A Web-based Analytical Urban Flood Damage and Loss Estimation Framework

Yazeed Alabbad[1,2,3], Enes Yildirim[1,4], Ibrahim Demir[1,2,5]

[1] IIHR Hydroscience and Engineering, University of Iowa, Iowa City, US
[2] Civil and Environmental Engineering, University of Iowa, Iowa City, US
[3] Civil Engineering, King Saud University, Riyadh, Saudi Arabia
[4] Iowa Department of Natural Resources, Iowa City, US
[5] Electrical and Computer Engineering, University of Iowa, Iowa City, US

Abstract

Information and communication technology serves a crucial role in communicating flood risk and consequences to a broad range of stakeholders and facilitating mitigation decisions. While studies extensively utilize flood inundation maps for communicating flood risks, there is a need to integrate a broad spectrum of physical vulnerability parameters into risk estimates at various spatial scales. This research aims to build a publicly accessible web platform to analyze and estimate riverine flood-related damages using HAZUS and HEC-FIA damage functions at community and property spatial scales. This framework will provide loss estimation for properties, business interruption, vehicles, bridges, and lives, as well as debris generation. The analysis is available for two scopes, including community and property. The community extent enables the user to explore socioeconomic flood information in the event of 100- and 500-year flood return periods for several communities in the State of Iowa. In the property scope, the user can generate outcomes for the impacts of "what if" flood scenarios using user-provided data. The framework disseminates flood information without requiring extra software to be installed on the user's local workstation. It offers a guidance tool to help decision-makers with flood management, such as identifying vulnerable areas and investigating mitigation interventions.

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1. Introduction

Flooding is one of the most destructive and recurrent natural threats to communities worldwide, causing severe social, environmental, and economic consequences. Flood risk is anticipated to grow due to climate change, increasing population, land use development, and infrastructure decay (Quintero et al., 2018; Yang et al., 2011). Most regions in U.S. have been impacted by a flood event, with average annual flood losses of $32.1 billion and projected to increase to $40.6 billion by 2050 (Wing et al., 2022). Among the U.S. states, Iowa is considered a flood-prone state, and throughout the last two decades, many individuals, structures, and infrastructure (Alabbad et al., 2021) have been impacted due to flooding (Holmes et al., 2010). Developing innovative visualization and communication methods (Sermet and Demir, 2020) that can quickly disseminate flood-risk information to various stakeholders, including the general public, enhances flood risk knowledge, resulting in early planning and mitigation, and a more effective response to a flood event (Albano et al., 2015).

Flood vulnerability assessment is critical to understanding how floods affect infrastructure and communities and what mitigation strategies and measures are appropriate to take place in order to minimize the negative impacts. It involves analyzing the exposure and vulnerability of people and the built environment resulting from a flood event (Alabbad and Demir, 2022). Flood control projects and floodplain management contribute to reducing the risk of flooding (Hyde, 2010). Although flood risk cannot be avoided altogether in most cases, it is a challenge due to environmental and land use changes and limited resources, including data and computational limitations (Li et al., 2022) and modeling challenges (Salman & Li, 2018; Yildirim et al., 2022). While most studies focus on mapping flood hazards, it is necessary to disseminate flood-related information, including exposure and vulnerability, to increase awareness of the impact of flooding and evaluate alternative solutions (Mohanty et al., 2019) to support mitigation decisions (Teague et al., 2021).

Most decisions on flood mitigation need a multitude of data, information, and modeling efforts, which might be time-consuming and resource-intensive (Ewing and Demir, 2021). An interactive decision support system can increase the efficiency of common flood mitigation and response decisions, for instance, by decreasing the time the decision maker spends evaluating "what-if" scenarios (Wang, 2007; Yildirim, 2022). Flood event repositories and information and communication technologies have facilitated addressing challenges in flood risk management (Almoradie et al., 2013; Haltas et al., 2021). In the U.S., HAZUS and HEC-FIA are common tools used widely by decision makers to estimate flood-related damage and play an essential role in planning purposes. The flood risk products can be used to prepare urban and agricultural flood response plans (e.g., shelter needs, inundated area, projected losses) (Yildirim and Demir, 2022). However, these systems often require a specialized Geographic Information System (GIS) workstation and a skilled operator to access and run these tools and interpret the results (Hearn et al., 2013; Yildirim and Demir, 2021).

Web-based systems are actively used in hydrology and water resources for informing the public on watershed management (Demir and Beck, 2009), water quality, and sedimentation (Xu et al., 2019). In the event of a destructive flood event, web-based systems are aimed at increasing the public's awareness, warning the public for an upcoming flood event, preparing citizens and crisis managers for efficient protection and rescue measures, and improving the quality of information made available to all flood crisis stakeholders before, during, and after the event (Holz et al., 2006; Kochilakis et al., 2016). Transferring such a complex system into a friendly web interface eliminates many barriers (e.g., technical skills) for different stakeholders, including the public. The analysis helps identify vulnerable areas to flooding and enhances the implementation of mitigation measures at community (e.g., levees) and property (e.g., elevating a house) levels (Cikmaz et al., 2022). Also, it contributes efficiently to allocating resources to better respond to and recover from flooding.

Communicating information about flood risk is essential to inform the general public and decision makers (e.g., emergency managers) of flood impacts and help them plan well to reduce future flood damage (Jonoski & Popescu, 2011; Maidl & Buchecker, 2015). A web-based system is regarded as a crucial tool for providing information on flood risk (Mohanty & Karmakar, 2021). It promotes an interdisciplinary approach to exploring flood scenarios and potential flood damage and losses, contributing to taking actions to minimize the impacts. Research on developing web-based systems for flood risk calculations is rare (Holz et al., 2006) and limited to monitoring (Muste et al., 2017), early warning, forecasting, inundation mapping (Hu and Demir, 2021), and flood zoning information. Recently, researchers have developed web-based systems for flood risk management, including flood inundation map generation (Li & Demir, 2022), communicating flood maps and real-time water level forecasts (Khalid & Ferreira, 2020), flood damage estimation (Alabbad & Demir, 2022), and a property-level flood mitigation decision support system (Alabbad et al., 2022). Nonetheless, there are flaws in the available web-based flood analysis tools at the property level, which may lead to individuals making incorrect decisions when purchasing a home (Mostafiz et al., 2022). Flood vulnerability and management need additional research and resources in the scope of disseminating flood knowledge through web applications to provide a comprehensive picture of flood risk and management at various spatial scales.

FEMA has founded the National Flood Insurance Program (NFIP) to offer flood insurance to property owners, renters, and businesses in communities that achieve its minimum standards to regulate flood-prone areas. In fact, the NFIP is still limited to minimizing the impacts, which led FEMA to create a Community Rating System (CRS) and give insurance discounts of up to 45% (FEMA, 2021). To enroll in the CRS, communities should implement activities and programs that exceed the minimum requirements of the NFIP. Indeed, less than 10% of US communities participated in the CRS, indicating a lack of community preparedness to deal with flooding. One of the CRS-creditable activities is establishing a local public library or website that provides flood-related information to a community.

This research aims to bridge the scientific knowledge gap in the literature on the communication of flood vulnerability information at the property and community geographical scales using a web platform with the goal of increasing awareness of flood impacts, supporting CRS activities for a community, and facilitating individual and community level access to flood-related information. We have demonstrated the platform's capabilities to generate detailed flood impact information on demand for several Iowa communities during 100- and 500-year flood events. Also, we looked into how updating the default HAZUS building inventory data would change the way flood damage was estimated.

The following sections are devoted to explaining the development and components of the web application in the methodology section, the framework capabilities and functions, the pilot use case and findings, and investigating and discussing outcomes in the results section before delivering the final remarks of the research in conclusion.

2. Methodology

The objective of this research is to develop an easily accessible web framework for decision-makers and the public to be aware of direct and indirect flood impacts, including damage to buildings, bridges, and utility systems; business interruption; loss of life; vehicle damage; and debris amount. Running a similar analysis using HAZUS or HEC-FIA requires significant effort on data preparation, computation, presentation, and interpretation and could take hours to days based on the spatial scale. The proposed framework automates the entire process, prepares the results, and presents them in a matter of seconds using the latest web technologies and standards. The following sections focus on the details of back-end and front-end development for the web system (section 2.1), flood damage and loss functionalities integrated into the system (section 2.2), and a case study and data preparation (section 2.3).

2.1. Framework Development

The Geographic Information System (GIS) is a common tool that has the ability to manage, visualize, and analyze spatial and non-spatial data. It is utilized by HAZUS and HEC-FIA software to visualize flood analysis. However, it requires GIS specialists to deal with complex tools and translate outcomes into meaningful maps. Therefore, creating a web-based flood vulnerability system facilitates accessibility, offers understandable results, and avoids software complexity for the end-users.

Server-Side Components

Developing the web-based application starts with preparing the data, then data processing, and ends with outcome visualization and analysis. Our web interface was developed (Figure 1) using scripting languages: HyperText Markup Language (HTML), Cascading Style Sheets (CSS), and JavaScript. We utilized Leaflet, an open-source JavaScript library for interactive web maps, to build a graphical user interface (GUI). It converts data into map layers and uses mouse interactions to show and interact with map data.

First, the map object is initialized with OpenStreetMap and Mapbox tile layers using HTML, CSS, and Leaflet libraries. Besides the tile layers, zoom, scale, area measurement, print function, and attribution controls are added to the map. Also, the control geocoder is attached to the map, enabling the end-user to look up a location. The leaflet library offers the capability to interact with map vectors (points, lines, and polygons) created from GeoJSON objects.

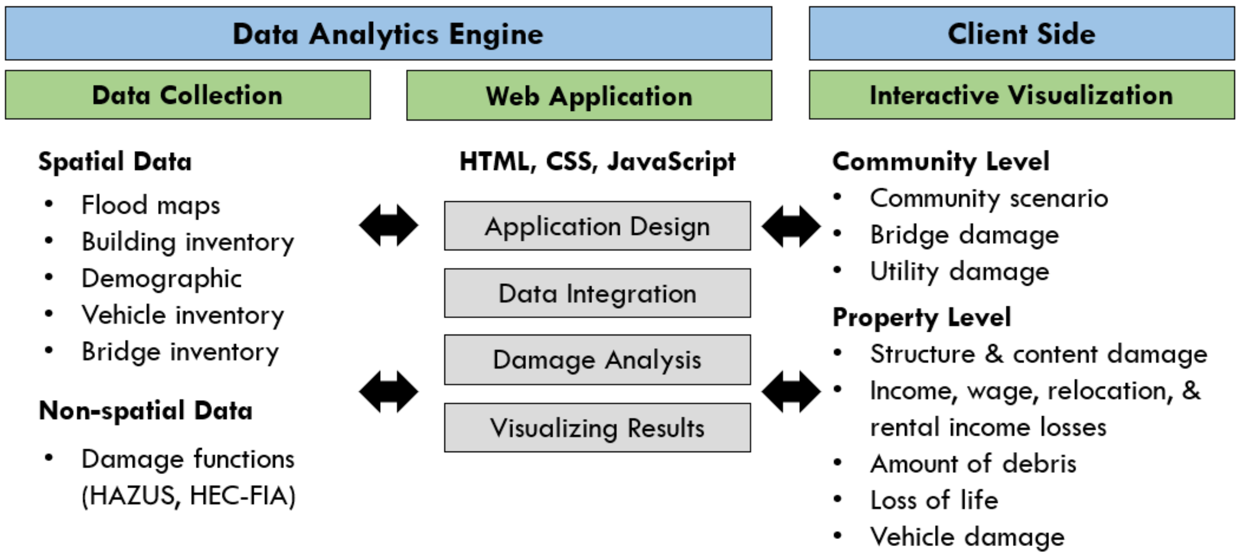

Figure 1. The overall architecture and components of web-based flood vulnerability application

For creating the interactive map of flood vulnerability, spatial and non-spatial data are required, including flood depth and extent, buildings, essential facilities, vehicles, demographics, and damage functions. They are organized into CSV tables and converted to JavaScript Object Notation (JSON) files as a database. JavaScript functions, including Leaflet and jQuery, are used to read, integrate, and map JSON data. JSON files may need to be reduced in size by deleting extraneous attributes. In addition, QGIS was used to extract the flood depth at the centroid of each structure and census block within a community to investigate flood damage and loss at community and property levels. Section 2.2 illustrates the flood analysis functions utilized in the system.

Client-Side Components

On the client side, community and property level analysis functions are developed to enable the user to interact with the map data and features and explore structure and content damage, business interruption losses, the amount of debris, vehicle damage, and potential life losses resulting from flooding. At the community level, the analysis is performed for the 100- and 500-year flood scenarios for several communities in Iowa. The user can select a community and access each impacted building to see the analysis. The summary statistics information panel, map legend, and layer control are displayed on the map once the community scenario is selected. Finally, the utility system's (i.e., wastewater treatment plant) damage can be estimated in the system as well. In addition, we used a leaflet plugin that will allow the system to upload and read user-provided building, vehicle, and bridge files locally and visualize the outcomes of flood analysis on the map.

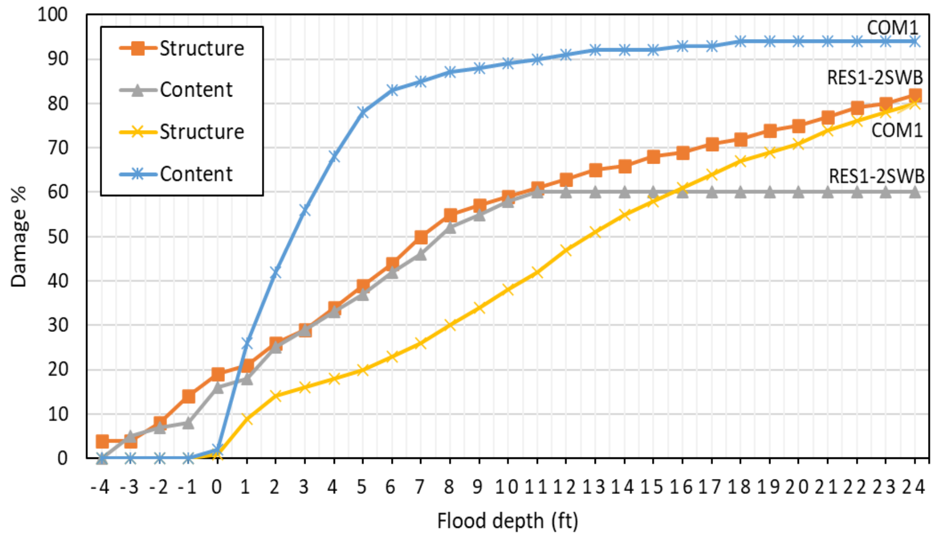

Figure 2. An example of structure and content depth-damage curves for a single-family dwelling, 2 stories with basement (RES1-2SWB) and a retail trade (COM1) (HAZUS, 2020)

In the property scope, the user can explore "what if" scenarios according to various flood levels. The system allows individuals to understand and visualize the impact of flooding on their property by using flood depth and property information (i.e., area, structure value, number of people) as inputs. The system covers 33 occupancy types (i.e., residential, commercial, and industrial) and also provides information for estimating vehicle damage for various vehicle types (i.e., passenger cars, light trucks, sedans, and pickups). Figure 1 shows the flow chart of the flood impact platform developed in this study.

2.2. Flood Vulnerability Analysis

Building Damage: Structure and content damage are calculated once a building is within the floodplain. At the property level, we extract flood depth at the centroid of each building to determine the damage percentage. After that, the damage estimation is determined by multiplying the damage percentage by the structure and content values. We consider the default HAZUS flood depth damage curves (Figure 2). The percentage of structure and content damage associated with flood depths is extracted from curves developed by the Federal Insurance Administration and the US Army Corps of Engineers for 33 specific occupancy types (i.e., residential, commercial, industrial, educational, and government).

Business Interruption Losses: Business interruption losses are composed of income, wages, relocation expenses, and rental income. Loss functions embed multiple parameters (i.e., flood depth, occupancy type, and area) and utilize the equations for estimating the losses as listed in Table 1.

Debris Amount: Debris weight estimation due to flooding is limited to the finishes, structure, and foundation of buildings. The debris estimation relies on the occupancy type, area, and foundation. The debris generation per occupancy type is the area of a building multiplied by the weight of debris associated with a flood depth.

Table 1. Business interruption terminology and equations.

Loss Type	Equation	Abbreviation
Income ($)	$(1\text{-}IRF_i) * A_i * ID_i * LOF_i$	*i:* represents different flood depths, *IRF:* income recapture factor, *ID:* income per day per sq.ft ($), *LOF:* loss of function, *A:* area, *WR:* wage recapture factor, *WD:* wage per day per sq.ft ($), *OO:* percent owner occupied, *DC:* disruption cost ($), *RD:* rental per day per sq.ft ($)
Wage ($)	$(1\text{-}WRF_i) * A_i * WD_i * LOF_i$	
Relocation expenses ($) (for damages > 10%)	$A_i * [\ (1\text{-}OO_i) * (DC_i) + OO_i * (DC_i + RD_i * LOF_i)]$	
Rental income ($) (for damages > 10%)	$(1\text{-}OO_i) * A_i * RD_i * LOF_i$	

Loss of Life: We use the simplified LifeSim methodology, which is applied with HEC-FIA software (HEC-FIA, 2018), to estimate the potential number of fatalities during a flooding event. The LifeSim approach (McClelland & Bowles, 2002; Lehman & Light, 2016) requires user input data, including inundation maps, building and population information, warning and evacuation information, and the arrival time of the flood. Due to the absence of flood arrival data in our study, our analysis assumes that people remain at home during flooding and seek safety inside. Three fatality zones (safe, compromised, and chance) are assigned to the impacted buildings based on the occupancy type, flood depth, and the age of the population (under 65, over 65) (Table 2). Each zone is limited by a flood level and has an average fatality rate (safe = 0.00002, compromised = 0.12, chance = 0.90). The expected life loss per occupancy type is the number of people multiplied by the average fatality rate.

Vehicle Damage: Estimating vehicle damage during flooding is dependent on flood depth and vehicle type (car, light truck, heavy truck). The percentage of vehicle damage is extracted from curves developed by FEMA (Figure 3). To estimate the damage, the percent of vehicle damage is multiplied by the vehicle value (Equation 1).

$$\text{Vehicle damage (\$)} = \%D * V * \%A \qquad \text{(Eq.1)}$$

where %D is the damage percentage for a specific vehicle type, V is the vehicle value, and %A is the impacted area percentage per a census block.

Due to the absence of vehicle information per occupancy type within the study area, our day and night vehicle inventory is based on a census block aggregation level. In the community scenario, we consider the average value of flood depth through a census block to reflect the flood level variation within a census block. During the flooding, some census blocks were partially impacted, so we weighed the damage in the flooded area. We assume all vehicles are on the ground and present in the flood event. At the property level, besides the HAZUS vehicle categories, we integrate the depth-damage relationships available (USACE, 2009) for different types of vehicles (e.g., sedans). Therefore, the user can select the flood depth, vehicle type, and vehicle value, and then the system can estimate the damage.

Table 2. An example of default values for flood lethality zone by occupancy type and age group adopted from (USACE, 2018).

Occupancy type	Zone height (ft)					
	Over 65			Under 65		
	Safe	Compromised	Chance	Safe	Compromised	Chance
Residential, 1 Story, No basement	2 ft or foundation height	4	6	2 ft or foundation height	4	6
Educational Facility	2 ft or foundation height	13	15	2 ft or foundation height	22	24

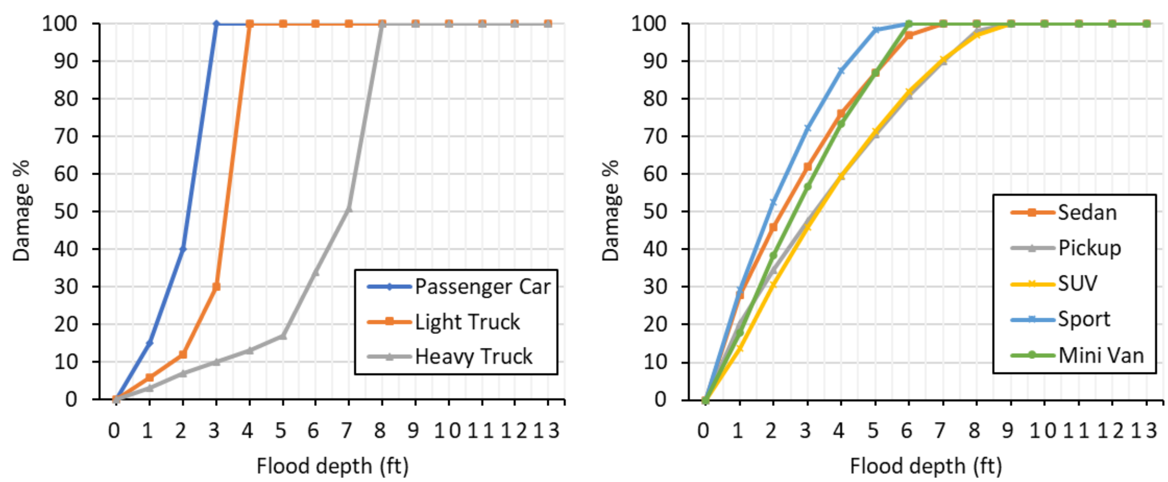

Figure 3. The vehicle damage functions adapted from (HAZUS, 2020; USACE, 2009).

<u>Bridge and Utility System Damage:</u> HAZUS bridge damage function is based on the scour index, flood scenario, and bridge value and type. The utility system damage estimation involves flood depth, utility replacement value, and the percentage of damage extracted from depth damage curves.

2.3. Case Study

The State of Iowa is bounded by the Mississippi River on the east and the Missouri River on the west, with major rivers (e.g., Cedar, Iowa) running into its communities. The state has been experiencing extreme flood events over the last 50 years. In 2008, a major flood event inundated most of the Iowa communities and caused devastating damage. Cedar Rapids, for example, recorded flood extent beyond the mapped 500-year floodplain for several weeks, resulting in the displacement of 18,000 residents and causing $5.4 billion in losses (USACE, 2018). As a comprehensive case study, several Iowa communities named Cedar Rapids, Iowa City, Waterloo, Davenport, Cedar Falls, Bettendorf, and Waverly are integrated into the web application to investigate and visualize the impacts of the 1% (100-yr) and 0.2% (500-yr) flood probabilities at the property and community levels (Figure 4). Our research focuses on communities with available tax assessor data for property information. Also, each of the selected communities lies on a riverbank, making them at risk of riverine flooding.

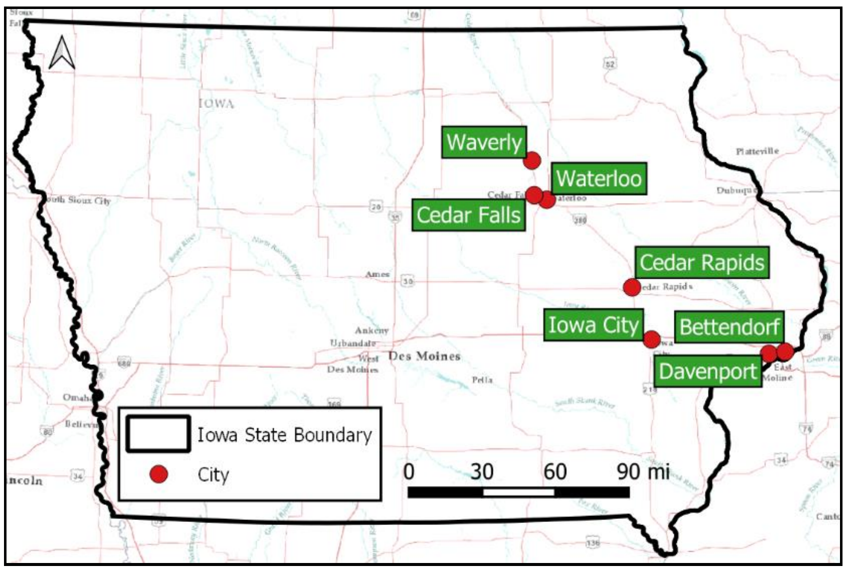

Figure 4. Iowa communities integrated into the web system.

2.4. Data Summary

Flood Maps: 1meter resolution flood maps are obtained from the Iowa Flood Center (IFC). IFC produced statewide flood inundation mapping (1D) and community-level flood scenarios (2D) associated with 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual-chance flows using the HEC-RAS models and a coupled hydrodynamic modeling software package (MIKE FLOOD) (Gilles et al., 2012).

Building Inventory: The census block is the geographic scale used in the HAZUS database to map building inventory compiled from the 2010 US Census Bureau. Buildings are distributed evenly within each census block, leading to overestimating or underestimating flood damage. Our research utilizes building inventory collected from county tax offices, which provides a more complete dataset for building information represented spatially as a point.

Demographic: HEC-FIA software (HEC-FIA, 2015) can import the population information per occupancy type from the HAZUS database using the 2010 US Census Bureau, taking into account population age (i.e., over 65 years) and time (day and night).

Business Interruption: Variables associated with business interruption (i.e., $ income per square foot per day, $ wage per square foot per day, $ disruption cost per square foot, $ rental income per square foot per day, recapture factor, percent owner occupied, recovery time) are obtained from the HAZUS technical document for each occupancy type. The last update to economic values was in 2017.

Debris Weight: Damaged buildings generate three types of debris (finishes, structure, and foundation). The debris weights per occupancy type associated with flood depths are collected from the HAZUS database (2020). In our analysis, we assume footing foundations for all buildings at the community level due to the tax assessor's lack of foundation type in the dataset. We provide options at the property level to modify the foundation choices by user.

Vehicle Inventory: Per census-block spatial level, the HAZUS database includes day and night vehicle counts from the 2000 Census building areas and 2006 Dun & Bradstreet data, and vehicle values and ages from the National Automobile Dealers Association (NADA, 2011) updated in 2014. Vehicles are grouped into three types: passenger cars, light trucks (i.e., SUVs), and heavy trucks (industrial and commercial trucks up to 18-wheelers).

Bridge and Utility Inventory: Bridges data are imported from the National Bridge Inventory (2018) and represented as a point location. Each bridge is classified based on its structural characteristics (i.e., number of spans). Continuous and single-span bridges are two types of bridges that are used for flood analysis. Besides a bridge's classification and geographical location, parameters such as the replacement value and scour index for each bridge are provided by the Federal Highway Administration (last updated: 2019). Utility system data has been compiled from different sources (HIFLD, 2019).

Data Challenges: We found that some census blocks from the 2010 US Census Bureau missed demographic information, limiting the estimation of the number of people in buildings. Also, vehicle inventory is missing for census blocks. The County Tax building inventory database is missing some information (for example, foundation type and first-floor elevation). We used the default HAZUS values in the absence of information for some parameters. For example, for locations with missing values, residential buildings are given a foundation height of 4 ft.

3. Results and Discussions

3.1. Flood Impact Data Analytics System (FiDAS)

The web-based flood vulnerability application is composed of two spatial frames (community and property), designated to help the end-user explore flood damage to buildings, highway bridges, utility systems, and vehicles, as well as the amount of debris and loss of life (Figure 5). The framework is named FiDAS, which stands for Flood Impact Data Analytics System, and is accessible publicly at https://hydroinformatics.uiowa.edu/lab/fidas.

On the main web interface, two spatial levels (community and property) are available to the user for analysis. Through the community level, three flood impact analysis options (Figure 6) are available for properties, bridges, and utilities. First, a community scenario option allows the user to see the impacts of 100-year (1% chance) and 500-year (0.2% chance) flood scenarios on seven communities in Iowa named Cedar Rapids, Iowa City, Waterloo, Cedar Falls, Davenport, Bettendorf, and Waverly. Once a community is selected, an impacted geographical location of buildings, bridges, and census blocks appears on the interface. Besides, a summary panel for the selected community provides the total building, vehicle, and bridge damage under the selected flood scenario.

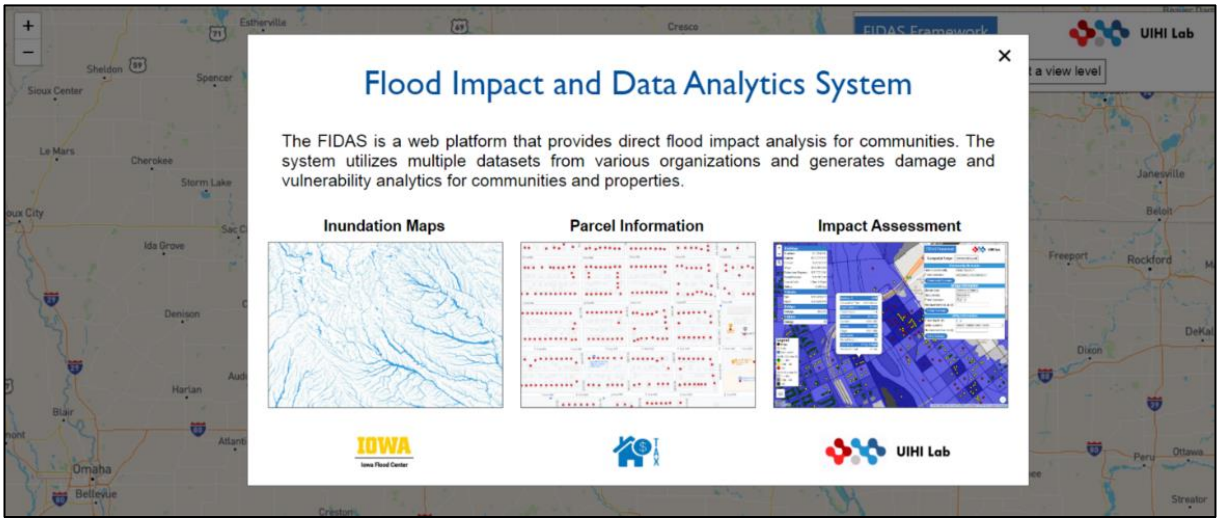

Figure 5. The landing page for FiDAS

Within a specified community border, the user can access damage analysis for each building. The analysis results include building ID, occupancy type (i.e., residential or commercial), flood depth associated with the flood scenario, structure, content, income, wage, rental income losses, relocation expenses, expected life losses during the day and night timeframes, and finally, the debris amount. Since the available vehicle inventory data comes at the census block level, we use an average flood depth value for each impacted census block to calculate the vehicle damage. The user can access the analysis summary at each census block, including the census block ID, vehicle count during day and night, average flood depth, and damage during day and night for cars, light trucks, and heavy trucks. Also, highway bridge damage information can be explored by locating a bridge point on the map. Then, the bridge ID, type, scour index, damage percentage, damage cost, and functional percentage are shown on the map.

An additional option under the community scenario is "upload file," which allows users to run analysis on their own data. This option will enable the user to load local files in KML and GeoJSON format, and then the flood analysis mentioned above will be revealed spatially on the framework. In the case of loading a building file, the data for each building in the file must include the following information: the building's geolocation, occupancy type, foundation and area, structure and content values, number of people under and over 65 years old, and the flood depth. To load vehicle inventory files, vehicle types, counts, and costs, as well as the average flood depth for the impacted area and the impacted area percentage, should be prepared to proceed with the analysis.

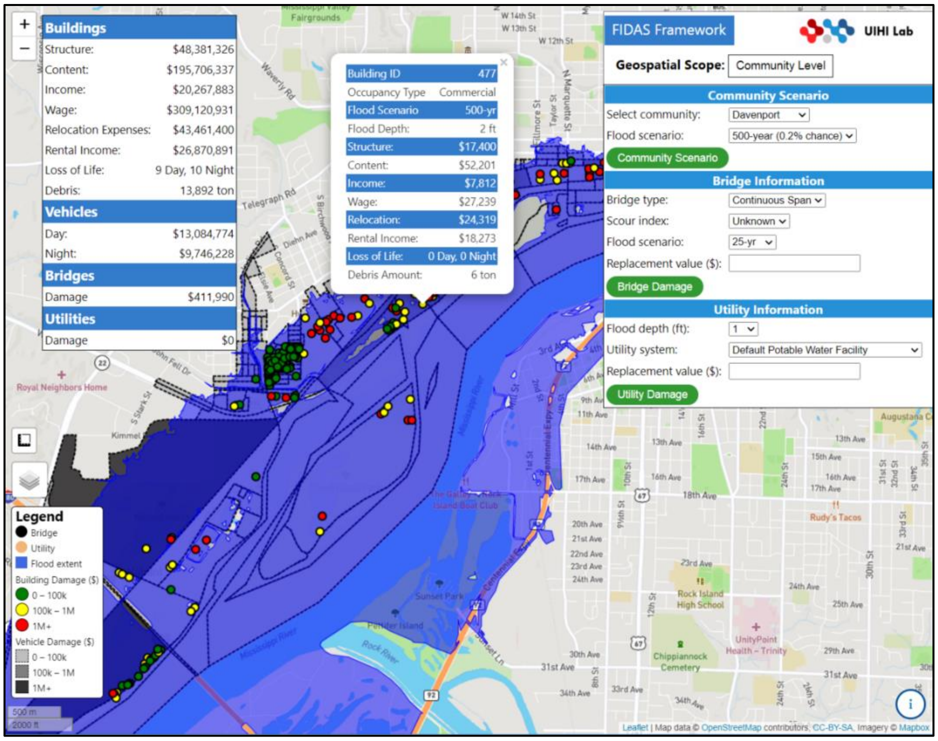

Figure 6. An example of flood impact visualization at the community and property levels.

For loading the bridge file, the analysis requires data that has bridge type (continuous or single span), scour index, flood scenario (i.e., 25-yr, 50-yr, 100-yr), and replacement value. Also, utility system datasets can be imported into FiDAS to analyze and visualize the damage on the map. We provided a data-structure template for each analysis to simplify the process and guide the user. The user can print the analysis outcomes, including map components (Figure 7), as a PDF file. The upload file option provides easily accessible flood-related analysis information without the need to deal with complex software requirements or time related challenges.

In the case of missing data regarding bridge and utility systems within a community, we provide a user input panel under community-level analysis to discover bridge and utility system damage. For bridge damage estimation, the user can select the bridge type, scour index, and flood scenario and enter the replacement value. Then, the damage percentage and amount can be determined and visualized on the interface. Also, utility damage can be calculated once the user selects the flood depth, utility system type, and replacement value.

The second level of analysis is property-oriented. In many cases, building and vehicle information is not available or limited for most communities. Therefore, we created an additional analysis function to allow the user to explore flood-related losses at the property level (Figure 8). First, the user can select the flood depth and provide information regarding the property (occupancy type, foundation type, area, structure and content value, and the number of people). We use 46 occupancy types in the analysis, considering the basement exists for some types. Also, two types of foundations (footing and slab on grade) are available to the user.

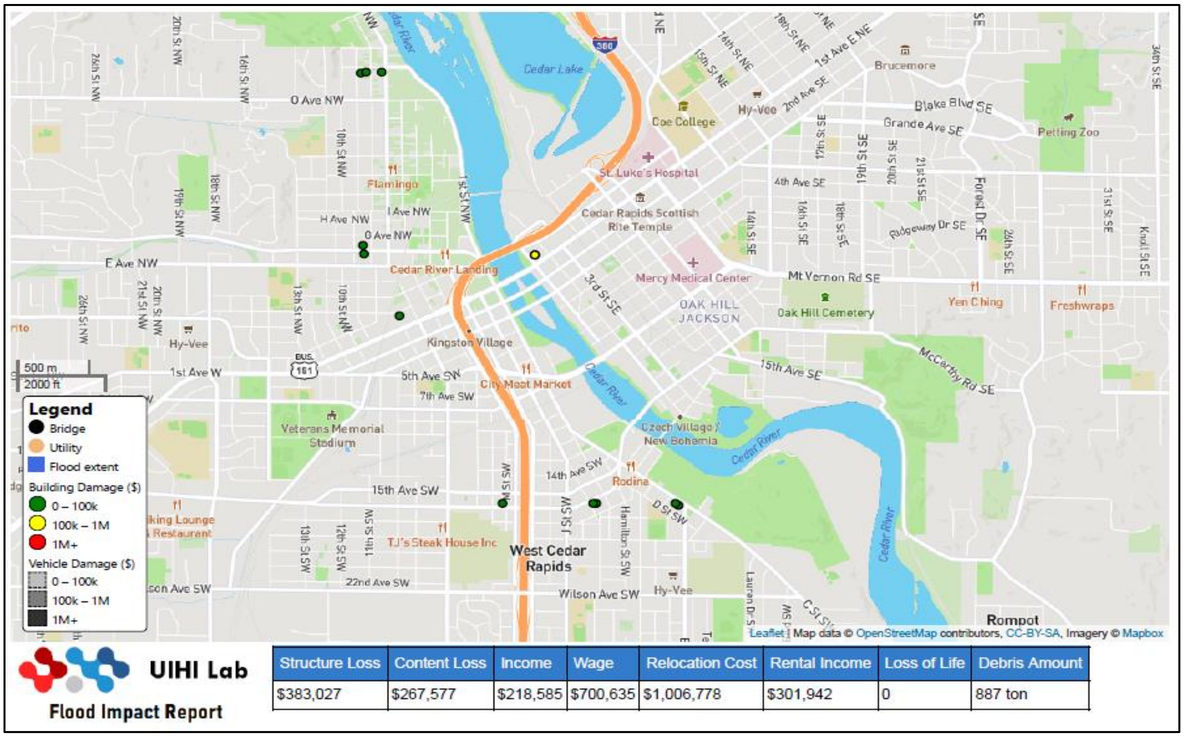

Figure 7. An example of flood impact analysis report.

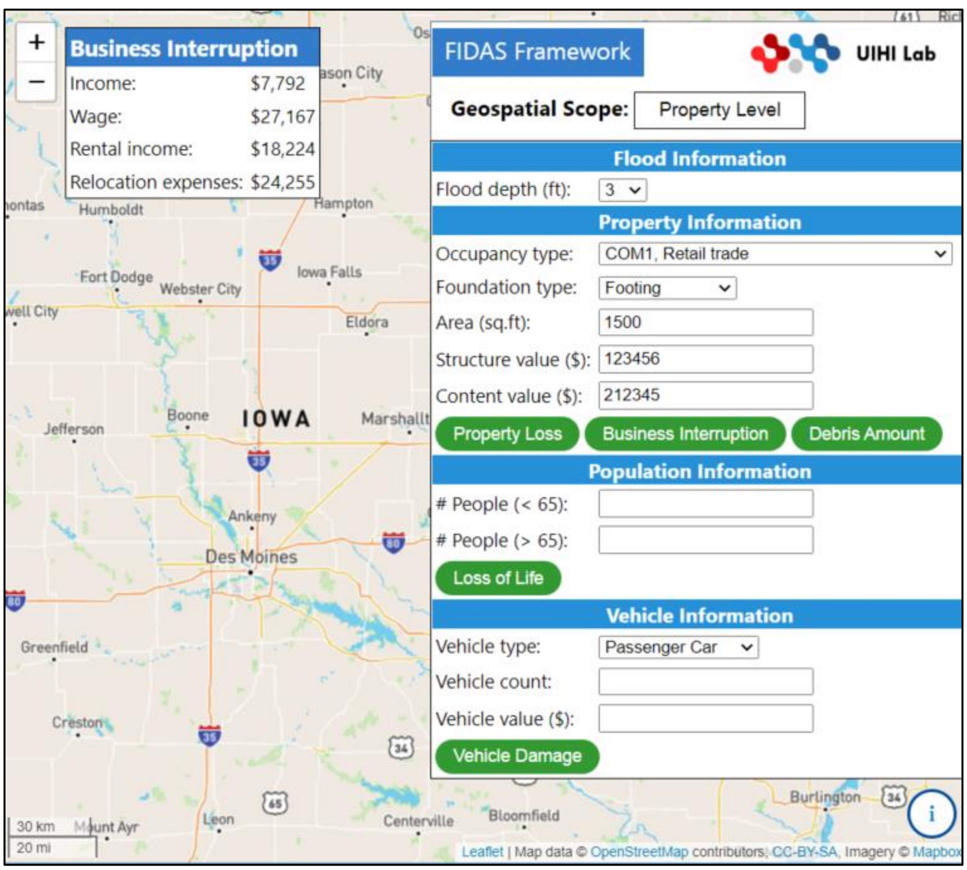

Figure 8. An example of the business interruption losses at the property scope.

Once property-related information is provided, the "property losses" module allows the system to compute structure, content, and percent damage, while accessing the "business interruption" function leads to estimated income, wage and rental income losses, and relocation expenses. The weight of debris resulting from the specified inputs can be computed after executing the "amount of debris" function. Also, the "loss of life" function will estimate the expected life losses for people caught in a building during a flood event. For vehicle damage analysis, the system provides different types of vehicle classes based on HAZUS and USACE functions for the user to choose, and then the user provides the vehicle count and value. As a result, vehicle damage information will be shown on the result panel, including damage percentage and damage dollar amount.

3.2. Community-level Flood Impact Analysis

Buildings, vehicles, and other critical infrastructure datasets for several Iowa communities have been integrated into the FiDAS to investigate flood scenario-based community impacts. Table 3 shows a summary of the total property damage (structure + content + business interruption) per occupancy class for the analyzed communities. During the 100- and 500-year flood events, residential buildings were the most affected class among the studied communities. However, the total damage for other classes with lower building counts (e.g., commercial and government) can exceed the residential losses due to business interruption losses, as seen in Waterloo and Davenport. Also, we found that losses generated by education and agricultural classes had the lowest impacts. When it comes to total loss, Waterloo, Davenport, Iowa City, and Cedar Rapids will experience significant damage and losses, especially during the 500-year flood, while Bettendorf and Waverly would be the least vulnerable communities during the two flood scenarios.

Table 3. Total damage ($Million) and number of impacted buildings per occupancy class.

Community	Flood	Residential		Commercial		Industrial		Government		Education		Agricultural	
		$	#	$	#	$	#	$	#	$	#	$	#
Waterloo	100-yr	0.6	10	0.2	1	-	-	26.6	6	-	-	-	-
	500-yr	218.7	5038	261.7	590	10.6	36	933.4	144	37.3	5.0	0.3	2
Davenport	100-yr	5.8	84	95.0	60	7.4	6	118.4	19	-	-	0.3	3
	500-yr	11.3	161	192.0	102	40.6	17	399.5	28	-	-	0.3	3
Iowa City	100-yr	261.7	540	38.9	105	-	-	-	-	0.2	1	-	-
	500-yr	462.6	566	72.7	175	0.1	2	-	-	0.2	1	-	-
Cedar Rapids	100-yr	43.9	415	59.4	145	8.6	7	31.7	1	-	-	3.5	13
	500-yr	175.8	2049	223.2	345	23.7	23	42.8	1	5.1	1	4.8	22
Cedar Falls	100-yr	9.1	114	4.9	21	1.2	5	25.2	10	-	-	0.1	1
	500-yr	18.2	222	33.2	123	2.1	7	142.4	22	-	-	0.2	1
Bettendorf	100-yr	2.9	38	4.8	8	0.8	3	-	-	-	-	-	-
	500-yr	5.5	60	6.9	10	1.7	6	4.0	1	-	-	-	-
Waverly	100-yr	3.1	40	1.2	3	-	-	-	-	-	-	0.2	2
	500-yr	5.7	81	1.2	3	-	-	-	-	1.7	1.0	0.3	2

Table 4 shows the potential life losses for the studied communities during the 100- and 500-year flood events with the assumption that no evacuation happened. It has been found that Cedar Rapids, Waterloo, Iowa City, Cedar Falls, and Bettendorf are resilient to life loss during the 100-year flood, while Davenport and Waverly appear vulnerable. In the 500-year flood, some communities (i.e., Davenport) would be threatened with up to 10 deaths. In contrast, there would be no life loss in Iowa City, Cedar Falls, or Bettendorf based on this research methodology. Identifying homes that are vulnerable to life losses helps support mitigation decisions for flood losses (i.e., give them priority for evacuation).

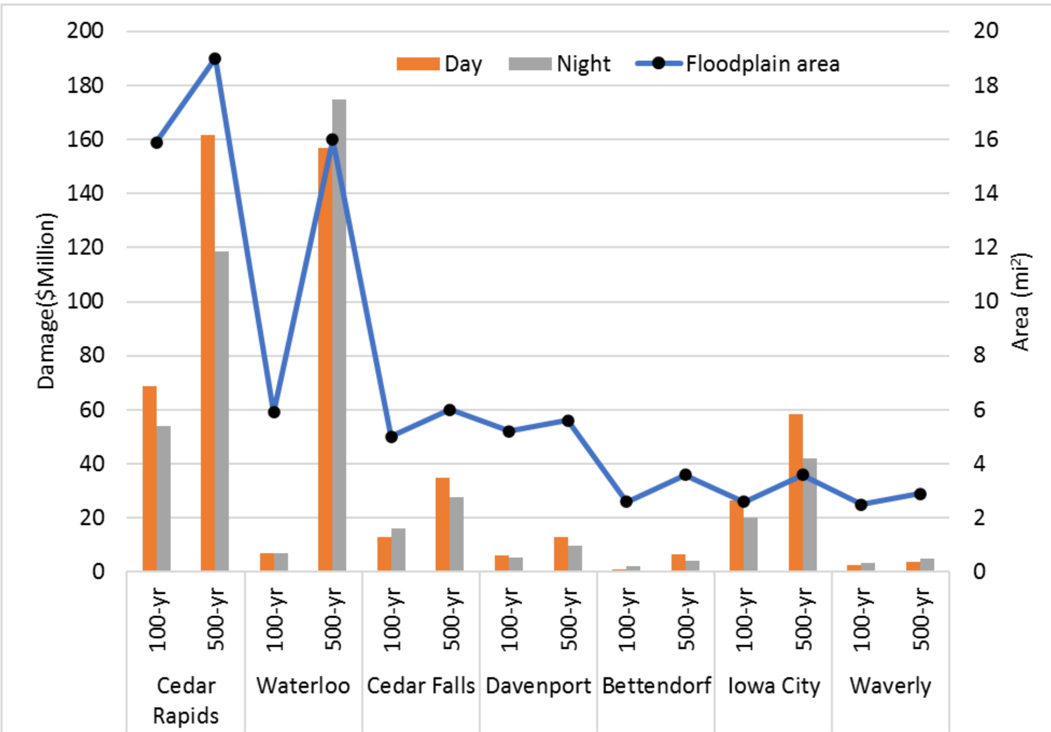

Figure 9. Day and nighttime vehicle damage sorted by floodplain area.

Table 4. Total loss of life during day and nighttime.

Community	**Loss of life**			
	100-yr		500-yr	
	Day	*Night*	*Day*	*Night*
Davenport	3	6	9	10
Waverly	1	1	1	2
Waterloo	-	-	1	2
Cedar Rapids	-	-	1	-
Iowa City	-	-	-	-
Cedar Falls	-	-	-	-
Bettendorf	-	-	-	-

Vehicle damage during the 100- and 500-year flood scenarios for the study area is presented in Figure 9. In the event of a 100-year flood, vehicle damage for some communities could reach up to $70 million, while under a 500-year flood, the damage could reach $160 million, as in Cedar Rapids and Waterloo. The floodplain areas for the studied communities vary in size and property distribution. We found that some communities have similar floodplain areas but different vehicle damage, like Cedar Falls and Davenport. That might be due to the differences in flood levels or the vehicle counts, values, and distributions.

3.3. Comparative Damage Analysis

This section explores how the quality of the building inventory data impacts flood damage estimation. The HAZUS default data is based on the 2010 US Census and is aggregated at the census block level, with the assumption that building stock is evenly distributed across each census block.Also, area-weighted damage estimation is utilized in the HAZUS software. As a result, flood damage analysis can be overestimated or underestimated, but it can give good insights into flood risk (Ghimire, E., & Sharma, 2021). A study was conducted for several Iowa communities to analyze the flood damage using the default HAZUS building inventory data from the national building inventory database (Alabbad & Demir, 2022). In this study, we compare property damage resulting from using the default HAZUS data and the tax assessor data. The tax assessor data is spatially represented as a point location, which enhances building location accuracy over the HAZUS approach. However, tax data regarding building characteristics (e.g., foundation type, number of stories) is not complete in the tax assessor's dataset. In this analysis, we assume residential buildings collected from tax assessor data have one story and no basement. Also, HAZUS provides two values (full and depreciated) as a replacement value for a building to estimate structure and content damage. We use depreciated replacement values to estimate damage and compare it to county data-based damage.

Figure 10 represents the comparative analysis of damage and losses derived from the tax assessor data and HAZUS. A positive percentage indicates that damage is overestimated by HAZUS compared to tax assessor data results, while a negative percentage points to underestimated damage by HAZUS. It is obvious that HAZUS default data overestimates the impacted buildings during the two flood scenarios (1% and 0.2% chance) for the analyzed communities. That can be attributed to the HAZUS aggregation method, which considers that all buildings within a census block are affected even if they are inundated partially or not at all.

Within the analyzed communities, our results indicated that the HAZUS default data methodology could affect damage and losses differently. We found that HAZUS overestimated the damage for Cedar Rapids, Waterloo, and Cedar Falls, while Iowa City appeared underestimated. The HAZUS building data information (i.e., counts, occupancy types), along with the area-weighted approach and building replacement valuation, may lead to differences in the structure and content damage estimation. In addition, building characteristics (i.e., occupancy type, square footage) play an important factor in estimating income, wages, relocation, and rental income losses. In HAZUS default data, square footage by occupancy is assumed by census regions.

Our results indicate that HAZUS can overestimate and underestimate the business interruption losses within the studied communities. For example, during the 500-year flood, Davenport's wage losses exceeded HAZUS's estimation by nearly 250%, while HAZUS overestimated Cedar Rapids' wage losses during the two flood scenarios by 80%. Providing accurate geographic locations of buildings along with their detailed characteristics is a major driver for robust building damage estimation. Still, it is a challenge to obtain complete building inventory data for most communities in the US.

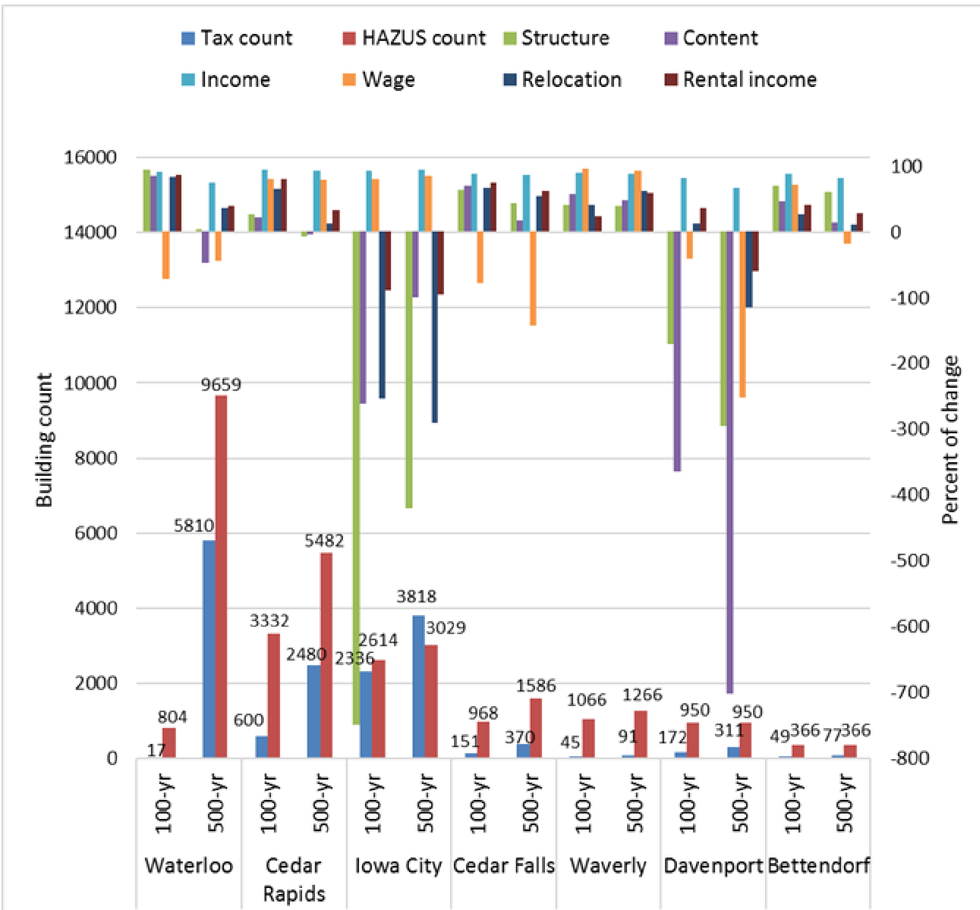

Figure 10: Comparison between damage derived from the default HAZUS and tax assessor data.

4. Conclusion

Flood vulnerability assessment is an important step in informing decision-makers about the consequences of flooding and performing benefit-cost analyses for mitigation measures. We integrated an extensive flood damage assessment methodology based on HAZUS and HEC-FIA for the built environment into a web-based system (https://hydroinformatics.uiowa.edu/lab/fidas) to investigate flood impacts at community and property levels. Our system covers damage to buildings, vehicles, infrastructure, and expected loss of life. Promoting such flood information through a friendly, accessible web tool and making it understandable by different stakeholders (i.e., the public) helps increase awareness of flood impacts, take actions to protect communities and properties, obtain credits in the CRS, and avoid flood losses. The introduced web applications enable non-expert users to quickly find information while avoiding complex models that require technical skills and resources regarding data manipulation and analysis. This research emphasizes updating default building inventory data in HAZUS to gain more accurate damage estimation.

Data accuracy and non-monetary loss quantification are the main challenges of this research. The tax assessor's dataset often ignores public and non-profit buildings due to their exempt status for tax purposes. Particularly in larger communities, enabling public infrastructure can allow us to estimate more accurate results. On the other hand, loss of life and vehicle losses are quantified based on certain assumptions, such as population age and vehicle intensity in a census block. Also, the role of early warning systems is ignored in these methodologies. However, the research employed the best available datasets and methodologies to conduct damage and loss assessments. Because the study presented a scalable web-based model, new datasets can be easily enabled, and more accurate analysis can be provided to the public.

Further research can be conducted to provide an easily accessible data analytics framework during flooding, including evacuation routes and location allocation. A more complete assessment of flood impacts can be derived by investigating scenario-based climate projections and other flood variables such as velocity and duration. Also, flood vulnerability can be linked with river forecasts (e.g., for the next five days), giving a community enough time to prepare for and react to flooding (e.g., moving building content and vehicles out of hazard areas). This study presents an opportunity for researchers to convert other natural disaster analyses (e.g., earthquake, tsunami) from package software (i.e., HAZUS) into interactive maps and make them available and more accessible to the public, non-technical people, and communities with limited resources.

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