Advanced Flood Crisis Management in Rende: Utilizing Fuzzy AHP for Emergency Evacuation Assessment and Risk Mitigation

Sina Shaffiee Haghshenas, *Student Member, IEEE*, Vittorio Astarita, Sami Shaffiee Haghshenas, *Student Member, IEEE*, Giuseppe Guido, *Member, IEEE*, Giulia Martino

Abstract— **The flood crisis management in Rende, which is located in southern Italy, especially with its proximity to the Crati River, requires innovative solutions for rapid and efficient emergency evacuation. This study presents the potential of intelligent response technologies to maximize emergency response, minimize casualties, and enhance evacuation planning. Seven various evacuation scenarios are examined, ranging from the latest technologies such as AI-driven early warning systems, real-time mapping, self-driving automobiles, intelligent transportation, and drone-assisted rescue missions. We evaluate all these scenarios based on their execution speed, safety, people coverage, cost-effectiveness, tech feasibility, flexibility, and impact on infrastructure. Utilizing the fuzzy hierarchical analysis process (FAHP), this research systematically ranks these options to determine the most effective flood response strategies. The research identifies AI-driven early warning systems and preemptive evacuation plans as the most cost-effective, fastest, and risk-reduction measures. Smart transport networks coupled with autonomous vehicles can also increase evacuation effectiveness by a significant percentage. The report emphasizes connecting digital solutions and traditional emergency response systems with the aim of making Rende a more flood-resilient town. With these innovative technologies, Rende can become a model for Italy's flood crisis management, demonstrating how smart city infrastructure and AI-informed decision-making can transform disaster response. This research provides policy-relevant findings for policymakers, emergency planners, and city planners who want to implement technology-based crisis management in flood-prone regions.**

* This study was carried out within the research project "RISK: Recovery Increasing by Social Knowledge"—2022B4TT2M (CUP C53D23004800006), PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) Missione 4 "Istruzione e Ricerca"—Componente C2, Investimento 1.1 "Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN)", D.D. n. 104 del 2 febbraio 2022, ERC SH7 "Human Mobility, Environment, and Space". This paper reflects only the authors' views and opinions; neither the European Union, the European Commission nor Italian Ministry for Universities and Research can be considered responsible for them.

Sina. S. H. Department of Civil Engineering, University of Calabria, Via Bucci, 87036 Rende, Italy (Corresponding author; e-mail: Sina.Shaffieehaghshenas@unical.it).

V. A. Department of Civil Engineering, University of Calabria, Via Bucci, 87036 Rende, Italy (e-mail: Vittorio.astarita@unical.it).

Sami. S. H. Department of Civil Engineering, University of Calabria, Via Bucci, 87036 Rende, Italy (e-mail: Sami. Shaffieehaghshenas@unical.it).

G. G. Department of Civil Engineering, University of Calabria, Via Bucci, 87036 Rende, Italy (e-mail: Giuseppe.guido@unical.it).

G. M. Department of Civil Engineering, University of Calabria, Via Bucci, 87036 Rende, Italy (e-mail: Giuliachiara.martino@unical.it).

I. Introduction

Floods are some of the most destructive natural disasters, affecting millions of people all over the world every year. They cause extensive loss of life, disrupt society, and result in huge economic and infrastructural losses. Urban areas, particularly those near rivers, are more prone to flash floods due to the rapid accumulation of water, inadequate drainage facilities, and heavy population density. The city of Rende in the southern region of Italy, which houses the University of Calabria, is particularly vulnerable to floods as it lies merely a few hundred meters from the Crati River. Due to the escalating impacts of climate change and the growing frequency of severe weather patterns, managing flood crisis measures to curtail loss and damage must be given due consideration. Traditional flood control relies on weather predictions, emergency teams, and public alert systems to warn residents of impending danger. These technologies are typically marred by late information, ill-coordination, and weak infrastructure. In the majority of cases, floods escalate rapidly, leaving little time for efficient evacuation planning. The unpredictability surrounding flash floods necessitates a more proactive, technology-driven approach to crisis management [1]–[3].

One of the essential components of flood control is risk analysis and preparedness. A correct understanding of flood risk in a particular region involves bringing together hydrological information, past floods, and current weather trends. Machine learning and Geographic Information Systems (GIS) can be used to foretell areas most likely to flood and communities most likely to suffer from the flood [4], [5]. From this information, governments can implement targeted mitigation measures, such as constructing flood walls, improved drainage systems, and delineating safe areas for evacuation. Another essential aspect of flood crisis management is awareness and education among people. Involvement of the people is an important condition for ensuring sufficient reaction to a disaster. Governments and local authorities must spend money on education programs to sensitize residents about flood risk, emergency response, and evacuation procedures. Community programs such as volunteer organizations and local neighborhood emergency response teams could supplement action at the individual level. Education at the school level should also include awareness about flood risk so that disaster resilience is instilled early in life [6], [7].

Flood resilience is a key player in flood management, too. Many metropolitan areas lack the infrastructure necessary to be flood-resilient, leading to widespread devastation. The installation of flood-resilient infrastructure like elevated roads, reinforced bridges, and flood-absorbing vegetation can significantly reduce the impact of floods. Furthermore, enhancing urban resilience and disaster response capacity are smart city technologies that include automatic drainage controls and real-time flood monitoring systems [8], [9]. Climate change has raised the intensity and frequency of extreme weather events, so there is a requirement for long-term adaptation strategies. Short-term disaster relief and long-term flood prevention policies must be given priority by governments. Wetland restoration, afforestation activities, and green urban planning can mitigate flood risk by enhancing water infiltration and reducing surface runoff. Moreover, the integration of climate risk assessments in urban planning documents can prevent buildings from being constructed in high-risk areas and promote sustainable land use practices [10], [11].

Collaboration between the stakeholders is instrumental in effective management of flood crises. Governments, relief agencies, universities, and voluntary groups need to collaborate and create comprehensive disaster response plans. International collaboration is also essential because measures to mitigate flooding can be enhanced through collaboration on expertise and technology [12], [13]. Establishing partnerships across the local-global scales, Rende cities for example, are able to derive maximum benefits from the latest solution options and the best practices that exist in terms of minimizing flooding threats. While there are encouraging technological options for managing floods, there are also significant challenges that must be overcome. Installation of cutting-edge flood sensing and evacuation systems would take a giant investment that might be out of the reach of many local governments. Furthermore, ensuring provision of access to technology for different levels of society is essential in the fact that disaster-endemic communities predominantly suffer the greatest impact. Policymakers will need to consider such factors in developing the solutions to the flood management in a way that they are realistic and justifiable [14], [15].

To sum up, managing flood crises needs to be done in a way that considers a number of factors, such as assessing risk, making sure communities are ready, making sure infrastructure is strong, making sure communities adapt to changing weather, and coordinating between all stakeholders. While traditional methods are still effective, the integration of emerging technologies and data-driven decision-making can significantly enhance flood response operations. Cities like Rende can become more flood-resistant and serve as a model for other flood-prone areas by implementing a proactive and flexible approach. This study is meant to address the most important aspects of effective flood management and highlight the importance of merging new solutions in the framework of disaster response.

II. Case Study

Rende is a city in the province of Cosenza, Calabria, which has experienced strong growth, particularly after the establishment of the University of Calabria, whose seat is in the city. Rende is geographically divided into two areas: the old town center, atop a hill, and the new urban area, stretching along the valley of the Crati River and fully linked to Cosenza. This spread onto low-lying flat ground has further subjected Rende to the threat of floods, particularly from the Crati River and its tributaries, including the Campagnano, Surdo, and Emoli rivers [16], [17].

The city's physical geography, whereby mountainous areas in the west increasingly give way to hills and plains in the east, also controls flood patterns, since runoff from intense rainfall in the Serre Cosentine mountains has the potential to rapidly lead to water accumulation in the Crati valley. In addition, Rende's new residential areas, such as Quattromiglia, Commenda, and Roges, are built on lowland areas, which subject them to flash flooding and river overflows. With more people living in cities and more unpredictable weather, it's important to have an integrated flood management strategy that includes early warning systems, resilient infrastructure, and smart evacuation planning to protect people and important institutions like the university from impending flood disasters [16], [17].

III. Fuzzy Analytical Hierarchy Process (FAHP)

Soft computing methods have proven to be effective in simulating complex phenomena in the last decade, particularly in handling imprecision, uncertainty, and partial truths [18]–[20]. Of all these methods, fuzzy set theory is one of the most significant for handling uncertain and vague issues, enhancing decision-making mechanisms [21], [22]. Zadeh (1965) came up with fuzzy set theory, which changed the way people think about dealing with uncertainty by giving us a way to use math to model vague information using membership functions and values ranging from 0 to 1 [23], [24]. In contrast to traditional set theory, fuzzy logic is more tolerant in approaching the world's realities, especially within decision analysis. Fuzzy logic supports mathematical calculation under conditions of uncertainty and finds extensive use in fuzzy decision-making. One such concept utilized here is the triangular fuzzy number (TFN) with three parameters: the minimum (l), most likely (m), and the maximum (u) values. Most commonly, we use TFNs to model uncertainty, and we represent their membership functions with linear ones. With its precise reflection on imprecision in human reasoning, fuzzy logic optimizes decision-making in many areas. Its ability to represent fuzzy information renders it invaluable in those situations where traditional mathematical methods are not sufficient, offering more efficient and stable solutions. The membership function of a triangular fuzzy number (TFN) is defined using linear representations on its left and right sides (Eq (1)). The left representation is designated as $l(y)$, while the right representation is designated as $r(y)$. The degree of membership in a fuzzy number may be articulated by the associated left and right representations as delineated in Eq (2) [25], [26].

$$\mu(x|\tilde{M}) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le x \le m \\ (x-l)/(m-l) & m \le x \le u \\ 0 & x > u \end{cases} \quad (1)$$

$$\tilde{M} = (M^{l(y)}, M^{r(y)}) = (l + (m-l)y, u + (m-u)y), y \in [0,1], \quad (2)$$

The fuzzy analytical hierarchy process (FAHP) is among the most achievable fuzzy multi-criteria decision-making (MCDM) methods that may be implemented extensively in many projects. Various scholars have conducted research on designing and applying FAHP methods. Chang (1996) specifically focused on multiple techniques and procedures within the realm of the fuzzy analytical hierarchy process. Chang's FAHP method provides a structured system for fuzzy MCDM. Using TFNs, a series of procedures is defined as follows [27]:

• Hierarchical graph (I): create a hierarchical graph based on the criteria, alternatives, and study objective.

• Fuzzy number definitions for pairwise comparisons (II): For making pairwise comparisons more convenient, we offer fuzzy numbers, that is, TFNs in this research.

• Build a pairwise comparison (A) matrix with fuzzy numbers (III): The pairwise comparison (A) matrix is built by the experts according to their opinions, and fuzzy numbers are added as follows (Eq (3)) [27-28]:

$$\tilde{A} = \begin{pmatrix} 1 & \tilde{a}_{ij} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & & 1 \end{pmatrix} \tag{3}$$

$$\tilde{a}_{ij} = \begin{cases} 1 & i = j \\ \tilde{1},\tilde{2},\tilde{3},\tilde{4},\tilde{5},\tilde{6},\tilde{7},\tilde{8},\tilde{9}\ or\ \tilde{1}^{-1},\tilde{2}^{-1},\tilde{3}^{-1},\tilde{4}^{-1},\tilde{5}^{-1},\tilde{6}^{-1},\tilde{7}^{-1},\tilde{8}^{-1},\tilde{9}^{-1} & i \neq j \end{cases}$$

• Determination of *Si* in every row of pairwise comparison matrix (IV): *Si* is determined for every row of the pairwise comparison matrix. It's a fuzzy triangular number and is determined by using Eq (4). The equation is derived using the fuzzy triangular number of the pairwise comparison matrix as M_{gi}^{j} and the row number (*i*) and column number (*j*).

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \tag{4}$$

Subsequently, the values of $\sum_{j-1}^{m} M_{gi}^{j}$, $\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}$ and $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ are computed from Eqs (5) and (7) by utilizing the already calculated Si values.

$$\sum_{j-1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{5}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{6}$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{m} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{7}$$

• Calculating the degree of possibility between two fuzzy triangular numbers (*Si*) (V): Calculate the degree of possibility between two fuzzy triangular numbers, Si and S2, from Eq (8). Figure 1 depicts Eq (8), in which *d* is the ordinate of the highest intersection point of membership functions µs1 and µs2. $V(S_1 \geq S_2)$ and $V(S_2 \geq S_1)$ values are needed to be calculated. Finally, the degree of possibility of a fuzzy triangular number being greater than *k* fuzzy triangular numbers is obtained using Eq (9) [27], [28].

$$V(S_2 \geq S_1) = hgt(S_1 \cap S_2) = \mu s_2(d) = \begin{cases} 1 & \text{if } m_2 \geq m_2 \\ 0 & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \tag{8}$$

$$V(S \geq S_1, S_2, \ldots, S_k) = V\left[(S \geq S_1) \text{ and } (S \geq S_2) \text{ and....and } (S \geq S_k)\right] = \text{Min}V(S \geq S_i),\ \ i=1,2,3,\ldots,k \tag{9}$$

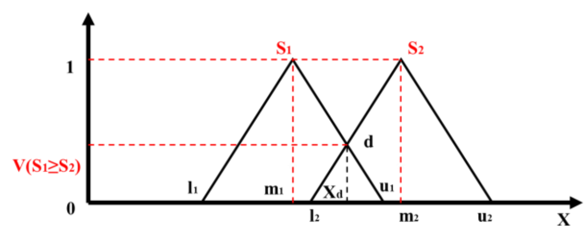

Figure 1. The degree of possibility between two triangular fuzzy numbers (*S1, S2*) with respect to each other.

• Determination of Criterion and Alternative Weights in the Pairwise Comparison Matrix (VI): To compute the weights of criteria and alternatives within the pairwise comparison matrix, the weight vector is derived by utilizing Eq. (10). In this formulation, $d'(A_i) = MinV(S_i \geq S_k)$ represents the corresponding fuzzy triangular number associated with $k = 1, 2, \ldots, n$, $k \neq i$. By applying Eq. (10), the respective weight vector is obtained [27], [28].

$$w'(d'(A_1), d'(A_2), \ldots, d'(A_n))^T \tag{10}$$

• Calculation of the Final Weight Vector (VII): In the concluding phase, the computed weight vector undergoes a normalization process to derive the final normalized weight vector. This normalization is performed using Eq. (11).

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \tag{11}$$

IV. Results and Discussions

To make decisions on the best flood evacuation strategies in Rende, we conducted a comprehensive analysis of seven technologically advanced scenarios (Table 1). After the initial feasibility study, there were seven main decision factors: Execution Speed (C1), Safety (C2), Population Coverage (C3), Cost (C4), Technology (C5), Flexibility (C6), and Infrastructure Impact (C7). These factors form the foundation for comparing and ranking the best flood control measures in the area. With the application of these factors, the research adopts a holistic approach in enhancing Rende's flood resilience through evidence-based decision-making.

TABLE I. SEVEN TECHNOLOGICALLY ADVANCED SCENARIOS.

No	Scenarios
S1	Evacuation Based on Smart Alert Systems
S2	Evacuation Using Smart Routes and Live
S3	Rapid Evacuation Using Autonomous Vehicles & Smart Transport
S4	Vertical Evacuation Using Smart Buildings & Rescue Drones
S5	Emergency Night Evacuation Using Smart Lighting & Augmented Reality (AR)
S6	Preemptive Evacuation Using AI & Data Mining
S7	Evacuation of Vulnerable Groups Using Assistive Technologies

In Scenario 1, smart alert systems, including water level sensors and emergency notifications via mobile apps and public address systems, help people prepare for evacuation before a predicted flood. Scenario 2 utilizes AI-powered live maps, drone reconnaissance, and smart road signs to guide evacuees through safe routes when regular roads are blocked. For rapid evacuation, Scenario 3 leverages autonomous shuttle buses, ride-hailing, and AI-driven traffic control for efficient transportation. If evacuation from the zone is not feasible, Scenario 4 aims for vertical evacuation by using specially identified shelter zones in tall buildings, rescue drones for delivering supplies, and satellite communication. Scenario 5 addresses night evacuations through the utilization of drones equipped with spotlights, AR glasses for the rescue team, and intelligent audio navigation systems. In the event of the necessity for early intervention, Scenario 6 employs AI-driven flood forecasting, intelligent transport bookings, and timely notifications to facilitate preemptive evacuation. Lastly, Scenario 7 prioritizes assisting vulnerable individuals through robotic patient transfer, GPS-based tracking for evacuee monitoring, and biometric identification of the missing.

The research team made a pairwise comparison matrix to find out how much each criterion matters when comparing the different evacuation options. This was done to make sure that the analysis looked at everything. Fuzzy triangular numbers were employed in the research to offer comparative values ranging from 1 to 9, thus enabling a better measurement of every factor. In the end, the fuzzy hierarchical analysis process (FAHP) was employed in making an orderly ranking of the evacuation scenarios.

After constructing the pairwise comparison matrices, the decision variable weights were determined using Eqs 1 to 11 and subsequently normalized. The findings indicate that execution speed (C1) holds the greatest weight at 0.30, underscoring its vital role in flood evacuation strategies. Safety (C2) and population coverage (C3) follow; they are both assigned a weight of 0.20 since they are both important in the area of safe and inclusive evacuations. Technology feasibility (C5) is assigned a weight of 0.15, highlighting its importance in the effectiveness of high-tech evacuation technologies. Cost (C4), flexibility (C6), and infrastructure impact (C7) each were assigned a weight of 0.11, showing their comparatively lower functions in emergency flood response planning. Figure 2 illustrates the final ranking of the seven evacuation scenarios.

Technically proficient staff design and develop DT infrastructure, code algorithms, develop data links, and deploy scalable systems. Social scientists mature through research on human culture and behavior, context, and impact on humans in an attempt to ensure fair and respectful management of DT programs. Emergency professionals introduce expertise in adapting best in the event of an emergency, planning resources, and assessing threats for the purpose of ensuring DT system harmony with life.

Another fundamental aspect of collaboration is integrating knowledge from different areas, i.e., urban infrastructure, environmental systems, and population behavior. Stable data standards and interoperable solutions prevent fragmentation and waste, enabling DT solutions to be scalable and transportable to various contexts. Interdisciplinary communities must also resolve conflicts by planning common platforms to share data, formulating standards that include the integration of technology and ethics, and making available the ease with which researchers, the government, and the corporate sector can share work among each other. All these processes create resources and knowledge to address technical and organizational challenges. Table 1 summarizes some key roles and contributions of different disciplines in the interdisciplinary collaboration required for effective DT development and implementation in urban management and disaster response.

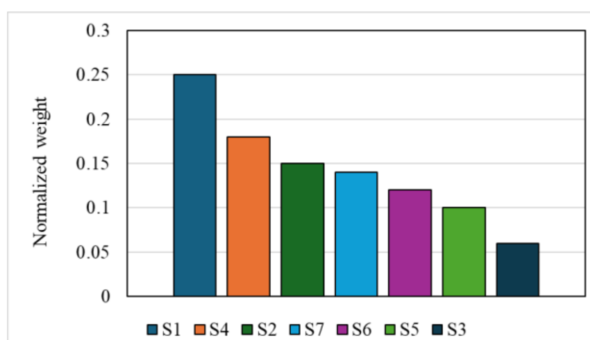

Figure 2. Comparison of Ranking Results for the Seven Evacuation Scenarios Using FAHP.

This study highlights the importance of technology-driven evacuation strategies in flood crisis management for Rende. Based on the FAHP, we evaluated seven evacuation plans regarding the speed of execution, safety, population reach, cost, technology viability, flexibility, and impact on infrastructure. While smart systems require high investment, they significantly reduce long-term economic losses.

The ranking of the evacuation strategy provides a benchmark for maximizing cities' responses to floods. Scenario 1 (Smart Alert Systems) was the most effective, as ensuring timely real-time alerts and predictive analytics optimizes evacuation efficiency. Mobile emergency alerts and AI-based weather forecasting need to be commonplace. Scenario 4 (Vertical Evacuation with Smart Buildings & Drones) was second, which highlights multi-level evacuation strategies. Vertical evacuation shelters need to be designated and send emergency aid through drones. Scenario 3 (Smart Vehicles & Autonomous Transport) was the lowest score, which shows that autonomous transport systems alone would not be reliable during floods. Autonomous evacuation cars would need to be complemented with human-run emergency forces in order to be effective and flexible.

This study demonstrates that integrating AI, intelligent infrastructure, and real-time data analytics significantly improves flood evacuation planning. Policymakers need to prioritize AI-driven early warning systems, expand vertical evacuation capacity in intelligent buildings and drones, invest in intelligent transport with human intervention, and weigh innovation against cost-effective, scalable solutions. Through the adoption of a hybrid approach that integrates predictive analytics, automation, and community engagement, Rende and other similar cities can boost disaster resilience and reduce flood-related deaths.

V. Conclusions

This study emphasizes the importance of smart technologies in managing flood crises in Rende, a city at risk due to its proximity to the Crati River and ongoing urban expansion. Based on seven evacuation scenarios analyzed through FAHP, the research establishes AI-based early warning systems and preemptive evacuation plans as the best and most cost-effective solutions. These initiatives enable faster response time, larger population coverage, and reduced interference with infrastructure. The study highlights the need to combine digital solutions and traditional emergency response systems to have an integrated and responsive method. Though technologies like drones, live maps with AI, and intelligent lighting enhance real-time coordination, specialized evacuation plans for vulnerable populations are still essential. Through these strategies, Rende can be an example of flood resilience in Italy, illustrating how technology-based policies can transform disaster preparedness. The results are useful for policymakers, emergency planners, and urban developers, and they inform a safer and more resilient future for flood-exposed areas.

Acknowledgment

This study was carried out within the research project "RISK: Recovery Increasing by Social Knowledge"—2022B4TT2M (CUP C53D23004800006), PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) Missione 4 "Istruzione e Ricerca"—Componente C2, Investimento 1.1 "Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN)", D.D. n. 104 del 2 febbraio 2022, ERC SH7 "Human Mobility, Environment, and Space". This paper reflects only the authors' views and opinions; neither the European Union, the European Commission nor Italian Ministry for Universities and Research can be considered responsible for them.

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