Understanding Flood Risk in Public Transit Systems:
Insights from Accessibility and Vulnerability Analysis in Iowa

Yazeed Alabbad [1,*], Ibrahim Demir [2,3]

[1] Department of Civil Engineering, King Saud University, Riyadh, Saudi Arabia
[2] River-Coastal Science and Engineering, Tulane University, New Orleans, LA, USA
[3] ByWater Institute, Tulane University, New Orleans, LA, USA

[*] Corresponding Author, Email: yalabbad@ksu.edu.sa

Abstract
Flooding is a major challenge for urban transportation systems, hindering access to essential services and jobs, especially for vulnerable populations. This study examines the impact of large flood extents on public transportation in Johnson and Linn counties, Iowa, United States, focusing on flood-prone bus routes, reduced service frequency, and access to job locations. Using Geographic Information System (GIS) tools, flood maps were integrated with General Transit Feed Specification (GTFS) data, while a demographic analysis highlighted the social vulnerability of the impacted communities. The findings reveal that transit disruptions during flooding are significant, with service losses totaling 526 visits during AM peak hours in Johnson County under a 500-year flood scenario. Job accessibility decreased by 11.5% in Linn County and 7.2% in Johnson County, disproportionately affecting low-income households and those without vehicles. These findings point to the significance of flood resilience improvement in transport planning, amongst measures such as more durable infrastructure and the use of adaptive routing or temporary transit services that would deliver fair access to inhabitants during extreme weather events.

Keywords: Flood Risk, Public Transit, Accessibility Analysis, Vulnerability Analysis, Geographic Information System, General Transit Feed Specification, Job Accessibility, Social Vulnerability

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1. Introduction

Public transit systems serve as vital connectors for communities to critical destinations like jobs, schools, and health care. Systems that facilitate daily mobility are promoting social and economic development, while improving the residents' quality of life, especially for the population that uses public transportation as their main travel mode (Sun & Cui, 2018). However, with the expanding cities and growing population, public transport systems are under pressure and need careful planning and adjustment to cater to the changing needs of urban citizens (Porru et al., 2020).

Beyond urban growth and development hurdles, climate change adds another layer of complexity to transit planning (Moraci et al., 2020). Extreme weather events, especially flooding, occur more frequently and with greater intensity, putting vast urban infrastructure and public transit systems at significant risk (Alabbad et al., 2021). Floodwater can impede transit routes, damage infrastructure, and create hazards for passengers and walkers (He et al., 2021). As a result, the ability of public transportation systems to withstand flooding is becoming an immediate concern for urban planners, transit agencies, and local governments (Singh et al., 2021).

Public transit infrastructure is also a key component of disaster response and is frequently employed for emergency management operations, such as during evacuations and transporting people to safety or emergency shelters (Godfrey et al., 2019). However, there is too little awareness of how flooding translates into transit impacts, so transit agencies are not best positioned to operate the agency as efficiently as possible when extreme weather events strike. Such unpreparedness can result in sudden service outages, passenger safety threats, and, in the most severe instances, a total failure of transit services (Abenayake et al., 2022). Flooding threatens not just the safety of public transportation crews but also the operation of transit systems in general (Wang et al., 2020). While, identifying which routes and stops are in flood-prone areas can help mitigate such risks, the data on which these decisions would be made is limited (Alabbad & Demir, 2024).

Previous studies have explored and analyzed the adverse impact of flooding on communities from various scop. Researchers have analyzed direct and indirect consequences such as damage to buildings (Yildirim et al., 2023) and essential facilities (Grant et al., 2024), income and wage losses (Alabbad & Demir, 2022), road network topology and increase travel time to reach critical destinations (Alabbad et al., 2021). Advancement in technology has garnered attention, leading to the development of web platforms for communicating flood risk information to different stakeholders, including non-experts (e.g., citizens) (Alabbad et al., 2022, 2023, 2024; Li et al., 2023).

Public transit systems during disasters have been investigated at various levels of area and approach. Previous studies have analyzed the vulnerability of public transit during different incidents, including flooding (Hong et al., 2019; Pulcinella et al., 2019; Tessler & Traut, 2022; Zhao et al., 2022). Models to evacuate people in the event of flooding using public transit have been proposed (Insani et al., 2022; Nadeem et al., 2020). During a disaster, a GIS-based model has been used to assess audible warnings via bus sirens (Nishino et al., 2021). In addition, researchers have analyzed the impact of COVID-19 on the public transit (Liu Luyu & Miller, 2020; Qi et al., 2023). Nonetheless, there are still important deficiencies in assessing the ability of public transit systems to cope with and adapt to flood events in terms of planning, response, and recovery. A wide range of areas, particularly those with high exposures, are still under studied despite the importance of public transportation systems during and after disasters.

This research analyzes flood impacts on public transit systems in communities within Linn and Johnson counties in the State of Iowa, United States by identifying flooded routes and bus stops, frequency analysis, and accessibility disruption. The geographic analysis of transit accessibility under simulated flooding conditions in this study supports understanding how flooding impacts transit accessibility and operations in those vulnerable areas.

The results could aid transit agencies and planners in determining where impacts from floods are most likely to occur, leading to route or bus stop relocation to safer areas, as well as measures to protect passengers from flood-related impacts. This study highlights the need to develop flood-resilient urban transit systems to respond to disruptive climate-driven events targeting transit systems. Incorporating flood risk into transit planning and adding climate adaptation elements into their plans can help growing cities become more resilient to persistent weather issues. This research offers valuable information for communities planning for and recovering from flooding, so transportation equitably reaches those who need to evacuate during flooding through flexible and responsive transit networks.

The following sections of the study go into detail on the methodology for analyzing the public transit system during different flood scenarios (Section 2). Section 3 presents and discusses the research results, followed by the conclusion and future work (Section 4).

2. Methodology

2.1. Case Study

There are 19 urban public transit systems and 16 regional transit systems across Iowa, United States, providing essential mobility to residents. Indeed, the state has endured catastrophic flooding events recently, and its infrastructure seems susceptible to extreme weather (Yildirim et al., 2022; Cikmaz et al., 2023). This research concentrates on public transit systems operating in two counties, Linn and Johnson, which are both outlined in red in Figure 1. Linn County includes the cities of Cedar Rapids, Hiawatha, and Marion, while Johnson County includes Iowa City, University Heights, Coralville, and North Liberty. These cities capture the breadth of differing transit needs and geographic challenges, providing a rich context in which to evaluate the effects of flooding on transit systems. Public transit networks for each county intersect, allowing for trips between cities and regional mobility. The intersection of these variables makes it difficult to discern what floods will break or disrupt, further highlighting the need for resilient transit design policies.

Linn County, with Cedar Rapids as its central hub, is known for its diverse economy and pivotal role in regional transportation. Cedar Rapids, being the second-largest city in Iowa, experiences significant daily commuter traffic, making its transit system vital for economic activities. Meanwhile, Johnson County is home to the University of Iowa in Iowa City, attracting a large student population that heavily relies on public transit for daily commuting. Coralville and North Liberty are rapidly growing suburbs in Johnson County, contributing to increased transit demand as more residents opt for public transportation to reach employment centers and educational institutions. In both counties, transit services include a mix of fixed-route buses and demand-responsive transportation, aiming to cater to urban and rural populations. The unique geographical features of these areas, such as proximity to rivers and low-lying topographies, further underscore their vulnerability to flooding (Tanir et al., 2024). These characteristics necessitate a nuanced understanding of local transit operations and community needs, emphasizing the importance of strategic planning and adaptive responses to ensure continued accessibility and mobility during extreme weather events.

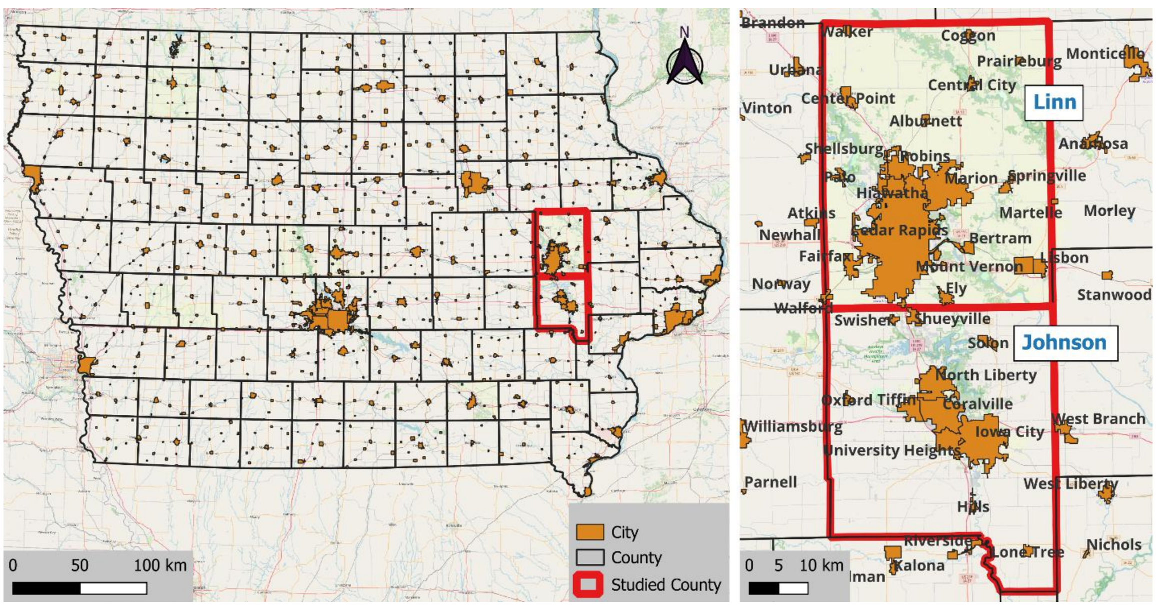

Figure 1. Study area map for selected counties and their location in Iowa

2.2. Data Collection

2.2.1. Flood Maps

Flood return period maps provided by the Iowa Flood Center are crucial for understanding flood risk. The U.S. Army Corps of Engineers, the Federal Emergency Management Agency (FEMA), and the Iowa Natural Heritage Foundation have collaborated to create comprehensive flood plans for urban communities, alongside high-resolution statewide flood maps produced through advanced hydrological modeling, such as HEC-RAS (Gilles et al., 2012). These maps serve as invaluable resources for various stakeholders, including citizens and floodplain managers, offering essential information that aids in informed decision-making and strategic flood preparedness.

In our analysis, we examined both 100-year and 500-year flood scenarios to assess their potential impacts on public transit systems. A 100-year flood scenario indicates a 1% chance of occurrence each year, while a 500-year flood scenario reflects a 0.2% annual chance. FEMA classifies areas at high hazard as those associated with 100-year flood risk, while those at moderate hazard correspond to 500-year flood risk (FEMA, 2020). By comprehensively understanding these risks, communities can better prepare for and mitigate the effects of future flooding events.

2.2.2. Public Transit Systems

The General Transit Feed Specification (GTFS) (GTFS, n.d.) data was used to record crucial information about the public transport systems present in Johnson and Linn counties (i.e., bus routes, bus stops, bus schedules, and service frequencies). GTFS is a data format that can be used to share public transportation schedules and related geographic information in a standardized way, which makes it a perfect data source for performing accessibility and flood impact analysis.

GTFS data for the transit systems covering Johnson and Linn counties were obtained from (Transitland, 2024). In total, there are many files that make up a complete view of the transit network and allow us to, for example, map routes, compute the frequency of service, and evaluate the potential impact of flood events on access. Important files used in this analysis are:

- *stops.txt:* Data for all bus stop locations, including latitude and longitude coordinates, providing the ability to map out where stops are located and the risk of being inundated under flood scenarios.
- *routes.txt:* Information on all transit routes; includes an assessment of route coverage, network structure, and routes that intersect flooded areas.
- *trips.txt:* Contains the sequence of stops for each route and trip, which is used to evaluate accessibility from the census blocks to the job locations during the morning (am) peak and from the job locations to the census blocks during the evening (pm) peak. It also helped determine what routes and stops would be hardest hit by flooding.
- *stop_times.txt:* Specifies the arrival and departure times at all the stops, which helps us calculate commutation freqs at the stop, and model how flooding will affect service levels through different times of the day throughout peak hours (7-9 am and 4-6 pm).
- *calendar.txt:* Sets the service schedules for weekdays, weekends, and specific days of the year, used in both processes to inform our analysis of accessibility changes over different temporal conditions and the extent of variation in service levels over weekday and weekend schedules.

2.2.3. Road Networks and Demographics

We used OpenStreetMap (OSM) to fill out the road network for each community. This open-access dataset provided by the Geofabrik platform (Geofabrik, 2024) contains a comprehensive description of transportation modes and infrastructure, and serves as enabling data for the current analysis. The data was used to assess how well pedestrians can reach bus stops and how far people can realistically walk. This provides important insight into how well the transit system connects with surrounding pedestrian infrastructure.

Origin (census block) datasets for the studied communities are obtained from the U.S. Census Bureau (US Census Bureau, 2020). Destination (jobs) datasets was extracted from the U.S. Census Bureau, including job location, number of jobs, and job type (e.g., health and education) (U.S. Census Bureau, 2022). Per census block, the number of populations, owners and renters with zero vehicles, and households with income below poverty are obtained from Business Analyst Tools through ArcGIS pro (ESRI, 2024b).

2.3. Public Transit Analysis

2.3.1. Inundated Public Transit Structures

Public transit systems have two fundamental types of data: routes and stops. Using Geographic Information System (GIS) analysis, flooding maps were overlaid against the locations of bus routes and stops to determine those impacted under 100-year and 500-year flooding events. A route is a series of trips that go through a set of stops. We have calculated the percentage of inundation for each route. This analysis provides a spatially detailed, exploratory assessment of the degree to which flooding disrupts public transit systems, improving the understanding of the vulnerability of transit systems to extreme events.

2.3.2. Frequency Analysis

ArcGIS Pro's public transit tools (ESRI, 2024a) allowed us to analyze GTFS public transit data effectively. One key tool we used was the frequency analysis tool, which helps determine how often a bus visits each stop. Our research focused on morning and evening rush hours on both a typical weekday and a weekend day. This helped us estimate how much service frequency each bus stop would lose during flooding, giving us a clearer picture of how floods disrupt public transit services.

2.3.3. Accessibility Analysis

During a flood event, it is essential to analyze the accessibility of the public transit system to reach destinations. Using Calculate Accessibility Matrix function in ArcGIS Pro (ESRI, 2024a), we wired in two rush hours, a weekday morning (7–9 am) and an evening (4–6 pm). We used census blocks as origin locations and job locations as destinations for the morning analysis, and we weighed the results by the number of jobs. This allowed us to determine the number of jobs accessible during this time period. For the evening analysis, we reversed the origin and destination, setting job locations as origins and census blocks as destinations. We then calculated the percentage of destination access before and after flooding to measure the impact of flooding on transit accessibility.

Additionally, we analyzed demographic variables to understand who benefits most from destination accessibility during the morning rush hour. Using the Calculate Composite Index tool in ArcGIS Pro (ESRI, n.d.), we combined multiple demographic variables for each census block into a single value. This approach provided insights into how different populations, particularly those with greater social vulnerability, are affected by changes in transit accessibility due to flooding.

3. Results and Discussion

3.1. Inundated Bus Stops

During 100-year and 500-year flood events, our analysis shows that many bus stops in Linn and Johnson counties are at risk of flooding (Figure 2). Most of these stops are located near major rivers, highlighting the strong link between proximity to water bodies and flood vulnerability. In Linn County, 6.8% of bus stops in Cedar Rapids are affected during a 100-year flood, rising to 11.8% during a 500-year flood. In Marion, the number of inundated stops increases from 5.0% to 8.5% between the two scenarios, while Hiawatha remains unaffected in both cases (Table 1).

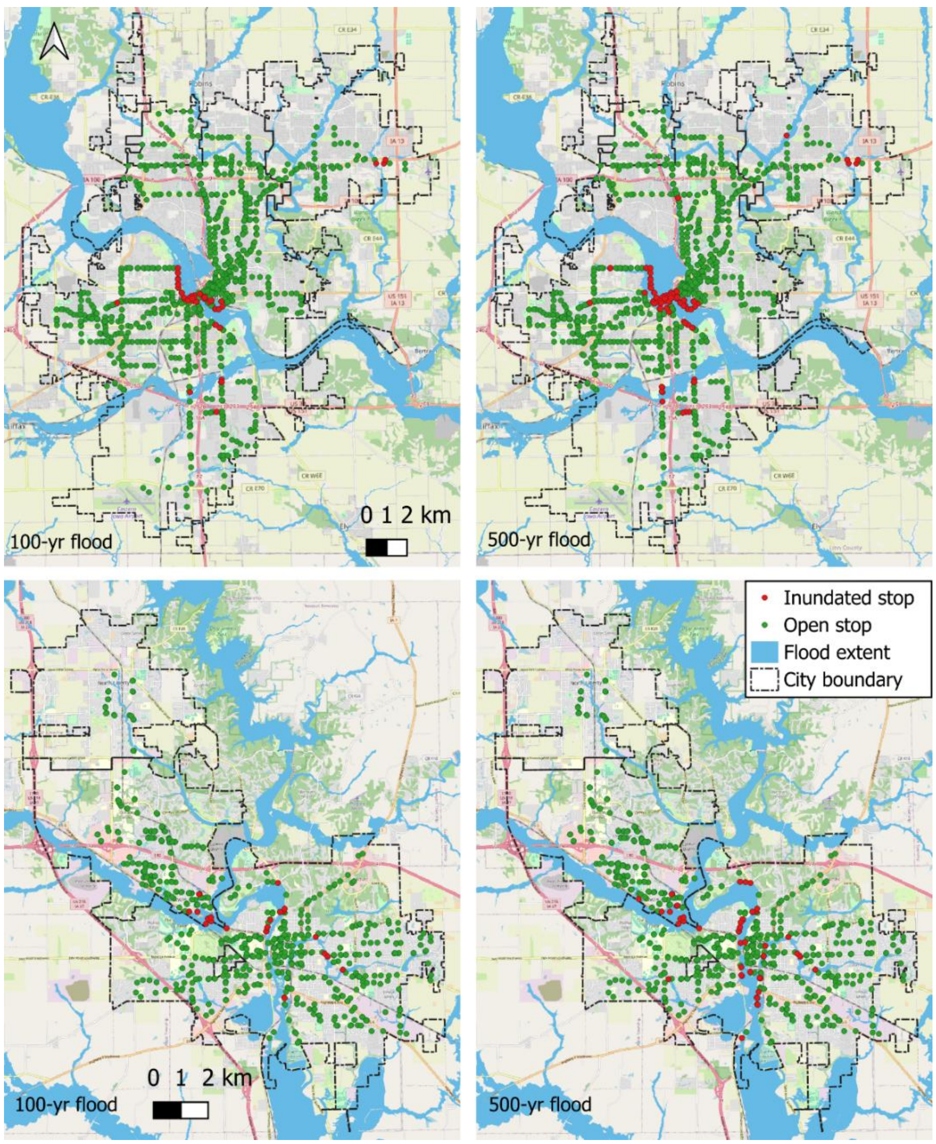

Figure 2. Inundated bus stops during the 100 and 500-yr floods

Table 1. Inundated bus stops during the 100 and 500-yr flood events

County	Community	# of stops	Inundated stops			
			# 100 yr	% 100 yr	# 500 yr	% 500 yr
Linn	Cedar Rapids	836	57	6.8%	99	11.8%
	Marion	59	3	5.0%	5	8.5%
	Hiawatha	32	0	0%	0	0%
Johnson	Iowa City	419	17	4.0%	43	10.30%
	Coralville	214	11	5.0%	13	6.10%
	North Liberty	37	0	0%	0	0%

In Johnson County, Iowa City faces 4% of its bus stops being inundated during a 100-year flood, which jumps to 10.3% in a 500-year flood. Similarly, Coralville sees an increase from 5.0% to 6.1% of affected stops between the two scenarios. North Liberty, like Hiawatha, experiences no impact under either flood condition. Flood risks to transit systems require practical solutions. Relocating bus stops to safer areas during floods or implementing protective measures can reduce disruptions and maintain reliable transportation for affected communities.

3.2. Inundated Bus Routes

Figure 3 illustrates the percentage of bus routes inundated during 100-year and 500-year flood events in Linn and Johnson counties. The visualization simplifies interpretation by grouping routes based on the percentage of inundation, despite the overlapping nature of many routes. The figure highlights a significant increase in inundation risk from the 100-year to the 500-year flood scenarios. For example, in Johnson County, some routes experience up to 20-42% inundation during the 500-year event, as indicated by the darker colors on the map.

Table 2 provides a detailed quantitative analysis of the impacts on bus routes. It includes the total number of trips, trip lengths, and the proportion of trips and routes affected in each flood scenario. In Johnson County, for instance, 99 trips cover a total of 894 km. During a 100-year flood, 60 trips and 61 km of route length are impacted, representing 7% of the routes. This increases to 81 trips and 93 km, or 10.4% of the routes, under the 500-year flood scenario. Similarly, in Linn County, 18 trips span a total of 501 km. Of these, 21 km (4.2%) are affected during a 100-year flood, increasing to 32.5 km (5.9%) during a 500-year flood.

Table 2. Impacts of Bus-route during the 100 and 500-yr flood events

County	# of Trips	Total Trip Length (km)	# Impacted Trips		% Impacted Trips		Inundated length (km)		% Inundated Route Length	
			100yr	500yr	100yr	500yr	100yr	500yr	100yr	500yr
Linn	18	501	16	16	89	89	21	32.5	4.2	5.9
Johnson	99	894	60	81	60.6	81.8	61	93	7	10.4

Flooding affects Johnson County bus routes more than those in Linn County. That data shows a significant rise in flooded routes, especially in urban areas in Johnson County, where transit networks are dense. To mitigate these risks, cities can relocate vulnerable routes, elevate infrastructure, or offer temporary transit solutions during floods. These kinds of steps can minimize disruptions and keep transit systems more functional during times of flooding.

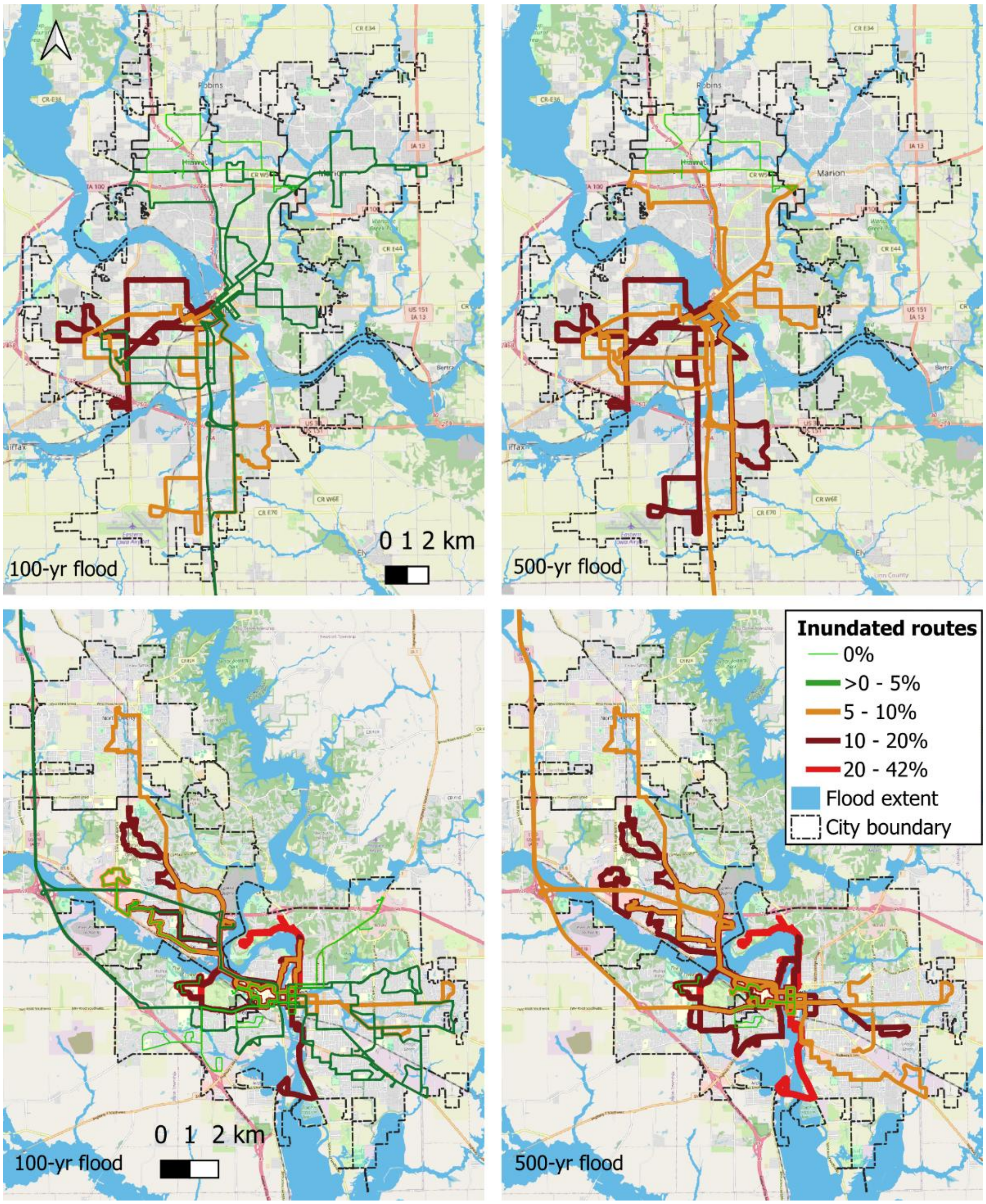

Figure 3. Inundated public transport rout percent during the 100 and 500-yr floods

3.3. Bus Stop Frequency Analysis

Figures (4 and 5) and Table 3 illustrate the impact of flooding on bus-stop frequencies in Linn and Johnson counties, highlighting service reductions across different temporal conditions—weekday and weekend, during morning (7–9 am) and evening (4–6 pm) peak hours. The analysis compares three scenarios: no flooding, 100-year flood, and 500-year flood, providing a comprehensive view of how bus-stop frequencies are affected under these conditions.

In Linn County, weekday morning (am) bus-stop frequencies experience losses of 94 visits during a 100-year flood and 171 visits during a 500-year flood, relative to the baseline total of 1,792 visits. Evening (pm) service exhibits similar reductions, with losses of 89 visits during a 100-year flood and 158 visits during a 500-year flood out of 763 baseline visits. On weekends, evening (pm) service frequencies decline by 46 and 79 visits during the 100-year and 500-year floods, respectively, while no service is observed for morning (am) periods under any condition.

In Johnson County, with a more extensive transit network, weekday morning (am) bus-stop frequencies could decline by 326 visits during a 100-year flood and 526 visits during a 500-year flood, out of a baseline total of 5,246 visits. Evening (pm) service losses amount to 284 visits during a 100-year flood and 464 visits during a 500-year flood, compared to the baseline total of 5,006 visits. Weekend morning (am) service experiences losses of 34 and 73 visits under the 100-year and 500-year flood scenarios, respectively, relative to a baseline of 1,017 visits. Similarly, evening (pm) weekend service exhibits frequency losses of 59 and 114 visits during the two flood events, compared to a baseline of 1,349 visits. While Johnson County experiences greater absolute reductions due to its larger transit network, Linn County faces proportionally significant losses in service availability.

Figure 4 visualizes these frequency losses in Linn County under the three scenarios: no flooding (first row), 100-year flood (second row), and 500-year flood (third row). The flood scenario images show the locations of flooded stops and quantify the number of frequencies lost. Under baseline conditions, weekday morning (am) and evening (pm) services exhibit the highest frequencies (6–12 visits) concentrated in Cedar Rapids, while weekend evening (pm) frequencies are lower, typically ranging between 3–6 visits in urban areas. During a 100-year flood, frequency losses are concentrated in areas near rivers and low-lying regions, with many stops losing service entirely or seeing reductions to 1–4 visits. The 500-year flood results in more severe disruptions, with many stops receiving fewer than 2 visits or becoming completely inaccessible, especially during weekend evening (pm) periods.

Figure 5 illustrates similar impacts in Johnson County. Under baseline conditions, weekday morning (am) and evening (pm) services exhibit high frequencies, with several stops receiving between 40 and 93 visits, particularly in urban centers such as Iowa City and Coralville. Weekend service is more limited, with morning (am) frequencies reaching up to 20 visits and evening (pm) frequencies up to 14 visits in key urban areas. During a 100-year flood, frequency losses are substantial, particularly in flood-prone areas, with weekday stops losing 20 or more visits and some weekend stops experiencing reductions below 10 visits. Under a 500-year flood, the losses become widespread, with many weekday and weekend stops dropping to 3–6 visits during evening (pm) service.

Table 3. Number of bus stop frequencies under no flood and losses of bus stop frequency for 100 and 500-yr floods (7-9 am, 4-6 pm)

County	Generic Day						Weekend Day					
	Morning (am)			Evening (pm)			Morning (am)			Evening (pm)		
	No flood	100 yr	500 yr	No flood	100 yr	500 yr	No flood	100 yr	500 yr	No flood	100 yr	500 yr
Linn	1792	94	171	763	89	158	0	0	0	763	46	79
Johnson	5246	326	526	5006	284	464	1017	34	73	1349	59	114

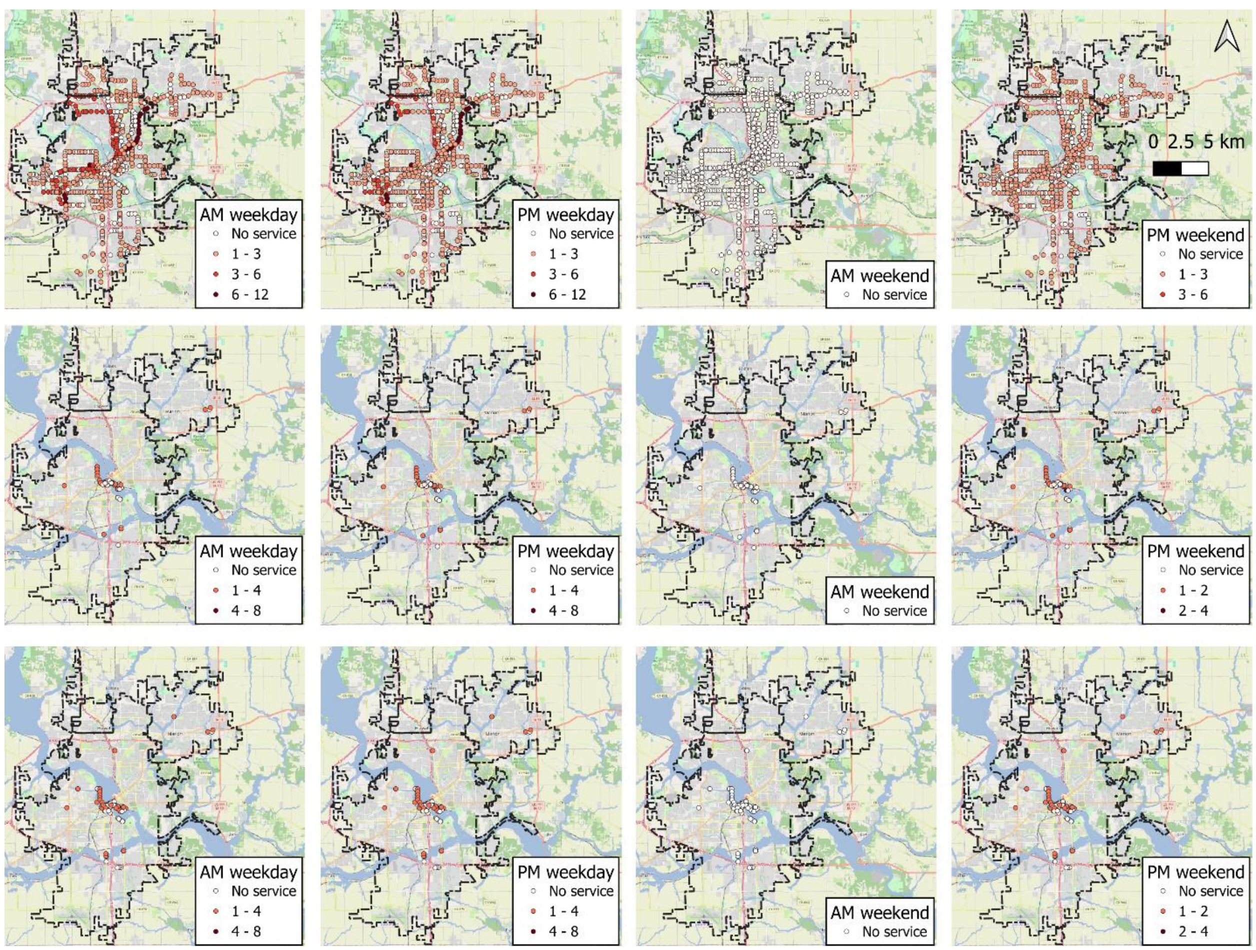

Figure 4. Linn County bus-stop frequency and loss of frequency during flooding on a weekday and weekend at 7-9am and 4-6pm.

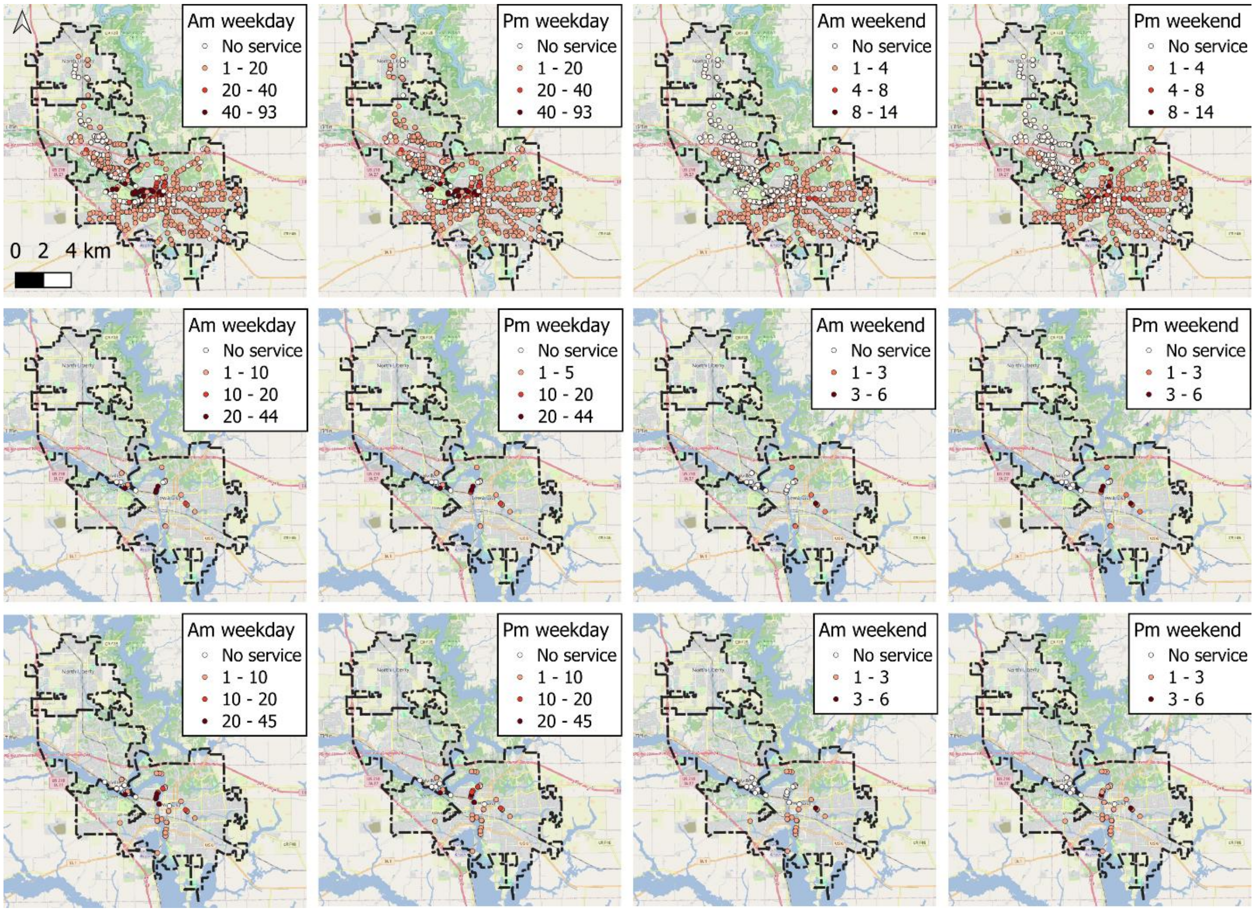

Figure 5. Johnson County bus-stop frequency and loss of frequency during flooding on a weekday and weekend at 7-9am and 4-6pm.

3.4. Origin-Destination Accessibility Analysis

3.4.1. Total Destinations Between Census Blocks and Jobs

This section evaluates the impact of flooding on the accessibility between census blocks and job locations during weekday peak hours under three scenarios: no flooding, 100-year flood, and 500-year flood. The analysis considers two peak periods. For the morning (am) peak hours (7–9 am), accessibility is measured from census blocks to job locations, reflecting how residents access employment opportunities. For the evening (pm) peak hours (4–6 pm), accessibility is assessed from job locations back to census blocks, illustrating how employees return to residential areas.

Table 4 provides descriptive statistics for the counties studied on the number of job locations and census blocks, along with the total number of destinations. Each job location can accommodate more than one employment opportunity, resulting in a discrepancy between job locations and total destinations. For instance, 1,250 job locations in Linn County correspond to 116,647 total destinations, while in Johnson County, 674 job locations correspond to 79,670 total destinations under no-flood conditions. These numbers give us a look into the counties' wider spread of jobs and census-level communities.

Figures 6 and 7 visualize these accessibility patterns for Linn and Johnson counties. In Linn County, the first row in Figure 6 visualizes morning (am) accessibility (from census blocks to job locations) under the three scenarios. Under no-flood conditions, the highest accessibility percentages (40–67%) are concentrated in urban centers such as Cedar Rapids. During a 100-year flood, accessibility is significantly reduced in flood-prone areas, with morning (am) access percentages dropping to 20–40% in affected regions. A 500-year flood exacerbates these reductions, with accessibility percentages falling below 20% across large portions of the county. The second row of Figure 6 shows evening (pm) accessibility (from job locations to census blocks). Similar trends are observed, with substantial losses in accessibility during flooding, particularly in areas near rivers. While no-flood conditions provide robust evening (pm) accessibility (30–55%), flood scenarios lead to sharp declines, especially under the 500-year flood.

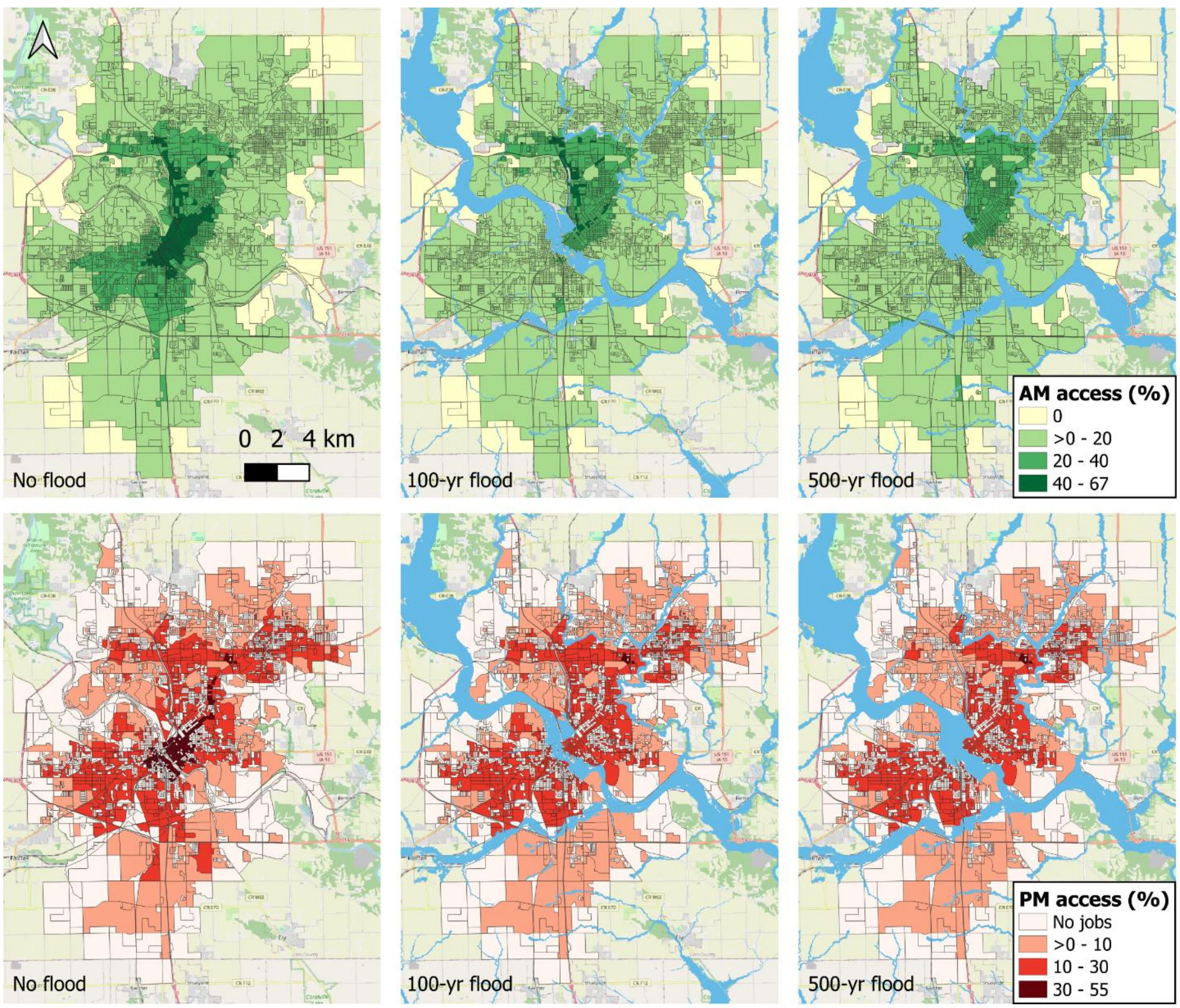

Figure 6. Linn County accessibility percent from census block to jobs (weekday 7-9 am) and vice versa (weekday 4-6 pm) before and after floods.

Table 4. Number of job locations, census blocks, and total destinations

Scenario	County	Job Locations	Census Blocks	Total Destinations
No Flood	Linn	1250	3,459	116,647
	Johnson	674	1,645	79,670
100-Year Flood	Linn	1,118	3,221	110,025
	Johnson	633	1,534	76,579
500-Year Flood	Linn	1,116	3,081	103,288
	Johnson	608	1,497	73,951

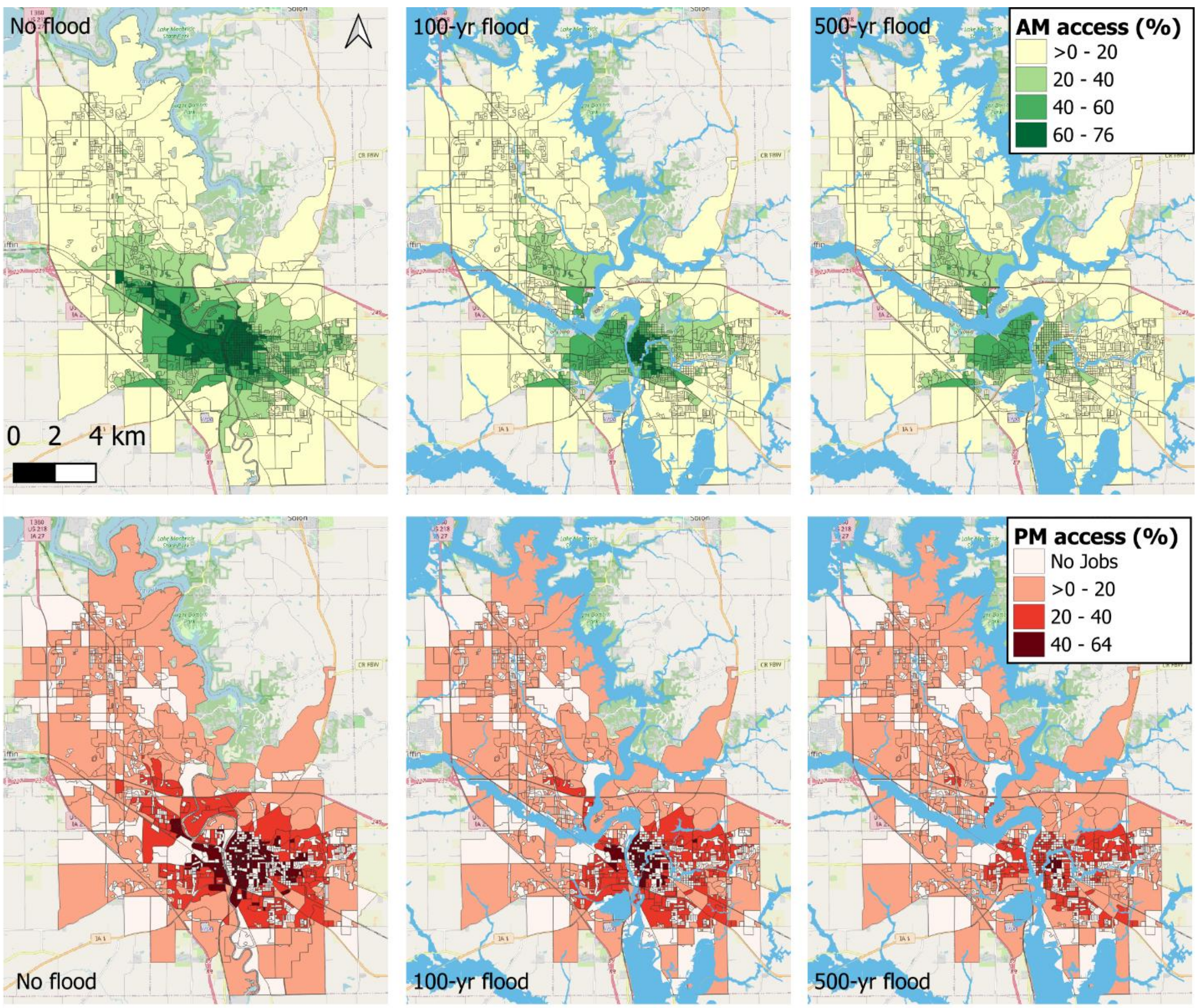

Figure 7. Johnson County accessibility percent from census blocks to jobs (weekday 7-9 AM) and vice versa (weekday 4-6 PM) before and after floods

In Johnson County, Figure 7 follows the same structure. The first row visualizes morning (am) accessibility (from census blocks to job locations) under no flooding, 100-year flood, and

500-year flood conditions. Under no flooding, morning (am) accessibility is highest in urban areas like Iowa City and Coralville, with percentages ranging from 40-76%. During a 100-year flood, morning (am) accessibility decreases significantly in flood-affected zones, with percentages dropping to 20-40%. Under a 500-year flood, accessibility is further reduced, with large sections of the served area falling below 20%. The second row of Figure 7 represents evening (pm) accessibility (from job locations to census blocks). Similar to morning (am) patterns, evening (pm) accessibility is robust under no-flood conditions (30-64%) but diminishes significantly under flood scenarios, particularly in flood-prone areas, with sharp losses under the 500-year flood.

3.4.2. Demographic Variables Investigation

This section explores the interaction between accessibility changes and social variables in Linn and Johnson Counties under no-flood, 100-year flood, and 500-year flood scenarios. Figures 8 and 9 illustrate accessibility patterns, with dots representing accessibility percentages under no-flood conditions and accessibility losses during flooding. The background shows a composite index of social variables, including total population, households below the poverty line, and households without vehicles. Darker shades indicate higher social vulnerability, highlighting populations more dependent on public transit.

In Linn County (Figure 8), under no-flood conditions, accessibility percentages (represented by dots) range from 0% to 67%. The highest accessibility is concentrated in urban areas like Cedar Rapids, where transit systems provide strong connections to job locations. These areas overlap with darker background regions, indicating neighborhoods with higher social vulnerability, such as low-income households and those without private vehicles. During a 100-year flood, accessibility reductions (represented by dots in orange and red) range from 10% to 40%. These reductions are concentrated in flood-prone zones near rivers, disproportionately affecting socially vulnerable areas. Under a 500-year flood, accessibility losses intensify, with reductions exceeding 40% in many regions, further isolating transit-dependent populations in darker backgrounds.

In Johnson County (Figure 9), no-flood accessibility percentages range from 0% to 75%, with the highest values found in urban centers such as Iowa City and Coralville. These areas align with darker regions on the demographic index, representing neighborhoods with higher proportions of low-income households and households without vehicles. During a 100-year flood, accessibility losses range from 10% to 40%, concentrated in flood-prone areas, including neighborhoods with greater social vulnerability. Under a 500-year flood, accessibility losses exceed 40% across large portions of the county, particularly in urban and suburban areas. These losses disproportionately affect transit-dependent populations in darker regions of the background.

The maps emphasize the uneven risk distribution of flooding on socially vulnerable populations within the analyzed counties. In Linn County, accessibility losses during floods primarily affect low-lying urban areas near rivers, while in Johnson County, urban centers like

Iowa City and Coralville experience severe reductions in accessibility. The alignment of accessibility losses with darker areas on the demographic index underscores the compounded challenges faced by populations with limited resources.

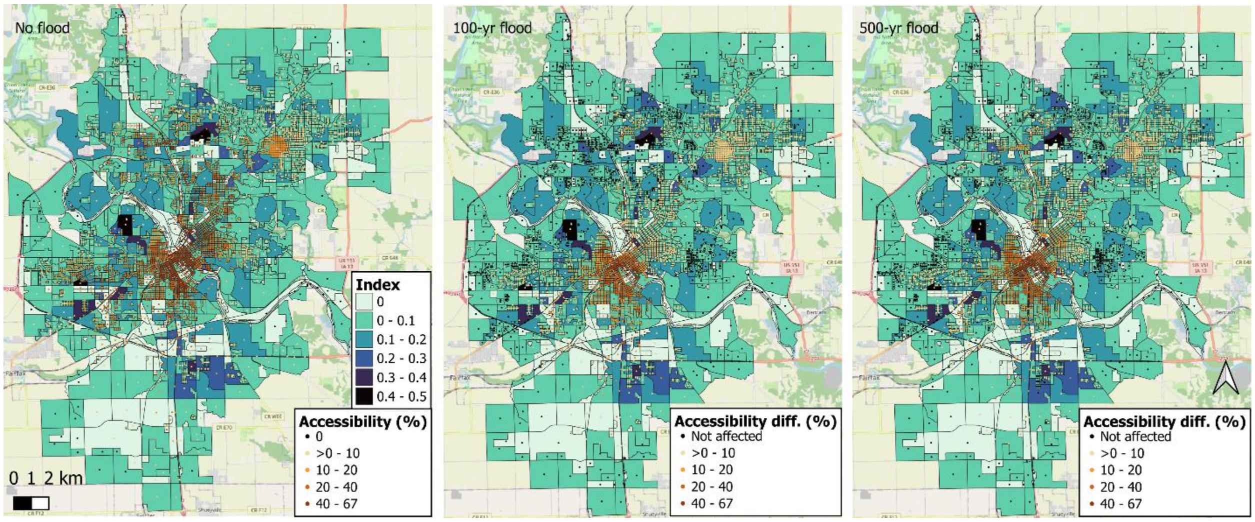

Figure 8. Linn County accessibility percent (no flood) and the loss of accessibility (100 and 500-yr floods) during morning rush hours (7-9), backgrounded by demographic variables.

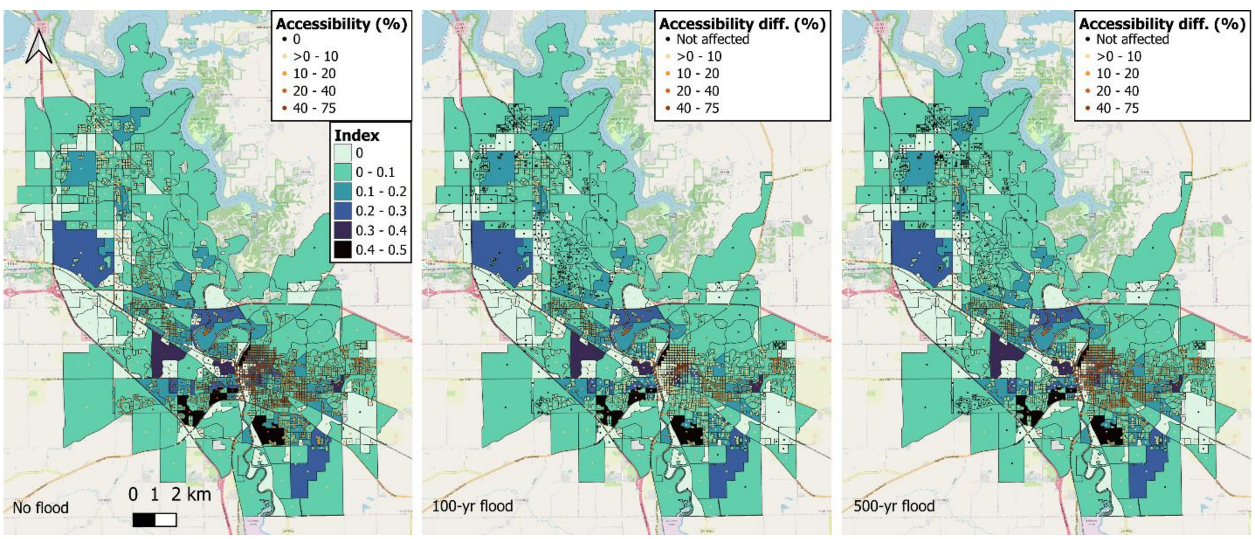

Figure 9. Johnson County accessibility percent (no flood) and the loss of accessibility (100 and 500-yr floods) during morning rush hours (7-9), backgrounded by demographic variables.

The findings highlight the importance of addressing social vulnerability in flood resilience plans. Prioritizing investments in flood-resistant infrastructure and improving transportation connectivity in highly vulnerable areas are essential steps to reduce the disproportionate impacts of flooding on disadvantaged communities. Further, effective emergency response planning with these communities needs to be prioritized so that vulnerable communities can mitigate the compounding effects of floods on disadvantaged populations. Highlighting the area where accessibility and social vulnerability collide can ensure that policymakers and urban planners target equitable and inclusive efforts during and post flood events.

4. Conclusion

This study examined the effects of 100- and 500- year flood scenarios on transit accessibility, specifically the inundated bus stops and routes, decreased bus-stop frequencies, and job-location accessibility. The results also emphasize the vulnerability of transit infrastructure to flooding in river-adjacent and low-lying regions and highlight how barriers are compounded for socially vulnerable populations.

Significant frequency losses were identified in the analysis of inundated stops and routes, with reductions reaching up to 526 visits during morning (am) peak hours under the 500-year flood event. These disruptions were the most severe in high-demand urban areas, where the impact on transit operations was intensified. Additionally, some stops experienced a complete cessation of service during peak periods, further isolating transit-dependent populations.

Flood events had a greater impact on areas with higher social vulnerability. Communities with many low-income households and limited vehicle access experienced notable reductions in transit accessibility. For instance, the number of destinations reachable from certain census blocks decreased sharply during flooding, disrupting connections to jobs and vital services for transit-dependent populations.

The study shows the importance of including flooding resiliency in transport planning. Key measures here are strengthening flood-affected routes and developing flexible alternative transport options such as rerouting or temporary stops whenever flooding occurs. Timely information dissemination to users on any flooding event is also essential. The provision of emergency transport services to socially vulnerable groups would also help to maintain access to employment and essential services during extreme weather conditions.

This study calls for thoughtful and inclusive approaches to make public transit more resilient to flooding. Strengthening infrastructure to withstand floods and addressing the needs of vulnerable communities can help ensure reliable service, equal access, and economic security during extreme weather events. Additionally, community organizations focused on social equity can advocate measures that address the needs of vulnerable populations, ensuring that these groups maintain access to jobs and services during floods.

For future work, expanding the study to include additional counties in Iowa or other states with similar flood risks could provide a broader understanding of regional challenges and solutions. Moreover, incorporating climate change projections into the analysis could offer insights into future vulnerabilities, helping transit systems to better prepare for increasing flood frequencies. Investigating the economic impacts of transit disruptions on communities could also provide compelling data to support further investment in resilient infrastructure.

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