Comprehensive Assessment of Flood Risk and Vulnerability for Essential Facilities: Iowa Case Study

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Abstract

Of all natural disasters that occur on this planet, flood events are universally one of the most common and most destructive. As climate change and human actions continue to cause the occurrence of flood events to rise, it becomes increasingly important that the effects of flooding are analyzed and understood. In this study, nine different types of critical amenities in the state of Iowa (such as hospitals, fire stations, schools, etc.) were analyzed on a county level in terms of flood depth, functionality and restoration time after flooding, and damage sustained during flooding. These critical amenities were also analyzed on the state level in terms of their location relative to the 100yr and 500yr flood zones. Results show that the number of critical amenities within the flood extent reached up to 39%, and during the 100yr flood scenario all but one of the six chosen counties lost functionality of 100% of their amenities. Most critical amenities were found to have a flood depth of 1 to 4 ft deep and a restoration time of 480 days. The purpose of this study is to bring awareness to decision makers regarding the risk that flooding events pose to critical amenities and highlight the increasing dangers of flooding on a broader scale. This study will be beneficial to improve mitigation strategies, emergency response plans, and ensuring that emergency services and amenities are available in the event of future floods for the affected areas.

Keywords

Floods, flood vulnerability, risk assessment, flood damage, essential facilities, amenities

1. Introduction

In recent years, the frequency and impact of natural disasters has risen significantly on a global scale (He et al., 2021). One of the more prevalent of these natural disasters is flood events, as they can leave a great amount of destruction in their wake, affecting not only people and their homes (Cikmaz et al., 2023), but infrastructure and the surrounding environment as a whole (Afreen, 2018; Rose, 2022). There are many factors that have made flood events more dangerous over the last decades, such as climate change and urban development (Mobini et al., 2021; Alharbi et al., 2022). The United States alone has seen a rise in damages due to flooding averaging 7.96 billion dollars per year from 1985 to 2014 (Andreadis et al., 2022).

As the planet warms, flood events become more common (Li and Demir, 2022) and intense (Dong et al., 2020; Allen et al., 2020), and they may also begin to occur in regions where they might not have before (Andreadis et al., 2022). This lack of exposure in certain areas to floods, or simply the level of flooding, has caught the people of those areas off-guard and in turn has shed light on their lack of preparedness to deal with modern flood events (Yusoff et al., 2017; Berwari, 2012). As the frequency and intensity of flood events increase, city officials and stakeholders need to be made aware of the risk to their communities so they might implement flood mitigation and emergency response strategies accordingly (Alabbad and Demir, 2024).

One critical aspect of flood preparedness is ensuring the availability of critical amenities (McAllister, 2013; Oh, 2010; Gangwal et al., 2023). While drowning accounts for a large portion of deaths caused by flooding, it is not the only way floods can be deadly. Floods can also lead to deaths caused by physical injury, electrocution, carbon monoxide poisoning and other chemical hazards, and even fire (World Health Organization, 2013). Therefore, in the event of a major flood, the availability and operation of several types of emergency services and shelters is imperative (Akhlaghi et al., 2023). Medical facilities and Emergency Medical Service (EMS) stations are needed to provide medical care to those affected by flood damage as quickly as possible (Baharuddin et al., 2015; Sirbaugh et al., 2002). Police and fire personnel are needed to help coordinate the public and enact emergency plans, such as evacuations, relocations, roadblocks (Mount et al., 2019), and other mitigation strategies (Thieken et al., 2016; Otto, 2019; Cikmaz et al., 2024a), as well as keeping fires and the risks of electrocution caused by downed wires at bay (Berwari, 2012).

Power plants provide electricity to other critical amenities so they can remain operational, such as by ensuring communications among personnel remain in-tact and medical equipment remains functional (Sirbaugh et al., 2002; Achour et al., 2014). Schools, lodging facilities, and other community buildings, such as churches and event centers, are important for providing shelter to those displaced by flooding (Ramm, 2016). Potable water and wastewater facilities are used to ensure that people and other critical amenities affected by flooding still have access to fresh water during and after a flood (Achour et al., 2014; World Health Organization, 2013). While it is of utmost importance to have at least one of each of these critical amenities operational within an area affected by flooding, it is best to have multiple, in the event that the amenity loses function or is inaccessible to the public (Alabbad et al., 2024; Yin et al., 2017).

As the frequency and intensity of flood events have increased worldwide, so has the interest in understanding their patterns and impacts on people and the environment (Tanir et al., 2024). Many researchers across the globe have conducted studies to determine damage and economic loss (Duran et al., 2023), population impact, loss of road and transportation access, mitigation strategies, and more to inform urban administrators of the potential dangers of flooding (Alabbad et al., 2023; Yu et al., 2020). The impact of flood events on infrastructure and critical amenities has also been studied in other parts of the world, such as Thailand (Rattanakanlaya et al., 2016), Australia (Loosemore et al., 2010), the United Kingdom (Coles et al., 2017; Pant et al., 2016), and the United States (Sun et al., 2023; Yildirim et al., 2023).

In March of 2023, a study was done on hospitals impacted by flooding in the state of Florida in the United States by assigning various hazard levels to buildings identified within the hazard zone (Sun et al., 2023). In another study the impact of flooding on critical infrastructure was analyzed in England in 2016 by using spatial network models and quantifying the impact in terms of how the population was affected (Pant et al., 2016). While the value of these studies cannot be overstated, there are still many areas susceptible to a high-risk of flooding that have not been studied. Furthermore, the studies that have been conducted on flood impact on critical amenities are largely focused on medical facilities specifically and less so on others, such as police stations, wastewater facilities, or shelters.

Although the impact of flooding has been frequently researched across the United States and other countries, there have been very little studies done on its impact in the State of Iowa (Cikmaz et al., 2024b). Fewer still are studies done on the impact of flooding on critical amenities. This study aims to fill that gap in research and to bring more awareness to the effects of flooding in Iowa. Specifically, this study looks at the impact of flooding on critical amenities in Iowa with the intention of informing city officials and stakeholders about the risk associated with flooding in their respective Iowan counties and communicating (Yesilkoy et al., 2023) the flood risk using novel visualization technologies (Sermet and Demir, 2022). This is done in hopes that the public will consider implementing appropriate mitigation strategies and emergency plans if they have not already done so in order to ensure the safety of their communities should a flood event occur.

The remaining sections of this paper are structured in the following manner. Section 2 describes the methodology used in this study. Section 3 reports and discusses the results generated from the study. Section 4 provides the conclusion and discussion of potential future research that could be done.

2. Methodology

2.1. Case Study

There were two general areas of interest chosen for this study (Figure 1). The first area was the entire state of Iowa, which is in the midwestern part of the United States. The second area consisted of 6 of the 99 counties within Iowa on which a deeper analysis was conducted. These counties were Pottawattamie, Polk, Linn, Johnson, Harrison, and Story counties. Iowa is considered one of the highest at-risk states for flood events, as its landscape is significantly influenced by several major waterways that run throughout the state and its borders are occupied by the Mississippi River in the east and the Missouri River in the west (Li et al., 2023).

One of the largest floods to occur in the state happened in June of 2008 during an onslaught of floods plaguing the entire Midwest. The Cedar River flooded, causing 14% of the city of Cedar Rapids, Iowa to be flooded, damaging or destroying approximately 6,100 structures and displacing approximately 24,000 people (Holmes et al., 2010). In August of 2016, Freeport, Iowa suffered the second 100yr flood event to occur within 10 years, which caused approximately 2.5 million dollars in damage (Brummel, 2019).

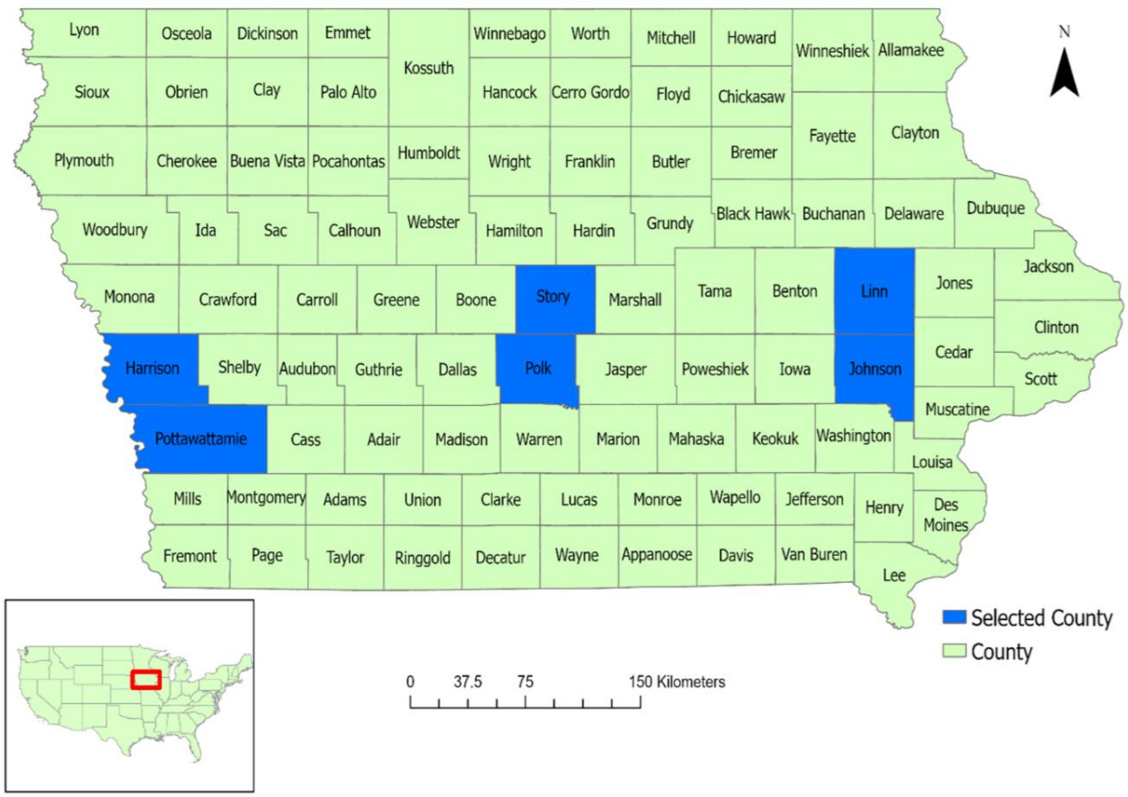

Figure 1. Map of State of Iowa delimited by county. Counties colored in blue indicate counties selected for analysis.

2.2. Data Collection

In this study, nine different types of critical amenities were observed. These amenities include medical facilities (hospitals, clinics), EMS (emergency medical services) stations, fire stations, police stations, schools (elementary, Jr.-Sr. high, colleges and universities, education and learning centers), shelters (churches, event centers, motels, hotels, and lodges), potable water facilities, wastewater facilities, and power plants. The geographic locations of critical amenities were collected from three different data sources. Initially, locations of all critical amenity types were pulled from each dataset and compared to each other to determine the best source for each amenity type. The data source with the highest representation of an individual amenity was the source chosen for that amenity. In the study, location data on wastewater facilities was pulled from the Inventory National Database within HAZUS (6.1) software; power plants, fire stations, and EMS stations were pulled from individual datasets within the HIFLD database; medical facilities, police stations, schools, shelters, and potable water facilities were pulled from the ArcGIS Business Analyst (2019) dataset.

HAZUS is a software tool developed by the Federal Emergency Management Agency (FEMA) for the purpose of analyzing the effects of natural disasters, including floods. The Inventory National Database is embedded within the HAZUS software and contains detailed information about various structures, including critical amenities, such as their location, occupancy type, size, and many others. It was last updated in 2023 (FEMA, 2023). The Homeland Infrastructure Foundation-Level Data (HIFLD) database is managed by the Department of Homeland Security (DHS) and is designed to support various homeland security and emergency management activities. This database contains detailed information about the location of critical facilities in the United States. The datasets containing information on fire stations, EMS stations, and power plants were all updated as of 2023 (HIFLD, 2023).

The ArcGIS Business Analyst dataset is licensed by Infogroup and is accessible through the ESRI Demographics database. The dataset contains basic information on each business in the entire state of Iowa as of 2019, including locations and business types (ArcGIS Business Analyst, 2019). Building data was retrieved from the National Structure Inventory (NSI), which is a dataset created and maintained by the US Army Corps of Engineers (USACE). It contains data detailing structural aspects of various buildings across the United States and was used in the creation of the Inventory National Database (FEMA Flood Map Service Center, 2023). This dataset was used to retrieve occupancy type, foundation height, structural value, and content value for each critical amenity. This dataset was updated as of 2022 (USACE, 2022). The two-dimensional 100yr and 500yr flood extent maps and the three-dimensional flood raster maps for the six chosen counties were both obtained from Iowa Flood Center in Iowa City, IA. The flood maps available include 2yr, 5yr, 10yr, 25yr, 50yr, 100yr, and 500yr extents and were produced using HEC-RAS models (Iowa Flood Center, 2023; Gilles et al., 2012).

2.3. Vulnerability of Critical Amenities to Flooding

2.3.1. Flood Exposure

The first analysis is conducted to determine which critical amenities were within the 100yr and 500yr flood extents. This was done over the entire State of Iowa using flood maps from both flood extents. These flood maps were layered individually over a map of Iowa delimited by county for each analysis using Geographic Information System. All three datasets were then loaded into ArcMap (10.8.2) software and were added as a layer on top of the 100yr and 500yr flood maps. To determine which critical amenities were within each flood zone, the 'Select by Location' tool was used to run an intersection between the critical amenity data points and the flood map. If the data points intersected with the flood map, they were considered to be within the flood extent and were recorded and organized in Excel by amenity type and county.

Schools often combine multiple education levels into one building. If multiple schools shared the same address and mostly the same name, they were considered to be one school. For example, Lynnville-Sully Middle School and Lynnville-Sully High School shared the same address, and thus, were considered as one amenity. Similarly, if a sheriff station shared the same address as a police station, it was considered to be one amenity. However, if two different amenity types occupied the same location, they were considered to be two separate amenities, such as EMS stations and fire stations or EMS and medical facilities located in the same building. Wastewater facilities often had duplicates of the same facility within the dataset, of which only one copy was chosen.

In this research, we analyzed the impact by calculating the percentage of critical amenities within each flood zone out of the total number of critical amenities within each county. The counties with the highest percentages of critical amenities within the flood zones were considered the most impacted. Pooling the analyses at the county-level spatial scale is advisable, given that the majority of disaster declarations and funding allocations are made at that level. The remaining analyses conducted were done on the selected counties, and therefore only took into consideration Pottawattamie, Polk, Linn, Johnson, Harrison, and Story counties. These counties were chosen because they had the highest number of critical amenities within the 100yr flood zone.

2.3.2. Flood Depth Analysis

The next analysis performed was that of flood depth across the six selected counties for both the 100yr and 500yr flood extents. This data was obtained by using flood depth raster layers of each county in QGIS (3.34.0) software. Flood depth analysis was conducted on each of the six counties individually, first by layering the critical amenity data over the county map, followed by the raster layer, then by using the ‘Sample raster values’ tool in QGIS to extract the flood depth measurements of each critical amenity per county. The flood depths were retrieved to be utilized with depth-damage functions used later in the study. For this analysis the foundation height of each amenity was not taken into consideration.

2.3.3. Functional Analysis of Amenities in Flooded Areas

Results from the flood depth analysis were used to perform the next analysis, which was to determine the functionality of critical amenities that had been considered flooded for both the 100yr and 500yr flood extents. Functionality was determined by comparing the flood depth of each critical amenity to that of the standard functionality threshold of each amenity type provided in the HAZUS Inventory Technical Manual (2.1), while taking into account the first-floor height and assuming no basement was present (HAZUS, n.d.). For the functionality threshold of each amenity type, the default option was chosen if present. If there was no default option, the medium level was chosen instead. Because the HAZUS documentation does not have a depth functionality threshold for shelters or EMS stations exclusively, the threshold for schools was used for shelters and the threshold for fire stations was used for EMS stations instead. If the flood depth was below the threshold provided in the manual, the critical amenity was considered to be functional. If it was at or above that threshold, the amenity was considered non-functional. For this analysis the foundation height of each amenity was taken into consideration. Critical amenities with flood depths less than 0.5ft were considered to have a flood depth of 0 and were not included in this analysis.

2.3.4. Estimation of Restoration Time for Affected Amenities

Results from the flood depth analysis were also used to determine the restoration time of critical amenities that were considered flooded for both the 100yr and 500yr flood extents. Restoration time was determined by comparing the flood depth of each critical amenity to that of the standard restoration time threshold range of each amenity type, which was also provided by the HAZUS Inventory Technical Manual (5.1). For the restoration time threshold range of each amenity type, the default range was chosen if present except in the case of power facilities, for which the restoration time threshold for the occupancy type IND2 was used which corresponds to light industrial building. If there was no default range, the medium level range was chosen instead. As there was no information in the HAZUS documentation regarding restoration time estimates for wastewater and potable water facilities, these amenity types were not considered for this analysis. Flood depth ranges are split into tiers that correspond to the number of days it would take for that amenity type to be restored after flooding occurred, as shown in Table 1 below. The number of days for restoration time required per amenity was determined by looking at its flood depth and then assigning it the number of days for restoration that corresponded to that flood depth as described in the HAZUS Inventory Technical Manual.

Table 1. Default medical restoration time information provided by the HAZUS Inventory Technical Manual.

HAZUS Label	Description	Minimum Flood Depth (ft)	Maximum Flood Depth (ft)	Maximum Days to Restoration
EFMC	Medical Clinics and Labs	-4	0	360
EFMC	Medical Clinics and Labs	0	4	480
EFMC	Medical Clinics and Labs	4	8	630
EFMC	Medical Clinics and Labs	8	12	720
EFMC	Medical Clinics and Labs	12	25	900

2.3.5. Damage Analysis of Amenities in Flood-Prone Areas

In this study, four types of damage analysis were performed per critical amenity for both the 100yr and 500yr flood extents. These analyses were the structural damage cost, percentage of structural damage, content damage cost, and the percentage of content damage. The structure value, content value, and occupancy type code were all provided by the building data from the NSI dataset, and the flood depth was provided by the previous analysis. If no building data was available for an amenity, the default values for structure and content values and occupancy type code provided by the HAZUS Inventory Technical Manual were used instead. These values were then used in a depth-damage function provided by HAZUS, which is used to determine the mathematical relationship between damage percentages and flood depth (Yildirim et al., 2022).

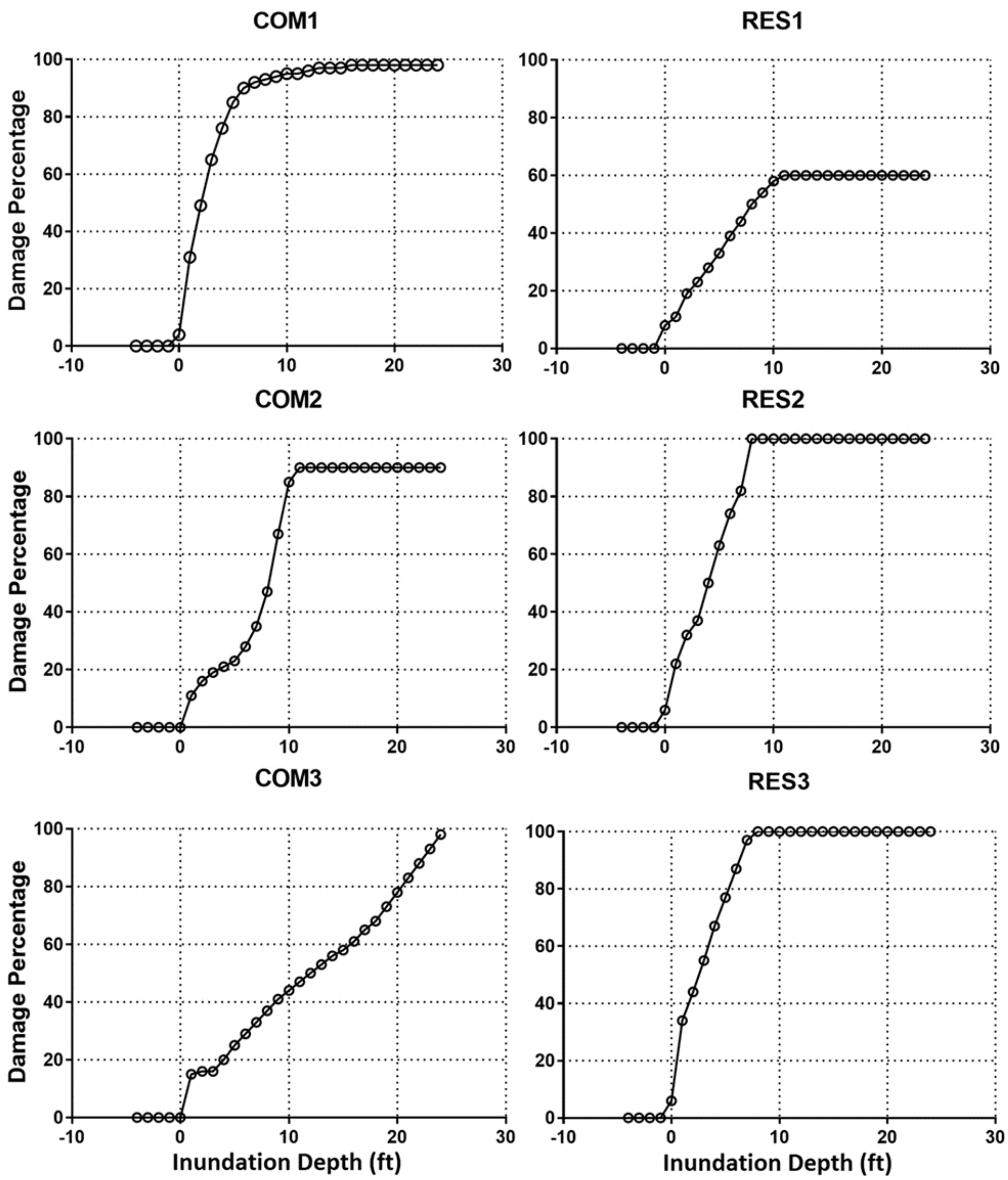

Figure 2. Structural flood depth–damage functions used in the study is provided by HAZUS (adapted from Yildirim et al., 2022)

Occupancy type is used to assign structure and content values to each critical amenity. These values are then used with the depth-damage curve, as shown in Figure 2, to estimate flood both structural and content damage (Alabbad & Demir, 2022). For wastewater facilities and power plants, structural and content values were not used in the calculation and the default replacement values per facility size provided in the HAZUS Inventory Technical Manual were used instead. This was done for consistency because the wastewater and power plants often had multiple buildings and therefore multiple NSI data points. The foundation height of the critical amenities was taken into consideration for this analysis. This analysis also operated under the assumption of critical amenities not having basements.

3. Results and Discussion

3.1. Statewide Flood Exposure Analysis

Figure 3 shows the percentage of critical amenities across the state of Iowa that are within each flood zone. Some counties had no critical amenities affected, while Pottawattamie was impacted the most in both the 100yr and 500yr flood events with 36% and 39% of its critical amenities affected respectively. The majority of percentages of critical amenities affected per county fell within the 1% - 5% range. There were 19 counties in the 100yr extent that their amenities were unaffected by flooding in the context of this study, and 11 counties that were unaffected in the 500yr extent. Only 3 counties in the 100yr flood extent had more than 11% of their critical amenities affected by flooding, while the 500yr extent saw 9 counties with more than 11% of its amenities affected. The overall percentage of amenities affected by flooding in the 100yr flood plain was 3%, while those affected in the 500yr flood plain was 5%.

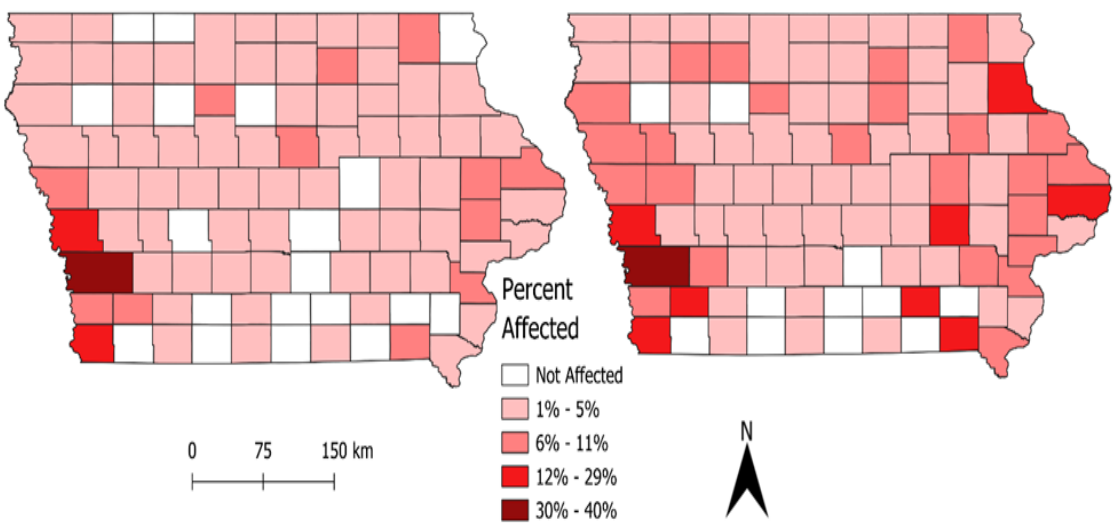

Figure 3. The percentage of critical amenities within the 100yr (left) and 500yr (right) flood extent in Iowa for each county.

Figure 4 shows the percentage of critical amenities affected across the entire state of Iowa based on the type of amenity. The chart also shows a comparison between these percentages between the 100yr and 500yr flood extents. Results show that in both the 100yr and 500yr flood plain, wastewater facilities were by far the most affected amenity type at 17% and 22% respectively. Schools overall were the least affected at 2% for both flood extents. However, within the 100yr flood extent, medical facilities and potable water facilities were also found to have only 2% of amenities affected. Overall, the rest of the amenity types are similarly impacted to each other across the state, ranging between 3-8% affected. Knowing which amenity types are most at-risk during a flood can allow decision makers to better prepare for those amenities being compromised.

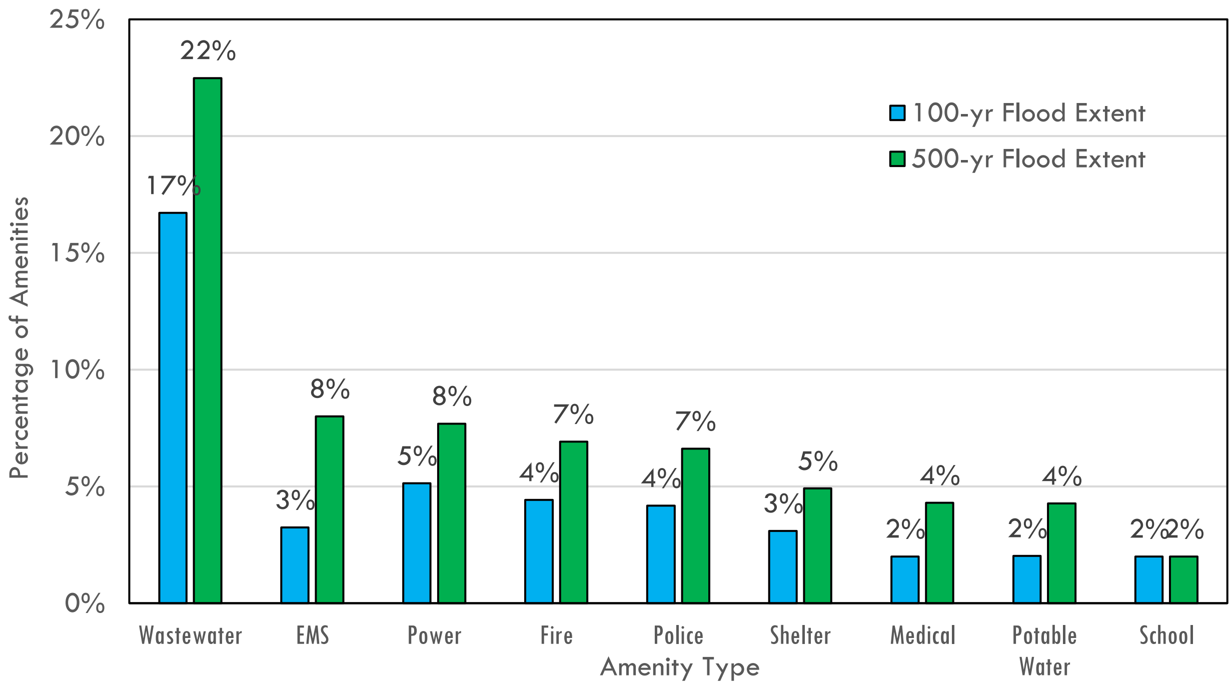

Figure 4. The percentage of critical amenity types affected in the 100yr and 500yr flood extent across the state of Iowa.

3.2. County-level Flood Vulnerability Analysis

Flood depth analysis is useful for informing other types of flood-related analyses, such as amenity damage costs and amenity functionality. Figure 5 shows the number of critical amenities at various flood depths in the 100yr and 500yr flood extents per county. This depth analysis was the first analysis done on the county level, which only covers the top six most affected counties in Iowa based on the 100yr flood extent. Results show that the vast majority of flood depths were between 1 and 4 feet. Pottawattamie County had the highest number of critical amenities within this depth range by far with 40 amenities in the 100yr extent and 51 in the 500yr extent. The next highest in this range is Polk County with 6 amenities in the 100yr extent and 20 in the 500yr extent. Pottawattamie also had the highest amount of amenities within the 4 to 8 feet flood depth range with 11 in the 100yr extent and 41 in the 500yr extent. The county impacted the least by flood depth was Story County with only 4 amenities within the 1 to 4 feet range in the 100yr extent and 10 in the 500yr extent.

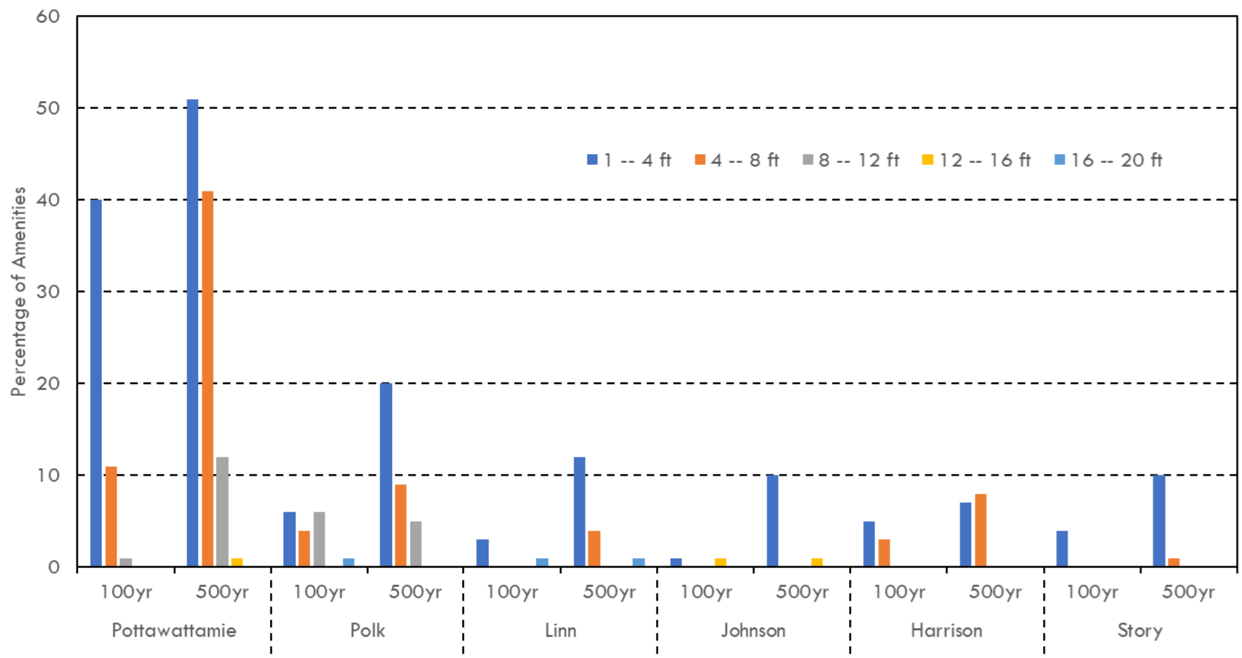

Figure 5. Number of critical amenities at various flood depths in feet for 100yr and 500yr flood extents. Shows the top 6 most affected counties in Iowa.

Table 2 shows the amount of impacted, but functional critical amenities on the county level for 100yr and 500yr flood extent. Results from the functionality analysis showed that Story County was the only county to have any functional amenities in the 100yr extent. In the 500yr extent, Pottawattamie County was found to have the highest number of functional amenities when compared to the others. However, for both the 100yr and 500yr extent, Pottawattamie County also had the highest amount of non-functionality. All 52 of its impacted amenities in the 100yr extent were considered non-functional, and 102 out of 105 of its impacted amenities in the 500yr extent were considered non-functional. Story and Johnson counties tied for the least number of non-functioning amenities in the 500yr extent, both having only 9. It can be seen in the chart that overall, the 500yr extent had more functional critical amenities than the 100yr extent. This is because of a discrepancy between the flood raster maps to determine the flood depth at each critical amenity and the statewide flood extent maps used to determine the location of affected amenities.

Some of the critical amenities were within the extents of the statewide flood extent maps but were not in the flood extent used by the flood raster maps, and therefore returned a flood depth of 0. The functionality analysis only considered critical amenities that were flooded. If an amenity was found to have a flood depth of 0, it was not considered to be flooded, and therefore not included in this analysis. It is also caused by the fact that the 500yr extent has a wider range than the 100yr extent and therefore can reach more amenities. However, the flood depths at those amenities are often shallow, as they are often on the outskirts of the 500yr extent, or they are amenities that have higher thresholds for functionality, such as medical facilities. It is important to understand not just which critical amenities are being impacted by flood events, but to what extent. Functionality analysis informs decision makers which impacted amenities may still be accessed and used during an emergency.

Table 2. Functionality of impacted critical amenities within 100yr and 500yr flood extents. Shows the top 6 most affected counties in Iowa.

	Impacted Amenities		**Yes**		**No**	
County Name	100yr	500yr	100yr	500yr	100yr	500yr
Pottawattamie	52	105	0	3	52	102
Polk	17	34	0	2	17	32
Johnson	2	11	0	2	2	9
Linn	4	17	0	1	4	16
Story	4	11	3	2	1	9
Harrison	8	15	0	1	8	14
Total	87	193	3	11	84	182

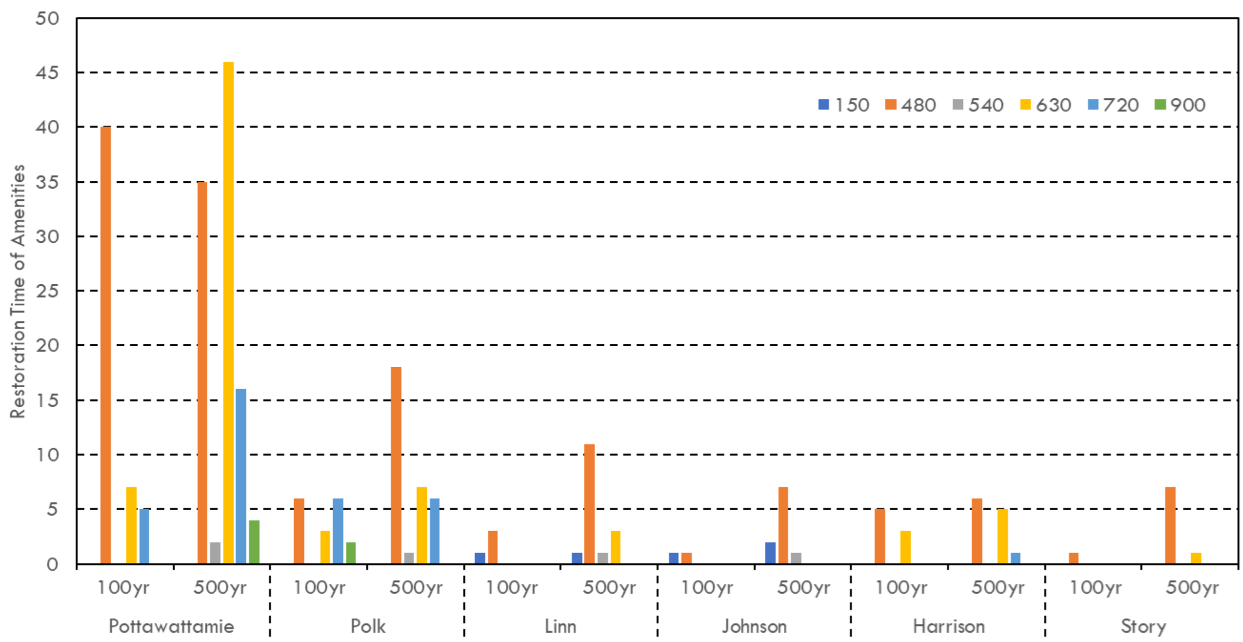

Figure 6. Restoration time of impacted critical amenities measured in days for 100yr and 500yr flood extents. Shows the top 6 most affected counties in Iowa.

Figure 6 shows the number of days estimated for the restoration time of flooded critical amenities based on the type of amenity impacted for both 100yr and 500yr flood extents per county. Results from the restoration time analysis show that the majority of flooded amenities take approximately 480 days to be restored. Pottawattamie County is the most affected, with 40 amenities requiring 480 days to recover in the 100yr extent and 35 amenities requiring 480 days to recover in the 500yr extent. While the number of amenities requiring 480 days decreases from the 100yr to 500yr extent in this case, the number of amenities requiring 630 days of recovery time in the 500yr extent increases from only 7 in the 100yr extent to 46 in the 500yr extent for Pottawattamie County. Pottawattamie and Polk counties are the only ones with any critical amenities requiring 900 days of restoration time.

The county that appears to be the least affected is Story County, with only 1 amenity requiring 480 days in the 100yr extent and 7 in the 500yr extent. Providing insight to restoration times can allow for more thorough preparation ensure timely service delivery, thus enhancing overall disaster response effectiveness. It is important decision makers understand the economic impact that flooding events may cause on critical buildings in their communities so that proper funding may be allocated ahead of time to ensure restoration can begin swiftly and effectively. Table 3 shows the structural damage cost estimations of impacted critical amenities in the 100yr and 500yr flood extents per county.

Shelters were found to be the amenity type with the highest damage costs in both the 100yr and 500yr extent across all six counties, with approximately $26.3 million and $62.2 million worth of damages respectively. Generally, shelters were also found to sustain the highest damage costs in each individual county. However, Linn County is an exception to this, with schools being the highest costing amenity instead at approximately $1.2 million and $6.1 million in the 100yr and 500yr extents respectively. Story County also saw a higher damage cost in wastewater facilities than shelters in the 100yr extent scenario specifically. Pottawattamie county was found to have the highest overall structural damage costs in both the 100yr and 500yr flood extents at approximately $27.7 million and $75.5 million worth of damage respectively.

Structural damage costs were found to consistently increase from the 100yr to the 500yr extents, except for fire stations in Polk County. Overall, the total damage to critical amenities across all six chosen counties amounted to approximately $39.3 million and $108.3 million for the 100yr and 500yr extents respectively. Table 4 shows the content damage cost estimations of impacted critical amenities in the 100yr and 500yr flood extents per county. Shelters were again found to be the amenity type with the highest damage costs in both the 100yr and 500yr extent across all six counties, with approximately $81.2 million and $195.8 million worth of damage respectively.

Generally, shelters were found to sustain the highest damage costs in each individual county as well. However, Linn County is an exception to this in the 500yr extent, with schools being the highest costing amenity at approximately $29.3 million. Johnson County also saw a higher damage cost in power facilities than shelter in the 100yr extent. Pottawattamie County was again found to have the highest overall content damage costs in both the 100yr and 500yr flood extents at approximately $100.7 million and $271 million worth of damages respectively. Content damage costs were found to consistently increase from the 100yr to the 500yr extents.

Table 3. Structural damage in USD ($) for impacted amenities in 100yr and 500yr flood extents rounded to the nearest 100,000.

	Pottawattamie		Polk		Linn		Harrison		Story		Johnson		Total	
Flood Extent	100yr	500yr	100yr	500yr	100yr	500yr	100yr	500yr	100yr	500yr	100yr	500yr	100yr	500yr
Medical	$677k	$3.5M	-	$2.1M	-	$360k	-	-	-	$96k	-	$47k	$677k	$6.2M
EMS	-	-	-	136k	-	-	-	-	-	-	-	-	-	$136k
Fire	$278k	$976k	$1.6M	$1.1M	-	-	$470k	$494k	-	-	-	-	$2.4M	$2.5M
Police	$371k	$1.5M	-	-	-	$642k	$61k	$195k	-	-	-	-	$433k	$2.4M
School	$6.9M	$25.1M	$1.3M	$2.2M	$1.2M	$6.1M	-	-	-	-	-	$946k	$9.4M	$34.4M
Shelter	$19.4M	$44.3M	$5.5M	$9.8M	$397k	$2.4M	$866k	$2M	$42k	$1M	$48k	$2.7M	$26.3M	$62.2M
Wastewater	-	$24k	-	-	-	$24k	-	$48k	$80k	$104k	-	-	$80k	$200k
Potable Water	-	-	-	$194k	-	-	-	-	-	-	-	-	-	$194k
Power	-	-	-	-	$15k	$15k	-	-	-	-	$75k	$110k	$90k	$125k
Total	**$27.7M**	**$75.5M**	**$8.4M**	**$15.6M**	**$1.6M**	**$9.5M**	**$1.4M**	**$2.7M**	**$122k**	**$1.2M**	**$123k**	**$3.8M**	**$39.3M**	**$108.3M**

Table 4. Content damage in USD ($) for impacted amenities in 100yr and 500yr flood extents rounded to the nearest 100,000.

	Pottawattamie		Polk		Linn		Harrison		Story		Johnson		Total	
Flood Extent	100yr	500yr	100yr	500yr	100yr	500yr	100yr	500yr	100yr	500yr	100yr	500yr	100yr	500yr
Medical	$2.6M	$15.1M	-	$12.4M	-	$589k	-	-	-	$369k	-	$178k	$2.6M	$28.6M
EMS	-	-	-	$1M	-	-	-	-	-	-	-	-	-	$1M
Fire	$1.4M	$2.7M	$3.5M	$3.7M	-	-	$646k	$2.2M	-	-	-	-	$5.5M	$8.6M
Police	$1.9M	$10.1M	-	-	-	$4.4M	$100k	$273k	-	-	-	-	$2M	$14.9M
School	$36.5M	$110.5M	$8M	$9.6M	$1.9M	$29.3M	-	-	-	-	-	$7.2M	$46.5M	$156.6M
Shelter	$58.3M	$132.6M	$19M	$30.9M	$2M	$16.1M	$1.6M	$2.2M	$160k	$3.6M	$30k	$10.4M	$81.2M	$195.8M
Wastewater	-	$24k	-	-	-	$24k	-	$48k	$80k	$104k	-	-	$80k	$200k
Potable water	-	-	-	$194k	-	-	-	-	-	-	-	-	-	$194k
Power	-	-	-	-	$15k	$15k	-	-	-	-	$75k	$110k	$90k	$125k
Total	**$100.7M**	**$271M**	**$30.6M**	**$57.7M**	**$4M**	**$50.5M**	**$2.4M**	**$4.7M**	**$240k**	**$4.1M**	**$105k**	**$17.9M**	**$138M**	**$406M**

Overall, the total damage to critical amenities across all six chosen counties amounted to approximately $138 million and $406 million for the 100yr and 500yr extents respectively. The loss of a critical amenity's equipment and other items necessary for its function can be just as financially impactful as flood damage done to its exterior. The cost of restoring content damage should also be considered when implementing flood disaster prevention. Table 5 shows the structural damage percentage of impacted critical amenities in the 100yr and 500yr flood extents per county. Each county was broken up into relevant damage percent ranges and a count was taken of the number of critical amenities within those ranges per flood extent. Shelters were generally found to be the most impacted amenity type.

EMS stations proved to be the least impacted with only 1 facility affected in Polk County in the 500yr flood extent. Pottawattamie County was found to be the most affected county in both the 100yr and 500yr flood extents, with 32 and 58 amenities respectively within the 1 to 20% damage percent range alone. Johnson County was found to be the least affected county with only 2 critical amenities impacted in the 100yr extent and 10 in the 500yr extent, and most falling within the 1 to 20% damage percent range. Understanding which critical amenities have higher percentages of structural damage can provide perspective for decision makers that may be useful in determining where best to focus recovery efforts.

Table 5. The percentage of structural damage to critical amenities in 100yr and 500yr flood.

	Damage	**Shelter**		**School**		**Medical**		**Fire**		**Police**		**Potable Water**		**EMS**		**Waste-water**		**Power**	
		100	500	100	500	100	500	100	500	100	500	100	500	100	500	100	500	100	500
Pottawattamie	1-20%	32	58	9	14	1	3	2	1	1	1	-	-	-	-	-	-	-	-
	21-40%	5	10	-	4	-	1	-	2	-	1	-	-	-	-	-	-	-	-
	41-60%	2	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polk	1-20%	9	19	3	4	-	2	-	1	-	-	-	1	-	1	-	-	-	-
	21-40%	4	3	-	1	-	-	-	1	-	-	-	1	-	-	-	-	-	-
	41-60%	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Harrison	1-20%	4	2	-	-	-	-	2	2	1	-	-	-	-	-	-	-	-	-
	21-40%	2	5	-	-	-	-	-	1	-	1	-	-	-	-	-	2	-	-
	41-60%	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	81-90%	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Linn	1-20%	2	8	-	3	-	1	-	-	-	1	-	-	-	-	-	-	1	1
	21-40%	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-
	41-60%	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Johnson	1-20%	1	5	-	1	-	1	-	-	-	-	-	-	-	-	-	-	1	2
	21-40%	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Story	1-20%	1	7	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
	21-40%	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	2	-	-

Table 6. Percent of content damage to impacted critical amenities in 100yr and 500yr flood extents.

	Damage	Shelter		School		Medical		Fire		Police		Potable Water		EMS		Waste-water		Power	
		100	500	100	500	100	500	100	500	100	500	100	500	100	500	100	500	100	500
Pottawattamie	1-20%	5	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	21-40%	8	12	4	4	-	-	1	-	1	-	-	-	-	-	-	1	-	-
	41-60%	14	19	1	3	-	2	-	1	-	-	-	-	-	-	-	-	-	-
	61-80%	5	7	3	8	1	1	-	1	-	1	-	-	-	-	-	-	-	-
	81-100%	7	36	-	3	-	1	1	1	-	1	-	-	-	-	-	-	-	-
Polk	1-20%	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	21-40%	1	2	-	1	-	-	-	-	-	-	-	2	-	-	-	-	-	-
	41-60%	3	2	1	2	-	1	-	1	-	-	-	-	-	1	-	-	-	-
	61-80%	1	4	2	2	-	1	1	1	-	-	-	-	-	-	-	-	-	-
	81-100%	8	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Harrison	1-20%	3	-	-	-	-	-	2	-	1	-	-	-	-	-	-	-	-	-
	21-40%	-	1	-	-	-	-	-	2	-	-	-	-	-	-	-	2	-	-
	41-60%	2	3	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
	61-80%		2																
	81-100%	2	2	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Linn	1-20%	-	1	-	1	-	1	-	-	-	-	-	-	-	-	-	-	1	1
	21-40%	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-
	41-60%	1	3	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	-
	61-80%	-	2	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	81-100%	-	2	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Johnson	1-20%	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2
	21-40%	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	41-60%	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
	81-100%	-	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Story	1-20%	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	21-40%	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-
	41-60%	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
	81-100%	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6 shows the content damage percentage of impacted critical amenities in the 100yr and 500yr flood extents per county. Just like with the structural damage percentage, each county was broken up into relevant damage percent ranges and a count was taken of the number of critical amenities within those ranges per flood extent. Shelters again were generally found to be the most impacted amenity type. Also, just as in the previous results, EMS stations proved to be the least impacted with only 1 facility affected in Polk County in the 500yr flood extent.

Pottawattamie County was again found to be the most affected county in both the 100yr and 500yr flood extents, having 36 critical amenities within the 81 to 100% damage range of the 500yr extent. However, its distribution of critical amenities across the damage ranges was more evenly spread than that of the structural damage. Johnson County was also again found to be the least affected county with only 2 critical amenities impacted in the 100yr extent and 10 in the 500yr extent, although 2 did land within the 81 to 100% damage range. Like Pottawattamie's case, its distribution of amenities across Johnson County's damage ranges is also more even than the previous analysis. Similarly to the case of structural damage, critical amenities with higher percentages of content damage may take precedent in restoration efforts that those less impacted.

4. Conclusion

Over the course of this study, critical amenities of six counties within the state of Iowa were analyzed during the 100yr and 500yr annual flood extents in terms of flood depth, functionality, restoration time, and damage in addition to an overall location analysis that was conducted on the statewide level. Findings show that for both the county and statewide levels Pottawattamie County was by far the most impacted county overall, with over 35% of its amenities impacted in both flood extents and loss of functionality of 100% and 97% of its critical amenities in the 100yr and 500yr extents respectively. Results from the damage cost analyses showed total costs across all six counties chosen for the secondary analysis typically exceeded $100 million and almost reached half a billion dollars in the case of the content damage in the 500yr extent. These findings can be used to shed light on potential losses and the risk to affected communities in terms of critical amenity availability during and after a flood.

It should be stated that there were some roadblocks throughout the course of this study that were not previously mentioned. The largest of these were the discrepancies of critical amenity location data provided by the ArcGIS Business Analyst dataset. There were several data points that were found to have incorrect addresses and these data points had to be relocated within ArcMap to their correct locations before an accurate depth analysis could be conducted. These locations were verified with Google Maps. Another issue came with the identification of occupancy types for the damage analyses. Some critical amenities were not listed in the NSI dataset as traditional occupancy types for their respective type of amenity. For example, some churches were given residential (RES) occupancy types when they would typically be classified as religious institutions (REL1). Other times, a critical amenity would have more than one occupancy type given and none of them would be the traditional code used.

In these cases, best judgment was used to pick the occupancy type closest to the amenity of the occupancy types provided for the amenity by the NSI dataset. Lastly, the 500yr flood extent map layer had portions missing from it for Johnson, Harrison, and Pottawattamie counties. This had no impact on the analysis for Johnson County, as there were no critical amenities in that portion of the map, while Harrison County was only lightly affected. Pottawattamie County was largely affected by this as the portion missing from the 500yr flood extent was the area with a large concentration of critical amenities within Pottawattamie County. Fortunately, for both Pottawattamie and Harrison counties, all critical amenities that could have reasonably been within the missing pieces of the 500yr extent map were within the 100yr extent map and were therefore automatically considered to be within the 500yr extent as well. This discrepancy only impacted the location analysis, as all other analyses conducted were based on the depth analysis and the flood depth analysis used different flood extent maps.

For future study, researchers might consider conducting a population impact analysis to better understand the value of critical amenities within an area to its respective population. It might very well be the case that two out of four hospitals are non-functional, but the two that are functional serve 90% of the population in that area, so really the impact is minimal. Another area of this study that might be improved would be the process in which functionality of a critical amenity is determined. For this study, a critical amenity's functionality was determined based on flood depth alone and was considered strictly either functional or not functional based on that depth. This was done for simplicity and consistency across amenity types, but a more in-depth analysis might be conducted to determine the functionality of critical amenities more accurately.

Furthermore, this study did not consider basement levels for any analysis. Many studies have found that hospitals tend to keep their power supply in their basements and loss of power is one of the top reasons that hospitals are forced to evacuate during a flood (Yusoff et al., 2017; Ware, 2013; Choi, 2018). Therefore, it might be reasonable to deem a hospital non-functional even at minimal flood depth due to potential loss of power. On a broader note, this study could be expanded to look beyond the selected counties in Iowa and instead perform the secondary set of analyses on every county in the state or even to other parts of the United States lacking such a study.

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