopting climate information services in the water management sector, raising awareness and putting in place educative programs aimed at reducing water pollution – will be needed to reduce water insecurity in SSA.

6. Conclusions

This paper focuses on quantitative and spatial assessments of FEW security in sub-Saharan Africa using data from the Rand corporation. Previous studies investigating FEW security have mostly relied on small datasets focusing on small spatial (regional) scales in SSA. Our analysis: identifies countries and sub-regions in SSA that are at low and high risk of FEW insecurity; describes how FEW varies spatially in SSA; and unpacks the local drivers reinforcing FEW insecurity as well as important needs-based approaches for tackling FEW insecurity in SSA. Our analyses show that (as at 2016) 41 countries (87%) obtained a PR-Index score below 0.50; indicating that many SSA countries are on a 'relatively high risk' position in terms of food, energy and water insecurity. Taking together, Burundi had the highest level of food, energy and water insecurity. Our findings provide insights on regional variation of FEW in SSA

A review of existing literature indicates that FEW insecurity across SSA can be attributed to factors such as: top-down FEW development approaches that relegate local FEW needs; increasing population and low economic growth; natural disasters and large-scale land acquisition; and overexploitation of FEW resources. Other factors such as conflicts, poorly coordinated market reforms, unfavourable climatic conditions, poor governance and poor land management have continued to constrain the achievement of FEW in majority of SSA countries.

We envisage that findings from this study will (1) provide policy makers, NGOs and development partners with clear evidence on the state of food, energy and water security in SSA, (2) enable development actors to better identify countries and sub-regions with high risk of food, energy and water insecurity, (3) provide countries with a clearer picture of critical development targets in the FEW sectors to pursue and (4) redirect the focus of future research, for example, by helping scientists to take informed decisions on critical research areas to prioritise.

Future research, e.g., in the form of case studies at local levels, can build on the findings from this study to systematically unpack the complex socio-economic, political, and ecological factors driving availability and access to food, energy and water in SSA. To do this will require a combination of quantitative and qualitative techniques to provide rich data on dynamic socio-economic and ecological forces across multiple scales.

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Authors' contributions

Elias Nkiaka: Conceptualization; Data curation; Formal analysis, Writing - original draft. **Uche Okpara:** Conceptualization, Writing and editing - original and revised drafts. **Murat Okumah:** Conceptualization; Data curation; Formal analysis, Writing - original draft.

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Table 1: Basic demographic and economic outlook of the different economic regions in SSA

Region	Number of countries	Total surface area (km^2 thousand)	Population (thousand)	GDP per capita ($)	Ave. Annual GDP growth 2010-20 (%)
CEMAC	7	5,365	137,555	2,185	3.50
ECOWAS	15	5,115	377,437	4,483	4.00
EAC	13	6,214	362,265	2,603	3.50
SADC	13	6,571	208,704	6,340	2.60

Note: Available from African Development Bank (AfDB, 2019). GDP per capital is based on purchasing power parity valuation.

Table 2: Countries rankings for PR-FEW Index and sub-Indices from the highest to lowest

Country	FEW Index	Country	Food sub-index	Country	Energy sub-index	Country	Water sub-index
Mauritius	0.68	Sudan	0.6	Seychelles	0.85	Gabon	0.75
Gabon	0.64	Djibouti	0.57	Mauritius	0.82	Botswana	0.75
S. Africa	0.63	S. Africa	0.57	S. Africa	0.81	Mauritius	0.75
Botswana	0.62	Mauritius	0.52	Gabon	0.72	Namibia	0.61
Namibia	0.54	Botswana	0.51	Cabo Verde	0.64	Eswatini	0.59
Eswatini	0.54	G. Bissau	0.5	Botswana	0.62	Gambia	0.56
Zimbabwe	0.46	Eswatini	0.5	Djibouti	0.61	Eq. Guinea	0.53
Cote d'Ivoire	0.45	Zimbabwe	0.5	Namibia	0.56	S. Africa	0.53
Angola	0.44	CAR	0.49	Eswatini	0.53	Cote d'Ivoire	0.51
Cameroon	0.43	Gabon	0.49	Eq. Guinea	0.5	Zambia	0.51
Djibouti	0.42	Ghana	0.49	Senegal	0.5	G. Bissau	0.47
Gambia	0.41	Cabo Verde	0.48	Sao T & P	0.47	Guinea	0.46
Nigeria	0.40	Liberia	0.48	Zimbabwe	0.46	Cameroon	0.44
Congo-Brazza	0.39	Uganda	0.47	Angola	0.45	Liberia	0.44
Sudan	0.39	Comoros	0.46	Cameroon	0.43	Angola	0.44
Senegal	0.39	Namibia	0.45	Cote d'Ivoire	0.42	Zimbabwe	0.42
Ghana	0.38	Cote d'Ivoire	0.43	Nigeria	0.42	Sierra Leon	0.41
G. Bissau	0.38	Gambia	0.43	Comoros	0.41	CAR	0.40
Zambia	0.38	Cameroon	0.42	Ghana	0.41	Congo-Brazza	0.40
Cabo Verde	0.37	Kenya	0.42	Lesotho	0.39	Nigeria	0.35
Comoros	0.36	Mali	0.42	Congo-Brazza	0.38	Madagascar	0.35
Lesotho	0.34	Niger	0.42	Eritrea	0.38	Mozambique	0.34
Kenya	0.33	Nigeria	0.42	Sudan	0.36	S Sudan	0.33
Guinea	0.33	Angola	0.42	Zambia	0.34	Mali	0.33

Liberia	0.33	Sao T & P	0.42	Kenya	0.32	DR Congo	0.32
CAR	0.31	Rwanda	0.4	Benin	0.28	Senegal	0.31
Togo	0.31	Burkina Faso	0.4	Gambia	0.28	Togo	0.31
Mali	0.3	Sierra Leon	0.4	Togo	0.25	Sudan	0.28
Mozambique	0.3	Lesotho	0.4	Mozambique	0.24	Kenya	0.27
Sierra Leon	0.29	Congo-Brazza	0.39	G. Bissau	0.23	Chad	0.26
Uganda	0.28	Benin	0.39	DR Congo	0.21	Burkina Faso	0.26
Benin	0.28	Senegal	0.39	Ethiopia	0.21	Ghana	0.26
Madagascar	0.28	Togo	0.39	Guinea	0.21	Lesotho	0.26
Eritrea	0.27	Guinea	0.38	Tazania	0.2	Comoros	0.25
Burkina Faso	0.27	Malawi	0.37	Uganda	0.2	Tazania	0.25
Tazania	0.26	Chad	0.36	Burkina Faso	0.2	Uganda	0.24
Ethiopia	0.25	Ethiopia	0.35	Mali	0.2	Malawi	0.24
Rwanda	0.25	Tazania	0.35	Madagascar	0.19	Djibouti	0.22
Malawi	0.25	Mozambique	0.35	Rwanda	0.18	Ethiopia	0.22
Chad	0.24	Seychelles	0.33	Malawi	0.18	Rwanda	0.22
Niger	0.23	Madagascar	0.32	Liberia	0.17	Benin	0.22
Burundi	0.19	Zambia	0.31	Niger	0.17	Burundi	0.20
DR Congo	-	Eritrea	0.30	CAR	0.16	Eritrea	0.18
Eq. Guinea	-	Burundi	0.26	Chad	0.15	Cabo Verde	0.16
Seychelles	-	DR Congo	-	Sierra Leon	0.15	Niger	0.16
S Sudan	-	Eq. Guinea	-	Burundi	0.13	Seychelles	-
Sao T & P	-	S Sudan	-	S Sudan	-	Sao T & P	-

(-) indicates no data

Appendix A: Pardee Rand FEW Index scores for different countries in each sub-region

Code	Country	FEW Index	Food sub-index	Energy sub-index	Water sub-index
	Economic Community of Central African States (CEMAC)				
CAM	Cameroon	0.43	0.42	0.43	0.44
CAR	Central Africa Republic	0.31	0.49	0.16	0.4
CHA	Chad	0.24	0.36	0.15	0.26
CNG	Congo-Brazzaville	0.39	0.39	0.38	0.4
DRC	DR Congo	-	-	0.21	0.32
EQG	Equatorial. Guinea	-	-	0.5	0.53
GAB	Gabon	0.64	0.49	0.72	0.75
	Economic Community of East African States (EAC)				
BUR	Burundi	0.19	0.26	0.13	0.20
COM	Comoros	0.36	0.46	0.41	0.25
DJI	Djibouti	0.42	0.57	0.61	0.22
ERI	Eritrea	0.27	0.30	0.38	0.18
ETH	Ethiopia	0.25	0.35	0.21	0.22
KEN	Kenya	0.33	0.42	0.32	0.27
RWA	Rwanda	0.25	0.4	0.18	0.22
SEY	Seychelles	-	0.33	0.85	-
SUD	Sudan	0.39	0.60	0.36	0.28
SS	S Sudan	-	-	-	0.33
TAN	Tanzania	0.26	0.35	0.20	0.25
UGA	Uganda	0.28	0.47	0.20	0.24
	Economic Community of West African States (ECOWAS)				
BEN	Benin	0.28	0.39	0.28	0.22
BUR	Burkina Faso	0.27	0.4	0.2	0.26
CAP	Cabo Verde	0.37	0.48	0.64	0.16
CDI	Cote d'Ivoire	0.45	0.43	0.42	0.51
GAM	Gambia	0.41	0.43	0.28	0.56
GHA	Ghana	0.38	0.49	0.41	0.26
GIN	Guinea	0.33	0.38	0.21	0.46
GIB	G. Bissau	0.38	0.5	0.23	0.47
LIB	Liberia	0.33	0.48	0.17	0.44
MAL	Mali	0.3	0.42	0.2	0.33
NIG	Niger	0.23	0.42	0.17	0.16
NIR	Nigeria	0.4	0.42	0.42	0.35
SEN	Senegal	0.39	0.39	0.5	0.31
SIL	Sierra Leon	0.29	0.4	0.15	0.41
TOG	Togo	0.31	0.39	0.25	0.31
	South African Development Community (SADC)				
ANG	Angola	0.44	0.42	0.45	0.44
BOT	Botswana	0.62	0.51	0.62	0.75
LES	Lesotho	0.34	0.4	0.39	0.26
MAD	Madagascar	0.28	0.32	0.19	0.35

MAA	Malawi	0.25	0.37	0.18	0.24
MU	Mauritius	0.68	0.52	0.82	0.75
MOZ	Mozambique	0.3	0.35	0.24	0.34
NAM	Namibia	0.54	0.45	0.56	0.61
STP	Sao Tome & Principe	-	0.42	0.47	-
SOU	South Africa	0.63	0.57	0.81	0.53
SWA	Eswatini	0.54	0.5	0.53	0.59
ZAM	Zambia	0.38	0.31	0.34	0.51
ZIM	Zimbabwe	0.46	0.5	0.46	0.42