

# Intersections of Barriers to Equitable Food-Energy-Water System Resources Across the United States



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## Introduction

Optimization of biophysical Food, Energy, and Water Systems (FEWS) to increase sustainability and meet challenges related to climate change has been an important focus of research over the past decade. However, less is known about the relationship between FEWS and social equity – an important consideration as the systems provide resources vital to human health and well-being. Barriers to affordable, accessible, and high quality FEWS resources can impede social equity and increase vulnerability. Inherent connections within and across the respective FEW systems suggest that co-occurring barriers to equity can intersect and compound vulnerability. We define vulnerability as being at risk of not obtaining FEWS resources due to lack of affordability, access, or quality.

In this study, we explored geographic relationships between FEWS barriers and social equity through spatial analysis of census tracts within the US.

## Objectives

1. Identify potential clusters of barriers to each FEWS resource
2. Evaluate if barriers within each food-energy-water system co-occur spatially
3. Evaluate if barriers to resources across FEWS co-occur spatially
4. Create an index of barriers to FEWS Equity

## Materials and Methods

Indicator variables were selected to represent affordability, access, and quality barriers to FEWS in the United States (Table 1).

**Table 1. Data sources.** Each data source was available for all 50 U.S. states and Washington, DC. at the census tract scale.

System	Barrier Type	Measurement	Data Source
Food	Affordability	Annual spending/household income	Esri U.S. Consumer Spending
	Access	% of population further than 0.5 miles (urban) or 10 miles (rural) from a supermarket	USDA ERS
	Quality	% of healthy food retailers <sup>1</sup>	U.S. CDC
Energy	Affordability	Annual spending/household income	Esri U.S. Consumer Spending
	Access	Customer Average Interruption Duration Index (CAIDI) without major event days <sup>2</sup>	U.S. EIA
	Quality	Energy consumption intensity <sup>3</sup>	National Renewable Energy Lab
Water	Affordability	Annual spending/household income	Esri U.S. Consumer Spending
	Access	% of households with incomplete plumbing <sup>4</sup>	U.S. Census: 2020 ACS
	Quality	# of community water system violation points <sup>5</sup>	U.S. EPA – ECHO
Nexus	Climate Vulnerability	Community resilience to natural hazards or disasters <sup>6</sup>	U.S. FEMA

Each indicator variable was tested for spatial autocorrelation using Global Moran's I, where values closer to 1 indicate spatial clustering (Figure 1).

Each indicator variable was scaled from 0-100. Values in the top 20<sup>th</sup> percentile or bottom 20<sup>th</sup> percentile of each indicator were flagged as having "high barriers" or "low barriers" to FEWS, respectively (Figures 2 & 3).

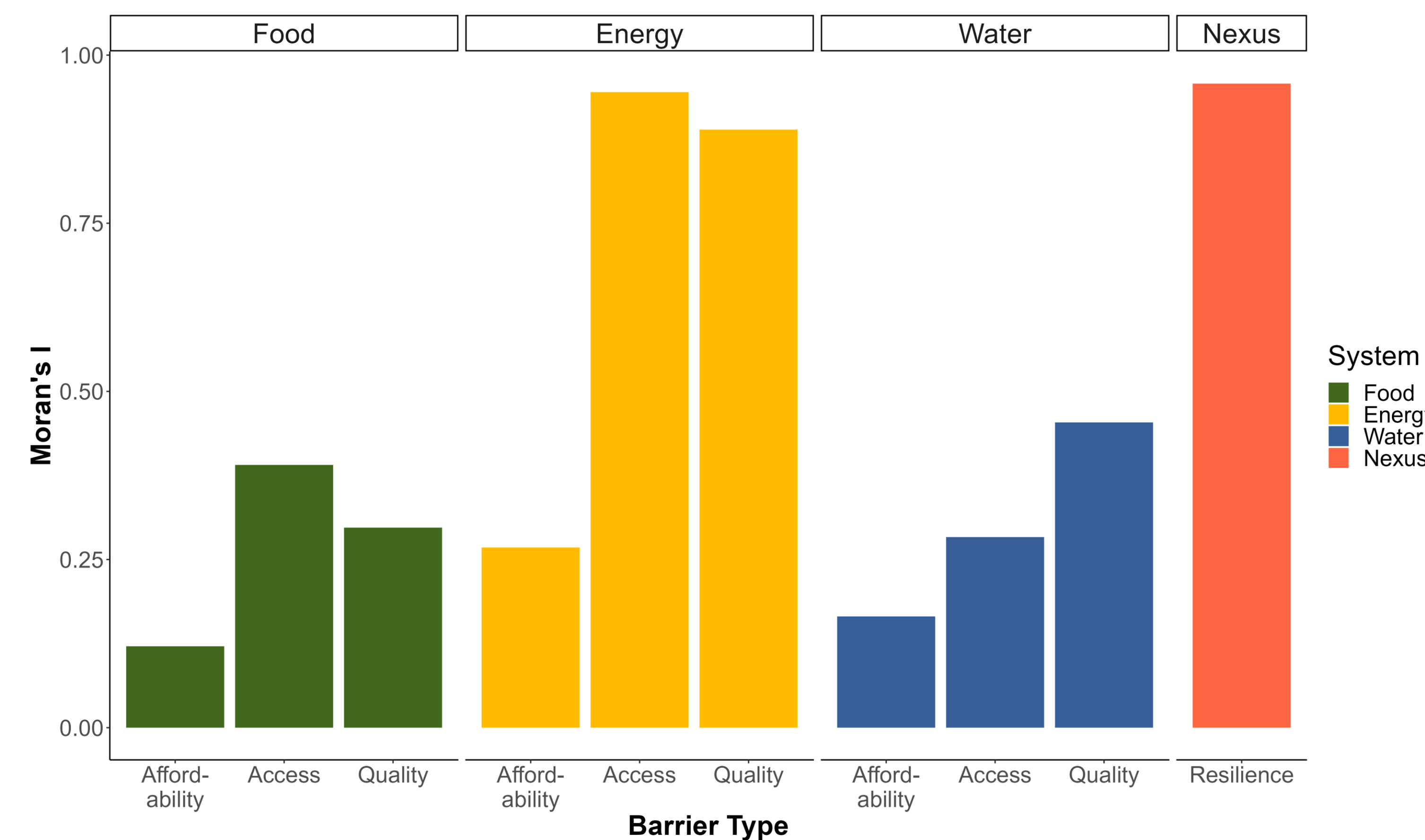
The FEWS Equity Index was calculated using the equation below to identify census tracts with high or low barriers (Figure 4).

In each system, the average (overbar) of affordability, access, and quality barriers were multiplied by a weighting factor such that each barrier is weighted equally.

$$\text{FEWS EQUITY INDEX} = 0.3 \times \overline{\text{Food barriers}} + 0.3 \times \overline{\text{Energy barriers}} + 0.3 \times \overline{\text{Water barriers}} + 0.1 \times \overline{\text{Climate Resilience}}$$

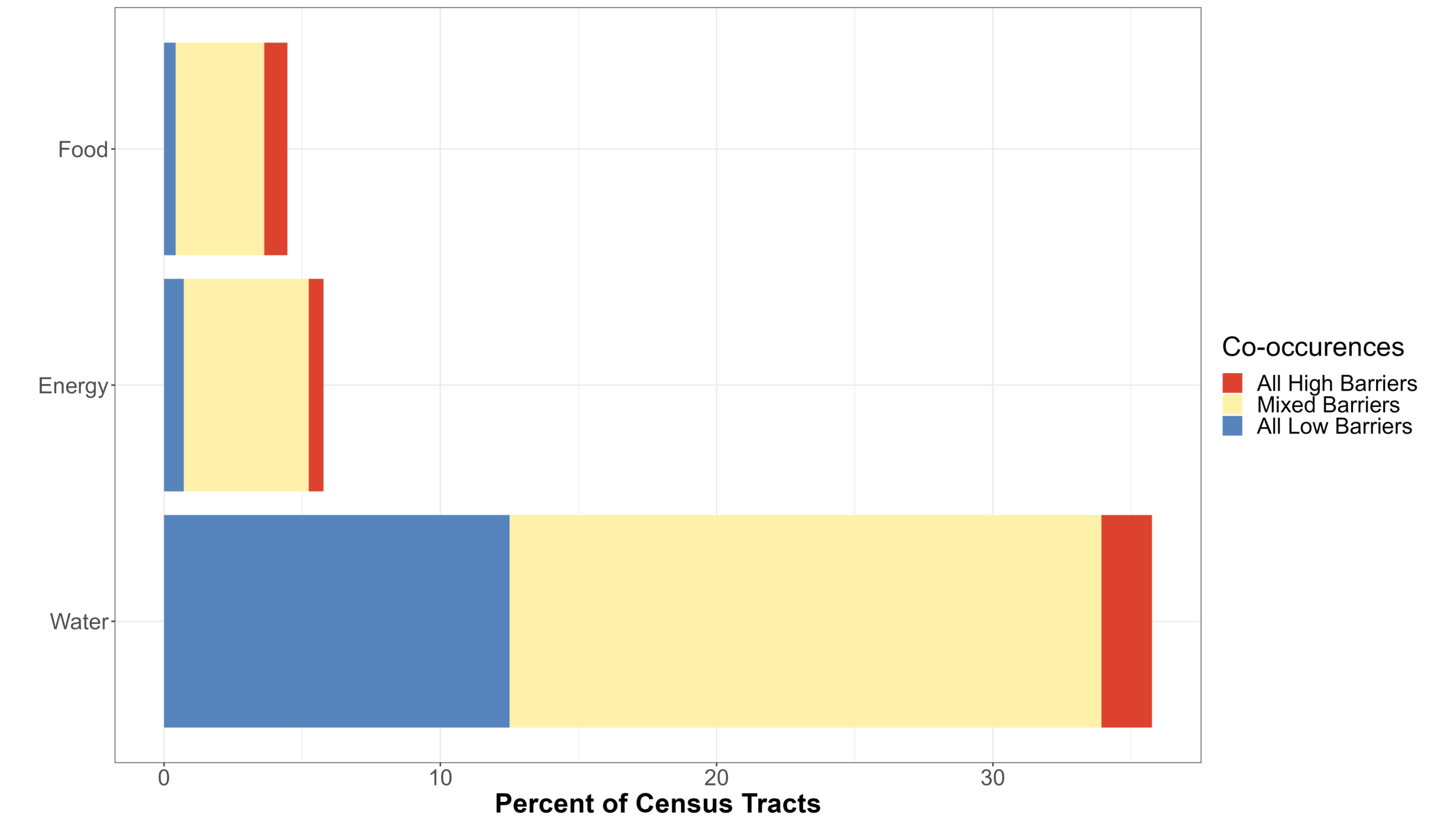
## Results

1. All indicators were spatially clustered. Energy and nexus barriers were the most clustered.



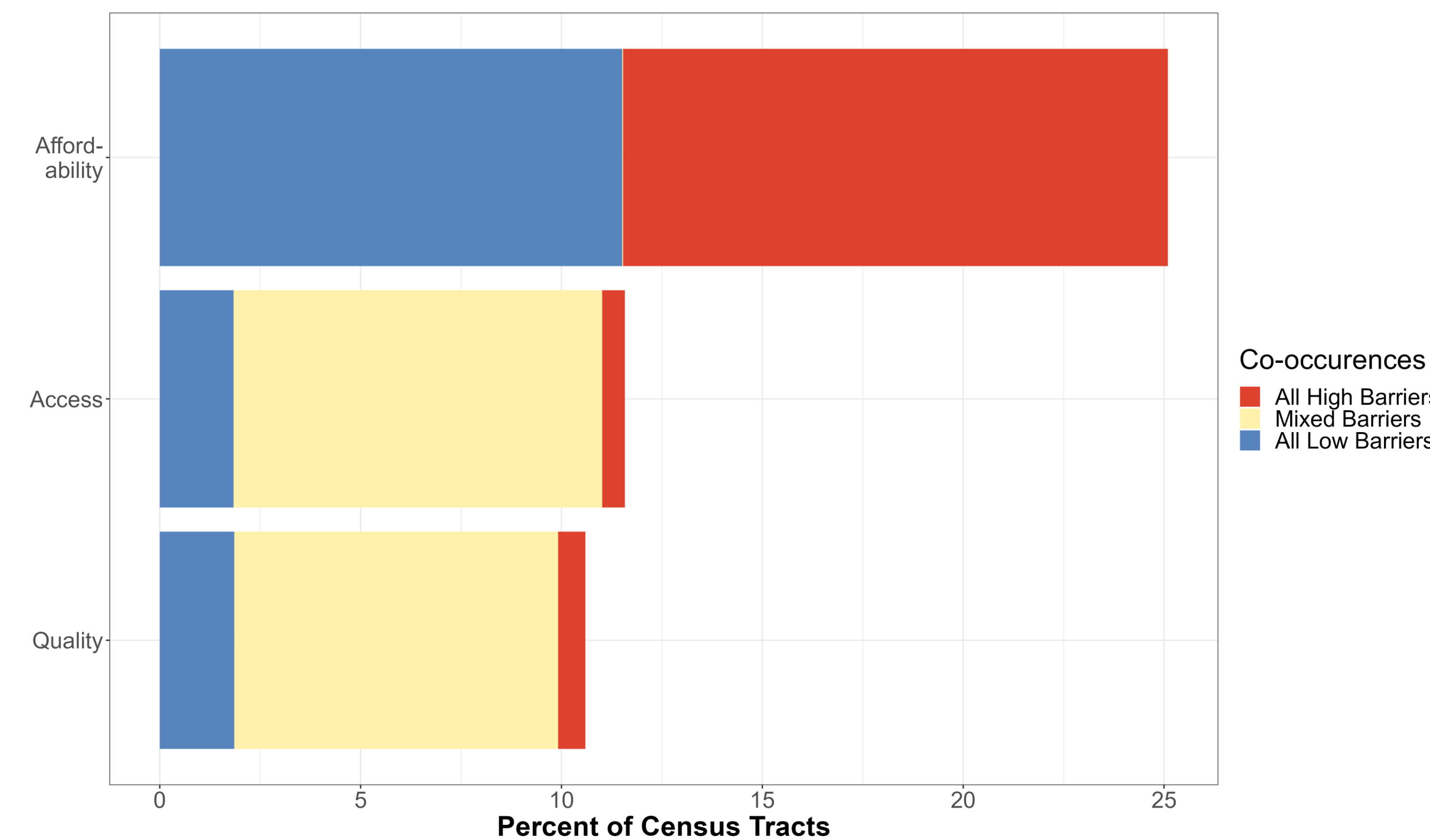
**Figure 1. Moran's I values of each barrier to FEWS.** Higher values indicate more spatial clustering. All values were significant (p<0.01).

2. Water system barriers were more likely to co-occur within census tracts.



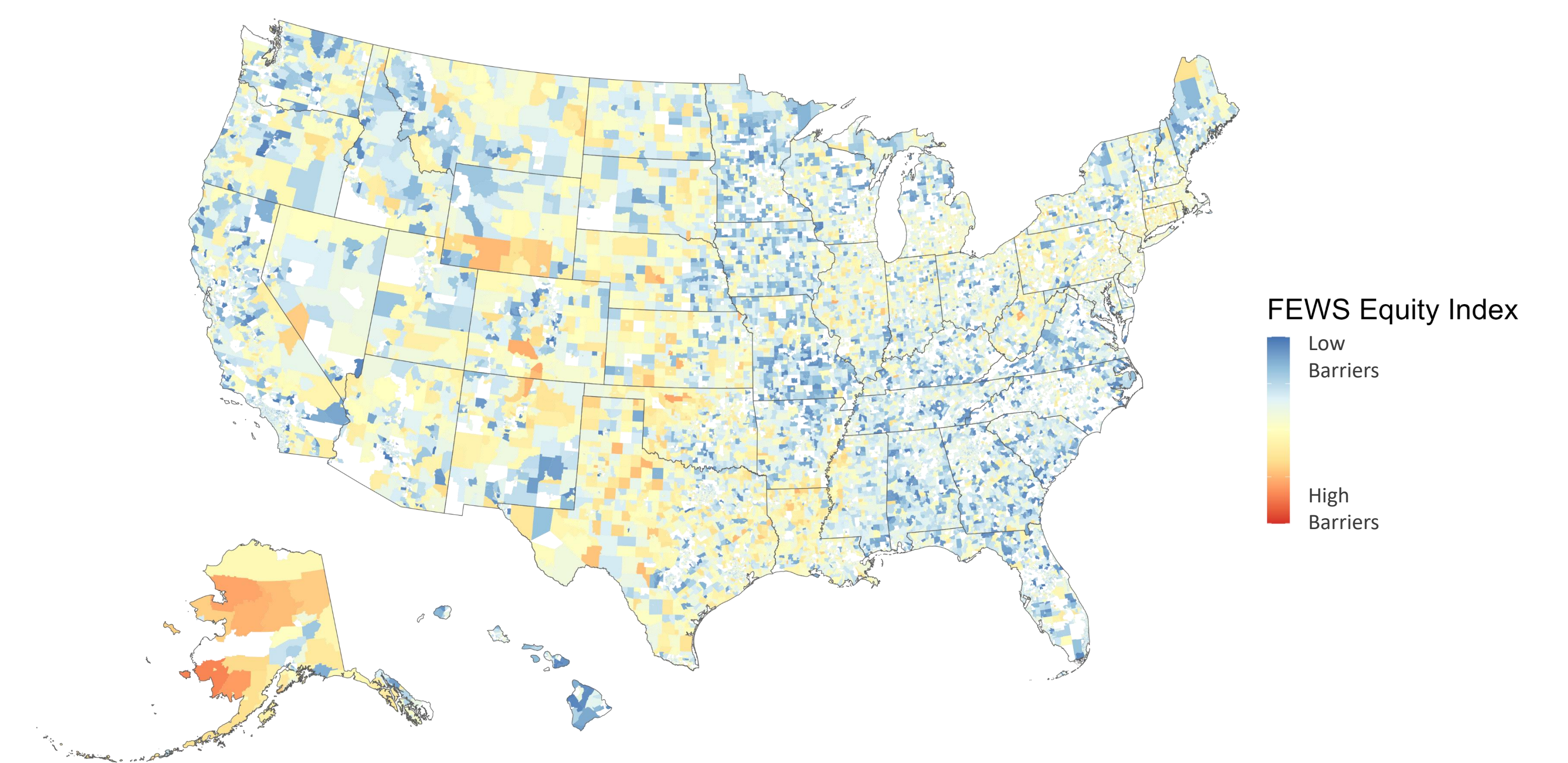
**Figure 2. Co-Occurrence of barriers to FEWS.** High Barriers and Low Barriers indicate that the census tract was in the top and bottom 20<sup>th</sup> percentile, respectively, of affordability, access, and quality barriers in each system. Mixed barriers indicate some barriers were in the top 20<sup>th</sup> percentile and some barriers were in the bottom 20<sup>th</sup> percentile.

3. FEWS affordability barriers were more likely to co-occur within census tracts.



**Figure 3. Co-occurrence of barriers across FEWS.** High Barriers and Low Barriers indicate that the census tract was within the top and bottom 20<sup>th</sup> percentile of barrier values across FEWS, respectively. Mixed barriers indicate some barriers were in the top 20<sup>th</sup> percentile and some barriers were in the bottom 20<sup>th</sup> percentile.

4. The FEWS Equity Index provides a snapshot of co-occurring barriers to FEWS across the United States.



**Figure 4. FEWS Equity Index Map.** Higher values (red) represent census tracts with more barriers to affordable, accessible, and good-quality FEWS resources. Missing values are shown in white.

## Discussion

- The quality and availability of national data limit our analysis and index.
- Clusters of FEWS barriers suggest that resource obtainment could be influenced locally by the built or natural environments.
- Areas with co-occurrences of high barriers face greater challenges to affordable, accessible, and high quality FEWS resources.

## Conclusions and Future Work

- Some census tracts have more barriers to FEWS than others.
- A FEWS Equity Index could help decision-makers identify where to target investments.
- Additional analyses at local scales can help identify barriers that are difficult to measure nationally, such as social and cultural preferences.
- Future work should focus on reducing the inequities exacerbated by climate change in census tracts with high barriers.

<sup>1</sup>: Healthy food is defined as grocery stores or produce stores, and unhealthy food is defined as small convenience stores and fast food restaurants.  
<sup>2</sup>: Major event days include events that exceed the designed limits of the electrical system.  
<sup>3</sup>: Energy use intensity is the energy used for temperature regulation divided by the square footage of livable space.  
<sup>4</sup>: A house is considered to have complete plumbing if it contains both hot and cold running water and a bathtub or shower.  
<sup>5</sup>: Violation points can be given for based on the health impacts of the water quality or for improper monitoring or notification of the water quality.  
<sup>6</sup>: The climate resilience score includes human well-being, economics, infrastructure, governance, social networks, and the environment.