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A systematic review of social equity in FEWS analyses

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Integrating social equity considerations into analyses of the food-energy-water systems nexus (FEWS) could improve understanding of how to meet increasing resource demands without impacting social vulnerabilities. Effective integration requires a robust definition of equity and an enhanced understanding of reliable FEWS analysis methods. By exploring how equity has been incorporated into FEWS research in the United States and countries with similar national development, this systematic literature review builds a knowledge base to address a critical research need. Our objectives were to 1) catalog analysis methods and metrics relevant to assessing FEWS equity at varying scales; 2) characterize current studies and interpret shared themes; and 3) identify opportunities for future research and the advancement of equitable FEWS governance. FEWS equity definitions and metrics were categorized by respective system (food, energy, water, overall nexus) and common governance scales (local, regional, national, global). Two central issues were climate change, which increases FEWS risks for vulnerable populations, and sustainable development, which offers a promising framework for integrating equity and FEWS in policy-making contexts. Social equity in FEWS was integrated into studies through affordability, access, and sociocultural elements. This framework could support researchers and practitioners to include equity in FEWS analysis tools based on study scale, purpose, and resource availability. Research gaps identified during the review included a lack of studies effectively integrating all three systems, a need for publicly available datasets, omission of issues related to energy conversion facilities, and opportunities for integration of environmental justice modalities into FEWS research. This paper synthesized how social equity has previously been incorporated into FEWS and outlines pathways for further consideration of equity within nexus studies. Our findings suggested that continued exploration of connections between FEWS, equity, and policy development across scales could reduce social risks and vulnerabilities associated with these systems.

KEYWORDS

food-energy-water systems, nexus, systematic literature review (SLR), assessment tools, social justice and equity, decision-making, governance

1 Introduction

Global demands on food, energy, and water systems (FEWS) are expected to increase by 35%–50% by 2030 (Endo et al., 2017). The growing human population and increasing affluence are important drivers for increased FEWS resource use, environmental impact, and social inequities (Hinrichs, 2014; James and Friel, 2015). The demand for increasingly productive and efficient FEWS has led to a growing focus on biophysical and engineered solutions, yet less focus has been on integrating social components within the FEWS framework (White et al., 2017). Based on these efforts, the concept of a FEWS nexus, emphasizing interdependencies between the production/conversion, distribution, and consumption of food, energy, and water resources, has emerged and garnered much attention over the past decade (Proctor et al., 2021).

The FEWS nexus is a growing research field involving systems thinking and integrated decision-making frameworks to balance tradeoffs between social, economic, and environmental goals (Kaddoura and El Khatib, 2017; Sodiq et al., 2019). FEWS research usually entails multidisciplinary studies, including tradeoffs and risks between systems (Zhang et al., 2019). The FEWS nexus concept has been successful as an analytical tool for optimizing select biophysical processes. However, it has been less successful as a tool to inform integrated policy and governance (Srigiri and Dombrowsky, 2022). Proctor et al. (2021) emphasized the need to incorporate aspects of sustainability, environmental equity, and resilience while criticizing the FEWS concept for merely rebranding existing paradigms, including the concept of sustainable development. Although improving sustainability is often an expressed purpose of FEWS research in many academic definitions, the methods and foci can be misaligned and fail to capture important aspects of sustainable systems necessary to guide coherent policy agendas (Endo et al., 2017; Srigiri and Dombrowsky, 2022).

The FEWS nexus has also been promoted as a valuable framework for confronting pressing climate and social changes (Endo et al., 2017). As FEWS research has grown over the last decade (Wang et al., 2022; Zhou et al., 2022), the majority of research efforts have focused on technical solutions to biophysical challenges of FEWS production, conversion and use (as per Newell et al., 2019). FEWS relationships have been well studied in many complex contexts, such as the relationship between food production and water use, as well as the interdependencies between energy demand and climate change impacts on food and water resources (Kaddoura and El Khatib, 2017). However, even with the growing body of literature, few studies incorporating social elements have emerged, and strategies for integrating the FEWS framework with social contexts remain scarce (Newell and Ramaswami, 2020).

FEWS are tightly linked to human activities, as their flows are essential influences on health, wellbeing, safety, economic opportunities, and sustainable development (Romero-Lankao and Gnatz, 2019). Understanding FEWS interactions from a sustainable system perspective while integrating social and economic factors is vital in the face of new and increasingly complex societal risks (White et al., 2017). Yet work by Newell and Ramaswami (2020) highlighted the lack of social equity and justice research relative to FEWS resource allocation, access, and affordability. To better account for these concepts, Proctor et al. (2021) demonstrated the need to integrate social science into quantitative FEWS analyses to understand power and equity dynamics that help to shape decision-making. FEWS nexus governance with coherence across sectors and scale while fostering principles of equitability, participation, sharing and empowerment is a framework highlighting the critical intersection between FEWS and social equity in this context (Yuan and Lo, 2022). Beyond including elements of social equity and justice into analytical frameworks, it is necessary to explicitly incorporate these considerations into policy and governance to better account for tradeoffs and identify inclusionary pathways to sustainable FEWS (Proctor et al., 2021).

To conceptualize equity in a FEWS context, various dimensions of social equality and justice must be considered. Social equality is a state of even distribution of resources across all people (Romero-Lankao and Gnatz, 2019). Social justice is a similar but more encompassing concept focusing on resource distribution and less quantifiable dimensions such as fair treatment and equal protection. As Smaal et al. (2020) epitomized, "the 'what' of justice [is] economic redistribution (equal share), cultural recognition (equal respect) and political representation (equal say)" (*p*. 712). Race, ethnicity, gender, and socioeconomic status are some of the identities that can act as cultural barriers to both distributional justice and effective participation or equal say in FEWS policy development (Romero-Lankao and Gnatz, 2019).

In an equitable system, high-quality FEWS resources are accessible regardless of power and assets of social, political, economic, or spatial nature. We consider equity analyses to entail explicit incorporation of social identity aspects and an attempt to measure the fair distribution of sufficient, affordable, and reliable FEWS resources (Romero-Lankao and Gnatz, 2019; Proctor et al., 2021). Additionally, a challenging but important consideration is cultural preferences, perceptions, and beliefs around FEWS resources, which can inform a more comprehensive understanding of FEWS equity (D'Odorico et al., 2018).

Interactions and interdependencies exist across spatial and temporal scales of social and biophysical systems, making scale a particularly important consideration for policy and decision-making related to FEWS equity (Garcia and You, 2016). Indeed, spatial scale is often cited as a challenging yet critical component of FEWS governance because resource management typically occurs across several policy scales (Pahl-Wostl et al., 2021). One study focused on governance outlined the importance of scale, finding that large-scale FEWS analyses generally supported policies that contextualized system interconnections yet missed impacts on communities and individuals, while smaller-scale analyses had the opposite strength and limitation (Tye et al., 2022). Another analytical governance framework used the perspective of overlapping centers of control (polycentricity) to explore biophysical and institutional interlinkages that support organization across scales for effective FEWS governance (Srigiri and Dombrowsky, 2022). Linkages between the respective FEWS exist at specific scales representing dependencies ranging from direct (e.g., local or regional energy use for pumping water to irrigate agricultural fields) to indirect (e.g., global virtual water exchanges via commodity crop trading) (Bijl et al., 2018). Furthermore, policy directives aimed at improving social equity outcomes are inherently scaled to the jurisdiction of the governing entity, such as in the United States, where often federal, state, and local governments have distinct roles in setting, implementing, and evaluating policy. Therefore, scale is an essential factor to include when evaluating social equity in FEWS.

Meaningful integration of social equity into FEWS research requires a robust understanding of how equity is defined and a toolbox of methods across spatial scales and applications. In this literature review, we collected and analyzed studies in the United States and countries with similar development that

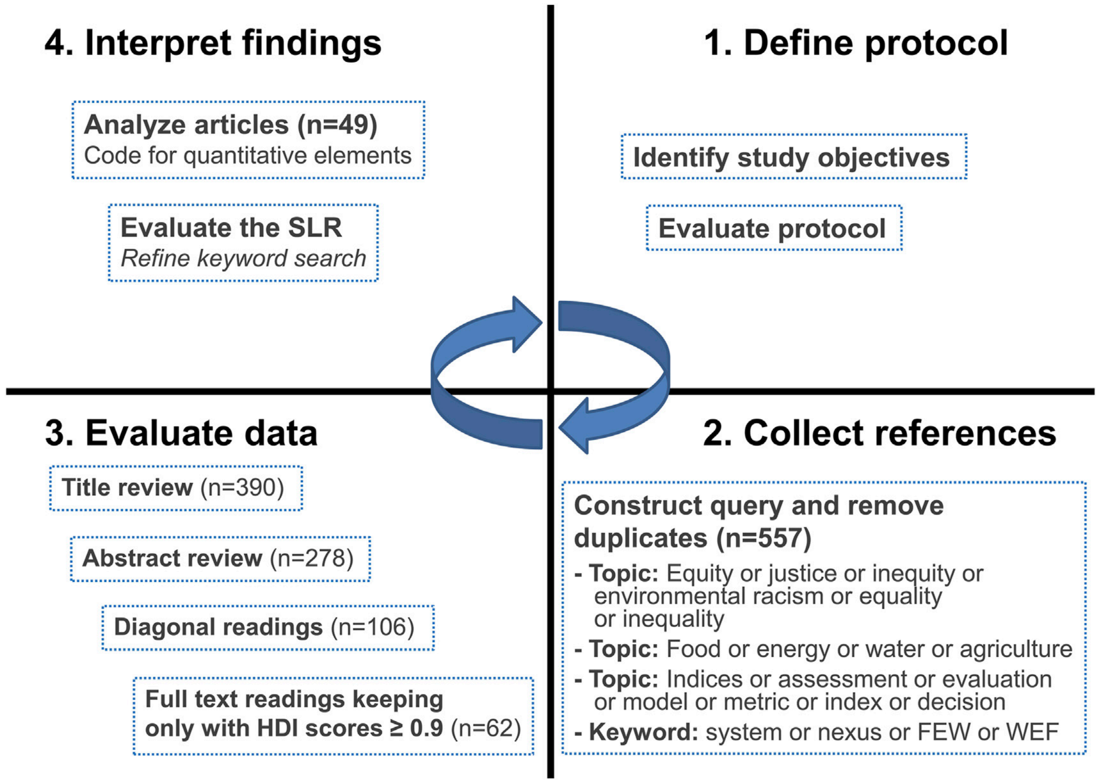

FIGURE 1
The process schematic for this social equity in FEWS analyses systematic literature review (SLR) followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and a framework developed by Marianao et al. (2017). The four-stage process is iterative and constructed to reduce bias in article selection. The notation "n =" refers to the number of articles reviewed at each stage of the process.

incorporated equity into FEWS research to build a knowledge base that begins to address the question of how to analyze social equity in the context of FEWS. Our objectives were to 1) catalog analysis methods and metrics relevant to assessing FEWS equity at varying scales; 2) characterize current studies and interpret shared themes; and 3) identify opportunities for future research and the advancement of equitable FEWS governance.

2 Materials and methods

A systematic literature review (SLR) was conducted to achieve the study objectives. SLRs are widely used for environmental studies, especially those addressing controversial or sensitive topics (Mariano et al., 2017). To avoid and mitigate potential selection bias, we followed a procedure developed by Mariano et al. (2017) that utilizes the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The procedure includes four iterative steps: define protocol, collect references, evaluate data, and interpret findings (Figure 1).

During the SLR process, papers were assessed, sorted, and analyzed based on working definitions of FEWS and social equity. Since these definitions served as a basis for inclusion (or exclusion) in the full SLR, it was important to establish a consensus between co-authors to maintain consistency. Indeed, Cairns and Krzywoszynska. (2016) found that FEWS can be an ambiguous concept often used to elicit normative reactions rather than serving as operational conceptual models for capturing interactions between the three systems. In the review process, we used the Food and Agriculture Organization (FAO) definition, which recognizes FEWS as a helpful concept that addresses interconnected food, energy, and water systems to better manage global resource systems to meet social, economic, and environmental aims (FAO, 2014). Similar to Allen. (2010), our working definition of FEWS equity is shared power and resources within the systems such that individuals and communities have defined needs adequately and sustainably met, with considerations for security and dignity.

While our focus was on attaining an operational concept of equity in specific relation to the FEWS nexus, we were hindered by a lack of studies that effectively connect the systems—a common finding among reviews of the FEWS field (Endo et al., 2017; Albrecht et al., 2018; Newell et al., 2019). Nevertheless, our approach followed a similar methodology to that of Tye et al. (2022) where we include nexus studies along with those focused on an individual sector with provisional relations to the other two. Including these individual system studies enabled a more comprehensive review of 49 studies, versus only six found for the overall nexus, and supports the identification of the most promising social equity integration methods across disciplines. However, the lack of integrated nexus studies does have implications, as discussed in Section 3.5.

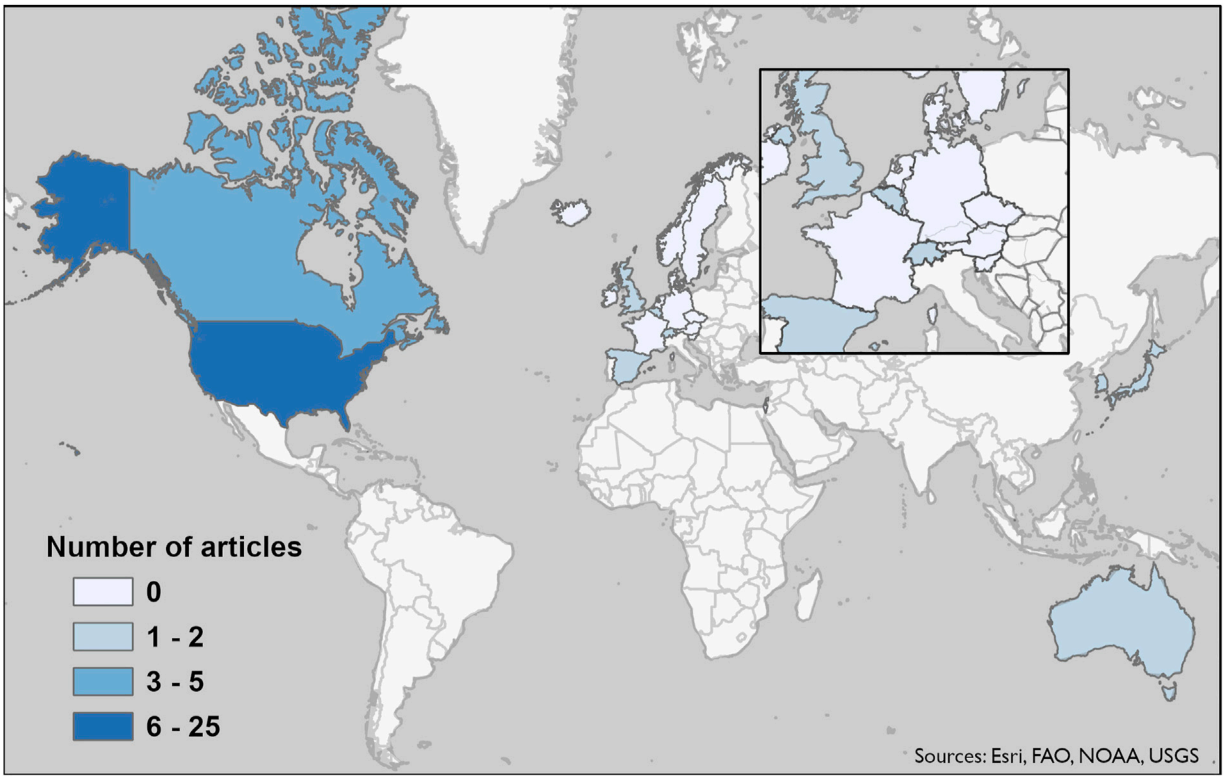

FIGURE 2
Number of articles from each country that were included in the literature review. Only countries with a Human Development Index (UNDP, 2020) of 0.9 or above were included.

2.1 Research protocol definitions

Our objective was to use SLR methods (Figure 1) to enhance understanding of how equity has been incorporated into recent FEWS analyses across scales. We assembled an advanced keyword search of three topics and one set of keywords. The topic keywords included three main categories: FEWS (food, energy, or water), analysis, and equity. Additionally, we searched for "system" and "nexus" as keywords to narrow our focus to only articles that used a systems approach. Relevant and synonymous keywords were also added as search terms (e.g., justice, equality) to establish a more comprehensive scope of material. An iterative search term approach was used; for example, "or agriculture" was added to the original "food or energy or water" search term to ensure that the food production stage was included. All search terms can be found in Figure 1.

All included articles met the following criteria: 1) articles published from 2000 until June 2021; 2) analyses focused on systems of food, energy, water, agriculture, and nexus (defined as any combination of the systems); and 3) analyses that tested or proposed methods for assessing, indexing, or modeling social equity using metrics. Although conceptual models or frameworks to enhance understanding of system dynamics without incorporating measurements were common, these studies were not included as they are not directly applicable to building FEWS analysis tools. Additional exclusion criteria included 1) self-contained case studies, 2) review articles, 3) articles not from a peer-reviewed journal (governmental and organizational reports or news articles), and 4) articles with full text not available in English.

To distinguish issues of social equity from disparities related to national development, we used the 2020 Human Development Index (HDI) value as a proxy to select nations at a similar development level (UNDP, 2020). The HDI is positively associated with increases in infrastructure services such as safe drinking water and electrical supply, thereby providing an indication of the degree of national development related to FEWS infrastructure (Kusharjanto and Kim, 2011; Amador-Jimenez and Willis, 2012; Bahadur, 2014; Mohanty et al., 2016; Liu et al., 2023). Our objective was to understand FEWS equity analyses at common scales (community, city, county, state, region) for application in the United States. Therefore, we evaluated articles that focused on countries with a similar 2020 HDI score to the United States (UNDP, 2020). We completed an in-depth analysis of articles containing countries with an HDI within the same decile as the United States (≥ 0.9) or an HDI ranking ≥ #27 (Figure 2). Literature associated with global analyses or that included countries both inside and outside the HDI range was included for full analysis. Articles corresponding to countries with lower HDI values were retained, but only diagonal readings (i.e., skimming the introduction, figures, tables, and conclusions of each paper; Mariano et al., 2017) were completed (n = 45).

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TABLE 1 Distribution of articles by FEWS focus (food, energy, water, nexus) and scale (local, regional, national, global). Each shape represents the methods used [square symbol used to denote quantitative methods, circle to denote qualitative methods, and triangle to denote mixed methods (quantitative and qualitative)]. The notation "n =" denotes the number and proportion of articles for each category.

Scale	Food	Energy	Water	Nexus	n =
Local	■■■■■■●●▲▲▲	■■■	■■■■■	■	20
Regional	■■▲	■■	■■■■■▲▲	■	13
National	■■■▲▲	■■		■■■	10
Global	■●	■■■		▲	6
n =	21 (43%)	10 (20%)	12 (24%)	6 (12%)	49

2.2 Reference collection, data evaluation, and interpretation

Reference collection involved an advanced search in three widely used science databases (Scopus, Web of Science Core Collection, and Web of Science CAB Abstracts). Initial search terms resulted in 557 unique articles. Using co-author consensus at each stage, we filtered articles according to our inclusion and exclusion criteria (Figure 1). We logged important article characteristics relevant to our objectives to analyze and identify trends across all sample articles. Characteristics cataloged included FEWS focus, assessment tool, analysis method, system scale, data type, FEWs and equity metrics and equity integration. These characteristics were then used as the basis to identify emergent themes, research gaps, and opportunities for future work.

3 Results

The 49 FEWS equity articles that met all inclusion criteria focused on food systems (n = 21), energy systems (n = 10), water systems (n = 12), or a combination of two or more systems (n = 6), referred to as the FEWS nexus. Each article incorporated social equity into system analyses (as an assessment, an index, or a model) at a given scale: local (n = 20), regional (n = 13), national (n = 10), and global (n = 6). This section addresses the first two objectives of the review by cataloging analysis methods and metrics, followed by characterizing equity topics across scales, providing an interpretation of equity integration methods and examining the relationship between scale and FEWS equity.

3.1 Analysis methods and metrics

The FEWS equity analyses we reviewed used quantitative, qualitative, or mixed (i.e., a combination of quantitative and qualitative) methods (Table 1). Most studies (n = 37) exclusively used quantitative data at national and global scales, nine used mixed methods, and the remaining three used qualitative data at these scales. All three studies that exclusively used qualitative data were food system-focused, though the study scale varied (two local and one global). Energy-focused articles exclusively used quantitative methods, whereas mixed methods were used for water at a regional scale (n = 2) and the nexus at a global scale (n = 1) (Supplementary Material).

The FEWS-related analysis tools found in the SLR were grouped into three types: assessment, model, or index. Each identified specific metrics or measures, setting a "tool" apart from a "framework." An assessment was the most straightforward tool evaluating a relationship between FEWS and equity, such as studies involving qualitative appraisals or linear regressions. An index is a mathematical combination of measures or metrics indicating a proportional relationship. The most complex tool was a model representing interactions within a system. Most articles created an index (n = 33) to evaluate system interactions. However, the majority of articles focused on food systems used an assessment (n = 11) due to the types of data commonly associated with food systems. Occasionally analysis tools were used in combination; for example, Guo et al. (2019) created a water system model to predict technological changes for irrigation water efficiency based on shared socioeconomic pathways by incorporating standardized indices to conceptualize water security and water stress based on a variety of factors.

The most common metric for incorporating social equity across FEWS was demographic data which were generally integrated using census or survey demographics. Depending on study scale, the census often included household data by census block or county (e.g., Herrera et al., 2009). Other studies primarily used economic data to incorporate FEWS equity (e.g., Jacobson et al., 2005). In addition to census metrics, survey demographics included perceptions of personal and community health, measurements of food insecurity, agricultural work practices and pesticide use (e.g., Dean and Sharkey, 2011).

Other equity metrics incorporated external variables such as spatial data, including a neighborhood walkability index, land use, distances from farmers' markets, community gardens, bus stops, and grocery stores (e.g., Lowery et al., 2016). Policy metrics were used only in food system-focused analyses. At the city scale, these included government spending on healthy local food, community gardens on city properties, grocery store area per capita, and the number of SNAP (Supplemental Nutrition Assistance Program) electronic benefit transfer operators (Freudenberg et al., 2018). At the national scale, these included a Healthy Food Policy Project framework that assessed regional food policy plans (Calancie et al., 2018). Other qualitative metrics included community wellbeing, risk probabilities, and perceptions (Simonovic, 2001).

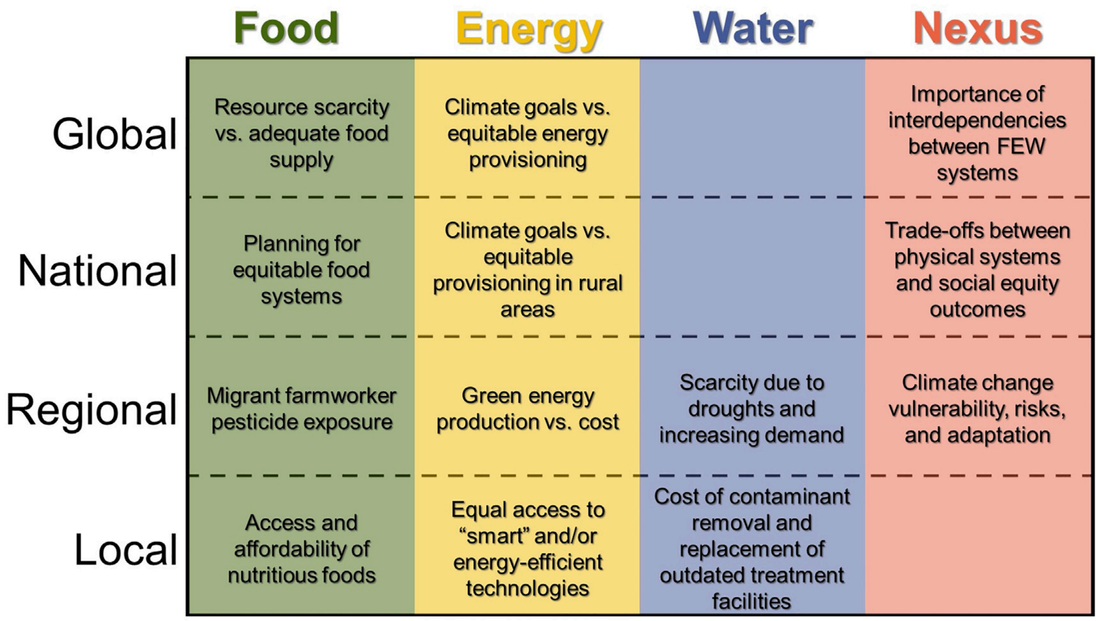

FIGURE 3
Major themes for food (green), energy (yellow), water (blue) and their nexus (red) identified for local, regional, national, and global scales.

Most analyses included specific metrics to characterize FEWS infrastructure for a given area, such as piped water leakages, water quality impairments, and complete plumbing access (e.g., Meehan et al., 2020). Land use was also incorporated with measures of agricultural land, livestock density, area of cropland, land area cleared for agriculture, rural population density, fertilizer use, and agricultural production (e.g., Tole, 2004; Schaider et al., 2019). Some studies also included environmental impact measures such as water quality, soil carbon density, correlation coefficients for land use, clusters of land use types and ecological benefits, energy balance, climate stabilization, clean air, biodiversity, and resource conservation (e.g., Zurek et al., 2018).

3.2 Equity topics across scales

Across scales of the reviewed FEWS articles, primary equity topics included the cost and affordability of resources, drinking water quality, access to healthy food, energy efficiency, exposure to environmental toxins, tradeoffs between climate goals and equity, and the ability to absorb risk and adapt to a changing climate (Figure 3). Disadvantaged or marginalized communities often experience barriers related to the cost of FEWS resources, which take up a disproportionately larger share of low-income households' financial resources and leave less for other necessities such as healthcare and education (e.g., Cory and Taylor, 2017). Inordinately, toxic environmental exposures affect minority and under-resourced populations through contaminated drinking water (e.g., Balazs et al., 2011; 2012), poor labor conditions (e.g., McCauley et al., 2001), or proximity to pollution-inducing resource extraction (e.g., Burbidge and Adams, 2020). Many articles focused on equity related to climate change; efforts to meet emissions goals can exclude the poorest and most disadvantaged people, regions, and countries from growth and development or leave them without the ability to adapt to changing conditions (e.g., McEvoy and Wilder, 2012; Chakravarty and Tavoni, 2013).

Food system analyses at the global scale focused on the equitable allocation of resources by assessing the relationship between land-use efficiency, food supply (Duro et al., 2020), and concerns related to the scarcity of phosphorus for crop production (Cordell and White, 2015). Articles at the national scale focused on food system policies (Calancie et al., 2018; Zurek et al., 2018; Hossain et al., 2021), the use of big data in agriculture (Fleming et al., 2018), and access to land for crop production (Tole, 2004). Issues related to pesticide exposure for migrant laborers (McCauley et al., 2001) and equitable access to food (Dean and Sharkey, 2011; Mui et al., 2020) were addressed at the regional scale. A range of analyses was conducted at the local scale, including food access and affordability (Herrera et al., 2009; Freedman et al., 2013; Freudenberg et al., 2018; Boyer and Ramaswami, 2020; Murrell and Jones, 2020; Smaal et al., 2020; Ong et al., 2021), food production in community and residential gardens (McClintock et al., 2016; Butterfield, 2020), availability of local produce at farmers' markets (Lowery et al., 2016), and access to organic foods (Garcia et al., 2020).

Energy articles focused on global climate change either by examining policy scenarios (Rozenberg et al., 2014) or by evaluating inequities in energy access arising from efforts to meet climate goals (Duro and Padilla, 2006; Chakravarty and Tavoni, 2013). Climate change was also addressed nationally; Tomás et al. (2020) analyzed carbon footprints versus municipal population sizes, and Xu and Chen's (2019) study examined barriers to accessing energy-efficient appliances and technologies. Regional studies included issues arising from shale gas extraction in the United Kingdom (Burbidge and Adams, 2020) and equitable

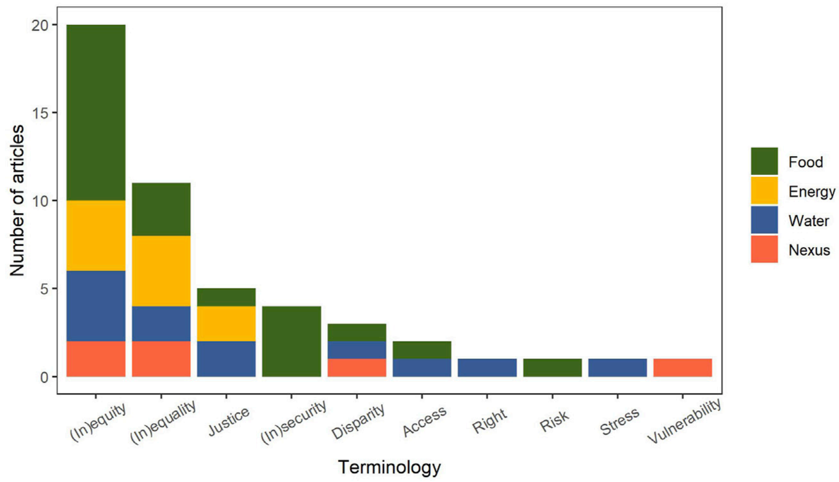

FIGURE 4
Equity terms found in articles included in this literature review, with number of articles using each and the system focus (food, energy, water, nexus) for each article.

distribution of renewable energy conversion facilities (Sasse and Trutnevyte, 2019). Locally, energy system articles explored energy access and affordability (Bartiaux et al., 2018), household energy consumption based on economic factors (Jacobson et al., 2005) and energy efficiency of multifamily rental units (Pivo, 2014).

All articles evaluating water systems were at the local (n = 5) or regional (n = 7) scales. At the regional scale, water pricing, and affordability issues were recurring topics (Ward and Pulido-Velázquez, 2008; Goddard et al., 2021), along with strategies for equitable water management or allocation (Simonovic, 2001; Kim et al., 2018; Gullotta et al., 2021). Issues of drinking water contamination spanned scales, with nitrate exposure disparities studied regionally (Talley et al., 2016; Goddard et al., 2021) and locally (Schaider et al., 2019). Arsenic exposure disparity was also considered regionally (Balazs et al., 2011), and tradeoffs due to the cost of removal treatments at the local scale were investigated (Cory and Taylor, 2017). Additional articles at the local scale focused on rural citizens' exposure to contaminants (Delpla et al., 2015), inequities in urban water infrastructure (Meehan et al., 2020), and water insecurity caused by climate change (Krueger et al., 2019).

Studies of the FEWS nexus focused on sustainability, resource allocation, and the effects of climate change. Schlör et al. (2018) explored metrics of equity and resilience of FEWS at a global scale and developed an index for comparing outcomes. National-scale articles described tradeoffs between sustainable growth and scarcity of FEW resources (Lee et al., 2021), interdependencies between food consumption and environmental impacts by demographic group (Bozeman et al., 2019), and equitable allocation of ecosystem services (Mullin et al., 2018). At a regional scale, McEvoy and Wilder. (2012) studied the compounding effect of energy-intensive desalination to solve water scarcity linked to climate change. Similarly, vulnerabilities to the consequences of climate change were studied locally to identify disparities in risk for varying demographic groups (English et al., 2013).

3.3 Equity characterization and integration

Understanding how equity, equality, and justice are defined and integrated into analyses in the context of FEWS provides insight into themes across systems and scales. "Equity" was the most widely used term among papers in the SLR, followed by equality and justice (Figure 4). There were many similarities in definitions, including a strong focus on resource access (n = 8) and distribution (n = 5) across both space (intragenerational) and time (intergenerational). Most articles that used "equity" as the primary term emphasized access, distribution, and affordability (e.g., McClintock et al., 2016). Resource quality was a significant component of many equity definitions, with healthy food, efficient energy systems, (Pivo, 2014; Freudenberg et al., 2018), and treated water specified as critical attributes of an equitable system (Ward and Pulido-Velázquez, 2008). Some articles that used "equity" also referenced the importance of inclusion and fair distribution across space and time (e.g., (Simonovic, 2001). Many articles that used "equality" used economic indicators and definitions to quantitatively measure resource distribution within FEWS (e.g., Lee et al., 2021). Articles using the term "justice" focused on distribution and qualitative definitions such as fair treatment and equal protection (e.g., Xu and Chen, 2019; Smaal et al., 2020).

3.4 Interpretation of equity themes

In the articles we reviewed, social equity was linked to FEWS in three major ways—affordability, access, and sociocultural context (Table 2). Affordability and access are accepted equity categorizations often used in conjunction with availability (Azuma et al., 2010; Kim and Blanck, 2011). However, in this review we found sufficient similarities between studies of access and availability to justify grouping them into a single category, while the analyses of complex issues related to sociocultural barriers to FEWS equity warranted their own category. Affordability (economic

TABLE 2 Equity integration in FEWS analyses in three categories based on metrics used and characteristics of affordability, access, and sociocultural equity. The scale, tools, and metrics listed are not comprehensive but represent examples commonly used.

Equity integration	Affordability	Access		Sociocultural
Type	Economic	Spatial	Quantity/Quality	Mixed method
Definition	Income, cost, or GDP are proxies for FEWS equity	Spatial access is central to FEWS equity	Equity is the measured quantity or quality of FEWS resources	Equity includes elements of accessibility, quality, and personal beliefs or perceptions about FEWS resources
Scales	National to global	Local to regional	Local to regional	Local
Analysis tools	Index (50%, n = 4) Model (50%, n = 4)	Assessment (40%, n = 12) Index (27%, n = 8) Model (33%, n = 10)		Assessment (70%, n = 7) Index (10%, n = 1) Model (20%, n = 2)
Methods	Economic indices Income distributions Affordability indices	Spatial indices Regressions Associations	Direct measurements of FEWS characteristics	Interviews Focus groups Surveys
Metrics	GWP Household income FEWS cost and spending	Distance from FEWS resources or risks	Equal quantity/quality resource	A combination of economic, access, and social metrics

equity) is the simplest of the three, defined through economic metrics of income, wealth, or ability to pay for resources. Access is more complex and refers to the spatial proximity, availability, or even quality of the FEWS resource available to obtain and utilize. Finally, sociocultural context incorporates social and cultural preferences, perceptions, beliefs, and barriers. These themes offer a framing device for practical FEWS analyses and interventions as they span all systems and scales.

Articles that were focused on affordability and economic factors (n = 8) commonly used gross domestic product (GDP) to compare equity in countries at a global scale (Chakravarty and Tavoni, 2013; Duro et al., 2020) and household income to compare households in neighborhoods at regional and/or local scales (Jacobson et al., 2005; Tomás et al., 2020). While affordability studies often eschewed complex data inputs, analysis methods were more complex, with all studies involving either an index or model. Simple metrics such as income and GDP are relatively easy to collect, publicly available in many countries, and favorable inputs for statistical modeling. Economic disparities can highlight inequity hotspots in FEWS and serve as a useful basis for further investigation. Additional value can be gained by considering the cost of the resource in relation to income (a measure of affordability), as done by Goddard et al. (2021) who analyzed the affordability of California's water system to identify tangible policies and solutions. However, a more powerful approach may be to combine these metrics with additional analyses that incorporate social, cultural, historical, and spatial considerations (Jacobson et al., 2005).

In the second category, article authors assessed quantitative data to explore spatial, quality, or quantity elements of FEWS access. Access equity was incorporated in 30 articles in our sample, with 12 studies at a local scale, eight at a regional, seven at a national and three at a global scale. These studies employed all analysis tools (assessments, indices, and models), with assessments being slightly more common (Table 2). Spatial elements of access capture essential nuances related to location (e.g., Garcia et al., 2020), such as the well-known phenomenon of food deserts (e.g., Murrell and Jones, 2020). Elements of quantity and quality were also used to indicate availability, such as whether a community or individual has access to enough of a high-quality resource. Access assessments are helpful for determining where to allocate additional resources or improve existing systems, as in the assessment by Balazs et al. (2012), which found that treatment facilities in low-income communities were ill-equipped to treat harmful arsenic in drinking water. Although indicators of access can be challenging to measure [food miles or environmental impacts as per Boyer and Ramaswami (2020)], the quantitative nature lends some ease to analysis allowing for statistical analysis and modeling. While access is an important element of equity that incorporates additional nuances, insights into sociocultural factors, such as social capital and personal preferences, are typically not captured (Mullin et al., 2018).

The final theme was the sociocultural context of FEWS equity. Sociocultural analyses usually require primary data collection through surveys, focus groups, and interviews. Close to one-quarter of the articles (n = 13) incorporated sociocultural equity, including ten studies at local and regional scales and three at national and global scales. These studies often use qualitative and quantitative data to understand multiple dimensions of access and equity beyond the biophysical context of FEWS equity. Analysis methods lean heavily towards assessments, reflecting the challenge of incorporating qualitative data in numerical and statistical modeling (Table 2). However, some studies overcame dual challenges related to data collection and analysis to model sociocultural elements of FEWS equity. For example, one study incorporated individual perceptions not easily determined using secondary datasets available at large scales, resulting in a model relating food insecurity to perceived disparity and social capital (e.g., Dean and Sharkey, 2011). Several of the studies in this category addressed risks and vulnerability associated with environmental factors and the ability of communities to adapt to changing climate conditions (McEvoy and Wilder, 2012; Krueger et al., 2019). Data collection for this type of analysis can be much more challenging and may require partnerships with organizations that have previously established relationships with local communities (e.g., Ong et al., 2021).

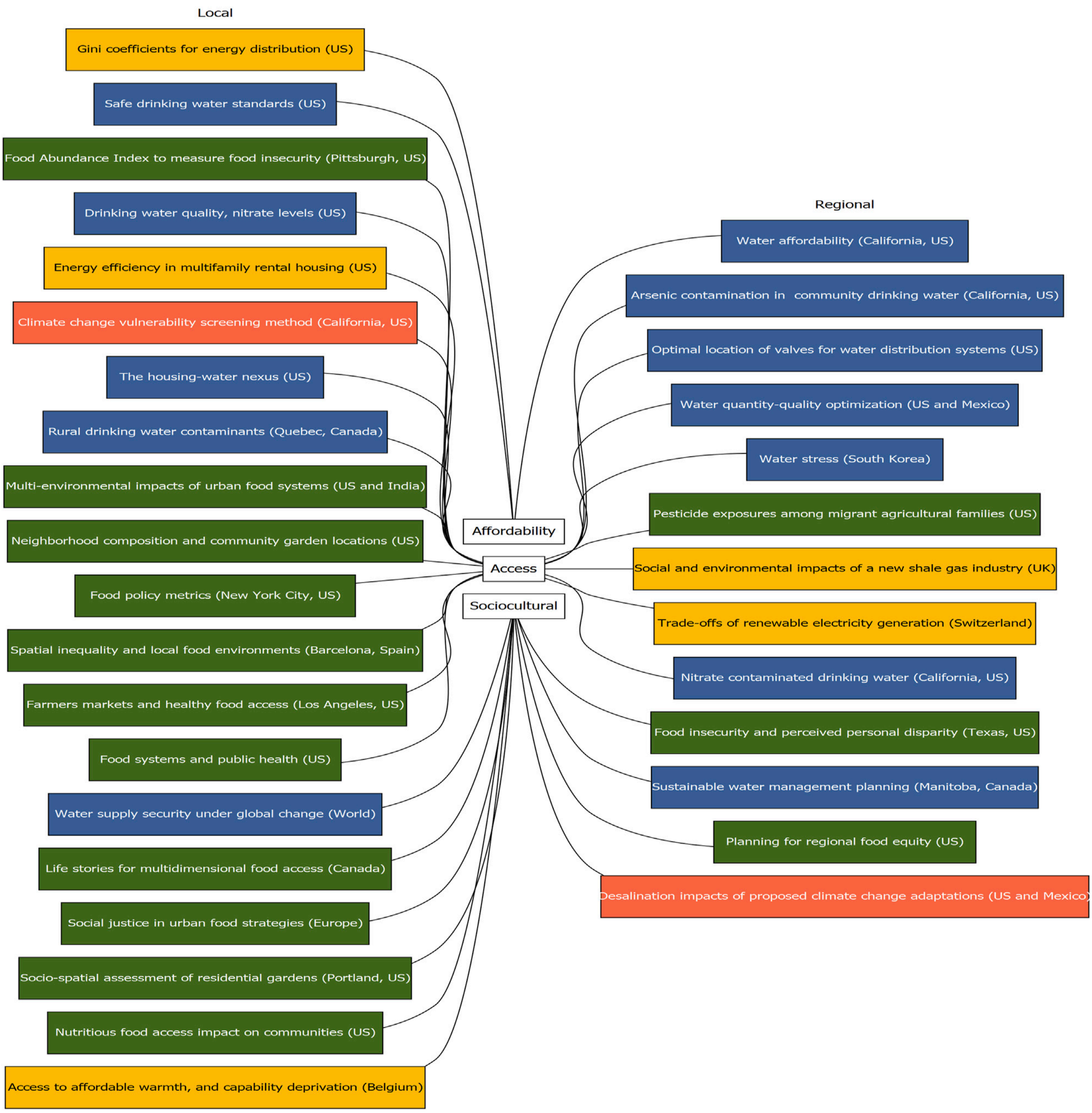

FIGURE 5
Local- and regional,-scale study topics, locations and interactions by type of equity integration (affordability, access, sociocultural). The colors in this figure follow those in Figure 3 and Figure 4: Green denotes food articles, yellow denotes energy articles, blue denotes water articles, and orange denotes nexus articles.

3.5 Relationship between scale and FEWS equity

Differences between where FEWS resources originate and how they are produced or converted have implications for the appropriate scale used to study social equity. Food system studies in our literature review included trade occurring at local to global scales. Energy systems were primarily studied regionally based on the electricity plants themselves; however, climate change impacts associated with the production and distribution of energy are global. Water systems were studied at the local (community water treatment plant) or regional (water source or watershed) scales and included water security metrics such as water use reduction and desalinization. Nexus articles most often studied equity in FEWS at the national scale and focused on environmental or ecosystem impacts of equitable systems.

Overall, the majority of studies assessed FEWS equity at local and regional scales, indicating that localized FEWS governance heavily influences equity outcomes. Local and regional studies were more likely to capture household-level nuances related to equity of access and sociocultural barriers to reduce inequities (Figure 5). For example, Meehan et al. (2020) found disparities in access to household plumbing between renters and homeowners, highlighting the need for policy coordination between city and state governments to address inadequacies in infrastructure and housing stock.

While energy and water systems are often inherently local, elements that influence equity in food systems also require consideration at smaller scales, such as cultural preferences and distance from sources of healthful foods. The underrepresentation of nexus studies at local and regional scales points to a lack of integrated FEWS planning tools for local governance. Careful selection of appropriate scale and further development of localized nexus tools could help bridge the gap between the nexus as a concept and implementation of solutions to address FEWS equity. By examining decision-making and policy implications for FEWS equity studies, pathways to address these challenges across scale can come to light.

4 Discussion

This review focused on how equity was studied across the FEWS nexus with an emphasis on opportunities for future research and improved governance. We found differences between the systems and the scale at which they were studied that have implications for decision-making and policy development. Furthermore, the strong connections to sustainable development concepts and major emphasis on climate change offers insights into how social elements of risk and vulnerability can be incorporated into future FEWS resource planning. However, many of the studies we reviewed lack comprehensive integration between respective FEW systems, which limits understanding of how system intersections affect social equity. Additionally, the FEWS lens can obscure the complexities of respective systems in favor of broad-scale resource planning and allocation. This deficit leaves opportunities for future research to understand methods for the holistic inclusion of equity within the FEWS framework. While the approach taken in this review is not an exhaustive study of social equity, our findings can help to inform a more comprehensive understanding of social equity in the context of FEWS governance and address current research gaps.

4.1 Decision-making and policy implications

Although the articles we reviewed covered a wide range of topics and drew ideas from around the world, the FEWS nexus also spans many intersecting scales (geographic, temporal, political, institutional). This breadth presents a unique challenge for analyzing or improving FEWS, as implications or negative impacts often do not correspond to political or geographic boundaries (e.g., hypoxia, acid rain). In the United States, there are critical federal funds and policies implemented nationwide to address environmental challenges across local and state boundaries (Farm Bill, Clean Energy for America Act, and the Clean Water Act). However, most food, energy and water systems are administered at smaller decision-making scales, such as at the city scale for urban spaces (Newell et al., 2019).

Many countries included in this assessment have a free-market food system (private companies/entities distributing food to consumers). In contrast, water and electricity distributed to consumers are generally government-owned or regulated utility companies that are, in some cases, obligated to provide information to government agencies and researchers (e.g., United States EPA Safe Drinking Water Information System, Residential Energy Consumption Survey). These differences in distribution channels have unique social equity implications. For example, consumers may be able to travel to obtain food from several nearby grocery stores based on cost, personal choice, and convenience, whereas many consumers do not have choices about sources or quality of energy or water in a given location. Energy markets from sustainable sources (wind or solar) are becoming more common across the United States but are not the norm for most households (Alola and Yildirim, 2019). Unlike food availability, both energy source options and water quality are usually tied to housing locations.

Context-specific (place-based) studies are of particular value and can inform sound decision-making across FEWS (White et al., 2017). Framing FEWS equity findings in terms of governance is a pathway toward practical analyses (Newell and Ramaswami, 2020). Food systems were the only focus area where an evaluation of city plans or self-assessments from food policy councils were used as proxies to assess the food system without validation to confirm their impacts (Calancie et al., 2018; Mui et al., 2020). Relying on plans and self-assessments can also be problematic because many city plans and pledges are voluntary (MUFPP, 2015). Yet, the interactions between FEWS resource planning and policy are also consequential for equity planning in these sectors (White et al., 2017). Linking sustainable FEWS development to research informed by local stakeholders is vital to finding solutions that hold up under realistic conditions (D'Odorico et al., 2018). These findings highlight the likelihood of increased inequity across FEWS without substantial social investments in infrastructure, welfare, and new technologies.

4.2 FEWS equity connection to sustainable development

Many of the FEWS studies we assessed expressed their equity analyses within the broader construct of sustainable development (e.g., Kim et al., 2018; Zurek et al., 2018; Smaal et al., 2020). Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). The 2030 Agenda for Sustainable Development created sustainable development goals (SDGs) and provided a framework in which FEWS goals (zero hunger, affordable and clean energy, and clean water and sanitation systems) can be tracked together with equity goals (reduced poverty, good health and wellbeing, reduced inequalities, sustainable cities and communities, and climate action) (United Nations, 2020). This agenda was often used to assess FEWS, such as in the index developed by Schlör et al. (2018), which offers novel insights into equity synergies and tradeoffs.

The stated purpose of the FEWS nexus, according to one review, was to inform decision-making for sustainable population and economic growth (Kaddoura and El Khatib, 2017). All FEWS studies are directly or indirectly connected to sustainability principles (Sodiq et al., 2019). However, for this approach to be an effective tool for sustainable development or poverty alleviation, research should be conducted within an environmental justice framework and explicitly identify winners and losers (Biggs et al., 2015). Combining the triple-bottom-line approach to incorporate environmental, economic, and social goals with the U.N. Sustainable

Development Goals (SDG) framework could offer a way to merge biophysical systems with human wellbeing (White et al., 2017; Proctor et al., 2021). For example, the New Urban Agenda set targets for SDG 11 (focused on urban development) and could support development of these integrated policies (Romero-Lankao and Gnatz, 2019). Sustainable development in FEWS must integrate these three vital resource systems and relevant science, technology, environmental, and socioeconomic systems (Sodiq et al., 2019). For effective decision-making, diverse (by knowledge, experience, and values) stakeholders should be involved in the governance of these systems to mitigate risks (Dobbie et al., 2018). Without equity and other vital social dimensions, the FEWS framework would not be an effective tool for sustainable development.

4.3 FEWS equity in a changing climate

More than a fifth of the papers reviewed (n = 11) explicitly focused on the effects of climate change on FEWS resources. Most of these papers discussed the intersection of emissions goals and social equity (e.g., Rozenberg et al., 2014; Bartiaux et al., 2018; Tomás et al., 2020). For example, Chakravarty and Tavoni (2013) found that global energy poverty could be reduced substantially without impairing climate goals via targeted policy initiatives. Global energy use produces significant greenhouse gas emissions, thereby accelerating climate change and impacting precipitation and temperature (IPCC, 2018). Although energy conversion is directly connected to climate change, food and water provisioning systems are also highly energy intensive. In the United States, food systems account for 14%–19% of total energy use (Canning et al., 2017). Furthermore, water supply efforts under changing weather regimes can lead to increased emissions and uneven social impacts, as shown in a 2012 case study of a proposed binational desalination plant near the United States and Mexico border (McEvoy and Wilder, 2012). These interactions across the FEWS nexus cumulatively increase climate change impacts more than individual systems do.

The FEWS lens has been discussed as a potential method for viewing challenges in a changing climate (Proctor et al., 2021). However, to be sustainable, approaches must account for increased social vulnerability and inequity due to unequal climate risk and the ability to mitigate environmental hazards (Romero-Lankao and Gnatz, 2019; Sasse and Trutnevyte, 2019). Shared socioeconomic pathways have been developed to connect biophysical systems to sociopolitical decisions to show how both shape future climate change impacts (Riahi et al., 2017). The degree to which an individual or community is vulnerable to risks associated with climate change depends on their capacity to adapt to changing conditions, with notable disparities observed based on race/ethnicity and socioeconomic status (English et al., 2013). For example, in the United States, individuals who identify as People of Color often have increased vulnerability to climate change, especially those who identify as Black or African American (EPA, 2021). Although social impacts are unequal, mitigating climate change through effective FEWS management is not charity; it invests in our shared future (Robinson and Shine, 2018).

Even as calls for urban ecological modernization encourage approaches that equally weigh social equity, green living environments, and job creation, equity considerations are not often treated as an equal concern (Sodiq et al., 2019). For example, despite widely accepted social vulnerability literature that connects social inequalities to increased climate risk and vulnerability, social equity is seldom part of climate change adaptation plans (Romero-Lankao and Gnatz, 2019). The FEWS nexus research we reviewed lacks explanations of interactions between these FEWS components, despite their inextricable links across scales (Endo et al., 2017). Some cities choose to confront less complex challenges than social equity to avoid plans that conflict with economic and climate change mitigating priorities, disregarding the potential for mutually beneficial synergies (Romero-Lankao and Gnatz, 2019).

4.4 Research gaps and future directions

Although we searched for articles focused on the FEWS nexus, these made up a relatively small proportion (n = 6) of all articles compared to those in which each system was studied individually, showing a lack of integration across FEWS at this time. Further, many articles (n = 16) initially collected referenced equity as a vital FEWS issue but had to be excluded from our review because they did not incorporate an analysis of equity. The lack of comprehensive FEWS studies incorporating equity leaves a large gap in understanding the effect of interactions between the systems and appropriate methods of study. Future research could focus on case studies of FEWS at varying scales emphasizing how reciprocal feedback impacts social equity outcomes.

While food system studies comprised the largest group of articles assessed in this literature review, many studies did not incorporate critical social and economic dimensions of food insecurity (Ong et al., 2021). Rather, they relied on spatial proximity data such as distance to grocery stores or community gardens as a measure of food system equity, despite evidence that food deserts do not capture sociocultural barriers to food access or preference in the United States (Sullivan, 2014; Usher, 2015). The use of proximity data could be due to the lack of robust and publicly-available food system data at functional scales in the United States, which may be a factor in the relatively large number of qualitative studies. A challenge in collecting food system data is that distribution channels are unlike energy and water systems where resources are often supplied to households via a publicly owned utility compelled to publish data. Future research to develop transparent and publicly-accessible United States food system datasets across scales would facilitate more robust analyses and better inform FEWS governance.

Within energy systems, there were few studies of the association between proximity to fuel refineries or energy conversion facilities and associated health concerns due to contaminated air or water. Marginalized communities historically have had lower political capital, leaving them unable to prevent the construction of refineries or power plants in their neighborhoods (Kaswan, 2009). Moreover, a lack of financial capital to move away from sources of harmful pollutants results in individuals within these communities experiencing intergenerational impacts of chronic exposure (Hajat et al., 2015; O'Brien et al., 2018). Also missing were studies focused on equity concerns centered around "green energy" conversion technologies, such as wind turbines and electric cars, which require rare earth elements. Mining rare earth elements can produce toxic and radioactive mine tailings that contaminate surface and groundwater (Filho, 2016). Finally, an additional crucial element related to equity and energy is the generation of nuclear power and the associated risks to communities near the reactors or their waste products (Kyne and Bolin, 2016). Future research to address these concerns may investigate whether the FEWS framework can be applied to find solutions that meet increasing energy demands while preventing exposures to toxic byproducts from energy facilities.

Elements of water system equity missing from the reviewed publications were related to water quality, flooding, and the impact of agricultural production on water resources. For example, the catastrophic lead exposure in Flint, MI reflects a widespread problem of environmental injustice that minority and marginalized communities face in obtaining clean drinking water that was not represented in the FEWS studies we reviewed (Wright et al., 2003; Flint Water Advisory Task Force, 2016; Sampson and Winter 2016). Flood risk and recovery were missing from the studies we reviewed but can also inequitably affect certain communities, such as United States Hispanic populations in or near 100-year flood zones (Maldonado et al., 2016), who also experience reduced monetary compensation for homes lost to catastrophic flooding (Muñoz and Tate, 2016). Additionally, our review lacked analyses that directly addressed the linkage between water quality and food systems—such as contamination of water supplies by farm chemicals. In the United States surface waters were found to be contaminated with pesticides in up to 10% of tested samples (Gilliom et al., 2006), and similar studies in Denmark found widespread contamination from herbicides and insecticides with concentrations up to twice the allowable amount in all sampled locations (McKnight et al., 2015). These gaps may be addressed by connecting the well-established field of environmental justice to the FEWS framework, which could provide many established methods and analysis tools for considering equity.

5 Conclusion

Social equity in FEWS was integrated into studies through affordability, access, and sociocultural elements. This framework could help researchers and practitioners consider which method of equity integration best suits their FEWS analysis based on study objectives, data availability, and scale. Additionally, we found a lack of tools for context-specific, integrated analyses of how the FEWS nexus intersects with social equity. However, implementation of local FEWS planning and governance provides a practical application for the nexus concept that can identify and address equity issues. Further exploration of equity issues identified as gaps in this review, along with additional validation of methods to assess equity in FEWS using a variety of data types (quantitative and qualitative), are important next steps. An analysis to understand FEWS equity issues in countries with lower HDI values would also be of great value to effectively incorporate equity into FEWS analyses worldwide.

Ultimately, climate change is projected to increase risks for vulnerable populations due to scarcity of FEWS resources and greater environmental hazards caused by changing weather patterns. Climate change impacts are connected to social equity and can reduce sustainable development at all scales because resource-poor individuals, communities, and countries will not have equal or sufficient capacity to adapt. Further exploration of FEWS governance, policy options, and social investments are necessary to reduce FEWS poverty and increase social equity given a changing climate.

Author contributions

TS, LD, and HS contributed to conception and design of the study and completed all aspects of analysis for the systematic literature review. TS wrote the first draft of the manuscript, while LD and HS wrote sections of the manuscript. TS, LD, and HS created tables and figures. All authors contributed to manuscript revision and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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