RISK ASSESSMENT DASHBOARD TO VISUALIZE THE CASCADING EFFECTS OF CRITICAL INFRASTRUCTURE SERVICE FAILURE DUE TO NATURAL HAZARDS

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[July,2021]

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Enschede, The Netherlands, [July,2021]

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ABSTRACT

Web-based interactive dashboards are an emerging technology and are useful in many sectors, majorly for decision-making through understanding the situation or the scenario in a composed view. Dashboards are commonly used in business for information management and to view the performance of the organization. The use of Dashboards in the field of Disaster management is still in the growing phase. Disasters are common, and they affect the community directly by impacting the lives or through Critical infrastructure (CI) service failures. Multiple Infrastructures are considered critical based on the country. These are affected directly or indirectly due to the hazards that occur in that area. The indirect impact on the CI is often not visible, and the delay in responding to them may cause heavy damage to the community residing in that area. The damage of one CI leads to the damage of another CI, resulting in cascading effects.

The CI are the country's backbone, and any disruptions to them will disturb the normal state of the community. Knowledge about CI service failures and the underlying impacts is crucial to improve the resilience of the community. Risk assessment and community participation in building a resilient neighborhood contribute to the development of the risk management sector of a country. Emerging technologies like web Dashboards using open-source software in risk assessment are widely used as it integrates the spatial data with related non-spatial data to understand the situation and aim to foster the communication through visualization.

This study deals with designing, developing, and evaluating the risk assessment Dashboard for visualizing the cascading effects on the CI due to natural hazards like floods and landslides for a neighborhood in Medellin, Villatina. This study follows Human-Centered Design incorporated into Feature Driven Development (FDD) agile methodology. It illustrates quantification of impacts linked with the spatial impact of cascading effect on CI services due to the natural hazards using an open-source web dashboard.

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Dedicated to my late grandparents Mr. Ramadoss, Mrs. Yasodha Ramadoss, Mr. Ramanujam, Mrs. Rukmani Ramanujam

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1. INTRODUCTION

1.1 Background

Innovations through open-source geospatial technologies have been increasing exponentially in recent times, and the development of a web-based interactive dashboard is one of them. Dashboards are tools designed, evaluated, developed, and tested for assisting decision-making processes through the integration of data and proper visualization. Dashboards in the business domain are more common than in disaster management sectors for tracking the progress and monitoring the key indicators. A web-based interactive dashboard is an emerging planning support system, i.e., a computer-based system that supports planners in core spatial planning processes (Geertman & Stillwell, 2009) in the disaster management sector. Disaster management consists of four phases that are not linear and interdependent, i.e., prevention from any disaster, preparedness before any disaster could happen, rescue when the disaster occurs, and finally, the community's resilience, the recovery phase. A country's disaster management sector addresses natural hazards like floods and landslides as they primarily affect the community in terms of lives, property, and critical infrastructure (CI) service failures. The CI is a collection of systems, such as water, energy, transportation, health systems, etc., essential for urban communities to sustain a living. The destruction of these infrastructures can weaken the whole economy of the country or the city as they are very critical for the population to survive. When one infrastructure or one of its elements' failure leads to the other system's failure, cascading effects occur. Cascading effects indirectly impact society and become dangerous over time as the personnel's response time increases due to the uncertainties in the dynamic environment (Thouret et al., 2014). Cascading effects on CI services are difficult to understand for a community without knowing the holistic view of the area (Hilly et al., 2018).

1.2 Justification and scientific significance

One of the main challenges in addressing cascading effects is to understand the interaction between the initiating event, originating system, and the dependent system, i.e., in this study, the initiating event is the natural hazards, the originating system is the primary infrastructure disrupted, and the dependent systems are the CI damaged due to the failure of the originating system. To address this challenge, the geospatial technologies like dashboards have been proposed to be used as they integrate different spatial and non-spatial data that supports the understanding of the overall situation of an area.

This research contributes to the Engagement principle of the Sendai Framework 2015-2030 and supports the Global target of reducing risks to the CIs. The dashboard will assist the decision-makers in the preparedness phase of the disaster management cycle and will also increase the community's resilience by fostering participation through visualization. This research can be implemented for any other disasters as well.
This research is in line with the research of Ph.D. Candidate [1] Ms.Deepshika Purwar on developing an approach for the co-creation process for managing cascading effects in disaster-prone communities.

[1] Ph.D. Research Details

1.3 Research problem

"With growing concerns in digital democracy, i.e., the use of information and communication processes in the governance processes, there is an increasing demand for software and tools that maximize human-centered design elements and include features that support participatory and collaborative processes" (Lock, Bednarz, Leao, & Pettit, 2020). In this emerging technical world, there is a need for software and tools designed by User experience (UX) and User Interface (UI) designer and developed by the web application developer that supports human interaction and increases the motivation of the human through its interface usability to understand problems by improving the perception of the whole set of data which can positively impact the community's resilience to natural hazards.
This research aims to fill the gap on how emerging technology like dashboards can be an advantage for improving the risk knowledge phase of the risk management system through visualizing the complex interaction of components disrupted due to natural hazards and how the dashboards can foster stakeholders' involvement and potentially lessen their hindrance in comprehending data. Open data has made available a vast set of free spatial data and non-spatial data accessible, but the main challenge is the integration of necessary data in a composed view that can support the cognitive skill of the stakeholder.

1.4 Research objectives and questions

1.4.1 Main objective

To design, develop and evaluate an open-source web-based interactive dashboard that supports the visualization of cascading effects on Critical Infrastructure service due to natural hazards for the neighborhood in Medellin, Villatina.

1.4.2 Specific objectives and research questions

1. To conduct a requirement analysis from the potential stakeholders, analyze the study area and collect the data to be included in the dashboard.

    a) Who are the stakeholders or the user groups?
    b) What is the problem that has to be addressed?
    c) What data are to be included in the dashboard design?

2. To create a high-fidelity prototype design of the components that are to be included in the interactive dashboard and to evaluate the prototype design.

    a) What are the suitable methods involved in developing the prototype design?
    b) What are the suitable methods for evaluating the prototype?

3. To develop the dashboard using web technologies by implementing the prototype designed and evaluated.

    a) What are the suitable methods involved in developing the open-source web-based interactive dashboard?
    b) What are the data analysis procedures used for visualizing the problem that has to be addressed?

c) What are the components that need to be included, and what is the level of interactivity between the components?

4. To evaluate the developed dashboard for the design, content, usability by the user groups

a) What are the suitable methods to evaluate the usability of the interface?
b) What are the methods to evaluate the effectiveness of the visualizations used?

1.5 Thesis outline:

Chapter 1 describes the background of the study, the research problem, the justification for the problem statement, the main research objective, research questions, and the sub-objectives followed to approach the research outcome.
Chapter 2 deals with the literature review of the key concepts such as natural hazards, critical infrastructures, cascading effect, existing visualization of cascading effects, existing dashboards. It also explains the cartographic interaction, Feature-Driven Development (FDD) of agile methodology, and Human-Centered Design (HCD) involved in this study.
Chapter 3 describes the overall methodology, including the case study area on which this research is focused, data used in this study, the open-source web-based technologies, and the research design matrix explaining the methods and expected outcome for each sub-objectives.
Chapter 4 explains the step-by-step process involved in designing the prototype by incorporating HCD. It involves the explanation about co-design sessions, insight clustering, component tracing method, low-fidelity prototype, high-fidelity prototype using Adobe XD software, and the evaluation method involved to assess the prototype design.
Chapter 5 explains the step-by-step development process of the dashboard using open-source web technologies following FDD of agile methodology. This chapter explains the geoprocessing of the data and the interactive elements involved in the dashboard. It explicates the user testing performed to evaluate the developed dashboard for content, usability, and effectiveness.
Chapter 6 summarizes the research by discussing the results, providing recommendations for future work, and briefs the limitation of the study.

2. Literature review

2.1 Natural hazards

Hazards are defined as the "Life-threatening event or the probability of damage that may occur at an area for a given period with different level of intensity" ('EM-DAT, 2021). Hazards are of two types, natural hazards, and anthropogenic (Man-made) hazards. Natural hazards are disruptions that occur naturally by different events at different paces. There are five categories of natural hazards, namely geophysical (landslides, earthquakes, tsunami, etc.), biological (pandemics, animal diseases), hydrological (torrential floods, avalanches, etc.,), climatological (drought, wildfires, extreme temperatures), and meteorological (cyclones, hurricanes, etc.) (IFRC, 2021)

Figure 1 : Types of Hazards

Source: (Kremser, 2020)

These hazards lead to social, economic, and political disruptions. The disruptions due to natural hazards are not due to the nature of the hazard, but it is seen as the problem arising from the interaction of the environment and the society's structure (Rodríguez-Gaviri & Verónica Botero-Fernández, 2013). These hazards result in loss of life, infrastructure, and degradation to the environment (Svalova, 2018). These hazards are a threat to the sustainable development of a human community.

2.2 Critical infrastructures

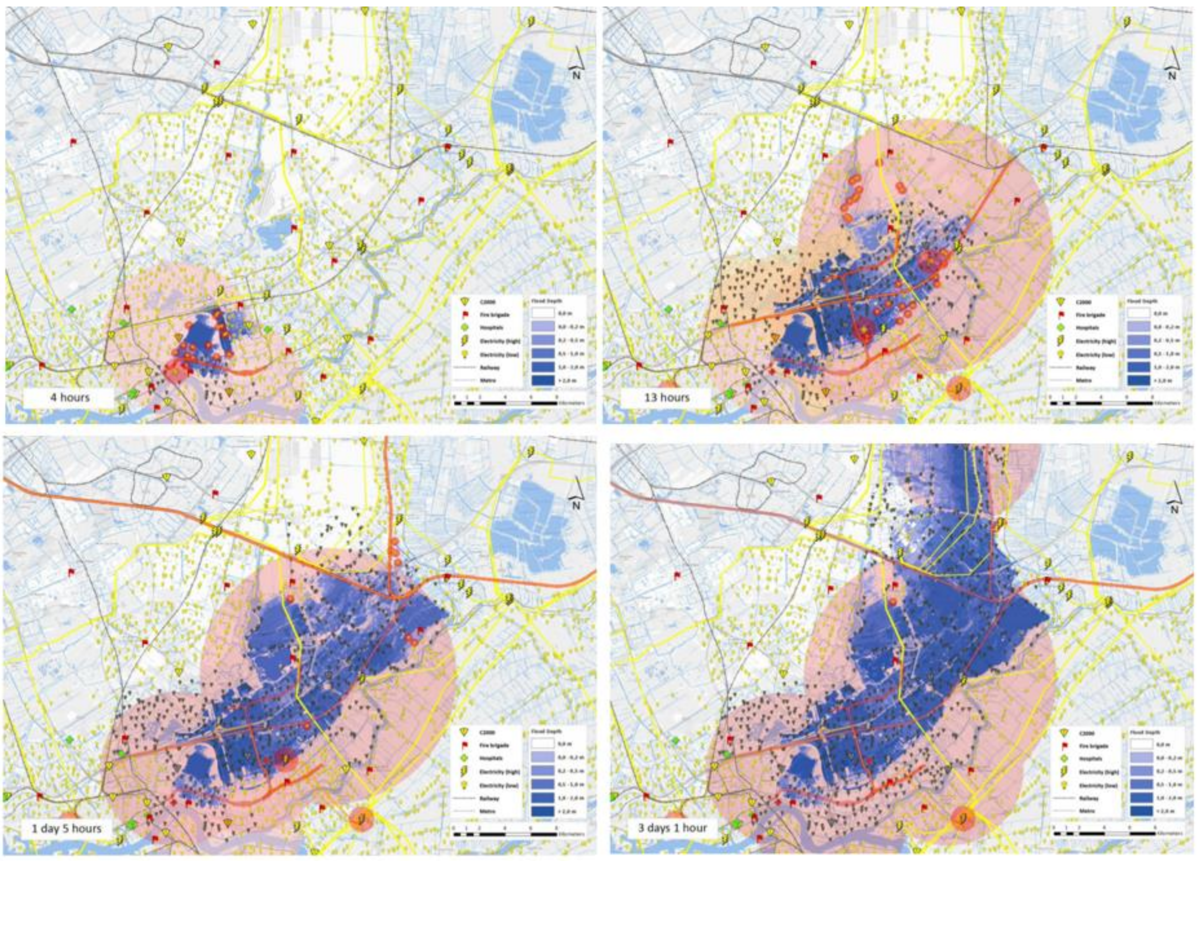
The Critical Infrastructure (CI) is a collection of systems such as water, energy, transportation, health systems, etc., essential for urban communities to sustain a living. The destruction of these infrastructures can weaken the whole economy of the country or the city as they are very critical for the population to survive. The destruction can be caused by many events such as terrorism, natural and technological hazards, human error, etc. (Serre & Heinzlef, 2018), and they lose their functionalities. Among these destructive events, floods and flood-induced landslides are considered the most crucial hazards that frequently cause damage to the CI (Serre & Heinzlef, 2018) and results in cascading effects or synergetic effects. The cascading effects will have an indirect impact on the CI, and therefore it is important to study the relationships between the infrastructure, i.e., dependencies and interdependencies, to understand the impacts due to the cascading effects.

2.3 Cascading effects

When one infrastructure or one of its elements' failure leads to the other system's failure, cascading effects occur. Cascading effects have an indirect impact on society and become dangerous over time as the personnel's response time increases due to the uncertainties in the dynamic environment (Thouret et al., 2014). Cascading effects consist of initiating events that affect the originating system and its dependent systems. For instance, if there is a power-grid failure, electricity distribution fails in an area, which might affect any roadworks carried out in that area, which needs electricity. This might further affect the rescue team's response time and negatively impact the rail transport system. The impact of these cascading effects may not be visible immediately, and the resilience depends on the intensity of the cause that triggered the event and the scale of impact (Pescaroli, Gianluca and Alexander & David, 2015). The intensity of the effect varies based on the level of risk the community is subjected to and how well the disaster preparedness measures are provided to the community (Thouret et al., 2014).

2.4 Visualization of cascading effects

Figure 2 below is the visualization of cascading effect on infrastructures for Rotterdam, The Netherlands. The visualization below illustrates the impacts due to floods increasing over time indicated through the flood depth and how it leads to cascading effects on CI present in that locality. For instance, if there is an electricity outage, the hospitals will be affected and depend on temporary sources, but the basements might be affected by floods.



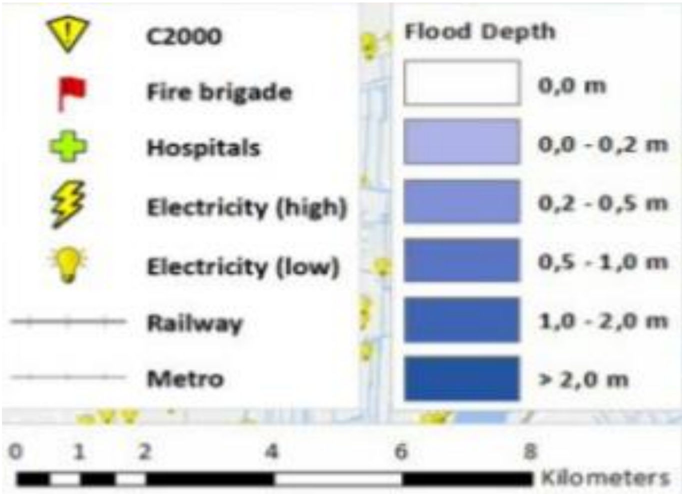


Figure 2: Flood Impact Analysis for Rotterdam

Source:(*Towards Adaptive Circular Cities Adaptation to Climate Change: Cascading Effects*, 2020)

2.5 Stakeholders

Stakeholders are individuals or groups of people involved in the study who are in a position to be involved in the direct or indirect decision-making process (Varvasovszky & Brugha, 2000). The study on cascading effects on CI failure due to natural hazards impacts the community as they co-exist in the environment; therefore, the community is considered as the essential stakeholder. It is also crucial to include multi-stakeholders because the complex problem needs a different perspective. Different stakeholders focus on different elements which are also part of the community and responsible for direct or indirect decision-making.

2.6 Dashboards

Dashboards are tools designed for assisting decision-making processes by analyzing the hidden data relationships (filtering functionality) from different perspectives, which in turn enables them to achieve a detailed review of the current situation (Nadj, Maedche, & Schieder, 2020). It involves data retrieved from different sources, and they hold a considerable role in information process chaining as the interaction between the decision-makers and the data generally occurs through the Graphical User Interface (GUI) (Few,2006). Dashboards are of three types based on their functionality, i.e., static, interactive, and interactive-analytical dashboards. The static dashboards are mainly used to display the underlying data and to keep people informed about the situations. It has minimal user interaction compared to the other two dashboards and mostly not accountable for analyzing complex and multi-dimensional data at the operational level (Nadj et al., 2020). The interactive dashboards and interactive-analytical dashboards have considerable user interaction such as filtering, sorting, searching, drill-downs, drill-throughs, zoom-in, zoom-out, etc., with the elements included in the dashboard design. These interactive dashboards involve the users at the data analysis stage and assist in assessing the current situation through filtering functionality as they are lively (Nadj et al., 2020). The interactive analytical dashboards are similar to the interactive dashboards with an added what-if analysis functionality. Historical data in disaster preparedness helps in decision-making through the designed functionalities.

The interactive-analytical dashboard helps to view the impact of the proposed changes, which helps arrive at a comprehensive and informed decision (Flacke & de Boer, 2017). It provides the ability to visualize the scenario and the outcomes through a "what-if analysis" and with the visual features and experiment with hypothetical situations. "A what-if analysis is a data-intensive simulation to inspect the behavior of the complex system under a hypothetical scenario, and it measures how the changes of the independent variables affect the dependent variables with reference to the simulation model"(Rizzi, 2009).

Dashboards are a part of the Decision Support System (DSS) that mainly assists the decision-makers at the operational level (Nadj et al., 2020). The DSS involves analyzing massive data and retrieving information, which helps understand the information related to the problem that arises in the community. Dashboards assist planners in making business-critical decisions in less time (Stadtler, 2015). Analytical reasoning can be increased through graphical interfaces (Thomas & Cook, 2006). Dashboards represent data in the graphical form, which helps in retrieving useful patterns of information from a large amount of collected data, i.e., Data mining that improves the understanding of the data and perceives the displayed information by the users.

Dashboards help the user groups explore the data in Spatio-temporal aspects and the attribute aspects, which consolidate information in unified views. The interaction with the collected data through dashboards helps to gain an improved understanding of the form, function, dynamics, and observe their behavior in reality and provide a response (Lock et al., 2020). They enhance engagement, communication, and spatial understanding (Lock et al., 2020). Understanding risk caused by natural and anthropogenic hazards through an interactive analytical dashboard is expected to play a vital role in improving risk knowledge.

Few existing dashboards are listed below. Figure 3 shows the community impact dashboard developed by the Environmental Systems Research Institute (ESRI), a Geographical Information Systems (GIS) Company, to assist the emergency managers in assessing the impacts of areas most affected by a disaster and understanding the ways to improve the area's resilience.

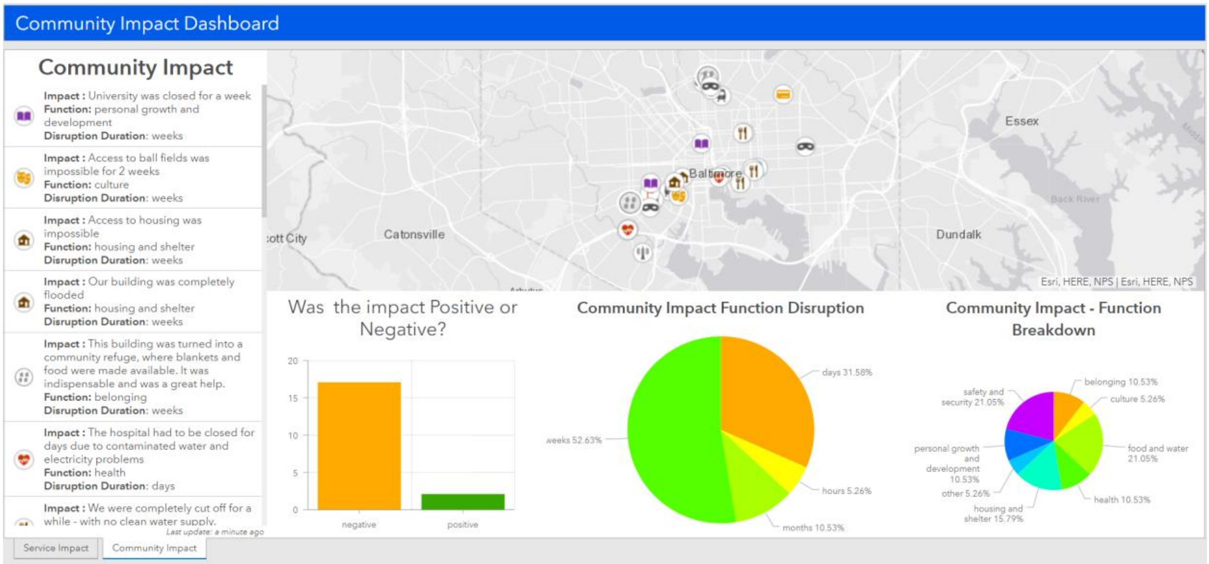


Figure 3: ESRI Community Impact Dashboard

Source: (ESRI, 2020)

Figure 4, the community risk assessment dashboard developed by the 510 Global, an initiative of the Netherlands Red Cross, serves as an example for displaying the most affected areas by humanitarian disasters. This dashboard helps identify the most vulnerable group of people affected by the disaster so that the recovery process can be done on a priority basis.

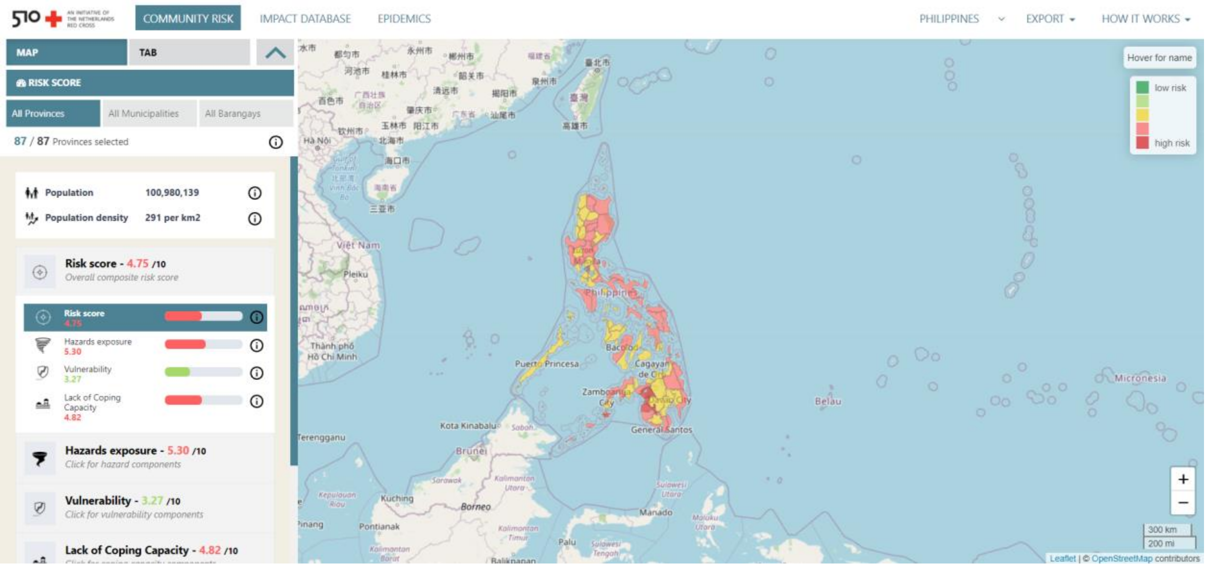


Figure 4: Red Cross community Risk assessment Dashboard

Source: ('Rode Kruis Dashboards', 2020)

Figure 5 shows the Impact Based Forecasting (IBF) system, a part of Forecast-Based Financing (FBF), which deals with releasing humanitarian funds based on the forecast information of the upcoming disasters like floods, droughts, rainfall, typhoons, epidemics, etc. The International Federation of the Red Cross (IFRC) implemented FBF in association with different countries' national societies and the Red Cross and Red Crescent Climate Centre's technical support. The IBF process is comprised of different data related to the communities and the disaster and the forecast information that supports the prediction of impacts from the disasters to occur. This helps to predict the damages in terms of social, economic aspects and the emergency aid required to respond to a disaster. IBF system supports the disaster management unit of the countries and plays a significant role in improving the overall efficiency of Disaster Risk Management (DRM) in disaster response. This system enhances the preparedness and response phase of the disaster management cycle and has planned activities such as early warnings and early action protocols to reduce the disaster risks. The system visualizes the impacts on the vulnerable population prone to the disasters and actions that need to be taken to activate the triggers.

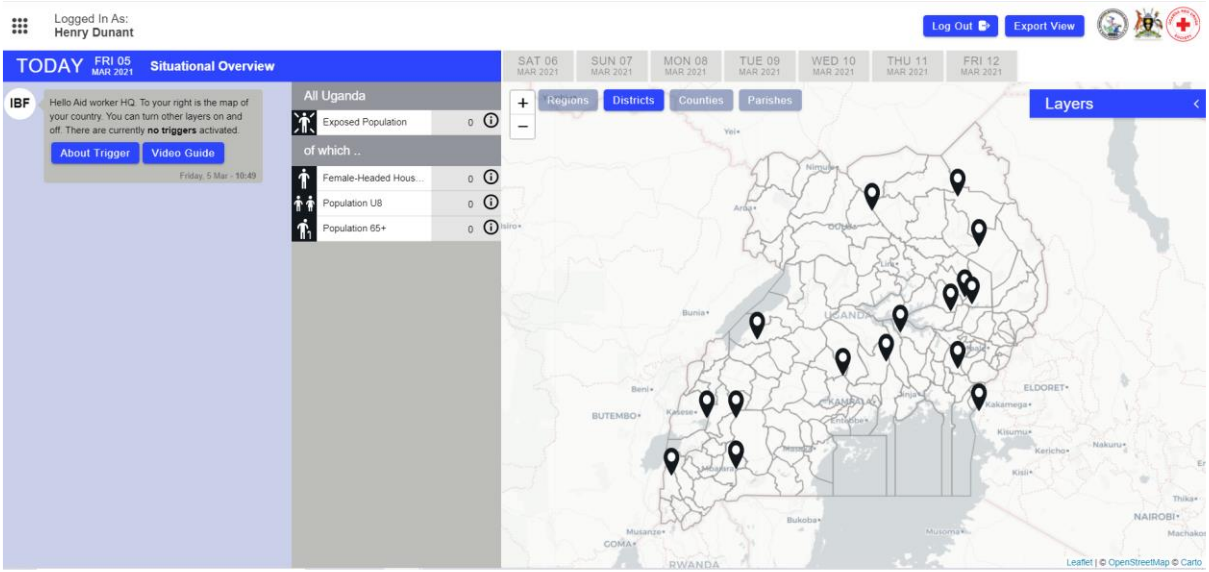


Figure 5: IBF Uganda MVP for floods,

Source: ('Rode Kruis Dashboards', 2020)

Figure 6 below shows Nepal's BIPAD system (Building Information Platform Against Disaster), by the Disaster Information Management System (DIMS) from the Ministry of Home Affairs Nepal (MoHA) and is owned by "the National Disaster Risk Reduction and Management Authority (NDRRMA)".

Figure 6:Nepal BIPAD System

Source: (NDRRMA, 2021)

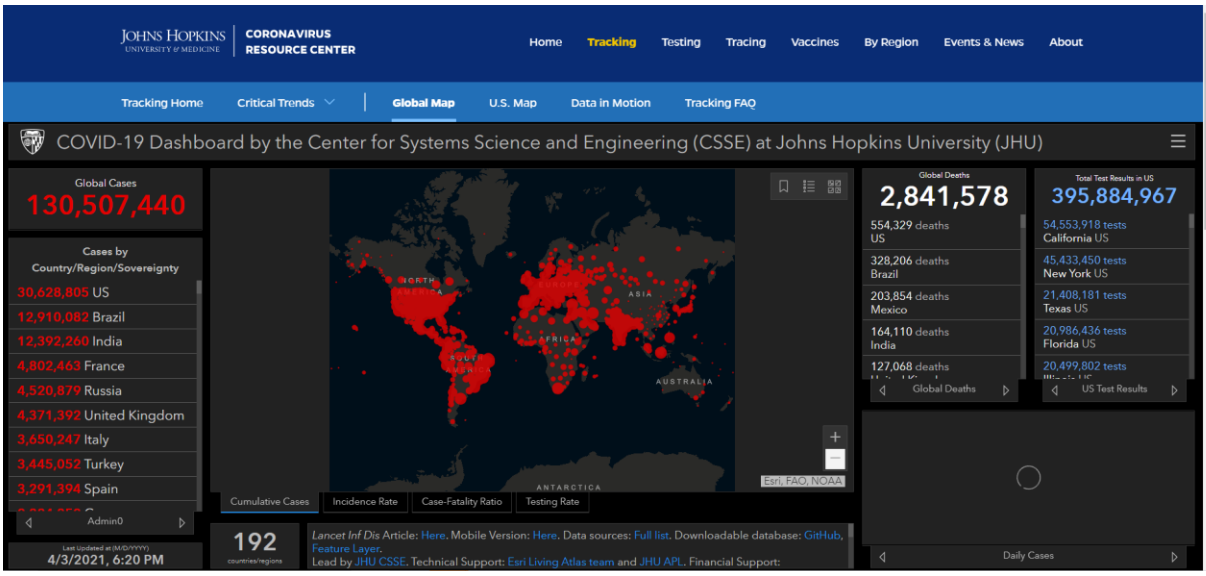


Figure 7: John Hopkins Covid-19 Dashboard

Source: ('COVID-19 Map - Johns Hopkins Coronavirus Resource Center', 2020)
Figure 7 shows the Covid-19 Dashboard developed by John Hopkins Coronavirus Resource Center ('COVID-19 Map - Johns Hopkins Coronavirus Resource Center', n.d.) to monitor global cases of the Covid-19. It includes different components to visualize the covid-19 situation worldwide.

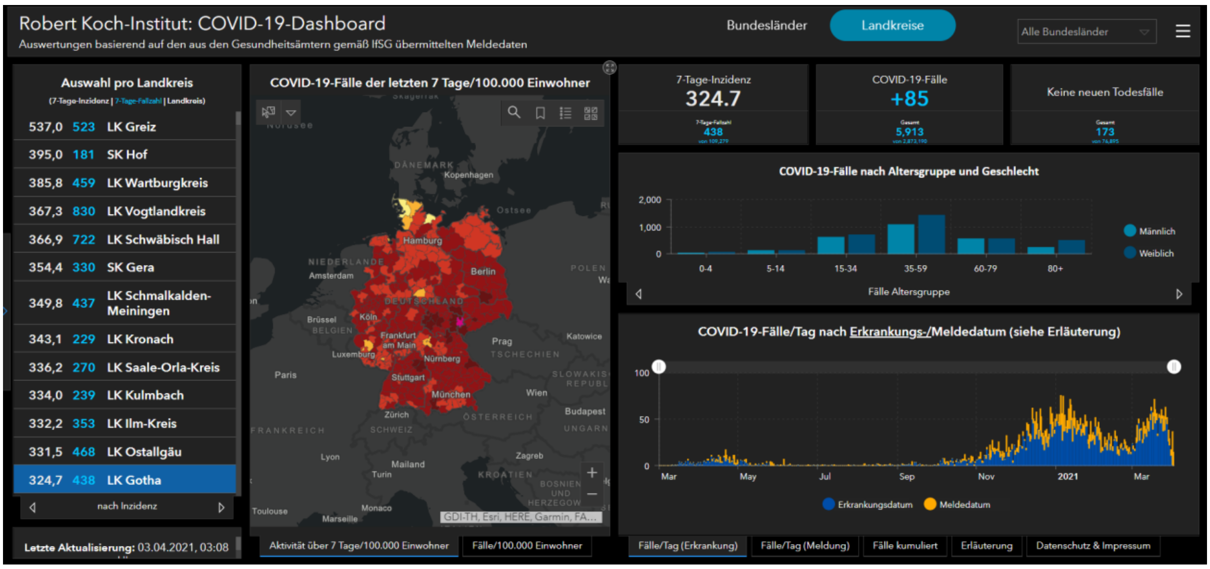


Figure 8:Robert Koch-Institute Covid-19 Dashboard

Figure 8 shows the Covid-19 dashboard developed by Robert Koch-Institute of Germany ('RKI COVID-19 Germany', n.d.) to visualize covid-19 cases in Germany.

2.7 Cartographic interaction:

Cartographic interaction is a study that deals with the interaction between the map and humans through a Graphical User Interface (GUI) (Roth, 2013). GUI offers more scope for interactivity with cartographic elements based on the users' requirements, data limitations, technical limitations, and the developer's skills (Fitts, 1992). The interface's usability highly depends on the interactions provided to the user (Roth, 2013).

The information graphics presented through the interface in the form of maps allow users to think visually by viewing the content, reasoning why, and interacting with the system, i.e., visual externalizations (A. M. Maceachren & Ganter, 1990). This supports in generating new insights and increases the informative perspective (Arnheim, 1969). Though this has knowledge constraints of the map maker, the main goal of the communication is to present the insights in terms of geographic data. There are two types of insights, namely knowledge-based and spontaneous.

Cartographic interaction supports the exploration process through visualization. Figure 9 illustrates the cartographic cube framework. The communication of the data to the users have infinite possible ideas i.e., visual thinking to an optimal way, i.e., visual communication. The human-map interaction highly fosters this process. Cartographic problematic, i.e., uncertainties that arise which abstracting the reality, can be avoided through cartographic interaction (Roth, 2009). The four stages in the cartographic cube framework, namely, Exploration, Confirmation, Synthesis, Presentation, supports the process of sense-making through geographic data (Murdock, Roth, & Maziekas, 2012).

The value of cartographic representation does not increase with the increase in interactions of the system (Roth, 2013). It is proven that Buxton's "less-is-more approach" is successful for the interface design (Buxton Buxton Design Toronto & Valentin, 2001). The interactions can affect the degree of freedom to perform the task. There is no optimal strategy for interactions that can provide optimal visual isomorph as the aim of the Geovisualization is to communicate through exploration (Roth, 2013). Flexibility in the interface brings universal usability to a wide range of users (Roth & Harrower, 2008).

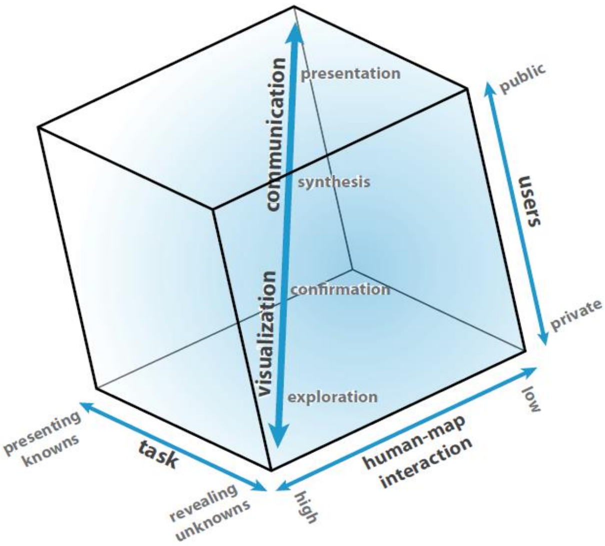


Figure 9: Cartographic cube

Source: (A.M. MacEachren & Taylor, 1994)

Cartographic interaction supports group activities through geo collaboration (Alan M. Maceachren & Brewer, 2004)(MacEachren, Boscoe, Haug, & Pickle, 1998). Geo collaboration has two primary distinctions: time and places for collaboration, i.e., synchronous (same time) vs. asynchronous (different time), and secondly, same place vs. different place (Ellis, Gibbs, & Rein, 1991).

Technologies used for the cartographic representation should encourage discovery rather than just be a presentation tool (Dykes, 1997). Help documents bridge the gap between the expert and the public by fostering the knowledge of the users about the system. If the user motivation is very high and the interface complexity is low, then it is a failure and vice versa (Roth & Harrower, 2008). Thus, the system's success depends both on the user motivation and the interface complexity.

2.7.1 Visual variables

Visual variables are the graphic elements included in the cartographic representation to encode information. Visual variables are pre-attentively processed at the human eye's sensory level. The cartographic interaction is provided through visual variables. Visual variables play a major role in conveying the map's message to the user.

- **Location** - necessary visual variable for representing the spatial component. It is the primary variable in the list of 12 visual variables (Roth, 2017)
- **Size** - size is used to denote the quantity of the element included in the visualization. In addition, size can indicate the importance of the variable for a particular scenario.
- **Shape -** shapes are used to denote the abstract of reality. It includes simple geometric shapes such as circles, rectangles, etc., to icons.
- **Orientation** - orientation is for representing the direction of flow
- **Color hue** - the color hue is part of the Color aspect of the visualization.
- **Color value** – color value the lightness or the darkness element of the visual.
- **Color saturation** - the intensity of the color included. The grey level in the visual denotes the color saturation.
- **Texture** - it can denote the difference in attributes when used as a fill element for polygons.
- **Arrangement** - placement of elements
- **Crispness** - crispness is the element boundary's sharpness amount.
- **Resolution –** resolution is the precision of the symbols displayed.
- **Transparency** - transparency determines the level of blending between the map symbol and the background.

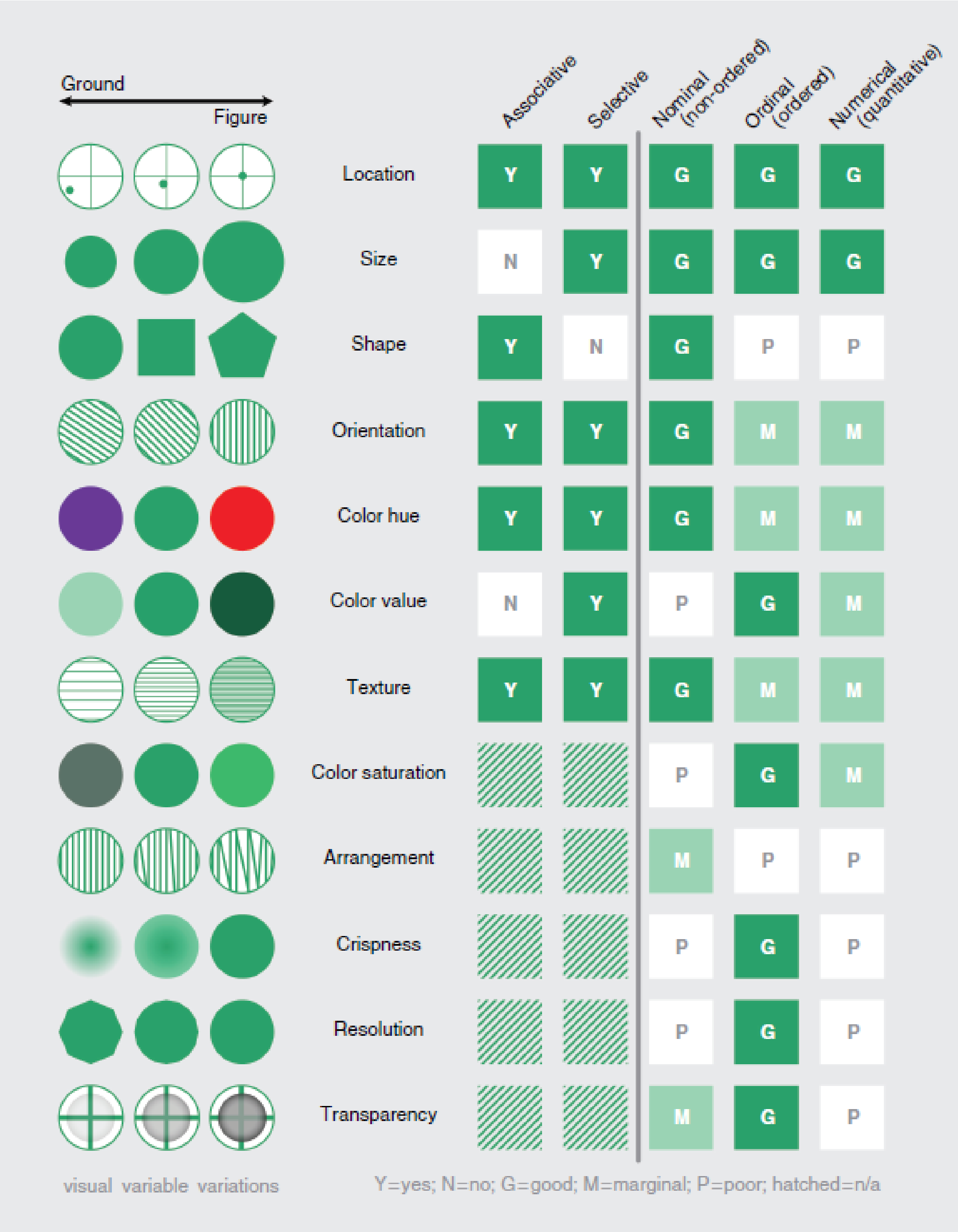


Figure 10:Visual Variables

Source: (Roth, 2013)

2.7.2 Cartographic design principles

Table 1 shows the cartographic principles which support in providing a legitimate representation of spatial data (Turchenko, 2018).

Cartographic Principle	Aim	Solutions
Balance	• The map should be represented with a possible zoom level without much white spaces. • The map center is below the visual center.	• The features in the top right are heavier than the bottom left. • Visual weight starts to decrease from the visual center. • Single features weigh more than the group of features.
Hierarchical organization	• Cohesivity in the arrangement of map elements	• Arrangement of features based on their importance. • Ordering based on size.
Clarity (Legibility)	• Clear differentiation of the map symbols • Readability of the symbols • Focus on important elements and removal of unnecessary elements.	• Proper allocation of visual variables including size of the symbols. • Proper readable labels
Visual contrast	• Distinguishable visuals by avoiding similar representation	• Distinguishable colours, intensity, size etc
Unity	• Representation of all elements as a single visualization	• Blend of map elements
Figure-ground contrast	• Appropriate difference between the base map and the overlaying layers	• Use of shadows, difference in hue, saturation, intensity

Table 1:Cartographic design principles

2.7.3 Interactivity:

Operator-based interactions are a part of cartographic interaction. They categorize interactions based on enabling operators, change in symbolization of the map, and vary according to the user's viewpoint, and most commonly used operators are focusing, linking, and brushing (Roth, 2012). Different authors define different interactivity components. For example, Becker & Cleveland (1987) describes four brushing operations over mouse control, i.e.., highlight, shadow highlight, delete and label. These offer immediate interaction with the map elements.

Buja, Cook, & Swayne (1996) defines three operators interactive view manipulations, i.e., focusing, linking, and arranging views. Dix & Ellis (1998) defines six operators i.e.., highlight and focus, overview and context, accessing extra information, same representation but different parameters, same data but different representation and linking representation

Table 2 describes Shneiderman,(1996) seven task-based operators.

Operators	Descriptions
• **Overview**	The overall outline of the elements
• **Zoom**	Zoom in, zoom out, zoom to a specific location, Zoom to the full extent
• **Filter**	Filter data on particular interest or filter out data
• **Details on demand**	Selection of data or narrowing down of data
• **Relate**	Find patterns or relationship between the data
• **History**	The sequence or the history of actions
• **Extract**	Extraction of the subset of data

Table 2:Seven task-based operators by Shneiderman (1996)

2.8 Human-Centered Design

Human-Centered Design (HCD) involves understanding the environment, users, and tasks for which the system is developed. This framework overcomes the system's failure due to a lack or incomplete understanding of the users' needs (ISO, 2020). HCD is an iterative process and can be incorporated into any development process like waterfall, agile, etc.

HCD is important as it increases the user's motivation to use the system, and it is proven that the system is more successful if the user likes to use it for their task. HCD has three aspects, i.e., spatial thinking, expertise, and motivation. User motivation can be increased by demonstrating real-life examples (Roth, 2013).

2.8.1 Advantages of HCD

Below listed are few advantages of HCD ('ISO 9241-210:2010(en), Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems', n.d.)

- HCD creates more space for design thinking and explore more designs before settling to one design
- It facilitates to incorporate user feedback in the early development process
- Supports several iterations of designs

2.9 Agile methodology

The advancement in software technologies led to the increase in the agile methodology for the software development process (Pathak & Saha, 2013). Agile methodology is useful for the incremental development of the product (Abbas, Gravell, & Wills, 2008). Agile is defined as the "Continual readiness of a product or an entity to reactively, proactively embrace change through simplistic, high-quality relationships with its surroundings"(Conboy & Fitzgerald, 2004). Different types of agile methodology are in practice specific to the business needs, namely scrum, kanban, extreme programming (XP), Feature-Driven Development (FDD) (Zielske & Held, 2021). Agile methodologies are considered successful as they follow iterations and detect early failures that lead to help the software development team rectify the errors or make changes at the early stage of development (Pathak & Saha, 2013). Among these agile methods, FDD is a feature-centered method. Following the FDD process, Minimum Viable Product (MVP) is developed.

MVP is the preliminary product of the software development process where it includes the essential features needed to satisfy the end-users and get feedback for further development. MVPs undergo many iterations before the product is complete, as there are continuous upgrades necessary for any software to attain saturation in development. The changes or bugs in each iteration are listed as product backlog items and are included in successive iterations of the development process.

2.9.1 Feature Driven Development

FDD is one of the most effective development processes in agile, which focuses on the features included in the development model. The development cycle can be two to four weeks period. FDD has five activities, among which the three activities of developing the overall model, building the feature list, and plan by the feature are done as preliminary steps. Then as the requirement adds up, the design feature and build feature are done in iterations in short sprints of two weeks (Tekinerdoğan, Moreira, Araújo, & Clements, 2004). Figure 11 describes the FDD lifecycle or the steps involved in developing the system. The initial modeling phase includes developing the overall model and building the features list; the model storming is a mix of building a model and brainstorming simultaneously. The issues in the model can be identified during the model storming phase, and the fix is included in the iteration process.

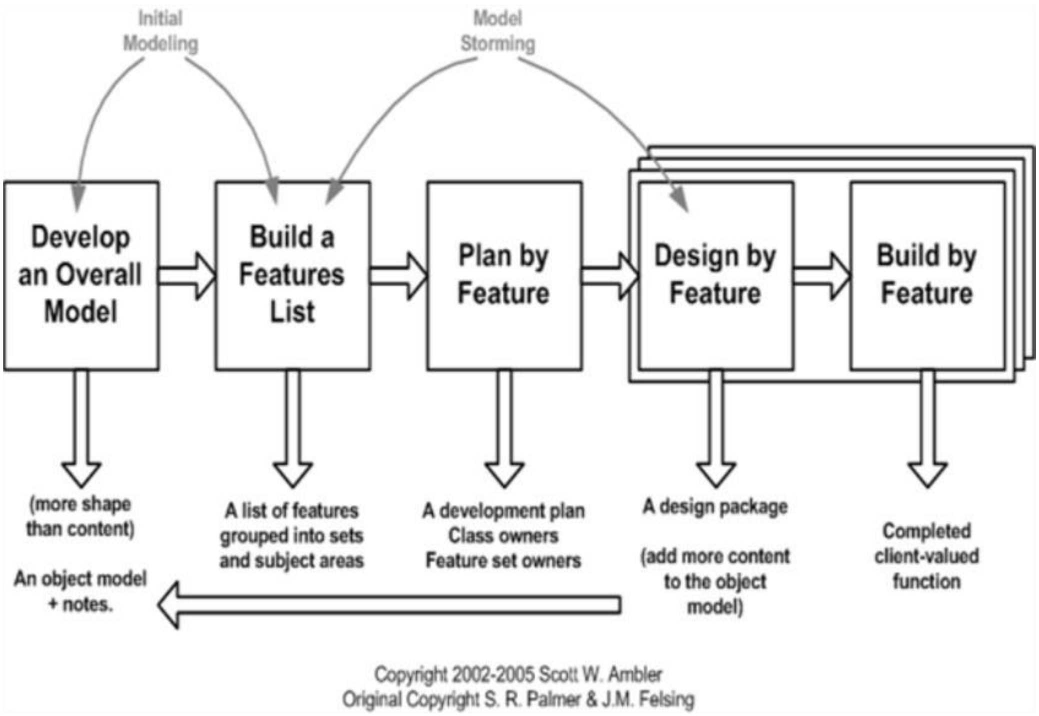


Figure 11: FDD Lifecycle

Source:(Abrahamsson & Ronkainen, 2017)

2.9.2 Technologies in web development

2.9.2.1 Front-end languages and file formats

In this growing digital world, there are numerous open-source and proprietary technologies involved in developing web applications. Among those, Hyper-text Markup Language (HTML), Cascading Styling Sheets (CSS), and JavaScript (JS) are indispensable and are known as front-end development languages or client-side programming. HTML is responsible for all the components displayed on the web, whereas CSS is responsible for the web pages' aesthetics. The components' behavior can be controlled and manipulated using the JS embedded in the HTML document. Different JS libraries support products that involve mapping components. Libraries consist of in-built functions that support the development of an interactive environment. Among the JS mapping libraries such as OpenLayers, Leaflet, Mapbox, Google maps, Polymaps, etc., Leaflet.js has considered the lightweight open-source JS library contributed by communities to create dynamic interactive spatial components in web pages. Leaflet.js library has well-supported documentation, which can be accessed through https://leafletjs.com/. Leaflet works well with data in GeoJSON file format https://geojson.org/. GeoJSON is the extended form of JSON (JavaScript Object Notation) used to handle geometry primitives such as point, lines, polygons, and multipart geometries like multipoint, multiLineString, multiPolygon, and geometry collections. GeoJSON is preferred because of its simplistic data structure for displaying vector data.

3. METHODOLOGY

This chapter describes the conceptual research framework, case study area, overview of the data and technologies used, and brief the methods and the outcomes through the research design matrix and the overall development plan used in the research.

3.1 Conceptual research framework

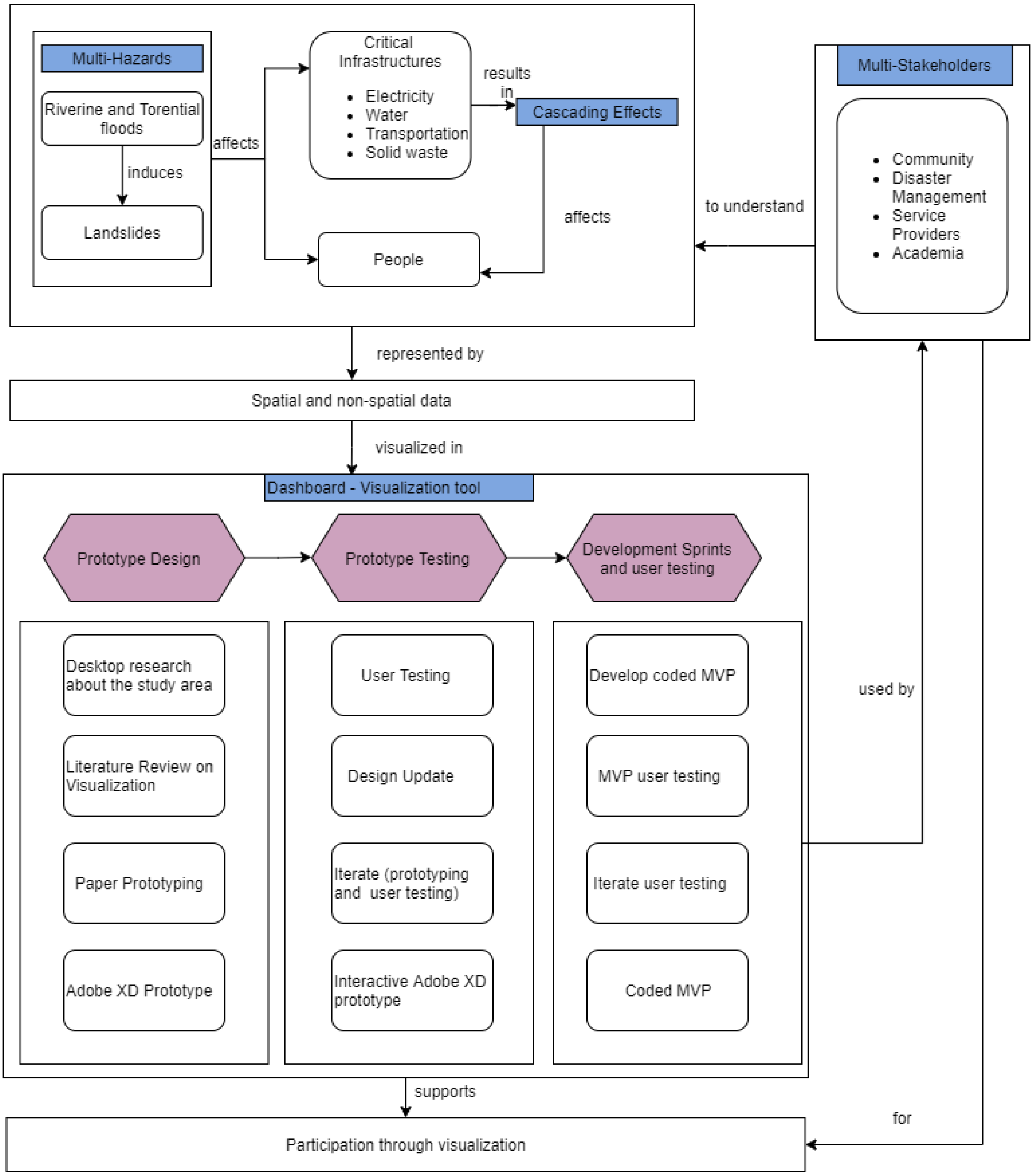


Figure 12:Conceptual framework

Figure 12 shows the conceptual framework involved in this research. Natural hazards such as floods and flood-induced landslides are the initiating events that affect people in terms of lives, property damage, and damages CIs such as water, roads, solid waste collection, etc., which leads to the cascading effects where one system negatively affects the other system. These cascading effects on CI also affect the everyday life of the people residing in that area. This cascading effect due to natural hazards is very complex to understand for a community without a holistic view of the scenario. To provide this holistic view, visualization tools such as dashboards come into play, supporting the involvement of different stakeholders to visualize spatial data and the associated non-spatial data. Dashboards help to have a bigger picture of the area through spatial and non-spatial data about an area. The dashboard development consists of three phases mainly. Firstly, the preliminary prototype is designed by integrating the inputs from the co-design session of HCD and from the literature review on the existing dashboards. The primary ideas generated are designed as paper sketches then transferred to the high-fidelity prototype using design software. This high-fidelity prototype is evaluated and then implemented to develop the interactive web dashboard using geospatial web development technologies. This developed MVP is then tested with the stakeholders, and the product is iterated over the process.

3.2 Research design matrix

Table 3 shows the research design matrix, which comprises the specific objectives, related research questions, corresponding methods, and the related outputs for each research objective.

Specific objective	Questions	Methods	Outcomes
1. To conduct a requirement analysis from the potential stakeholders, analyze the study area and collect the data to be included in the dashboard	Who are the stakeholders or the user groups?	Literature review	The participants or the potential stakeholders who will be the end-users of use the dashboard for their communication and planning purposes are determined. The datasets included in the dashboard are collected.
	What is the problem that has to be addressed?	Literature review	
	What data are to be included in the dashboard design?	Literature review and Co-design sessions from HCD	
2. To create a high-fidelity prototype design of the components that are to be included in the interactive analytical dashboard and to evaluate the prototype design	What are the suitable methods involved in developing the prototype design?	- HCD - Literature review on high-fidelity prototype designing tools -component tracing method	The final prototype of the dashboard used for the implementation of the dashboard using web technologies
3. To develop the	What are the suitable methods for evaluating the prototype?	Literature review, formative evaluation process through self-assessment	

dashboard using web technologies by implementing the prototype designed and evaluated			
	What are the suitable methods involved in developing an interactive dashboard?	The final prototype, developed from the second objective, is used to develop the dashboard. FDD, agile methodology is used for the development process. Web-based languages such as HTML, CSS, JS, and its libraries such as Leaflet JS for interactive web maps are used.	A preliminary dashboard or the MVP that includes the interactive components designed in the prototype
	What are the components that need to be included, and what is the level of interactivity between the components?	Literature review on cartographic interaction, prototype design, co-design sessions, component tracing	
	What are the data analysis procedures involved?	Exploratory spatial data analysis methods	
4. To evaluate the developed dashboard for the design, content, usability by the user groups	What are the suitable methods to evaluate the usability of the interface?	User testing with questionnaires. One-to-one face interviews.	The final MVP of the interactive dashboard.

	What are the methods to evaluate the effectiveness of the visualizations used?	User testing. Role-based interaction through group activities	

Table 3:Research Design Matrix

3.3 Case study area

In general, In Colombia, floods are the majorly occurring disaster (Rodríguez-Gaviri & Verónica Botero-Fernández, 2013) and affected millions of population and disrupted the CIs ('Colombia | HumanitarianResponse', n.d.). This study focuses on one of the barrios in the second-largest city of Colombia, the City of Medellin. The municipality of Medellin is in the valley located in the central region of the Andes Mountains in South America called Aburrá Valley. Medellín has six zones and 16 comunas that are districts, five corregimientos that are townships, and 271 barrios that are neighborhoods. The metropolitan area of Medellín lies at an elevation of 1,500 meters (4,900 feet) above sea level within the Aburrá valley and is divided by the Medellín River called Porce. At the central range, the Aburra-Medellin River basin is situated in the center of Antioquia. The river starts in the Alto de San Miguel, located in the Caldas municipality, and travels through 10 towns to join the Porce river.

Due to the rapid increase in Medellin's population and the high cost of living in the core city, the informal settlements have been increased. As a result, people started to build houses on the steep slopes of the valley, which are highly susceptible to landslides. Due to the lack of thick residual soils and the valley's steepness, the slopes are highly vulnerable to the landslides induced by torrential floods or flash floods due to heavy rainfall or torrential storms. These flood-induced landslides lead to loss of lives, destruction of homes. This also leads the town to isolation or cut-off from the rest of the city due to the failure of power supplies, communication networks, blocked roads, and other utilities that are considered to be CI (Ojeda & Donnelly, 2006).

Figure 13 below shows the overall location the Medellin, Colombia, South America, and the urban zones of Medellin.

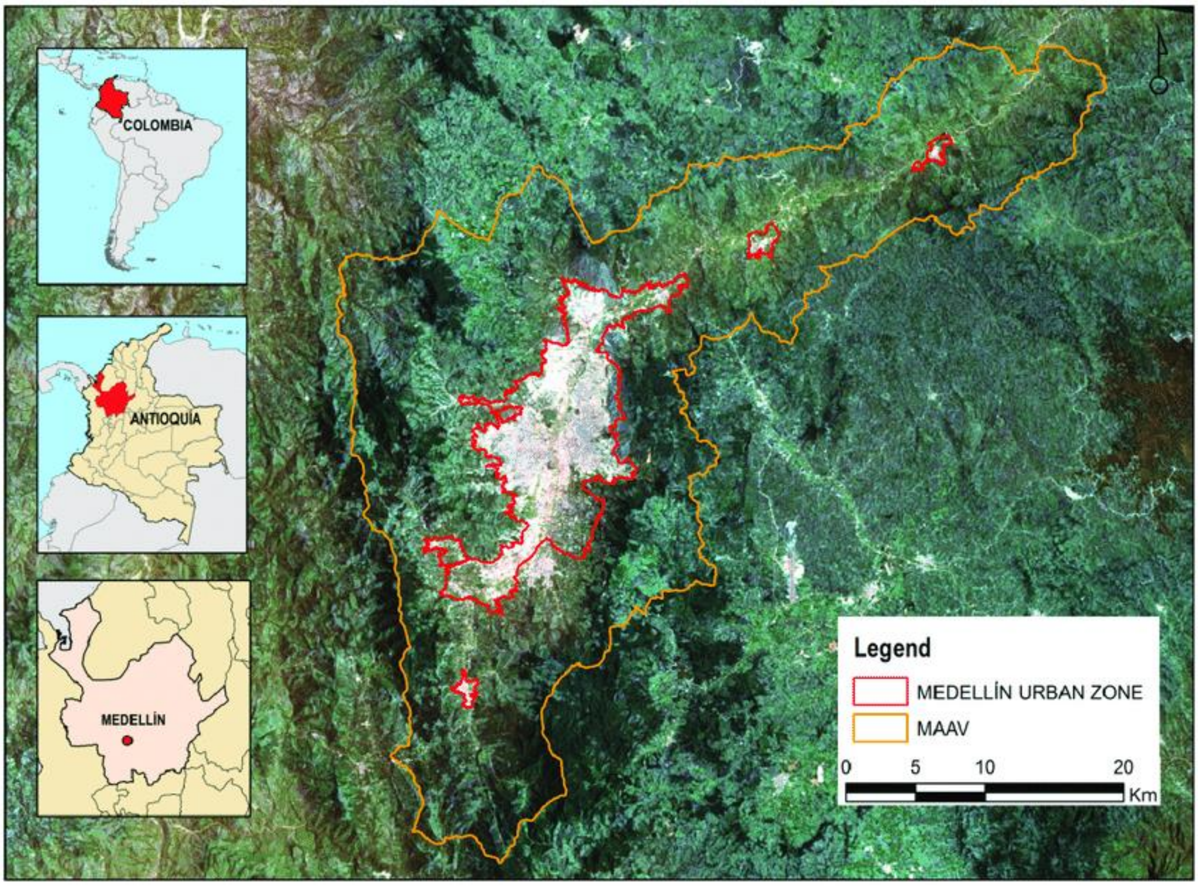


Figure 13: Map of Abura Valley with Colombia, Antioquia, Medellin

Source:(Reynolds, Escobedo, Clerici, & Zea-Camaño, 2017)

Villa Hermosa is one of the 16 communes of Medellin city, a densely populated district comprised of 18 barrios, predominantly an informal settlement with self-built housing and pathways. It is situated in the eastern-central part of Medellin city. Communa 8 is not easily accessible despite its proximity to the city center because of the steep slopes. The area has been declared under the high-risk zone for landslide events, and the presence of the Quebrada Santa Elena river stream makes the area even more vulnerable to flash floods and debris flow events (Areu-Rangel, Cea, Bonasia, & Espinosa-Echavarria, 2019).

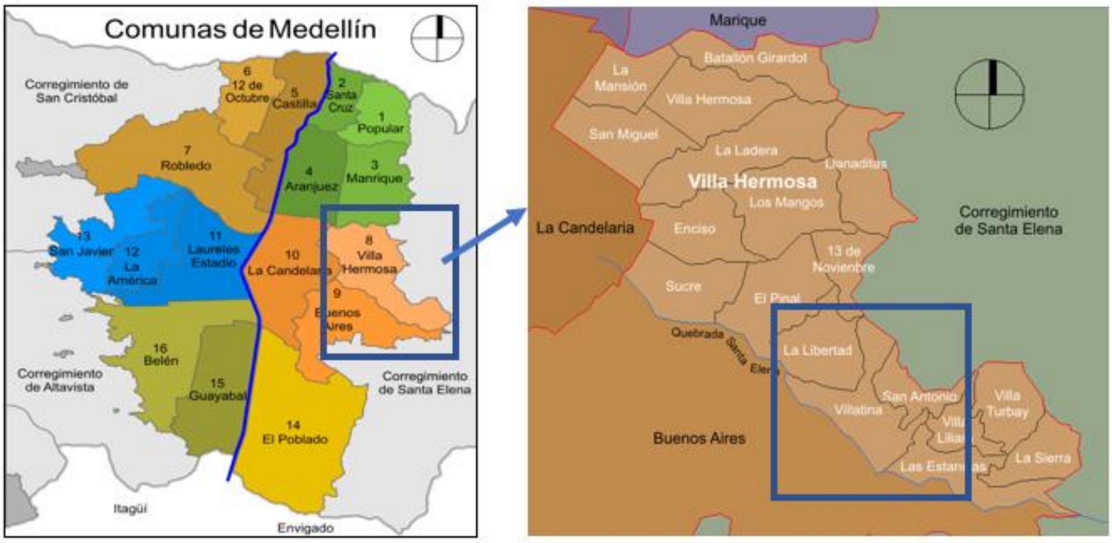


Figure 14:Communes of Medellin and Location of Villatina

Source:('Comunas de Medellín - Wikipedia, la enciclopedia libre', n.d.) and ('Mapa Villa Hermosa-Medellin - Villa Hermosa (Medellín) - Wikipedia, the free encyclopedia', n.d.)

3.3.1 Villatina

Villatina is one of the barrios of the Villa Hermosa, which was developed in the 1950s by the inhabitants from Eastern Antioquia, and the large portion of the Villatina are high prone zones for flood and landslides. Villatina landslides in 1987 caused a greater impact on the community. The Infrastructure facilities are provided by the large municipally-owned utility providers, Empresas Públicas de Medellín (EPM), or the public companies of Medellin, which is responsible for the electricity generation, solid waste management, sanitation, local telecommunication, water supply.

3.4 Datasets and software

Table 4 below shows the primary data collection used in this study.

Data type	Data collection method	Source
Primary	Co-design session	Community, Academia
	User testing and usability testing questionnaires	Academia
	User testing and usability testing interviews and workshops	Academia

Table 4:Data type and source of the data

	Spatial data	Source
1	Base maps (Open Street Map (OSM), OSM roads, Google satellite)	Base map links from Leafletprovider.js

2	Villatina boundary	OSM. Downloaded through QuickOSM plugin in QGIS(Quantum Geographical Information System)
3	Block data (Manzana catastral Layer)	Manzana catastral layer
4	Household's layer	Urban zones layer
5	Road's layer	Road mesh layer
6	Flood layer	Flood threat layer
7	Landslide's layer	Mass movements layer
8	Solid waste collection points	Random points generation using Geojson.io proximity to the roads

Table 5:Spatial Data Included in the Dashboard

Application development	Software
Front-end	Hyper-text markup language (HTML 5)
	Cascading Styling Sheet (CSS 3)
	Leaflet.js (JavaScript library for interactive maps)
Data pre-processing	QGIS, Geojson.io

3.5 Development plan

In the FDD method, the increment or iteration is done in development cycles. The development cycle followed in this research is a four-week duration, and in total, two development cycles were done. At the end of each development cycle, there was user testing.

Development cycles followed in this research:

Iteration number	Development cycle duration (4 weeks)	User testing date	Insights for next iteration
1.	April 5th, 2021 - April 29th,2021	April 30th, 2021	May 2nd, 2021
2.	May 3rd, 2021 - May 27th,2021	May 28th, 2021	May 31st, 2021

4 PROTOTYPE DESIGN

Prototype designing is a highly creative process and open-ended based on the interface designer. There are many probabilities of designing the interface considering the cartographic interactions, i.e., user requirements from the HCD, interface styling, and design principles. The design decisions can be global in terms of interface layout, navigation, fonts, colors, etc., or local in terms of graphics, haptics, text phrasing, etc. This section describes the methods involved in the prototype design using the HCD method by gathering the requirements through co-design sessions from the stakeholders supported by the literature review. Component tracing helps in the interface layout and placement of components.

4.1 Stakeholders

Initially, the people from the Villatina community and the government officials were planned to be the stakeholders for the study. Because of the Covid-19 situation, there were practical difficulties in reaching the original stakeholders from Medellin; the research was carried out with the recent graduates and students from the Faculty of ITC, University of Twente. They belong to different specializations such as Geoinformation and Earth Observation, Natural Resource Management, Urban Planning and Management, Applied remote sensing. In addition to students, two people from the affected community in Chennai, India, who are above the age of 50 and non-academic background, were chosen as the stakeholders for the study. They were involved in the co-design sessions, which are similar to interview sessions as part of the HCD.

4.2 Co-designs

Co-design sessions are similar to the standard interview where the designer will ask questions to the stakeholder about the stakeholder's experience with the hazards. In this multi-stakeholders scenario, each stakeholder will have a different perspective based on their experience with the hazards. For example, the affected person in a community might be more concerned about whether their locality is high-risk zones or whether their area comes under high risk predicted zones, whereas the service provider will be more concerned about their damaged services and the economic losses that occurred due to the hazard and ways to repair and provide alternate services. Municipality or disaster managers will be more concerned about activating their emergency services, identifying the most vulnerable groups and location of their volunteer groups, and selecting suitable shelters and food distribution sites. The academia will be concentrated on the flood model or the landslides model.

For this research, I conducted phone interviews with few people affected by floods in their area in the past and with students from different specializations such as Urban Planning and Management, Geoinformation Processing, Applied Remote sensing, Natural Resource Management from the Faculty of ITC, University of Twente.

The question was about their experience during the flood or any other hazards and what they want to view in a system like a dashboard if any hazard strikes their area. They were asked to role-play themselves as different stakeholders, i.e., a person in the affected community, a researcher, a service provider and a municipality officer, and a disaster manager. The interview was conducted with different age groups, and the answers might not be straightforward but accepted as a part of the co-design.

4.3 Insights clustering for components

Table 6 shows the collection of components that are to be included for the prototype design phase based on the co-designs and insights from the existing systems.

No.	Stakeholders	Elements/components needed in the system
1	**Affected community**	The risk for my area, stagnant water areas, damaged roads, shelter locations and which shelter is free, the road map to the shelters, animal shelters, damaged services, communication network damages, contact person, food distribution locations
2	**Academia**	Affected areas, flood zones, predicted hazard models, water depth, guidelines, water flow directions, location of water bodies, location of health cares, and other amenities
3	**Municipal officers**	Damaged roads and other services, stagnant water areas, drainage locations, and conditions, solid waste collection, shelters, debris locations
4	**Service providers**	Damaged services, economic loss, the ways to clear the damaged services, temporary service plans, find the area for high priority services, finding the elements affecting the service such as de-rooted trees, etc.
5	**Disaster managers**	Affected communities, high-risk zones, shelter locations, volunteer locations, evacuation routes, real-time status reports, emergency supplies, emergency transports, hospital locations

Table 6:Insight clustering table for components

4.4.Cascading effect included in the study

Figure 15 below describes the flowchart of the cascading effect included in the study. As mentioned before cascading effect has initiating events, first-order CI, which are directly impacted by the initiating event, and the second-order CI, which the initiating event may directly impact, but it also indirectly impacted due to the failure of the first order CI. In this study, roads, which are part of the transport infrastructure, are considered as the first order CI which are directly impacted by the initiating events, i.e., floods and Landslides. The second-order CIs are solid waste collections, electricity, and water supply. The inaccessible roads make it impossible to collect solid wastes.

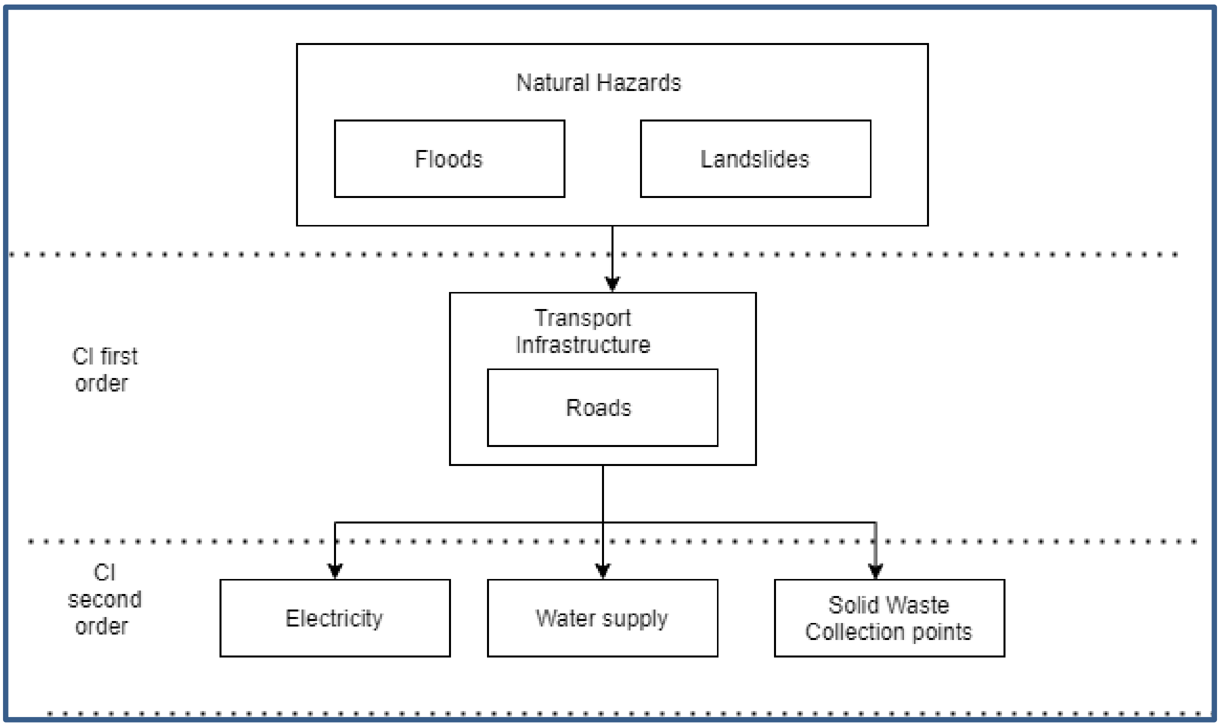


Figure 15:Cascading effect involved in the study

4.5 Components tracing of an existing dashboard

This section describes tracing or mapping the placements of components in the existing epidemics and pandemics dashboard. The below figure shows the covid-19 dashboard developed by John Hopkins Coronavirus Resource Center ('COVID-19 Map - Johns Hopkins Coronavirus Resource Center', n.d.). These tracings of components help to generalize the placement of dashboard components. This tracing is done in the miro board, an online collaborative whiteboard for collaborative design research.

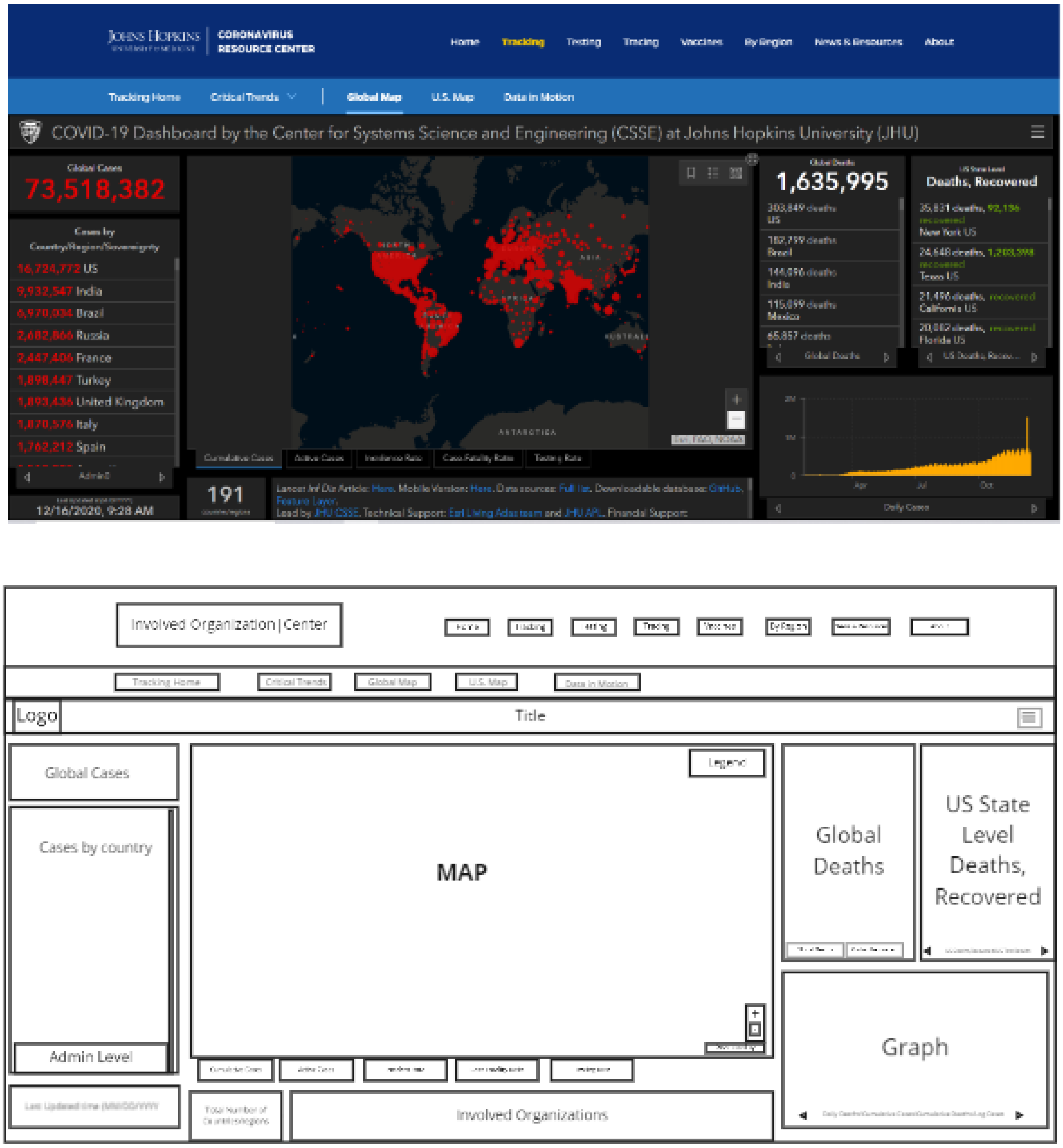


Figure 16: Components' tracing

4.6 Paper prototyping

Paper prototyping is the initial step, and it is considered important to organize the thoughts without the technology constraints. They are useful in testing initial ideas, and they form the basic skeleton for the prototype design.

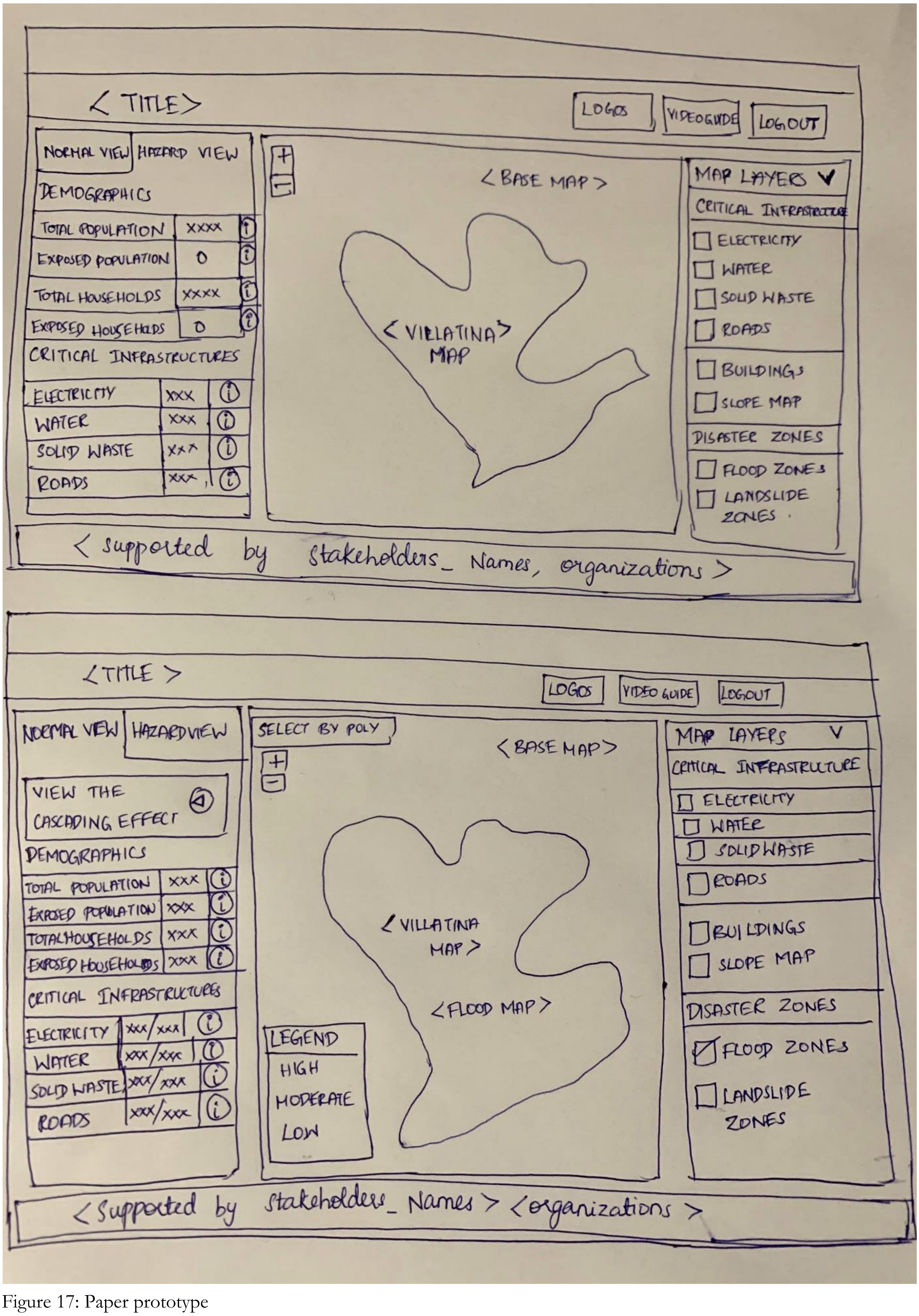


Figure 17: Paper prototype

4.7 High-fidelity prototyping

The prototype is designed using the Adobe XD software, an interactive and collaborative UI/UX vector-based design tool for creating interactive designs for various mobile and web applications. The prototype design is an essential process in MVP development as it reduces the chances of failure of the system at the development stage. The insights from the co-design sessions, literature review of the existing systems, and desktop research are used in the designing process.
The spatial data included in the prototype are as follows:

No.	Spatial data	Description
1	Base maps (OSM, OSM roads, Google satellite)	Base maps are the background maps used to convey more details of the area
2	Villatina boundary	The neighborhoods' boundary data
3	Block data (Manzana Catastral Layer)	The blocks are the administrative divisions of the neighborhood
4	Household's layer	The footprint of predominantly residence buildings located in the study area
5	Road's layer	The roads in the Villatina neighborhood
6	Flood layer	The high and medium flood threat zones in Villatina
7	Landslide's layer	The high and medium landslide threat zones in Villatina
8	Solid waste collection points	The solid waste collection points in the neighborhood

Table 7: Description of spatial data included in the prototype design.

No.	Non-spatial data	Description
1	Population	Total number of people living in the neighborhood
2	Exposed population	Total number of affected people due to the hazards in the neighborhood
3	Households	Total number of houses in the neighborhood
4	Exposed households	Total number of houses in the neighborhood
5	Number of blocks	Total number of blocks in the neighborhood
6	Block number	Block number corresponding to each block
7	Exposed blocks	Number of blocks affected with hazards

8	Roads	The total kilometer of roads
9	Solid waste collection	Total number of solid waste collection points per blocks
10	Electricity	Total number of electricity per household
11	Water supply	Water supply per household
12	Exposed roads	The total kilometer of roads affected
13	Exposed solid waste collection	Total number of exposed solid waste collection points
14	Exposed electricity	Total number of electricity exposed per household
15	Exposed water supply	Total number of water supply exposed per household

Table 8:Description of non-spatial data Included in the design

The prototype consists of 3 columns, i.e., non-spatial column, map column, spatial layers, and two views, i.e., normal view and hazard. The left column displays the non-spatial data, which quantifies the impact, including the total population, electricity per household, water points, solid waste collection points, and roads. The exposed population will be zero in normal view as there are no hazards, and there will be no CI affected. The central map column will display the layers, which can be turned on and off using the layers panel at the right. Figure 18 shows the normal view of the Villatina, where the area is not exposed to any hazard.

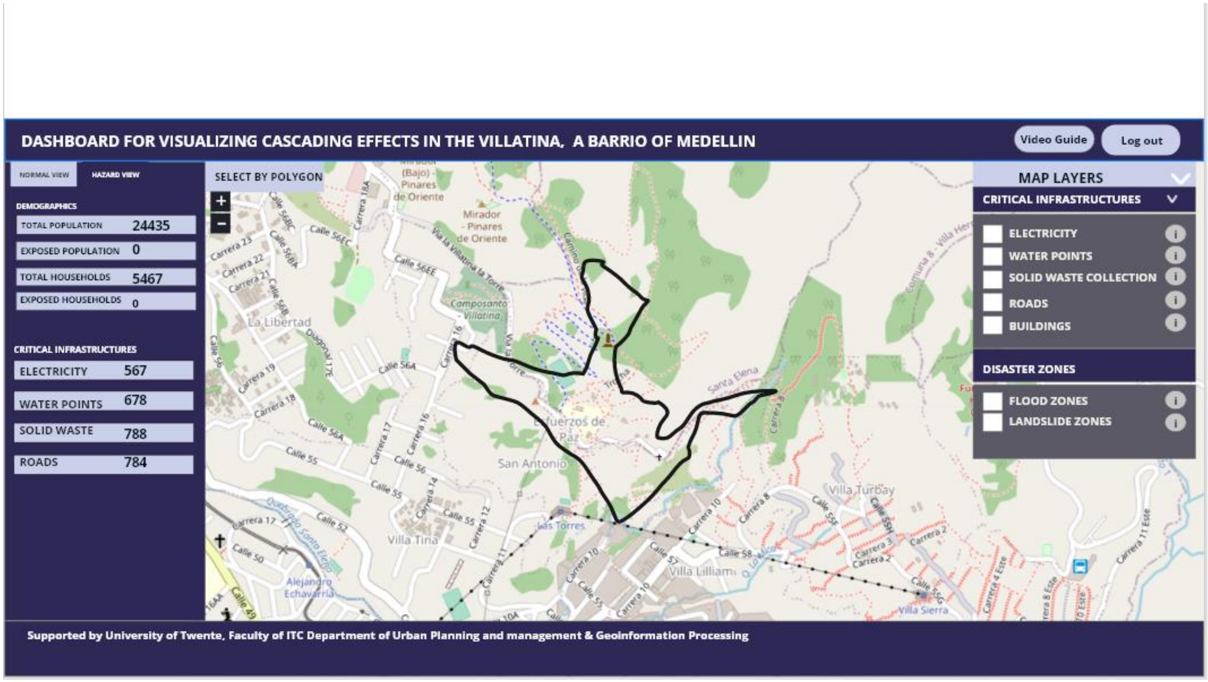


Figure 18:Adobe prototype for normal state of Villatina

Figure 19 shows the hazard view where the number of exposed populations is updated based on the damage. The exposed CIs are updated based on the damaged services. This view has an external connection to the visualization of the cascading effects, where it will link to an external video to understand the cascading effect.

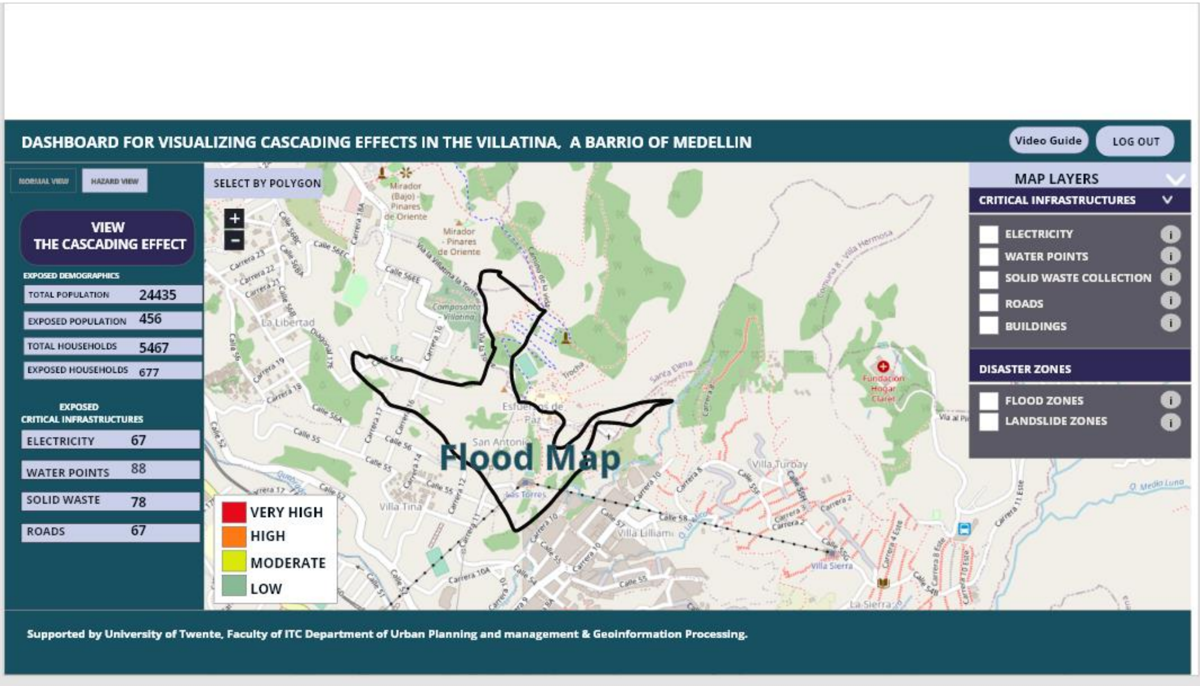


Figure 19:Hazard view of Villatina

4.8 Formative evaluation

The designed prototype is evaluated through a formative evaluation before used for the development of the dashboard. Formative evaluation is done in the form of self-assessment by the designer based on the insights from the co-design sessions, literature review on design and layout principles, component tracing methods. Prototype evaluation was initially planned with the stakeholders before the development phase, but it was carried out in the form of self-evaluation due to time constraints.
According to Human-Centered Design, for evaluating the prototype with the users, the prototype should support the interaction with the users by carrying out tasks instead of design layout.

Changes	Reasons
Changes made in the data:	
• Random selection of area using "select by polygon tool" is replaced with the block-level selection.	• Block-level selection is more appropriate than random selections
• The non-spatial column is added separately from the spatial column	• Summary of the total number of features is necessary rather than counting the number of features in the map area
• Separate selection column for flood risk zones are removed	• The block-level selection was sufficient and less complex.

• Chat bubble has been removed from left column changed to About dashboard to include more about the dashboard	• To include non-spatial column and have a composed view
• Login has been removed to keep the system open and easily accessible.	• Use of open data
• A separate container for legend	• Additional support
Changes made in the functionality:	
• The neighborhood is divided into block-level called Manzana.	• Availability of block-level data
• Disaster management branches are removed	• Lack of data
• Livestock and cropland column are removed	• Not included for the Minimum viable product (MVP)
• Slope map and elevation detail is removed	• Considered extra information for MVP
• Demographics categorization is removed	• Lack of data
• Electricity and water supply as non-spatial data	• Lack of data
• **Changes made in the aesthetics:**	
• The outline color is interchanged	• The outline colors are interchanged as the green represents normal state and blue represents water color and blends with flood data

Table 9: Formative evaluation of prototype design

5. DEVELOPMENT OF DASHBOARD AND USER TESTING

5.1 Data preparation and geoprocessing:

Spatial and non-spatial data related to the Villatina neighborhood are included in the development of the Minimum Viable Product (MVP). Spatial data is in the GeoJSON format. The spatial data is downloaded from geomedellin.org (https://www.medellin.gov.co/geomedellin/), an open data platform for Medellin data. Geomedellin platform offers data in the shapefile (.shp) format and GeoJSON(.geojson) format, and the data is accessible through Application Programming Interface (APIs) as geoservices. Filter option is also available for retrieving the data for the specific neighborhood. For this study, Villatina neighborhood data is downloaded using the option 'download filtered dataset' using the barrio (neighborhood) number column. The barrio number for Villatina is 0813, and the filtered dataset is downloaded as a compressed shapefile folder. For the block data and natural hazard threat layers, the barrio number was missing. In that case, the whole dataset for the Medellin is downloaded and clipped using the Villatina boundary as the source using the clip operator in QGIS. Villatina boundary was extracted through the quick OSM plugin of QGIS. The web page is translated from Spanish to English to understand the attributes and metadata better using the google translate browser plugin. Base maps included in the study were accessed using leaflet-provider.js https://leaflet-extras.github.io/leaflet-providers/preview/
The solid waste collection points are the random points generated using geojson.io and saved as a GeoJSON file. The flood and landslide layers are categorized as high risk (Alta in Spanish) and medium risk (Media in Spanish). The building data is filtered using the Predominantly residential attribute. The whole neighborhood of Villatina is divided into Block data and accessed through the Manzana catastral layer in the Geomedellin platform.

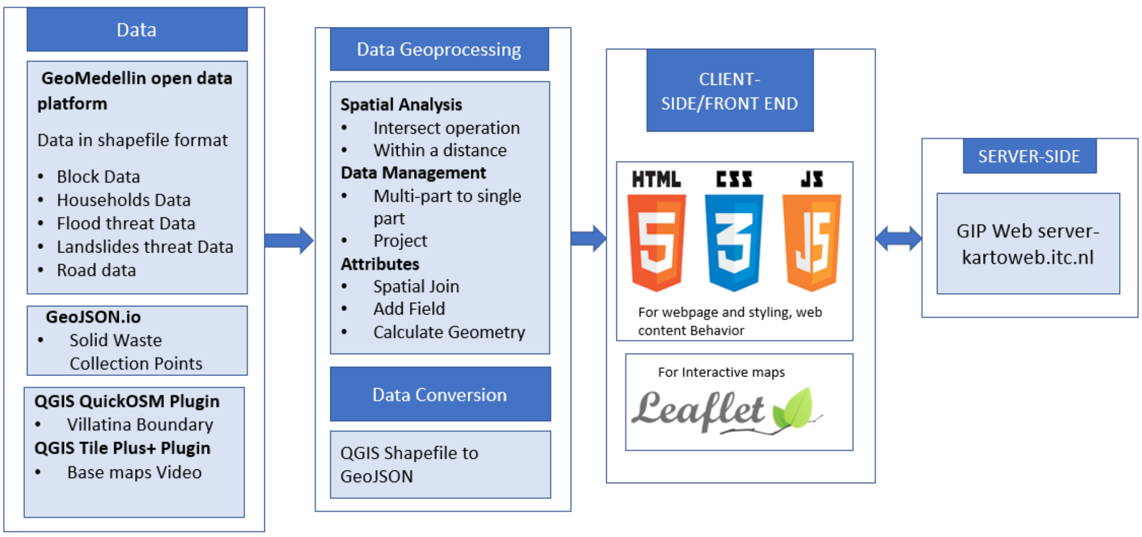


Figure 20: Development process carried out in this research

5.1.1 Geoprocessing for risk assessment:

Spatial analysis is done for analyzing the exposed CI layers. The CIs located in the hazard zones are considered to be exposed to natural hazards. Therefore, intersect operator is used in determining the CI elements at risk due to natural hazards. In this study, the exposure of first-order CI, i.e., exposed roads, is

determined by overlaying the road data with the natural hazard threat layer (Landslides and floods), which are the initiating events. The blocks and the households exposed are also determined by overlaying with the threat layer as the components that are located in the hazard zones are subjected to exposure.
Table 10 below explains the operations performed on each layer to find the exposure to the natural hazards.

Target feature	Source layer	Spatial relationship	Output layer
Road layer	Natural hazard layer(Mix of both flood and landslides)	Intersects	Exposed road layer
Solid waste layer	Natural hazard layer(Mix of both flood and landslides)	Intersects for direct impact	Directly exposed solid waste layer
Solid waste layer	Exposed road layer	Within a distance of 10m	Indirectly exposed solid waste collection points
Households	Natural hazard layer(Mix of both flood and landslides)	Intersects	Exposed households
Blocks	Natural hazard layer(Mix of both flood and landslides)	Intersects	Exposed blocks

Table 10: Spatial Analysis of layers

Outputs from the analysis:
Figure 21 shows the output of the exposed road layer to the floods and landslides.

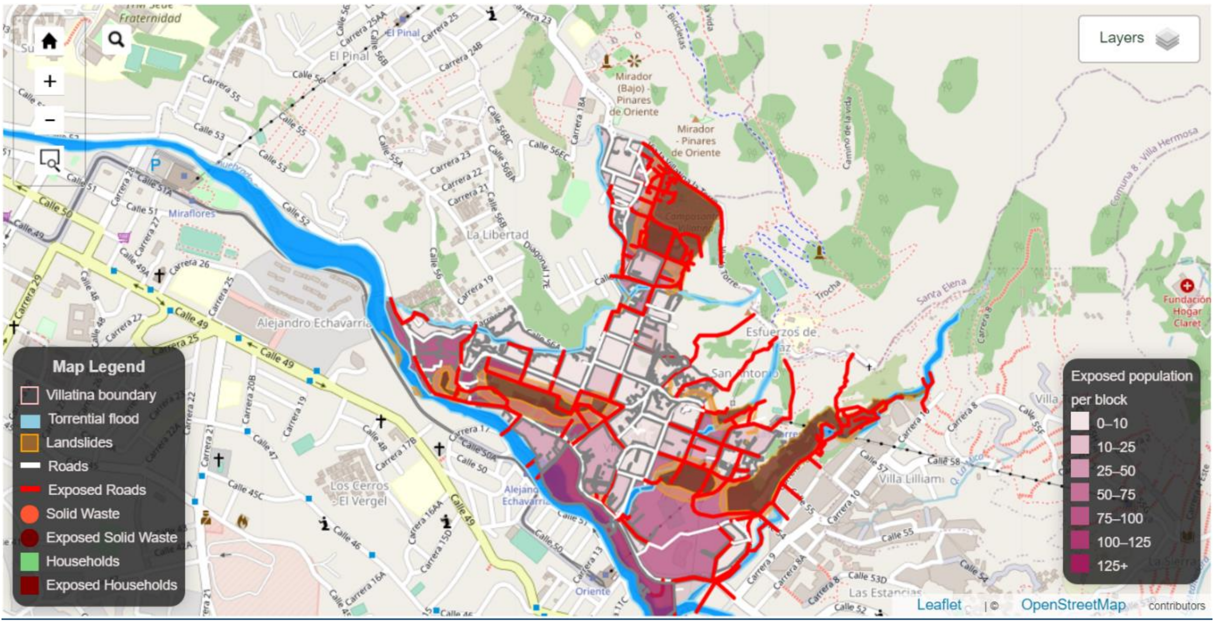


Figure 21:Exposed road layer overlaid on exposed blocks

Figure 22 shows the exposed solid waste collection points alongside the exposed roads and exposed blocks

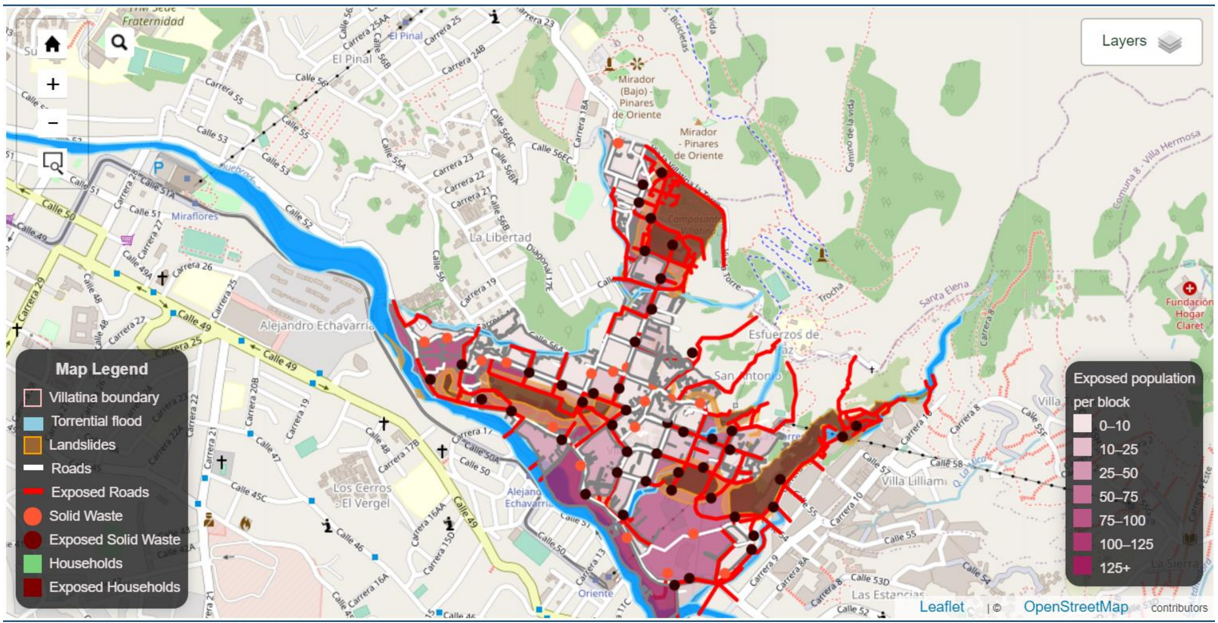


Figure 22:Exposed solid waste collection points

Figure 23 shows the exposed households layer to the floods and landslides

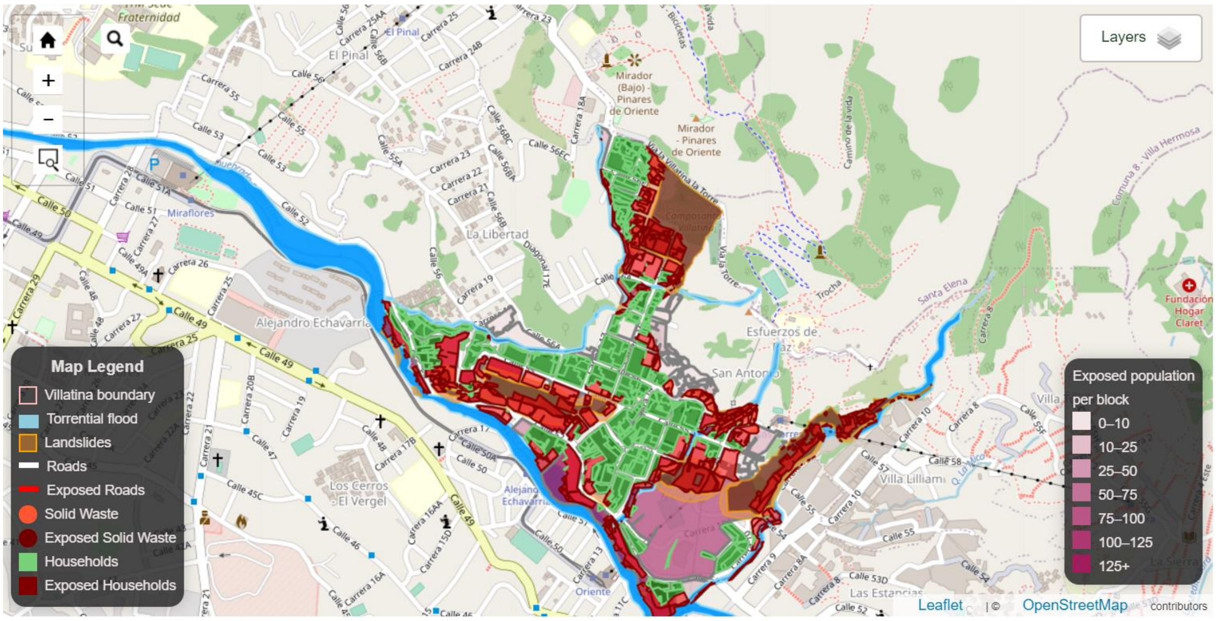


Figure 23:Exposed households

5.2 Components and interactivity

The developed components include the non-spatial column in the left, which displays the quantification of the impacts, the map area, which displays the spatial data such as CI, natural hazards, blocks, households, and the layer panel that controls the data added in the map area. The dashboard has two views. i.e., normal view or non-hazard view and hazard view. The major interaction of the system is associated with the block-level data. The figure below shows the overview of the two views included in the dashboard. i.e.,

Overview of the two views:

Normal View:

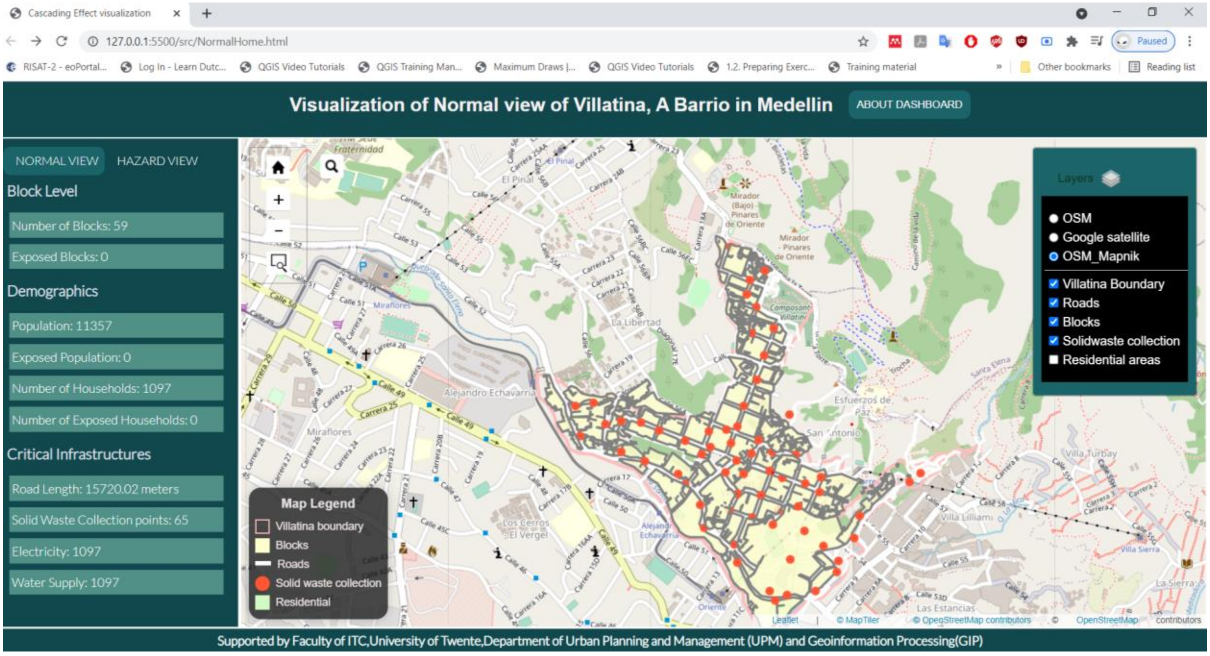


Figure 24:Normal view of the developed MVP

Hazard view:

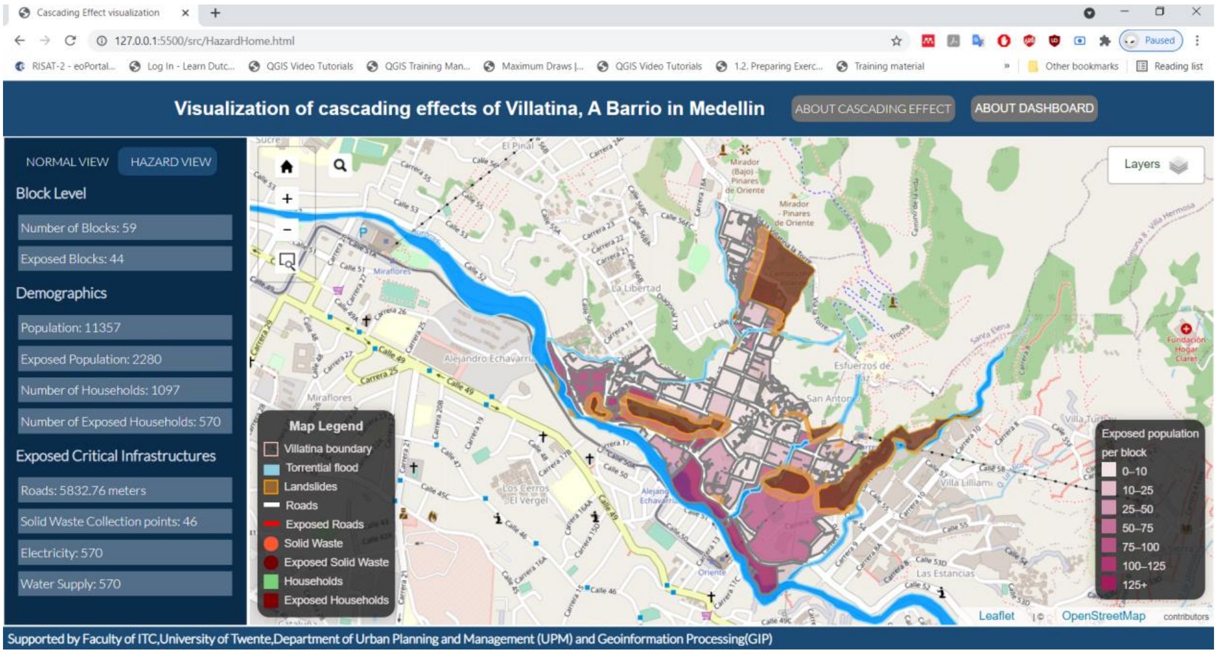


Figure 25: Hazard view of the developed MVP

Overview of quantification of impacts:

Figure 26: Quantification of impacts normal view(left),hazard view(right)

Interactivity

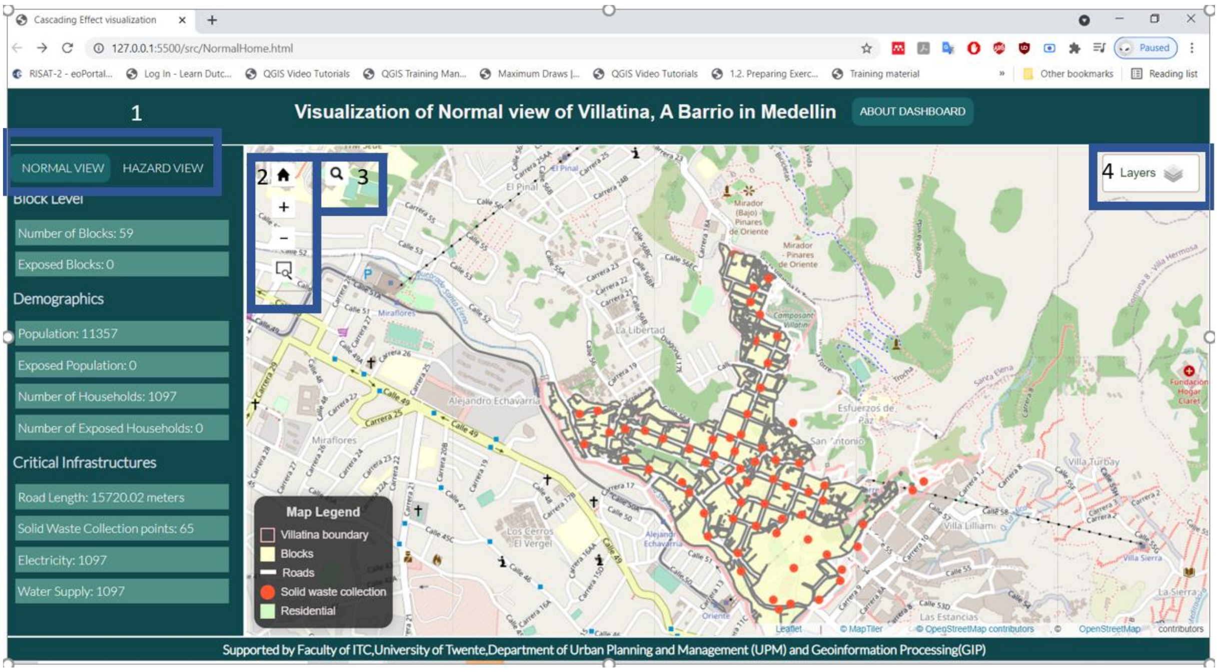


Figure 27: Normal view with interactive element

1.**Transition for two views** - the normal view with no hazards and the hazard view

2.**Zoom bar -** default or original zoom level, zoom in, zoom out, and selective zoom to an area
3.**Search bar** - search a specific block using the block number
4.**Layer panel** includes base maps and CI layers, natural hazard layers, block data, and residence layer. The layers visualized in the map area can be turned on and off using the layer panel.

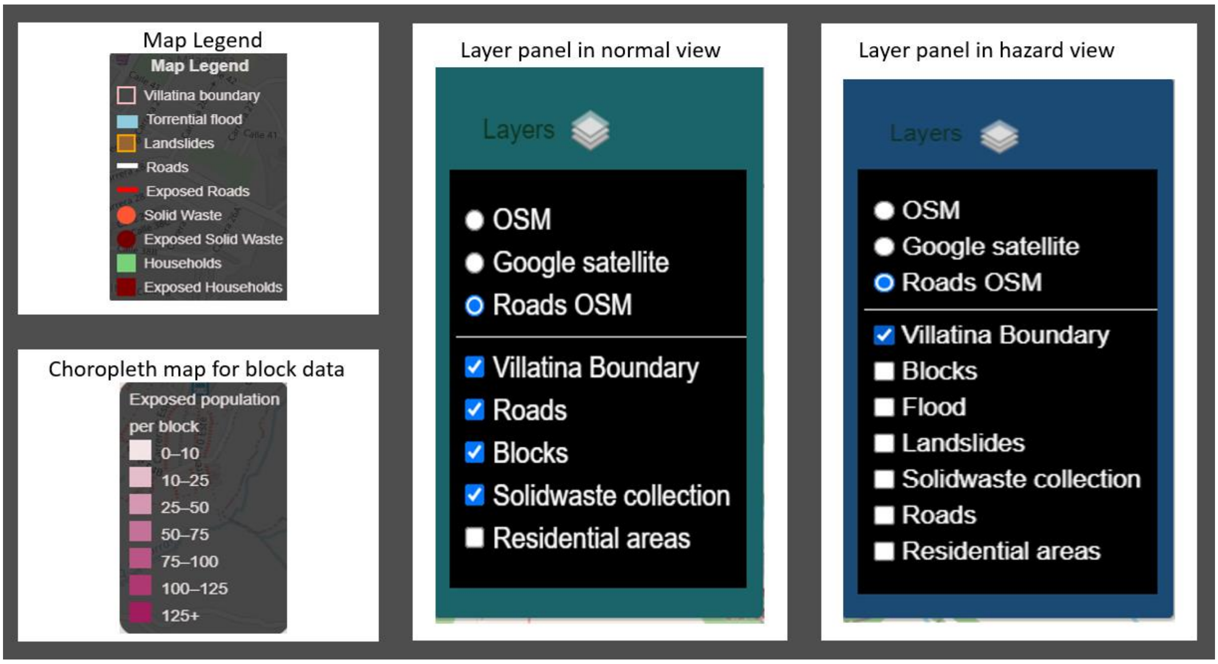


Figure 29 : Map legend, legend of choropleth map, layer panel of normal view and hazard view

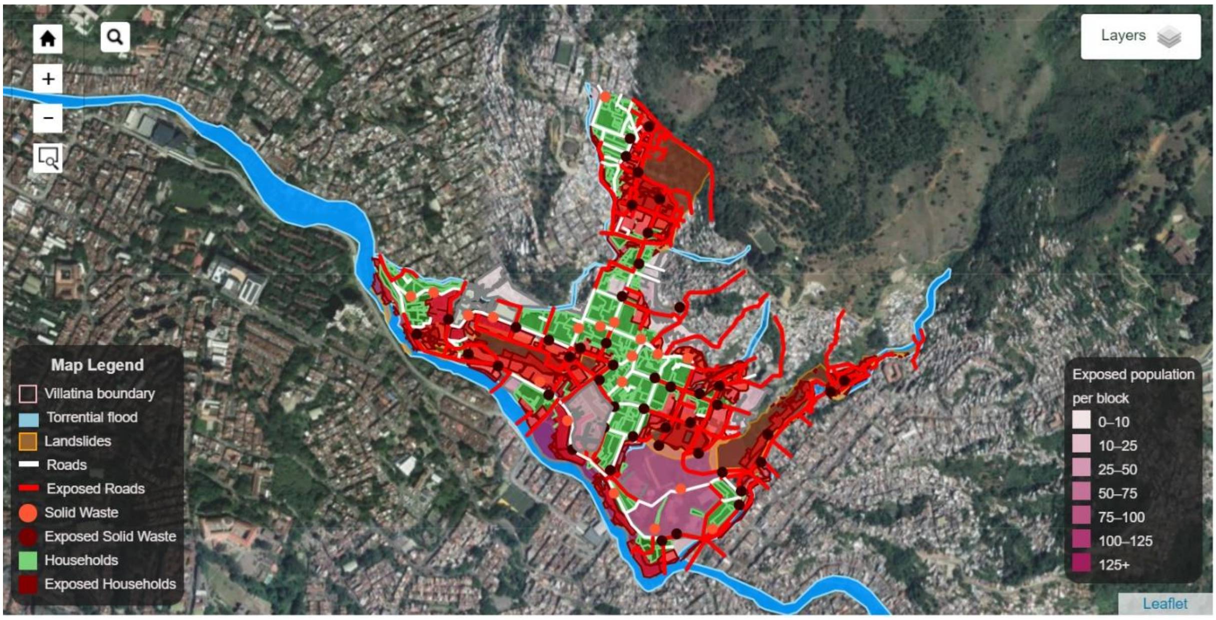


Figure 28:Hazard view with google satellite image as base map option

- Search using the block numbers, zoom, and highlight to a particular block number. Example: 0813030. The selected block is highlighted with the popup information.

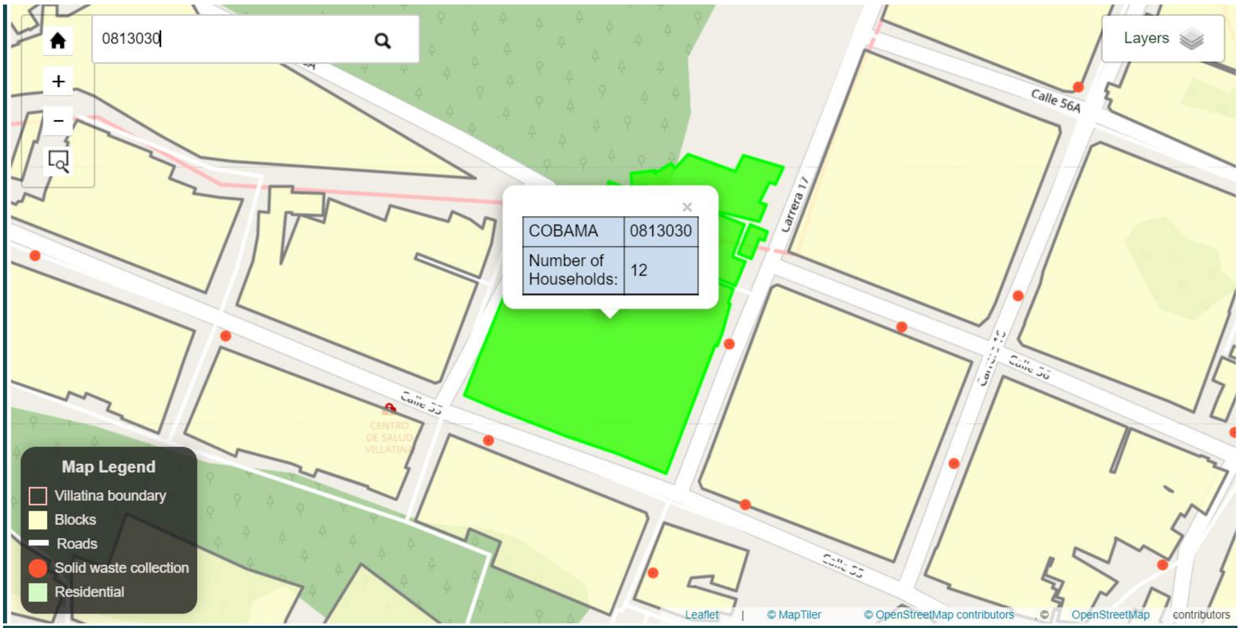


Figure 30:Highlighted search with popup

Figure 31 shows the updated non-spatial column for block number 0813004 in the hazard view

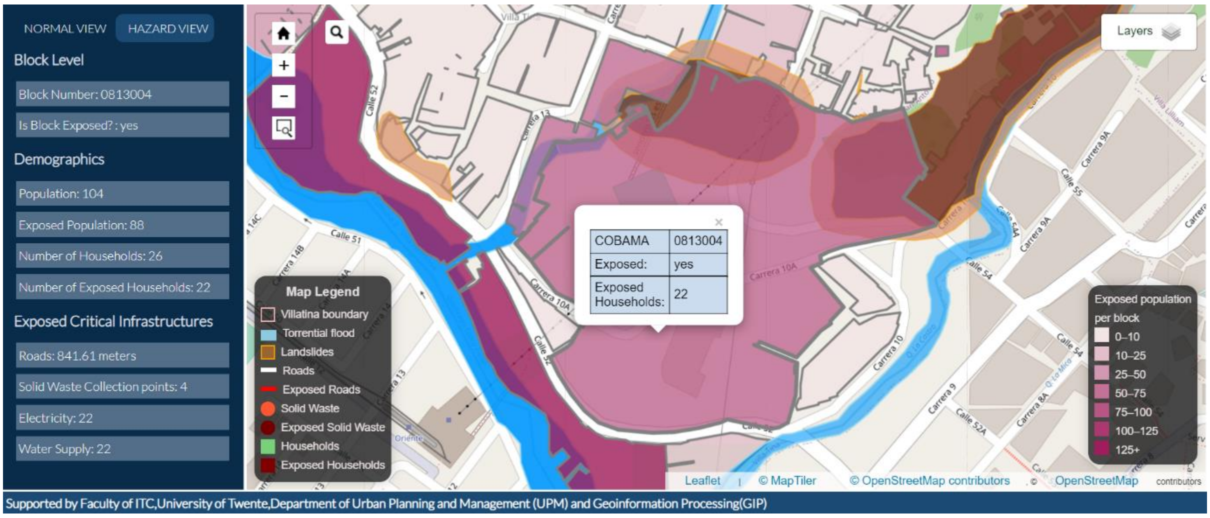


Figure 31: Updated non-spatial column for block 018004

5.3 Cascading effect video

Cascading effects video is created using QGIS and Microsoft PowerPoint screen recorder options. All layers included in the dashboard are added to the layer panel, and each frame of video is captured as screenshots. The order of screenshots is maintained as per concept, and the PowerPoint screen recorder is used to record the screenshot as a video. Cascading effect videos supports two languages, i.e., Spanish and English

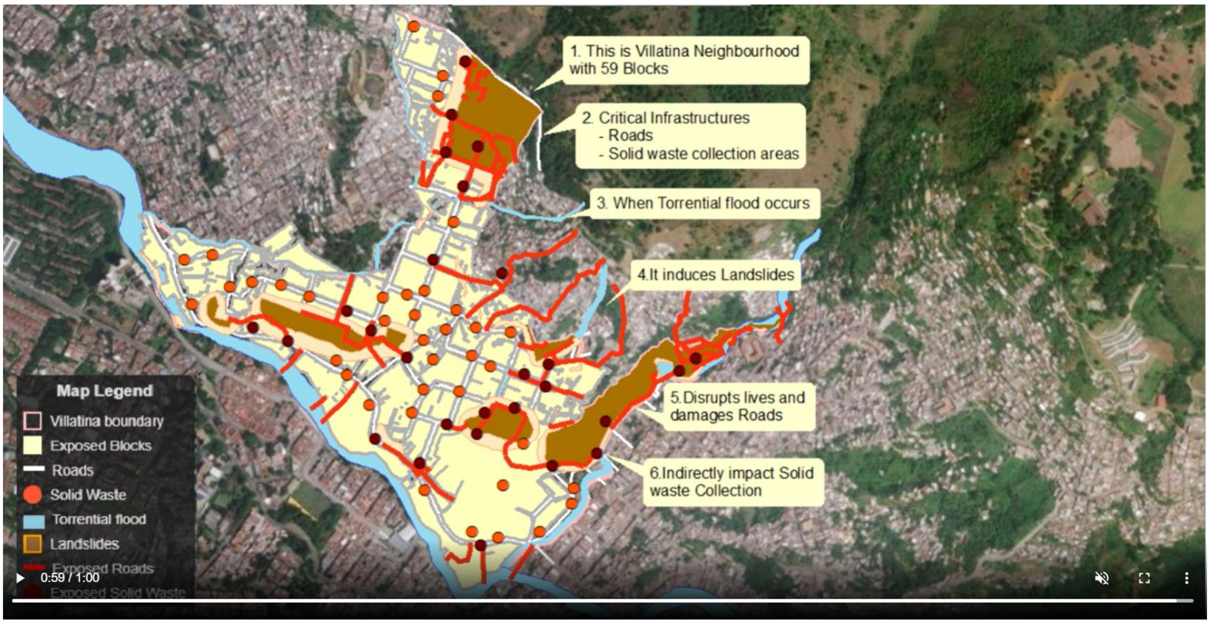


Figure 32:Screenshot of the cascading effect video

5.4 User testing

User testing plays a significant role in the HCD and in any agile software development methodology. It is essential because user motivation for any developed product is indispensable. In this research, two user testing were conducted at the end of each development cycle. First user testing was a summative evaluation in the form of one-on-one face interviews with stakeholders. A questionnaire was prepared based on the components included in the design.

The developed MVP is used for user testing. Students from different specializations participated in the user testing. The interview questionnaires had open-ended and closed questions at the visual and functional levels.

At the beginning of the interview, a brief introduction and demo were given to the user about the features included in MVP. They were asked to provide feedback about the functionality and design. In the user testing, the user is also observed for the mouse pointers' navigations to test the placement of components. The user testing feedbacks are noted, and the gathered insights are used in the successive iteration of development. The feedback is logged as the product backlog for the next development cycle.

5.4.1 First user testing questionnaire and feedback

Six students from Earth observation, Geoinformation processing, and Urban planning and management specialization of Faculty of ITC participated in the first user testing. The table below shows questionnaires and the collective user feedback from the first user testing.

No.	Category	Questions	User feedback
1	**Content**	What is the study area?	The users answered correctly. Barrio was a bit confusing instead of Neighborhood
2		What is the population?	The users answered correctly
3		What view are we in, and what is the general description of the view?	The normal view and hazard view was a bit misleading due to the highlight of the wrong view
4		Why is the exposed population zero?	The users answered correctly with the help of the introduction
5		What is the total number of households present?	The users answered correctly
6		What are the critical infrastructures present?	The users answered correctly. The roads can be represented using meters instead of the number of features
7		Where to find what layers are included in the map column?	The layer symbol should be replaced with the "layers" label for better identification
8		Which is the landslide layer?	The mass movements label for landslides is misleading and needs to be changed as landslides
9	**Functionality**	How to zoom in and zoom out the map?	• The users located the zoom in/zoom out button. • Two users zoomed using the keypad instead of the buttons
10		How to know more about the dashboard?	• Users identified The "About Dashboard" button correctly. About dashboard button needs to be added in Hazard view as well
11		How to turn on and turn off the layers?	Users located the layer panel correctly
12		How to navigate to hazard view?	Users located the hazard view button
13		How to find more about the cascading effects?	The cascading effects button has been located correctly but needs more explanation of what cascading effect is.
14		How to play/pause the video?	• The video has a Dutch legend that needs to be explained. • The video of the

			different case study areas should be explained.
15	**Aesthetics**	Is the layer styling appealing?	The layer styling is confusing and does not blend with the design.
16		Is the map legend readable?	The bottom left column is agreed to be a good place for a legend, but it is static.
17		Does the dashboard have a good look and feel to use?	• The outline color looks old-fashioned and needs to be changed. • The header and footer scrolling has to be fixed. • The video does not fit the window
18	**Others**	What are the other layers the user wants to see?	• The households' layer needs to be included in the map area as spatial data in addition to the non-spatial data. • A slope map can be included
19		What are the other functionalities needed?	• The user wants to search their localities to see the damages caused by the hazards. • Need popups to find more about the features

Table 11:First user testing questionnaire and feedback

5.4.2 Product backlogs from first user testing

Product backlogs are the list of changes or bugs or any extra element that has been done to get the required result. The feedbacks from the first user testing are collected and logged as product backlog items.

Serial No	Product Backlog Items	Solution/Fixes
1	Highlight the current view - normal view and hazard view	Changed the style of the button
2	Layer symbol should have a label	Inserted label using DOM (Data Object Manipulation) element
3	Change mass movements label to landslides	Changed the element to landslide in the legend
4	Add about the dashboard in the hazard view	Added the about dashboard button to the hazard view
5	Video legend is in Dutch and needs an explanation	Changed the video
6	Change layer styling	Updated the layer styling

7	Header and footer scrolling needs to be fixed	Fixed the scrolling with the container size
8	Households' data need to be added as a spatial data	Added households data
9	Search by locality function needed	Added search element using leaflet-search.js
10	Need more interaction through popups and dynamic sidebars	Added popups and made sidebar using DOM

Table 12:Product backlogs from first user testing

5.5 Second User testing

The product backlogs from the first user testing have been fixed in the second iteration of the development cycle. Second user testing was a role-based interaction as a part of geo collaboration combined with the open-ended and close-ended questions. The fixes from the first user testing, i.e., product backlogs from first user testing, are also included in the second user testing. The main focus of second user testing was the use of the dashboard for the group activity. Same as first user testing, a scenario walkthrough was done during this second user testing. As it is a group task, two groups of three members each, from different specializations, participated in the role-play. All six users have professional spatial thinking abilities and have an academic background.

Group 1 expertise:

User No.	Age	Expertise	Stakeholder role
1.	25-30	Geoinformation and Earth observation	Community
2.	30-35	Natural Resource Management	Service provider
3.	25-30	Urban Planning and Management	Municipal officer

Table 13:Group 1 expertise

Discussions of Group 1 in second user testing:

- Using this developed product, as a municipality officer, I can find the evacuation route through non-exposed roads and shelter locations. The high-risk zones can be determined, and settlements can be banned in that area, and alternate settlement areas can be found. Areas for construction of dams and ways to divert overflowing water can be established.
- As a service provider, I would find alternate routes for collecting solid wastes and find other locations for disposal sites.
- As a community, I can find whether my area is safe from hazards, and I can also find safe zones

Other general feedback from Group 1:

- Electricity is not clear.
- The flood layer should have the color of the water.
- Exposed roads are not clear.
- Popup is preferred.
- The cascading effect video should explain the effects in Villatina.
- The legend should follow the correct shapes.

Group 2 expertise:

Group 2 was three professionals who recently graduated from ITC.

User No.	Age	Expertise	Stakeholder role
1.	25-30	Geoinformation and Earth observation	Service provider
2.	20-25	Applied Remote sensing	Community
3.	20-25	Urban Planning and Management	Municipal officer

Table 14:Group 2 expertise

Discussions of group 2 in second user testing:

- Using this dashboard, as a municipal officer, I can see the overall statistics of how many households are affected, how many people are affected, and the length of roads exposed.
- As a community, I can find the status of my locality with respect to the floods and landslides. I can see which roads are exposed near my locality.
- As a service provider, I can find the exposed number of solid waste collection points and their locations due to their proximity to the affected roads.

Other general feedbacks from group 2:

- Colors indicating high to low affected blocks, based on the number of households affected
- The study area is not clear as Villatina is not familiar
- A particular highlight for flood-affected households would be helpful.
- The google satellite base map is not clear, and Roads OSM has more details and clarity.
- Manzana should be changed to blocks
- Solid waste collection points instead of solid waste collection
- When the residence layer, the block layer could not be selected
- About Dashboard should include more details about the study area, about the layers
- Searching using block numbers is not clear
- The Dashboard should have a help document
- Exposed population, exposed blocks are not needed in the normal view
- Normal view and hazard view can be changed as before and after hazard
- The back button is cascading effect page should be added
- The popup close is hiding the view
- Cascading effect video should be for the current study area
- Possibility to include charts and statistics

5.5.1 Questionnaire and feedback from second user testing

No.	Category	Questions	User feedbacks
1	**Content**	What is the total number of blocks present?	The groups answer correctly
2		Can you differentiate between exposed and unexposed blocks?	The groups answered correctly with the help of the legend
3		Which blocks are exposed?	The groups answered correctly with the help of the legend
4		Can you differentiate between exposed and unexposed roads?	The groups were confused due to the same color for blocks

			and roads
5		Can you differentiate between exposed and unexposed households?	The groups answered correctly with the help of the legend
6	**Functionality**	How to search a particular block?	The groups could not search without help
7		How to find the number of households per block?	The groups answered correctly
8		How to find the road names?	Group 2 used the OSM base map instead of a popup
9	**Aesthetics**	Are the colors appealing to the user?	Colors were confusing for roads and exposed blocks for both groups

Table 15:Questionnaire and feedback from second user testing

5.5.2 Product backlog from second user testing

Serial No.	Product backlog	Solutions/Fixes
1	More details in the popup	Added extra columns in popup
2	Need cascading effect video for the study area	Created cascading effect video for the study area
3	Change of default base map from google satellite to OSM	OSM map is set as a default map
4	Change Manzana to blocks	Changed the label in the legend
5	Change solid waste collection to solid waste collection points	Changed the label in the sidebar
6	Add help about the search process	Added content in the about dashboard
7	Add more details about the dashboard and layers	Added content about layers in the about Dashboard
8	Popup close button needs to be fixed	Fixed using CSS
9	The back button should be added in cascading effect	Changed the label of the hazard view as the back button

Table 16:Product backlog from second user testing

Summary of User testing:

Both the first and second user testing was crucial for this study. The first user testing was more focused on the interface usability and the placement of components, whereas the second user testing was focused on the use of the dashboard for group activity. First user testing was a face-to-face interview, and the participants conscious of getting the answers right. Second user testing was more like a group activity where the group member supported each other, generated more ideas, and had more feedback for the Dashboards features. The participants found the role-based interaction interesting, and it created more discussion and interactions with the system. In the second user testing, the dashboard included more nteractivity than the first. It took more time for the participants to adapt to the system, but the group members supported each other.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Research outcomes

The research presented the use of cartographic interaction in the form of an open-source web dashboard for visualizing cascading effects on critical infrastructure services failure due to natural hazards. Visualizing the cascading effect is considered important as their impacts are indirect, and they can increase the damages caused by the hazards (Hilly et al., 2018). The research outcome aimed to stimulate visual thinking and improve the spontaneous and knowledge-based insights on the underlying risk on Critical Infrastructures (CI) due to natural hazards like floods and landslides.

This research incorporates Human-Centered Design (HCD) framework integrated with the Feature Driven Development (FDD) agile methodology. HCD framework is considered essential for this study because the developed system is aimed to be used by the community, and it is crucial that the system motivates the user's interest to involve themselves in contributing to improve community's resilience and enhance their risk knowledge about their area through the support of visualization.

The dashboard can be accessed through https://kartoweb.itc.nl/students/cascade/. The dashboard was developed using the open-source web technologies HTML, CSS, and Leaflet.js. The data preprocessing was done using QGIS desktop and imported into the dashboard as a file-based system using GeoJSON format and hosted on the Geoinformation Processing (GIP) server of Faculty of ITC, University of Twente. Lealfet.js is an effective JS library for dynamic maps which works well with the data in GeoJSON format but with limited layer styling options. The Geomedellin open data platform provided the necessary data to carry out this research.

6.1.1. Research questions answered

RQ1 To conduct a requirement analysis from the potential stakeholders, analyze the study area and collect the data to be included in the Dashboard.

a. **Who are the stakeholders or the user groups?**

Stakeholders are the end-users who are entitled to use the developed system. Stakeholders are discussed in the stakeholder's section 2.5 in the literature review, and stakeholders involved in this study are discussed under the chapter 4 prototype design under the stakeholder's section 4.1. The research was initially planned to be conducted with the people from the Villatina community, government officials from Medellin, and academia from Medellin as they would have more local knowledge about the case study area. But due to practical difficulties in reaching the original stakeholders, this research was conducted with the students and recent graduates from the Faculty of ITC, University of Twente. It also included few people from the community in Chennai, India. The stakeholders are involved in co-design sessions as a part of HCD and in two user testing which was conducted during the development process.

b. What is the problem that has to be addressed?

The problem addressed in this research is discussed in chapter 1, Introduction, under the research problem section 1.3. One of the main challenges in addressing cascading effects is to understand the interaction between the initiating event, originating system, and the dependent system, i.e., in this study, the initiating event is the natural hazards, the originating system is the primary infrastructure disrupted, and the dependent systems are the CI damaged due to the failure of the originating system. To address this challenge, geospatial technologies like dashboards have been proposed to be used as they integrate different spatial and non-spatial data that supports the understanding of the overall situation of an area.

c. What data are to be included in the dashboard design?

The datasets used in the research are discussed in chapter 3 Methodology under section 3.4 Datasets and software. The data used in this research are downloaded from Geomedellin open data platform. Insights clustering from the co-design sessions discussed in the prototype design chapter under the insight clustering section 4.3 has elaborated on the data required for the prototype. Co-design sessions were conducted as a form of stakeholder role-play through phone interviews.

RQ2. To create a high-fidelity prototype design of the components that are to be included in the interactive-analytical Dashboard and to evaluate the prototype design.

a. What are the suitable methods involved in developing the prototype design?

Prototype designing is a highly creative process and depends mainly on the creativity of the UI/UX designer. The HCD principles discussed in the literature review section 2.8, the insights from the existing dashboards in the risk assessment section 2.6, component tracing methods section 4.5 supports the cognitive skill of the designer to design the high-fidelity prototype section 4.7. Prototype designing is supported by many designing software, and the prototype design was done using Adobe XD software.

b. What are the suitable methods for evaluating the prototype?

A formative evaluation discussed in section 4.8 was done through the self-assessment method based on the literature review of the existing dashboards in section 2.6; co-design sessions section 4.2 were done. The prototype design evaluation was initially planned with stakeholders through design user testing, but due to the time constraint and it would be more appealing to test a developed system rather than just design, the prototype design user testing was integrated with first development user testing.

RQ3. To develop the dashboard using visualization software by implementing the prototype designed and evaluated.

a. What are the suitable methods involved in developing the interactive analytical dashboard?

This research follows the Feature-Driven Development (FDD) agile methodology discussed under section 2.9,2.9.1 for the development using open-source web technologies section 2.92. FDD is a feature-centric iterative development approach. The open-source web technologies include HTML, CSS, and leaflet.js. The development cycle discussed in section 3.5 shows that the duration is four weeks, and there were two development cycle and at the end of each cycle, there was user testing conducted with the stakeholders of the study. The list of features that needs to be changed to achieve the desired outcome is logged into product backlog items and carried into the next development cycle.

b. What are the data analysis procedures used for visualizing the problem that has to be addressed?

The data used in the research are listed in Table 5 of the Methodology chapter. They are downloaded from Geomedellin, an open-source data platform of Medellin. The data curation is done using the QGIS desktop software, and geoprocessing is performed. The spatial overlay analysis operator is performed to determine the exposure of CIs to natural hazards.To associate CI data to the block level data spatial join operations are done, and this association is used for creating the interactions in the system. the data analysis procedures are explained in the table under the development section

c. What are the components that need to be included, and what is the level of interactivity between the components?

The components and the interactivity is discussed in the components and interactivity section 5.2 of the dashboard development chapter 5. The developed dashboard has two views, i.e., non-hazard or normal view and hazard view. Each view has a non-spatial column that quantifies the impacts, the map area, which visualizes the actual location of the features, the layer panel, which controls the addition and removal of layers to the map area. It has a map legend that explains symbols used to denote the layers in the map area. The system has various interactivity starting from zoom in, zoom out, zoom to the original level, zoom through rectangular selection. The search bar facilitates searching a block using the block number. Each block is associated with the number of households, population, roads at a distance of 10 meters, and solid waste collection points within 10 meters. There is also a simple video on cascading effects available in English and Spanish languages which explains how the cascading effect occurs during the natural hazards in the Villatina neighborhood. There is also a section that explains more about the dashboard.

RQ4. To evaluate the developed dashboard for the design, content, usability by the user groups.

a. What are the suitable methods to evaluate the usability of the interface?

The suitable method to evaluate the usability of the interface is through user testing in the form of interviews with the help of questionnaires. The first user testing conducted at the end of the first development cycle is oriented to test the usability of the primary interface developed. The user testing and the questionnaire used are discussed under section 5.4.1 in the development of the dashboard chapter 5. The first user testing was conducted in the form of one-on-one face interviews with questionnaires. Questionnaires were based on the components included in the dashboard and the interface design. The feedbacks are logged as product backlog items mentioned in table 12 and carried to the next iteration of the development cycle.

b. What are the methods to evaluate the effectiveness of the visualizations used?

The effectiveness of the visualization was evaluated through role-based interaction. The second user testing discussed under section 5.5 was a role-based interaction as a part of geo collaboration. Two groups of 3 students from the Faculty of ITC from different specializations and recent graduates from the Faculty of ITC are involved in this role-based interaction. Each person in a group chose a role of a stakeholder and interacted with the Dashboard.

6.2 Limitations

6.2.1 User limitations

This study has user limitations as there were practical difficulties in reaching the actual community members and the other stakeholders from the Villatina neighborhood, so this study was carried out with the students from the Faculty of ITC, University of Twente.

6.2.2 Data Limitations

The household data included are based on the attribute predominantly residential, and the data had topological errors and improper boundaries. Solid waste collection points are not available for the Villatina neighborhood, and therefore they are randomly generated. The attributes were in Spanish and needed to be translated to English for better understanding. The hazard data had minimal attributes and did not have flood depth or timeline attributes that can support 3D visualization. The robustness of the infrastructure is not considered.

6.2.3 Technical limitations

Layer styling options were limited in leaflet.js, and Leaflet mostly supports data in GeoJSON format, and the use of shapefile format is not handy. Minimal geospatial options were available, so the data was processed using QGIS and imported as the file-based system.

6.3 Recommendations for future work

MVP developed in the project can be extended for studying any other disasters that can be visualized through spatial data. The sub-categories of the demographics data can be included, and the vulnerable groups can be identified as the impacts of the disaster differ for different vulnerable groups. Poverty conditions can be analyzed, and the demographics can further sub-divided based on age, gender to identify the most vulnerable group to the hazards.

Interactivity can include network analysis, routing services, and geocoding services. The cascading effect can be visualized in 3-dimension for better visual understanding. This Dashboard can be extended by including more critical Infrastructures containing more characteristics about their robustness can be included.

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APPENDIX 1 TRANSCRIPTION OF HUMAN-CENTERED DESIGN INTERVIEWS:

Interview 1:
Background: Student at Faculty of ITC with Geoinformation specialization
"I was affected by Cyclones in Visakhapatnam. If given a system where I can visualize these hazards, then as an affected person, I would like to see the risk for my area, the contact person whom I should contact if my area is affected. I want to know which shelter has fewer occupancies and the road map to reach the shelter locations. I want to see where the roads are affected. If I were a service provider, I wanted to see where my services are affected and provide temporary service plans. If I were a disaster manager, I would want to see the affected communities, the volunteer locations, locations for providing food. If I were from the research background, I would dive deep into flood simulation models, the duration of floods, the flood prediction models, etc."
Interview 2:
Background: An older adult from a flood-affected community in Chennai, India
"I was affected by floods and cyclones in 2015 in Chennai, India. I am not aware of the system you are asking about. If flood affects my area, then I wanted to know the situation for my area and the evacuation route to reach a safer place. I wanted to find a safer place for my documents and belongings. I would like to know the food distribution areas and shelter locations. If I were a service provider, I want to see where my services are shut down and where to cut down the power supply for the safety of the people because it is dangerous if the electric wires touch the stagnant water in floods. I would want to find a way to clear the damaged services as well. If were from Municipality I would find which are the roads affected. If I were a disaster manager, I would want to provide emergency services in the prioritized order."
Interview 3:
Background: A homemaker from a flood-affected community in Chennai, India
"We had floods in Chennai, and our area was in a high raised location, so we were not affected by the floods to a greater extent. I do not know what you are talking about. During floods, I used to see the news channels to see which area is affected and how they report their area. From the news, I will understand the situation of my area and other areas."
Interview 4:
Background: An urban planning and management graduate with Disaster management expertise
"If I were a disaster manager, I wanted to have real-time on-ground reports, and I need to arrange emergency transports, rescue map. I wanted to provide emergency supplies, food and need to know the location of my volunteers. I want all these in addition to basic elements like location the most vulnerable group. If I were a municipal officer, I would like to know the blocked roads, and the debris flows, if any, the stagnant water area, and the drainage conditions. If I from an affected community, I want to know my zone and where the volunteers are available and whom I should contact, and where the animal shelters are available. I want to know the locations of the hospitals. If I were academic, then I want to know the weather forecast and the predicted duration of floods, flood mitigation zones, route for water to flow, groundwater table capacity, water bodies, amenities available, etc.

APPENDIX-2 USER TESTING 1 QUESTIONNAIRE:

S.no	Category	Questions
1	**Content**	What is the study area?
2		What is the population?
3		What view are we in, and what is the general description of the view?
4		Why is the exposed population zero?
5		What is the total number of households present?
6		What are the critical infrastructures present?
7		Where to find what layers are included in the map column?
8		Which is the landslide layer?
9	**Functionality**	How to zoom in and zoom out the map?
10		How to know more about the Dashboard?
11		How to turn on and turn off the layers?
12		How to navigate to Hazard view?
13		How to find about cascading effects?
14		How to play/pause the video?
15	**Aesthetics**	Is the layer styling appealing?
16		Is the Map legend Readable?
17		Does the Dashboard have a good look and feel to use?
18	**Others**	What are the other layers the user needs to see?
19		What are the other functionalities needed?

APPENDIX -3 USER TESTING 2 QUESTIONNAIRE:

User testing 2 is a combination of user testing 1, Questionnaire listed below and a scenario.
Scenario: In a group of 3, consider yourself as one of the stakeholders, i.e., Community, Municipality officer or a service provider.
In addition to the first user testing questions,

SNO	Category	Questions	User Feedbacks
1	**Content**	What is the total number of blocks present?	
2		Can you differentiate between exposed and unexposed blocks?	
3		Which blocks are exposed?	
4		Can you differentiate between exposed and unexposed roads?	
5		Can you differentiate between exposed and unexposed households?	
6	**Functionality**	How to search a particular block?	
7		How to find the number of households per block?	
8		How to find the road names?	
9	**Aesthetics**	Are the colors appealing to the user?	

APPENDIX 4 TRANSCRIPTION OF THE CASCADING EFFECT AUDIO-ENGLISH

Villatina is a neighborhood located in the most populous city of Colombia, Medellin. This neighborhood is divided into 59 blocks or Manzana. Critical Infrastructures such as roads, Electricity, Water supply, solid waste collection, among others, are crucial for the communities to sustain a living.

Villatina is prone to floods and floods-induced landslides. When floods and flood-induced landslides occur, people and Critical infrastructure are affected.

In this illustration, we can observe how these hazards create physical damage to the transport infrastructure and disrupt the movement of people and goods. These inaccessible roads, in turn, affect the collection of Solid waste.

This is a clear example of cascading effects on critical infrastructure.