



OPEN ACCESS

EDITED BY

Albie F. Miles,
University of Hawaii–West Oahu,
United States

REVIEWED BY

Michelle Miller,
University of Wisconsin–Madison,
United States
Celian Colon,
International Institute for Applied Systems
Analysis (IIASA), Austria

*CORRESPONDENCE

Shahadat Hossain
✉ shahadat@ksu.edu

RECEIVED 31 January 2025

ACCEPTED 15 August 2025

PUBLISHED 01 September 2025

CITATION

Hossain S and Kashem SB (2025)
Transportation resilience and food security:
developing a conceptual framework through
literature review.
Front. Sustain. Food Syst. 9:1569474.
doi: 10.3389/fsufs.2025.1569474

COPYRIGHT

© 2025 Hossain and Kashem. This is an
open-access article distributed under the
terms of the [Creative Commons Attribution
License \(CC BY\)](#). The use, distribution or
reproduction in other forums is permitted,
provided the original author(s) and the
copyright owner(s) are credited and that the
original publication in this journal is cited, in
accordance with accepted academic
practice. No use, distribution or reproduction
is permitted which does not comply with
these terms.

Transportation resilience and food security: developing a conceptual framework through literature review

Shahadat Hossain* and Shakil Bin Kashem

Department of Landscape Architecture and Regional and Community Planning, Kansas State University, Manhattan, KS, United States

Ensuring food security depends heavily on the resilience of transportation networks, which are vital for the consistent distribution and accessibility of food. Disruptions to these networks, whether caused by natural disasters, structural failure, or other crises, can significantly impair food availability, accessibility, and affordability, exacerbating food insecurity. Despite the critical role of transportation systems, existing research often overlooks the nuanced relationship between transportation resilience and food security. This review paper addresses this gap by thoroughly examining the structural and functional components of resilient transportation systems and their direct influence on food security. Findings from the literature highlight the critical role of robust infrastructure, social equity and governance, redundancy and adaptive capacity for maintaining stable food supply for all communities during disruptions. Through a systematic literature review, we propose a conceptual framework that integrates transportation system components, resilience indicators, and food security outcomes, demonstrating how collectively considering these key elements within specific local and regional context can enhance food security and reduce vulnerability to crises. The framework offers valuable insights for planners and policymakers, suggesting targeted strategies to improve transportation resilience and, by extension, food security. By adopting this integrated approach, cities can better prepare for and recover from disruptions, ensuring sustainable development and resilience in the face of growing global challenges.

KEYWORDS

transportation resilience, food security, natural hazards, resilience planning, transportation planning

1 Introduction

Food security, defined by the Food and Agriculture Organization (FAO) as the availability, access, usage, and stability of food for all people at all times (FAO, 2006), continues to be a cornerstone of sustainable development. However, ensuring food security has become more difficult due to disruptions in global and local food supply networks caused by natural catastrophes, structural failures, sociopolitical conflicts, and pandemics (Gray and Torshizi, 2021; Peng et al., 2024). The COVID-19 pandemic revealed substantial vulnerabilities in agricultural logistics and food supply chain across North America and Europe, resulting in disruptions that disproportionately affected vulnerable groups (Kashem et al., 2021; Hobbs, 2020; Wei et al., 2024). Transportation resilience, on the other hand, refers to a system's overall ability to endure, adapt to, and recover from disturbances while providing important services on many scales, from local to global networks (Moynihan et al., 2022; Raub et al., 2021). This complex notion brings together physical infrastructure durability, operational adaptability,

institutional coordination, and technological innovation (Davies et al., 2021). Here, we use the term infrastructure to refer broadly to physical facilities and networks (e.g., roads, bridges, railways) that enable transportation and distribution functions. Modern resilient transportation systems are distinguished by strong infrastructure design, network redundancy, fast recovery mechanisms, and advanced monitoring capabilities that allow for proactive responses to emerging threats (Alataş and Arslan, 2024; Sullivan and Novak, 2024). These systems must also ensure social equality, environmental sustainability, and economic efficiency while responding to dynamic problems such as climate change, urbanization, and technology innovation (Delgado et al., 2023; Wang et al., 2023). The importance of transportation resilience has grown in recent years as natural disasters, geopolitical tensions, and public health emergencies put increased pressure on global and local supply chains, emphasizing the necessity for integrated system design, community engagement, and adaptive management techniques (Hossain et al., 2023; Lloyd et al., 2024).

Transportation networks always play a critical role for food supply chains, carrying food from farm to table. These networks not only facilitate the physical movement of food, but they also contribute significantly to market integration and price stability (Brown et al., 2017). Studies using food access indices such as the Emergency Food Access Index (EFAI) have shown that transportation accessibility has a direct impact on food security outcomes in urban areas across the United States, particularly for vulnerable groups (Clark et al., 2024). Natural disaster-related disruptions in transportation infrastructure can quickly isolate populations from crucial food supply (Zeuli et al., 2018). The intensification of climate-related phenomena poses major risks to transportation infrastructure. Storms and increasing sea levels pose a combined threat to the food, energy, water, and transportation infrastructure in coastal communities across the United States (Raub et al., 2021; Romero-Lankao et al., 2018). Studies on urban floods show how extreme weather events might cut off access to key services such as food distribution facilities (Loreti et al., 2022). These consequences go beyond immediate infrastructure damage, causing cascading repercussions throughout the food chain, particularly in urban low food access and low-income neighborhoods.

Infrastructure inequity and the political economy of food distribution system can also exacerbate the link between transportation and food security. While affluent regions frequently have strong infrastructure, inequitable resource allocation can lead to infrastructure vulnerability, particularly in rural and politically disenfranchised areas (Rijsberman, 2017). This pattern is found in both Global North and South, ranging from Indigenous settlements in the Arctic confronting high transportation costs to urban low food access areas in major American cities (Childs and Lewis, 2012; Davies et al., 2021). Infrastructure for global trade routes add another degree of complexity, as agricultural export hubs rely on ports and trade corridors for food distribution (Neustroeva and Shishigina, 2022). Chokepoints in global food trade pose serious threats to food security because they are especially vulnerable to congestion, natural disasters, and geopolitical conflicts (Touili, 2021; Wellesley et al., 2017).

Technological innovation provides opportunity for logistics optimization, but adoption varies by location (Zimmerman et al., 2018). In the United States and Europe, current supply chain advancements, such as connected and autonomous vehicles (CAVs), have the potential to transform food transportation efficiency (Zhao and Lee, 2023). The combination of modern geospatial tools with

optimization-based contingency techniques has allowed for more exact targeting of infrastructure investments (Ribeiro, 2024; Santos et al., 2024). Use of technology for community-based solutions has also evolved as useful tactics. For example, volunteer-driven food delivery models in Houston during the COVID-19 pandemic revealed how crowdsourced logistics can improve community resilience (Bella et al., 2024).

Despite extensive study on food security and transportation systems separately, there is still a significant knowledge gap in comprehending their dynamic interactions, especially in the presence of numerous concurrent stressors. While studies have investigated specific areas like supply chain interruptions and infrastructure challenges, there is a notable lack of a holistic framework that connects transportation resilience and food security outcomes in literature. Such framework can help to better understand and evaluate the complex interplay of urbanization, climate change, and socioeconomic inequities that characterize modern food systems. This review seeks to develop a framework that synthesizes ideas from existing literature to investigate the complex relationship between transportation resilience and food security at various spatial and temporal scales. Through a systematic literature review, we create a conceptual framework that integrates governance, equity, and sustainability principles, providing policymakers, urban planners, and stakeholders with holistic guidance for developing resilient and equitable food systems that can withstand future challenges.

In this study, we specifically focus on the resilience of transportation systems to various disruptions such as natural disasters, extreme weather events, and socio-political shocks and their effects on food security outcomes. Here, “resilience” refers to a system’s capacity to adapt and recover, which overlaps with “robustness,” referring to a system’s inherent resistance to disturbances, and “efficiency,” that relates to optimal performance during normal conditions (Carpenter et al., 2001; Jenelius and Mattsson, 2021). The proposed framework is designed to be broadly applicable in different contexts recognizing the differences in context-specific challenges. For example, urban areas often face challenges such as market accessibility and last-mile distribution, while rural regions typically encounter infrastructure gaps, long supply routes, and higher risks of isolation. We focused on developing a framework that is adaptable to diverse contexts.

2 Study method

In this study, we applied a systematic literature search and review approach to explore the interplay between food system and transport resilience. This literature review guided us to the proposed framework discussed later in the paper. In this section we discuss our literature selection process and provide a brief overview of the selected literature.

2.1 Literature selection

For this systematic literature review, we carried out searches across two major academic databases: Web of Science and Scopus. We specifically searched for case studies that explored both transportation resilience and urban food system. To ensure comprehensive coverage, a carefully constructed Boolean search string

was applied combining three key components: transportation terms (“transport* system*”, “transport* network*”, “transport* infrastructure”), resilience concepts (resilien*, robust*, vulnerab*, adapt*, “disaster recovery”, “emergency response”), and food security aspects (“food security”, “food system*”, “food supply”, “food access*”, “food distribution”, “food availability”, “food afford*”). We used OR operator within the components to capture all possible alternatives and used the AND operator between these three components to ensure that retrieved articles addressed all three thematic areas (transportation, resilience, and food security) simultaneously, rather than any of them in isolation. We initially found 134 studies through this search method (62 from Web of Science and 72 from Scopus). After a thorough screening process (as explained below) and removing the duplicate studies, we selected 45 studies for this review. Figure 1 shows our literature selection process. Our screening procedure for literature selection was directed by three major sets of criteria: relevance, quality, and scope.

In the relevance criteria we evaluated whether the study focused on the relationship between transportation systems/networks and food security, discussed resilience, vulnerability, or adaptability in transportation contexts, and provided substantive coverage of food

system components. While our search strategy ensured that all retrieved studies touched on transportation, resilience, and food security keywords, we acknowledge that not every selected study fully integrates all three themes in equal depth. Quality requirements prioritized peer-reviewed journal articles with clearly articulated methodology and empirical findings and published in English language. The scope criteria comprised original research articles and case studies with applicable insights. This methodical screening process resulted in a final list of 45 articles that included a variety of methodological approaches, geographical contexts, and analytical frameworks, ensuring a thorough and comprehensive literature review. The majority of our reviewed articles were published in the last few years, as illustrated in Figure 2. The predominance of recent studies reflects the emerging and rapidly growing academic interest in the intersection of transportation resilience and food security, particularly following recent global disruptions caused by the COVID-19 pandemic, extreme climatic events, and geopolitical tensions.

2.2 Profile of selected literature

2.2.1 Geographical distribution

The geographic distribution of selected literature reveals some regional patterns on study focus, with studies on North America and Asia contributing substantially to literature focusing on resilience and supply chain innovation, respectively (Table 1). Studies on European cities and regions demonstrates a distinct focus on infrastructure optimization and policy frameworks, while studies on African countries provide crucial insights into rural accessibility challenges. Several studies also cover multiple countries and regions (identified as “global studies” in Table 1), which help to understand trade dynamics and systemic resilience by providing a more comprehensive perspective on interconnected transportation networks across regions.

2.2.2 Methodological approaches

Our reviewed studies employed diverse methodological approaches (Table 2). We found a significant variation in data sources and collection methods, reflecting the complex nature of transportation resilience and food security research. While quantitative studies predominantly relied on large-scale datasets and governmental statistics, qualitative research provided crucial contextual insights through stakeholder engagement and field observations. For example, as shown in Table 2, Santos et al. (2024) and Sullivan and Novak (2024) investigated system vulnerabilities and performance metrics using quantitative techniques such as network optimization and statistical modeling. On the other hand, Neustroeva and Shishigina (2022) and Vahabi and Damba (2013) used qualitative methods such as interviews and focus groups to investigate stakeholder viewpoints and cultural aspects.

2.2.3 Data sources and quality

The quality of data is a critical factor in research reliability. Studies employing primary data collection methods often face challenges in sample representativeness and data consistency, particularly in resource-constrained environments (Wang et al., 2023). However, these limitations can be offset by the richness of contextual information obtained. Secondary data sources, while offering broader

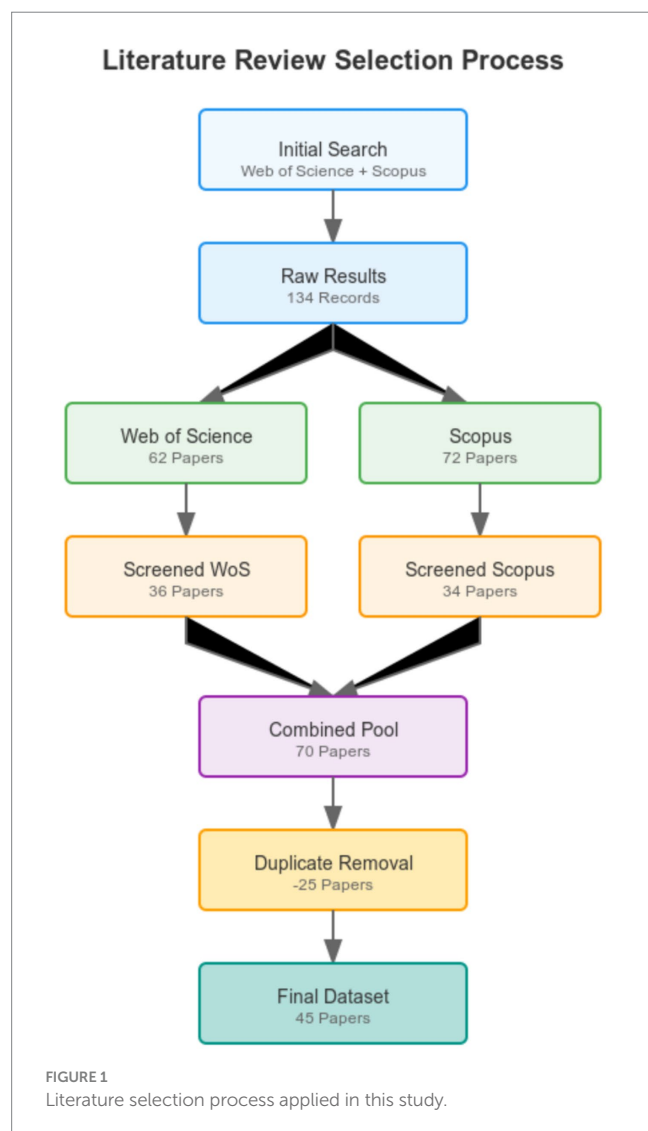




TABLE 1 Distribution of selected studies.

Region	Number of studies	Key studies	Primary focus
North America	13	(Clark et al., 2024; Zeuli et al., 2018)	Urban resilience, technology integration
Europe	8	(Agnusdei et al., 2022; Kolodiichuk et al., 2023)	Infrastructure optimization, policy frameworks
Asia	11	(Yang and Xu, 2015; Zhang et al., 2023)	Supply chain innovation, disaster recovery
Africa	9	(Achilana et al., 2020; Codjoe and Owusu, 2011)	Rural accessibility, market integration
Global studies	4	(Awokuse et al., 2024; Wellesley et al., 2017)	Trade dynamics, systemic resilience

TABLE 2 Research methods and applications.

Method type	Tools/techniques	Key findings	Key studies
Quantitative analysis	Network optimization, statistical modeling	System vulnerabilities, performance metrics	Santos et al. (2024), Sullivan and Novak (2024)
Qualitative studies	Interviews, focus groups	Stakeholder perspectives, cultural factors	Neustroeva and Shishigina (2022), Vahabi and Damba (2013)
Mixed methods	Surveys + GIS analysis	Integrated assessment frameworks	Wang et al. (2023), Zeuli et al. (2018)
Case studies	Field observations, document analysis	Context-specific solutions	Bella et al. (2024), Zhang et al. (2023)

coverage, sometimes present challenges in terms of data accuracy and standardization across different regions (Wei et al., 2024). Tables 3, 4 show the variations in data collection approaches, methods, sources, and quality metrics of the reviewed articles. For example, as shown in Table 3, Achilana et al. (2020) and Codjoe and Owusu (2011) conducted household surveys to measure food access difficulties, providing significant contextual insights despite sample size limits. In contrast, Table 4 highlights research such as Clark et al. (2024) and Yang and Xu (2015), which used national databases for policy analysis,

benefiting from comprehensive coverage but facing challenges such as outdated or inconsistent data.

Publicly available data sources relevant to this topic include national agricultural production datasets, global trade flow databases, national transportation infrastructure inventories, and open geospatial datasets such as OpenStreetMap. Despite these resources, substantial data gaps remain, particularly around seasonality effects on food supply and trade flows, detailed financing information related to transport infrastructure and supply chain logistics (including stock

TABLE 3 Primary data sources and quality assessment.

Data type	Collection method	Quality metrics	Key insights	Studies
Household surveys	Field interviews, questionnaires	Sample size, response rate	Direct assessment of food access challenges	Achilana et al. (2020), Codjoe and Owusu (2011)
Stakeholder interviews	Semi-structured interviews	Interview depth, participant diversity	Policy implementation insights	Neustroeva and Shishigina (2022), Vahabi and Damba (2013)
Field observations	Direct observation, documentation	Observation duration, coverage	Real-time system dynamics	Bella et al. (2024), Zhang et al. (2023)
Market assessments	Price tracking, supply monitoring	Data frequency, market coverage	Price volatility patterns	Sanogo and Maliki Amadou (2010), Wang et al. (2023)

TABLE 4 Secondary data sources and characteristics.

Data category	Source type	Reliability metrics	Application	Key studies
Government statistics	National databases	Data currency, completeness	Policy analysis	Clark et al. (2024), Yang and Xu (2015)
GIS data	Spatial databases	Resolution, coverage	Network analysis	Ribeiro (2024), Zeuli et al. (2018)
Trade data	International organizations	Standardization, consistency	Global patterns	Wei et al. (2024), Wellesley et al. (2017)
Climate records	Environmental agencies	Temporal coverage, accuracy	Risk assessment	Loreti et al. (2022), Touili (2021)

financing and insurance), and high-resolution data on localized, short supply chain (farm-to-fork) models.

2.2.4 Analytical techniques

Studies on transport resilience and food security, as reviewed in this study, applied a diverse range of analytical techniques, reflecting the multidimensional nature of this research domain (Table 5). While quantitative methods dominated in infrastructure and network analysis, qualitative approaches provided essential insights into social dynamics and policy implementation.

As shown in Table 5, the integration of analytical methodologies across the studied literature yielded numerous notable findings. Studies that used various analytical methodologies consistently yielded more robust results. For example, Zeuli et al. (2018) illustrated the need of combining geographical analysis with stakeholder insights to create comprehensive vulnerability assessments. This tendency toward methodological integration has grown significantly in recent years, with research from 2020 to 2024 indicating growing use of advanced computational methods, particularly in optimization and simulation techniques (Lin et al., 2023; Santos et al., 2024). The analysis also emphasized the significance of context sensitivity in methodological decisions. Studies conducted in resource-poor countries frequently used novel combinations of simple but effective procedures that were tailored to local skills and data availability constraints. For example, Achilana et al. (2020) utilized survey data collected through structured questionnaires administered before and after the harvest season, coupled with binomial regression analysis, for their study on two economically distinct districts in Tanzania. However, integration issues persisted, particularly in policy-oriented research where the effective coupling of modern analytical methodologies and qualitative

insights remained difficult (Neustroeva and Shishigina, 2022; Rijsberman, 2017).

We identified several significant methodological patterns in our reviewed literature. In recent years, there has been a rising emphasis on advanced computational methods, as well as enhanced integration of stakeholder viewpoints with technical assessments. Notable advances have emerged in tackling data restrictions, particularly in developing countries, resulting in the development of alternative analytical frameworks that attempt to incorporate numerous methodologies. Wang et al. (2023), for example, addressed data limitations in Zambia by examining the effects of transportation upgrades on agricultural supply chains using district-level trade data and GIS modeling. This methodological diversity has allowed studies to examine transportation resilience and food security in a variety of contexts and sizes. The next section discusses the key themes emerged from the literature we reviewed in this study.

3 Thematic literature review

This section synthesizes and summarizes previous studies into cohesive themes or patterns, providing a systematic examination of the links between transportation network resilience and food security outcomes. This thematic review helps to identify the complex mechanisms by which transportation systems influence food availability, accessibility, and affordability. It uncovers trends and interconnections across settings, providing insights into how transportation resilience influences food security outcomes at various dimensions and locations. We identified five broad themes in our reviewed literature as discussed below.

TABLE 5 Tools and techniques.

Analysis type	Tools/software	Key applications	Outcomes	Key studies
Spatial and network analysis techniques				
GIS modeling	ArcGIS, QGIS	Infrastructure mapping	Vulnerability hotspots	Ribeiro (2024), Zeuli et al. (2018)
Network analysis	NetworkX, GRASS	Accessibility assessment	Critical nodes	Clark et al. (2024), Sullivan and Novak (2024)
Remote sensing	Sentinel, MODIS	Environmental monitoring	Risk patterns	Loreti et al. (2022), Wei et al. (2024)
Method	Application	Key variables	Findings	Key studies
Statistical and mathematical methods				
Regression analysis	Impact assessment	Infrastructure indicators	Correlation patterns	Agnusdei et al. (2022), Blimpo et al. (2013)
Time series analysis	Trend identification	Temporal variations	Seasonal effects	Wei et al. (2024), Yang and Xu (2015)
Multivariate analysis	Pattern recognition	System components	Factor interactions	Peng et al. (2024), Santos et al. (2024)
Technique	Purpose	Model features	Outcomes	Key studies
Advanced modeling and simulation approaches				
Optimization	Route planning	Cost minimization	Efficiency gains	Lin et al. (2023), Zhao and Lee (2023)
System dynamics	Behavior simulation	Feedback loops	System responses	Moynihan et al. (2022), Zhang et al. (2023)
Risk modeling	Vulnerability assessment	Risk factors	Mitigation strategies	Kolodiichuk et al. (2023), Touili (2021)

3.1 Infrastructure resilience and accessibility

Transportation infrastructure is the backbone of a strong food supply chain, allowing efficient transit from producing locations to consumers. Research regularly shows that infrastructure quality has a major impact on food security outcomes in a variety of scenarios. For example, poor road conditions in Sub-Saharan Africa exacerbate food insecurity, disproportionately harming vulnerable populations (Brown et al., 2017). Similarly, Ghana's Afram Plains suffer major market access issues due to insufficient feeder roads, resulting in economic losses for farmers and increased food costs for consumers (Codjoe and Owusu, 2011). Studies on developed countries also show the importance of infrastructure quality in ensuring food accessibility. For example, Sullivan and Novak (2024) present a case study in Vermont focusing on the Bradford Area Circulator transit service, revealing how inadequate infrastructure frequently creates critical bottlenecks during emergencies while assessing food accessibility for socially vulnerable populations in rural areas. Similarly, Kolodiichuk et al. (2023) evaluate Ukraine's transportation and logistics systems, demonstrating how geopolitical tensions and poor infrastructure impede transit efficiency and jeopardize food security.

In urban context, redundancy in transport infrastructure is shown to improve food accessibility. Through their case study on Toronto, Canada (Zeuli et al., 2018) shows the benefits of infrastructure redundancy in reducing food distribution risks during extreme weather events, with investments in alternative transportation routes

and emergency preparedness. These findings underscore the importance of redundancy and interconnection in increasing transportation resilience.

3.2 Climate change and disaster resilience

Besides the quality of transport infrastructure, disruptions caused by natural hazards and climate change induced extreme weather events are putting transportation networks and food security at risk. For example, flooding frequently isolates rural populations in Nepal, preventing them from reaching important markets and worsening food insecurity (Sanogo and Maliki Amadou, 2010). Similar pattern emerged in Toronto, Canada, where studies examining the impacts of ice storms and heatwaves emphasizes the importance of including transportation resilience into larger urban planning frameworks (Zeuli et al., 2018). Loreti et al. (2022) show how floods severely impair urban road network serviceability, isolating populations from critical services in specific communities in Switzerland. Furthermore, maritime chokepoints in global food traffic, such as the Panama Canal and the Strait of Hormuz, are extremely vulnerable to both natural disasters and geopolitical conflicts, resulting in food supply disruptions and price volatility. The 2016 El Niño event caused depth limits in the Panama Canal due to low water levels, while sandstorms and high winds impacted the Suez Canal and Turkish Straits (Wellesley et al., 2017).

Considering the disruptions caused by natural hazards, studies have proposed solutions to improve adaptation and resilience. Adaptation solutions, such as climate-resilient road designs and renewable energy-based logistical systems, are increasingly seen as critical. The United States Food, Energy, and State Transportation (US-FEAST) model, developed by Moynihan et al. (2022), highlights the value of integrated frameworks for identifying vulnerabilities and improving supply chain resilience under stress. According to Wei et al. (2024), despite early disruptions caused by the COVID-19 pandemic, global agricultural trade displayed resilience by restructuring trade flows and using existing redundancies. Although not directly tied to climate change or natural hazards, this example emphasizes the necessity of considering all sorts of disruptions, whether biological, economic, or environmental, when assessing the resilience of any food systems.

3.3 Technological innovations and system optimization

Emerging technologies have the potential to significantly increase food security through technological innovations and transport system optimization. Zhao and Lee (2023) show how connected and autonomous vehicles (CAVs) can boost supply chain efficiency, shorten transit times, and minimize transportation costs in fresh produce supply chains. Innovations in real-time tracking systems have also shown to reduce delays, while predictive analytics enable proactive disruption response (Zimmerman et al., 2018).

System optimization within the existing transportation infrastructure and the use of machine learning approach can also assist with evaluating and improving food security. For example, Lin et al. (2023) demonstrate how vehicle routing with diverse fleets can optimize post-harvest activities, lowering losses and boosting food distribution in short supply chains. Machine learning applications, as shown by Xiong et al. (2024), can assist in filling data gaps in food security assessments across different economies, giving useful insights for optimizing transportation networks and improving food distribution.

3.4 Equity and socioeconomic dimensions

Socioeconomic inequity is another key dimension explored by the studies on transport resilience and food security. Research across different scales and contexts demonstrated how transportation disruptions disproportionately impact underprivileged groups. For example, Delgado et al. (2023) show that lower-income countries are more vulnerable to food supply disruptions, aggravating existing inequities. Similarly, Childs and Lewis (2012) describe how inefficient transportation networks create food deserts in Baltimore, limiting underprivileged groups' access to healthy food. Vahabi and Damba (2013), through their case study in Toronto, investigate how low financial resources and a lack of information about community-based food resources contribute to food insecurity among recent immigrants. They underline that transportation challenges, such as the high cost of public transportation and the lack of nearby affordable grocery stores, further limit access to nutritious and culturally appropriate food, especially for low-income households. Even in the Arctic, as

shown by Neustroeva and Shishigina (2022), logistical obstacles such as dependency on seasonal ice roads, high transit costs, and insufficient storage facilities raise food prices and limit access to fresh and healthy foods. These obstacles disproportionately affect low-income households, compounding socioeconomic disparities by making it difficult for disadvantaged groups to purchase a balanced diet while already dealing with high living costs.

3.5 Governance and policy decisions

Effective governance and policy decisions at local and regional levels are essential for developing resilient transportation systems that promote food security. Peng et al. (2024) highlights how national and international policies promote food security via sustainable transportation networks, developing a multidimensional indicator system that connects food security to governance structures. Cross-border and regional coordination is also critical, as evidenced by Awokuse et al. (2024) in their study of agri-food global value chains. Their study focuses on how international trade policies might reduce systemic risks and increase resilience. Wang et al. (2023) argue that infrastructure investments in Zambia's transportation networks can play an important role in eliminating structural barriers to agricultural commerce, with policy implications for lowering trade prices, improving supply chain efficiency, and increasing food security. They emphasize the necessity of strategic government decision-making and planning to ensure that infrastructure development promotes fair market access for smallholder farmers.

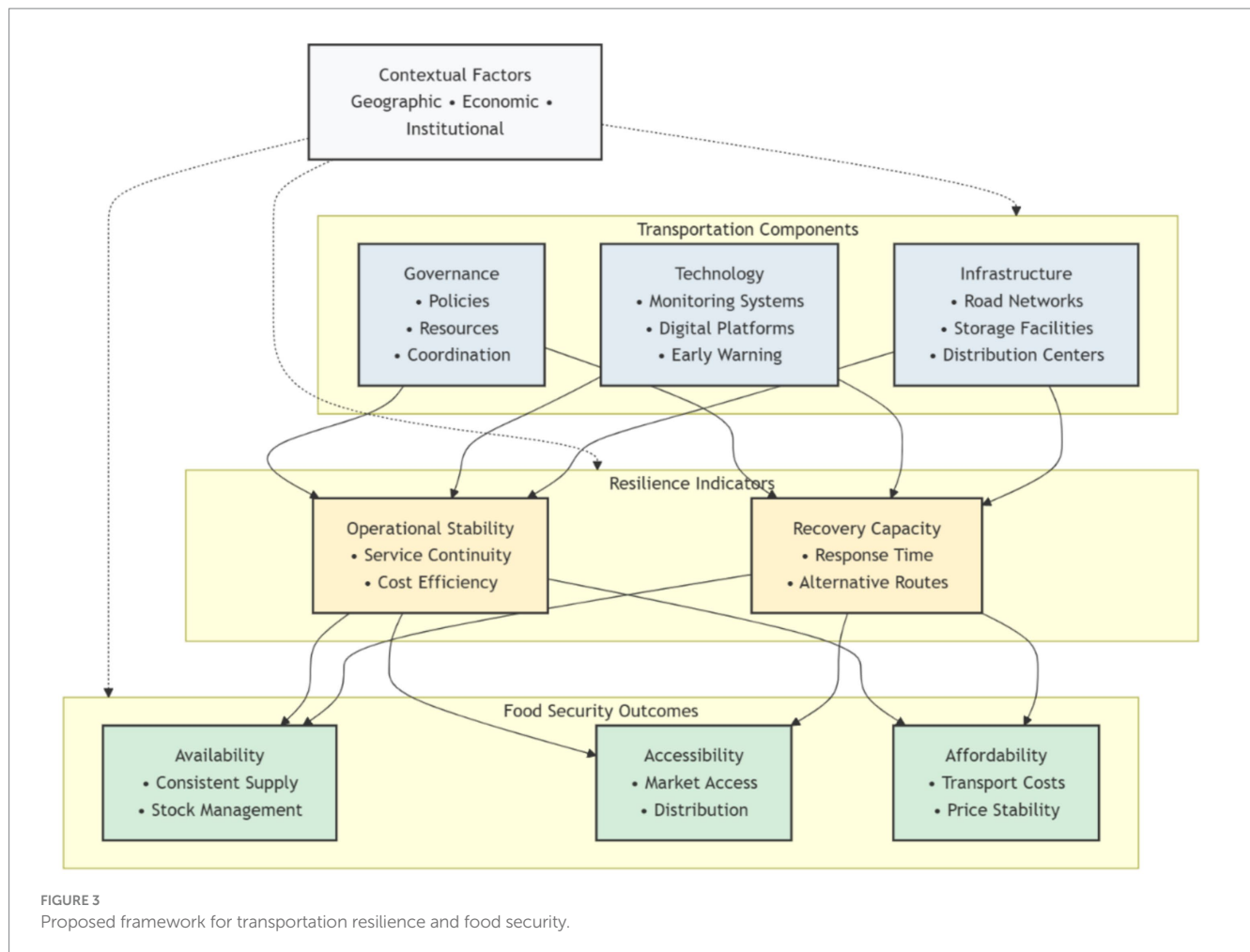
4 Conceptual framework

4.1 Framework development

Based on the literature reviewed, in this section we propose a conceptual framework showing how transportation resilience components contribute to food security outcomes. Our reviewed literature came from a variety of fields, including transportation systems, food security, and resilience theory. Insights gained from reviewing those literatures helped us develop this conceptual framework that can contribute to future research and policy decisions on food security and transportation planning. While several studies underline the importance of robust transportation networks in maintaining food security (Codjoe and Owusu, 2011; Neustroeva and Shishigina, 2022; Zimmerman et al., 2018), our proposed framework can help guide any future research on comprehensive food system planning at local and regional levels. Building on this foundation laid out by previous studies, the framework incorporates many dimensions of transportation resilience while recognizing the dynamic interplay of system components and contextual factors.

4.2 Framework components

Figure 3 shows our proposed framework for transportation resilience and food security. The framework comprises three interconnected layers that show how transportation system components contribute to food security outcomes via resilience



indicators. This section further elaborates each of these layers of the framework.

4.2.1 Transportation system components

Three components of a transportation system can be identified as the key drivers for transportation resilience: physical infrastructure, technology, and governance. Multiple studies have highlighted how the linkages between these three components can contribute to overall transport system efficiency and resilience (Raub et al., 2021; Sullivan and Novak, 2024).

Physical infrastructure acts as the foundation for transportation networks. Deliberate investments in durable roads and multimodal networks have shown dramatically decrease transportation costs and improve farmer market accessibility (Codjoe and Owusu, 2011). Additionally, flood-resistant transportation networks can significantly improve system resilience, as shown by Loreti et al. (2022). Wang et al. (2023) also showed it through a study in Zambia, where they demonstrated how improved road networks increased agricultural revenues and eliminated logistical barriers for smallholder farmers.

Another critical component of transportation systems is technological integration, which is especially important in streamlining food supply chains. Technological integration encompasses both information infrastructure such as data analytics, GIS, IoT systems for tracking and optimization, and physical or robotic technologies such as automated vehicles and mechanized

delivery systems. Gray and Torshizi (2021) demonstrate how Geographic Information Systems (GIS), and Internet of Things (IoT) sensors facilitate efficient supply chain tracking and rapid vulnerability discovery. Similarly, Zhao and Lee (2023) demonstrate how Connected and Autonomous Vehicles (CAVs) improve supply chain efficiency by shortening transit times and enhancing distribution predictability.

The third component, governance systems, is critical to ensure fair resource access and inclusive decision-making processes. Neustroeva and Shishigina's (2022) research in Arctic towns indicates how embracing multiple perspectives, particularly those of vulnerable people, improves system resilience. Delgado et al. (2023) also underline the critical significance of public-private partnerships in the development of robust systems, whereas Drummond et al. (2023) highlight the relevance of inclusive policy design in Kibera, Kenya. Governance structures inherently reflect power dynamics, including who owns and controls food supply networks. These ownership and control patterns influence whose needs are prioritized and how resources are allocated during crises, ultimately shaping food security outcomes.

4.2.2 Resilience indicators

While the operational efficiency of a transportation system relies on the three components discussed in the previous section, two essential resilience indicators can be identified that act as links between those system components and food security outcomes:

recovery capacity and operational stability (Delgado et al., 2023; Zimmerman et al., 2018).

Recovery capability assesses a system's ability to recover from interruptions. It primarily depends on two key aspects: service restoration capacity and network redundancy. Rapid service restoration requires effective resource mobilization and stakeholder coordination (Alataş and Arslan, 2024). Network redundancy is also critical, because embedding physical redundancy into transportation networks allows for sustained operations during disturbances (Touili, 2021). Studies have demonstrated how multi-modal transportation networks improve overall recovery capacity (Kolodiichuk et al., 2023).

The second essential factor, operational stability, focuses on ensuring consistent service delivery and cost effectiveness across the transportation network. Ensuring operational stability may require targeted investment in critical network segments and effective infrastructure maintenance. For example, Sullivan and Novak (2024) demonstrated how to use digital tools to assess transportation network accessibility and identify key roadway segments for operational stability. Their solution combines prescriptive analytics, demographic synthesis, and shortest-path routing to assess accessibility for socially vulnerable populations, allowing for more effective infrastructure investments and enhanced service delivery. Furthermore, Delgado et al. (2023) highlighted the importance of adaptive infrastructure in maintaining operational stability during disturbances.

While our framework emphasizes recovery capacity and operational stability as core resilience indicators, recent literature also highlights the importance of “adaptive capacity” in responding to long-term stresses such as climate change and evolving market dynamics (Bingham et al., 2022; Gomez and Grady, 2023; Karakoc et al., 2023; Umar and Wilson, 2024). We did not explicitly include adaptive capacity in our framework since it significantly overlaps with both recovery capacity and operational stability.

4.2.3 Food security outcomes

We identified three separate but interconnected food security outcomes in the proposed framework that result from robust transportation systems: availability, accessibility, and affordability. Food availability depends on stable and unobstructed supply routes and effective stock management. Wei et al. (2024) show that greater transport system capacity not only meets growing mobility demands, but also allows for increased trade volumes, which directly contributes to improved food supply across areas. Availability of agricultural land, labor, and capital, and timely production or import of food produce also contribute to the availability of food (Peng et al., 2024).

Food accessibility prioritizes strong market access and effective delivery networks. Wang et al. (2023) present evidence from low-resource contexts, demonstrating how enhanced infrastructure such as improved road and rail networks, reduced transportation costs, and integrated public-private supply chains directly improves community access to food sources. This finding is supported by Bella et al. (2024), who examine online food delivery systems and highlight the transformative significance of technological innovation in addressing last-mile delivery difficulties. Beyond these issues related to transport network, the location of grocery stores and availability of public transit are crucial to assuring food accessibility. Davies et al. (2021) highlights the impact of affordable retail food outlets on urban people's access to nutritious food, especially in areas with limited public transportation options.

Low-income households sometimes face inequitable food availability due to costly or time-consuming trips to distant grocery stores (Childs and Lewis, 2012). Studies have also shown that supermarket accessibility improve dramatically when transit choices cut trip times between households and retail sites (Sullivan and Novak, 2024).

The third outcome, affordability, deals with the essential concerns of transportation costs and pricing stability. While food costs are determined by several factors, production costs being the major component, in the proposed framework we primarily focus on how transportation system resilience influences final food prices, holding other variables constant. According to Childs and Lewis (2012), effective allocation, such as improved food availability, transit, community initiatives, and policy support, helps to keep affordable food available during emergencies.

Yang and Xu (2015) also show that targeted government interventions such as price stabilization policies, emergency grain reserves, and legislative oversight of grain operators can successfully stabilize food prices and promote speedy recovery after system disturbances, ensuring that food supplies remain affordable.

The three outcomes discussed above combine to form a complete measure of food security, emphasizing the critical significance of resilient transportation infrastructure in maintaining strong food supply chains.

4.3 Contextual considerations

Although the proposed framework targets to encompass the complex interaction between transport resilience and food security in general, geographic contexts also play a significant role in system performance. Geographic contexts influence infrastructure development patterns, as evidenced by research in Arctic locations (Neustroeva and Shishigina, 2022). Economic contexts act on multiple levels: at the systemic level, they determine resource availability and implementation capacity for transportation infrastructure, while at the household level, they influence consumers' purchasing power and ability to access available food distribution networks (Childs and Lewis, 2012). Institutional environments, on the other hand, influence policy creation and governance procedures. Awokuse et al. (2024) underlines the importance of these contextual elements in their analysis of global value chains, demonstrating how economic disparities at both the systemic and consumer levels influence food security results.

4.4 Framework implementation

Building on the framework components described in previous sections, practical implementation necessitates careful consideration of local settings and ongoing adaptation to evolving challenges. The empirically supported components of the framework, such as infrastructure expenditures prioritized using systematic vulnerability assessments (Blimpo et al., 2013), technology integration guided by local capability and requirements (Zhang et al., 2023), and governance systems tailored to existing institutional frameworks (Achilana et al., 2020), demonstrate the framework's adaptability to diverse circumstances.

This conceptual framework provides a comprehensive approach for better evaluation and improvement of food security through transportation resilience. It offers an organized method to address complex food security concerns by combining physical, technological, and governance components while considering contextual variability. The framework's strength comes from its ability to enrich theoretical understanding while also guiding practical solutions in a variety of circumstances. Municipalities might use the framework, for instance, to determine priority regions for emergency preparedness planning or infrastructure renovations by incorporating transportation risk indicators into their assessments of urban food access (Singh-Peterson and Lawrence, 2015). Similar to this, national organizations like the Ministry of Transportation might cooperate with the departments of agriculture and food security to create collaborative monitoring systems that keep tabs on the stability of the food supply as well as disturbances in the transportation network it (Sullivan and Novak, 2024). These applications show how the framework's tenets might be put into practice to dismantle management and policy silos and promote interagency cooperation. This adaptability makes it a valuable resource for scholars, policymakers, and practitioners seeking to strengthen the link between transportation networks and food security outcomes.

5 Discussion

The interplay between resilient transportation networks and food security tells a captivating story about interconnected systems and problems. At its core is robust and climate-resilient transportation infrastructure, which serves as the foundation for ensuring food security, particularly in places prone to disturbances. As prior studies showed, multi-modal systems that integrate road, rail, and waterways provide critical flexibility while reducing vulnerability to single-point failures (Kolodiichuk et al., 2023; Sullivan and Novak, 2024). This is especially important in marginalized areas like West Africa (Blimpo et al., 2013) and the Arctic (Neustroeva and Shishigina, 2022), where infrastructure constraints directly affect food access.

In addition to transportation infrastructure, technological innovations have emerged to play a crucial role in ensuring food security. Real-time monitoring systems, predictive analytics, and blockchain technologies show great promise for increasing supply chain transparency and adaptation to disturbances (Gray and Torshizi, 2021; Sullivan and Novak, 2024). Connected and autonomous vehicles (CAVs) and machine learning models hold special potential for improving efficiency and lowering costs in food supply chains (Xiong et al., 2024; Zhao and Lee, 2023). However, equity and accessibility remain critical concerns as we are gradually adopting these technological advancements.

The human dimension of this story reveals that socioeconomic disparities have a significant impact on food security outcomes, with inefficient transportation systems exacerbating low food access area and disproportionately affecting marginalized populations in both urban and rural areas (Childs and Lewis, 2012; Delgado et al., 2023). Marginalized populations, in this context, refer to groups systematically disadvantaged in terms of social, economic, or geographic access to resources, including food and transportation services. This inequality is especially pronounced in developing

countries, where weak infrastructure and limited resources create persistent risks (Drummond et al., 2023; Wang et al., 2023). However, hope emerges from integrated governance frameworks that encourage cross-sector collaboration and stakeholder participation, which prove critical in improving system resilience (Alataş and Arslan, 2024; Peng et al., 2024). During crises, community participation and volunteer-based efforts have also demonstrated promising results (Bella et al., 2024).

The findings we elaborated in this review have major implications for policymaking. Governments should prioritize investment for multimodal and climate-resilient transportation infrastructure, especially in vulnerable areas (Delgado et al., 2023; Kolodiichuk et al., 2023). There should be incentives for adopting modern technology while assuring equitable access (Gray and Torshizi, 2021; Sullivan and Novak, 2024), as well as focus on addressing socioeconomic vulnerabilities by enhancing transportation access for marginalized communities (Childs and Lewis, 2012; Delgado et al., 2023). Besides transportation resilience at the local level, international collaboration and multilateral agreements are still necessary to protect important chokepoints in the global food supply chain (Wellesley et al., 2017).

6 Conclusion

This literature review emphasizes the critical role of resilient transportation networks to ensure food security, especially in the light of rising climate-related disruptions, socioeconomic inequities, and technological revolutions. By combining studies from various dimensions—robust infrastructure, equitable food access, technological innovation, responsive governance, and adaptive capacity—we present a comprehensive framework for analyzing and improving transportation resilience in food systems. As our review shows, improving transportation resilience necessitates a multifaceted strategy that includes physical infrastructure improvements, technological innovation, and inclusionary governance initiatives. While sophisticated technology and infrastructure development can help improve system efficiency and responsiveness, challenges remain with resolving regional imbalances and ensuring equitable access.

Our review also identifies some critical research gaps. There is no longitudinal research on the long-term effects of resilience measures (Peng et al., 2024), and studies concentrating on resilience-building techniques in developing regions are lacking, despite their greater sensitivity to disruptions (Wang et al., 2023). Furthermore, practical guidance on integrating sophisticated technology in resource-constrained settings is significantly missing, with most studies focused on specific geographic contexts rather than identifying scalable solutions (Kolodiichuk et al., 2023). Our literature search and review also show the scarcity of research that specifically investigates the relationship between transportation resilience and food security, with just 45 relevant studies identified through our systematic search. It highlights the need for additional empirical study on this topic that can provide effective policy guidelines.

Moving forward, policymakers, researchers, and practitioners need to recognize the critical linkages between food security and resilient transportation networks, as demonstrated in our proposed framework. It can provide guidance for relevant stakeholders to work toward establishing more resilient and equitable food systems capable

of withstanding various natural and man-made disruptions and guaranteeing long-term food security for all communities.

Author contributions

SH: Data curation, Methodology, Software, Writing – original draft, Writing – review & editing. SK: Conceptualization, Supervision, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This study was conducted as part of the project titled “Development of resilient urban food systems that ensure food security in the face of climate change” (PI: Dr. Eleni Pliakoni), funded through the Game-changing Research Initiation Program (GRIP) of Kansas State University. Publication of this article was supported by the INFAS Junior Scholars for Agroecology and Sustainable Food Systems Publications Award from the Inter-institutional Network for Food, Agriculture, and Sustainability (INFAS).

Acknowledgments

The authors would like to acknowledge the Game-changing Research Initiation Program (GRIP) of Kansas State University and Dr. Eleni Pliakoni, the Principal Investigator (PI) of the GRIP project that this study is part of. The authors also acknowledge the support received from the Inter-institutional Network for Food, Agriculture,

and Sustainability (INFAS), and the reviewers of this article for their insightful feedback to improve it for publication.

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.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

- Achilana, M., O'Connor, D., and Mkamwa, T. F. (2020). Low income farm households' access to markets and household food security: the case of two economically distinct areas in rural Tanzania. *Afr. J. Food Agric. Nutr. Dev.* 20, 15876–15897. doi: 10.18697/AJFAND.91.18095
- Agusdei, G. P., Coluccia, B., Gnani, M. G., and Miglietta, P. P. (2022). Measuring the impact of transport infrastructure endowment on firms' performances: the case of Italian agri-food sector. *Transp. Res. Proc.* 67, 12–20. doi: 10.1016/j.trpro.2022.12.030
- Alataş, H., and Arslan, N. (2024). Challenges in the food supply chain following the great earthquake disaster in Turkey: a study of the regions of Malatya, Adiyaman and Kahramanmaraş. *J. Educ. Health Promot.* 13:452. doi: 10.4103/jehp.jehp_1961_23
- Awokuse, T., Lim, S., Santeramo, F., and Steinbach, S. (2024). Robust policy frameworks for strengthening the resilience and sustainability of Agri-food global value chains. *Food Policy* 127:102714. doi: 10.1016/j.foodpol.2024.102714
- Bella, G., Borowski, E., and Stathopoulos, A. (2024). Improving community resilience to disrupted food access: empirical spatio-temporal analysis of volunteer-based crowdsourced food delivery. *J. Transp. Geogr.* 121:104018. doi: 10.1016/j.jtrangeo.2024.104018
- Bingham, D. R., Rushforth, R. R., Stevens, B., and Ruddell, B. L. (2022). Mapping local food self-sufficiency in the U.S. and the tradeoffs for food system diversity. *Appl. Geogr.* 143:102687. doi: 10.1016/j.apgeog.2022.102687
- Blimpo, M. P., Harding, R., and Wantchekon, L. (2013). Public investment in rural infrastructure: some political economy considerations. *J. Afr. Econ.* 22, 57–83. doi: 10.1093/jae/ejt015
- Brown, M. E., Carr, E. R., Grace, K. L., Wiebe, K., Funk, C. C., Attavanich, W., et al. (2017). Do markets and trade help or hurt the global food system adapt to climate change? *Food Policy* 68, 154–159. doi: 10.1016/j.foodpol.2017.02.004
- Carpenter, S., Walker, B., Anderies, J. M., and Abel, N. (2001). From metaphor to measurement: resilience of what to what? *Ecosystems* 4, 765–781. doi: 10.1007/s10021-001-0045-9
- Childs, J., and Lewis, L. R. (2012). Food deserts and a southwest community of Baltimore city. *Food Cult. Soc.* 15, 395–414. doi: 10.2752/175174412X13276629245849
- Clark, C., Perfit, C., and Reznickova, A. (2024). A multi-dimensional access index: exploring emergency food assistance in new York City. *Health Place* 89:103319. doi: 10.1016/j.healthplace.2024.103319
- Codjoe, S. N. A., and Owusu, G. (2011). Climate change/variability and food systems: evidence from the Afram Plains, Ghana. *Reg. Environ. Chang.* 11, 753–765. doi: 10.1007/s10113-011-0211-3
- Davies, J., Hannah, C., Guido, Z., Zimmer, A., McCann, L., Battersby, J., et al. (2021). Barriers to urban agriculture in sub-Saharan Africa. *Food Policy* 103:101999. doi: 10.1016/j.foodpol.2020.101999
- Delgado, L. R., Gomez, M., Hinojos, S., Dennis, L., and Grady, C. (2023). Investigating social vulnerability, exposure, and transport network disruption in the mid-Atlantic region. *J. Infrastruct. Syst.* 29:04023026. doi: 10.1061/jitse4.iseng-2258
- Drummond, J. A., Malamud, B. D., Mulligan, J., Bukachi, V., Talib, M., Wandera, A., et al. (2023). COVID-19 interventions in an informal settlement: a spatial analysis of accessibility in Kibera, Kenya. *J. Transp. Geogr.* 113:103704. doi: 10.1016/j.jtrangeo.2023.103704
- FAO. (2006). Policy brief changing policy concepts of food security. Available online at: <http://www.foodsecinfoaction.org/>.
- Gomez, M., and Grady, C. (2023). A balancing act: the interplay of food supply chain resilience and environmental sustainability in American cities. *Environ. Res. Lett.* 18:124022. doi: 10.1088/1748-9326/ad0608
- Gray, R. S., and Torshizi, M. (2021). Update to agriculture, transportation, and the COVID-19 crisis. *Can. J. Agric. Econ.* 69, 281–289. doi: 10.1111/cjag.12280
- Hobbs, J. E. (2020). Food supply chains during the COVID-19 pandemic. *Can. J. Agric. Econ.* 68, 171–176. doi: 10.1111/cjag.12237

- Hossain, S., Islam, M. A., and Akther, M. S. (2023). COVID-19 impact on travel and work habits of office workers in Bangladesh. *Transp. Eng.* 11:100162. doi: 10.1016/j.treng.2023.100162
- Jenelius, E., and Mattsson, L. G. (2021). "Resilience of transport systems" in International encyclopedia of transportation: Volume 1–7. ed. International Encyclopedia of Transportation, vol. 7. (Amsterdam, Netherland: Elsevier), 258–267.
- Karakoc, D. B., Konar, M., Puma, M. J., and Varshney, L. R. (2023). Structural chokepoints determine the resilience of Agri-food supply chains in the United States. *Nat. Food* 4, 607–615. doi: 10.1038/s43016-023-00793-y
- Kashem, S. B., Baker, D. M., González, S. R., and Lee, C. A. (2021). Exploring the nexus between social vulnerability, built environment, and the prevalence of COVID-19: a case study of Chicago. *Sustain. Cities Soc.* 75:103261. doi: 10.1016/j.scs.2021.103261
- Kolodichuk, V., Cherevko, H., and Popivniak, R. (2023). Quality assessment of transit potential of the transport–logistics system of Ukraine. *Glob. Bus. Rev.* 24, 171–184. doi: 10.1177/0972150920907008
- Lin, N., Akkerman, R., Kanellopoulos, A., Hu, X., Wang, X., and Ruan, J. (2023). Vehicle routing with heterogeneous service types: optimizing post-harvest preprocessing operations for fruits and vegetables in short food supply chains. *Transp. Res. Part E Logist. Transp. Rev.* 172:103084. doi: 10.1016/j.tre.2023.103084
- Lloyd, J., Moore, E. R. H., Dowell, L., and Neff, R. (2024). A comparative national-level analysis of government food system resilience activities across four developed countries at varying stages of planning. *BMC Public Health* 24:461. doi: 10.1186/s12889-024-17919-x
- Loreti, S., Ser-Giacomi, E., Zischg, A., Keiler, M., and Barthelemy, M. (2022). Local impacts on road networks and access to critical locations during extreme floods. *Sci. Rep.* 12:1552. doi: 10.1038/s41598-022-04927-3
- Moynihan, E., Avraam, C., Siddiqui, S., and Neff, R. (2022). Optimization based modeling for the food supply chain's resilience to outbreaks. *Front. Sustain. Food Syst.* 6:887819. doi: 10.3389/fsufs.2022.887819
- Neustroeva, A. B., and Shishigina, A. N. (2022). Food supply in the Arctic: municipal authorities' opinion. *RUDN J. Sociol.* 22, 661–671. doi: 10.22363/2313-2272-2022-22-3-661-671
- Peng, B., Shuai, C., Yin, C., Qi, H., and Chen, X. (2024). Progress toward SDG-2: assessing food security in 93 countries with a multidimensional indicator system. *Sustain. Dev.* 32, 815–862. doi: 10.1002/sd.2672
- Raub, K. B., Stepenuck, K. F., Panikkar, B., and Stephens, J. C. (2021). An analysis of resilience planning at the nexus of food, energy, water, and transportation in coastal US cities. *Sustainability* 13:6316. doi: 10.3390/su13116316
- Ribeiro, N. (2024). Geospatial analysis for decision support, suitability assessment for value chain infrastructure interventions. 2024 12th International Conference on Agro-Geoinformatics (Agro-Geoinformatics). 1–6.
- Rijsberman, F. (2017). The key role of the meat industry in transformation to a low-carbon, climate resilient, sustainable economy. *Meat Sci.* 132, 2–5. doi: 10.1016/j.meatsci.2017.04.013
- Romero-Lankao, P., Bruns, A., and Wiegler, V. (2018). From risk to WEF security in the city: the influence of interdependent infrastructural systems. *Environ. Sci. Pol.* 90, 213–222. doi: 10.1016/j.envsci.2018.01.004
- Sanogo, I., and Maliki Amadou, M. (2010). Rice market integration and food security in Nepal: the role of cross-border trade with India. *Food Policy* 35, 312–322. doi: 10.1016/j.foodpol.2010.03.002
- Santos, S. A. B., Albrecht, S., Sollacher, R., Friedrich, H., and Hamacher, T. (2024). Resilience analysis of large-scale dynamic food flow networks using an optimization-based N-1 contingency approach. *AIP Conf. Proc.* 3034:070003. doi: 10.1063/5.0194964
- Singh-Peterson, L., and Lawrence, G. (2015). Insights into community vulnerability and resilience following natural disasters: perspectives with food retailers in northern NSW, Australia. *Local Environ.* 20, 782–795. doi: 10.1080/13549839.2013.873396
- Sullivan, J. L., and Novak, D. C. (2024). A method for evaluating accessibility in transportation problems considering social vulnerability. *Eur. J. Oper. Res.* 317, 646–659. doi: 10.1016/j.ejor.2023.04.015
- Touili, N. (2021). Hazards, infrastructure networks and unspecific resilience. *Sustainability* 13:4972. doi: 10.3390/su13094972
- Umar, M., and Wilson, M. M. J. (2024). Inherent and adaptive resilience of logistics operations in food supply chains. *J. Bus. Logist.* 45:e12362. doi: 10.1111/jbl.12362
- Vahabi, M., and Damba, C. (2013). Perceived barriers in accessing food among recent Latin American immigrants in Toronto. *Int. J. Equity Health* 12:1. doi: 10.1186/1475-9276-12-1
- Wang, J., Konar, M., Baylis, K., Estes, L., Hadunka, P., Xiong, S., et al. (2023). Potential impacts of transportation infrastructure improvements to maize and cassava supply chains in Zambia. *Environ. Res. Infrastruct. Sustain.* 3:045006. doi: 10.1088/2634-4505/ad04e4
- Wei, C., Liu, X., Zhang, L., Wan, Y., Huang, G., Lu, Y., et al. (2024). Resilience analysis of global agricultural trade. *Environ. Plann. B Urban Anal. City Sci.* 51, 1003–1006. doi: 10.1177/23998083241229846
- Wellesley, L., Preston, F., Lehne, J., and Bailey, R. (2017). Chokepoints in global food trade: assessing the risk. *Res. Transp. Bus. Manag.* 25, 15–28. doi: 10.1016/j.rtbm.2017.07.007
- Xiong, R., Peng, H., Chen, X., and Shuai, C. (2024). Machine learning-enhanced evaluation of food security across 169 economies. *Environ. Dev. Sustain.* 26, 26971–27000. doi: 10.1007/s10668-024-05212-1
- Yang, Y., and Xu, X. (2015). Post-disaster grain supply chain resilience with government aid. *Transp. Res. Part E Logist. Transp. Rev.* 76, 139–159. doi: 10.1016/j.tre.2015.02.007
- Zeuli, K., Nijhuis, A., Macfarlane, R., and Ridsdale, T. (2018). The impact of climate change on the food system in Toronto. *Int. J. Environ. Res. Public Health* 15:2344. doi: 10.3390/ijerph15112344
- Zhang, S., Luan, H., Zhen, F., Kong, Y., and Xi, G. (2023). Does online food delivery improve the equity of food accessibility? A case study of Nanjing, China. *J. Transp. Geogr.* 107:103516. doi: 10.1016/j.jtrangeo.2022.103516
- Zhao, J., and Lee, J. Y. (2023). Effect of connected and autonomous vehicles on supply chain performance. *Transp. Res. Rec.* 2677, 402–424. doi: 10.1177/03611981221115425
- Zimmerman, R., Zhu, Q., and Dimitri, C. (2018). A network framework for dynamic models of urban food, energy and water systems (FEWS). *Environ. Prog. Sustain. Energy* 37, 122–131. doi: 10.1002/ep.12699