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Operationalizing Social Resilience for Riverine Flood Risk Management in Urban Basins

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ABSTRACT: The conventional approach to River Basin Flood Management (RBFM) primarily focuses on enhancing the structural integrity of drainage systems to mitigate the impacts of heavy rainfall events. However, recent floods in urban catchments have revealed the necessity for a more resilient approach that incorporates the consequences of flooding. Resilience in the context of RBFM refers to the system's ability to endure diverse precipitation events, minimize flood damage, and restore normal conditions. This research presents a framework for selecting flood management options within a hierarchical system, with a specific emphasis on social resilience indicators. The study defines resilience by examining the response and recovery behaviors of RBFM systems during varying rainfall events. To implement the framework, a set of indicators related to social response, social recovery capacity, resistance points, and warning points has been established. A hierarchical fuzzy system has been developed to quantify these indicators, accounting for uncertainties in social variables and addressing dimensional inconsistencies. Application of this approach in the Gorganrood River basin demonstrates the efficacy of selected flood risk management options in terms of resilience, as compared to conventional decision-making methods. Analyzing the response-recovery curves for different management options underscores the importance of delineating distinct resilience indicators to evaluate the behavior of RBFM systems following performance failures. The findings of this study suggest that the proposed indicators can serve as decision-making criteria for selecting management options based on the behavior of the river basin system under rainfall events with varying return periods.

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1- Introduction

River Basin Flood Management (RBFM) systems, which encompass physical and social vulnerability components such as infrastructure, sensitive points, and inhabitants in flood-prone regions, are susceptible to flood impacts. Inadequacies in existing drainage systems during severe flood events can lead to disruptions and adverse consequences for affected communities [1]. Therefore, it is crucial to improve evaluation indicators and develop resilient drainage systems to enhance the effectiveness of flood management [2, 3].

Resilience refers to the capacity of a system to recover from flood-induced damages and adapt to hazards through response, recovery, and adaptation [3-5]. Quantifying resilience is crucial for reducing disaster impacts, but faces challenges such as uncertainty in vulnerability variables and the subjective nature of judgments concerning response and recovery [6]. Fuzzy set theory can address these challenges and provide clear solutions [7].

This study focuses on assessing the recovery capability of RBFM systems in response to varying rainfall events (Figure 1). Initially, the system exhibits complete recovery capability within its tolerance range. However, as rainfall intensity increases and drainage management options prove insufficient, the system's response intensifies while recovery capability diminishes. Implementing appropriate measures can enhance the system's recovery capability against future damages. Response-Recovery Curves (RRCs) illustrate these processes, with the intersection point serving as an alert threshold. Beyond this threshold, damages occur that require increased attention as the response surpasses recovery, exacerbating disruptions.

This research aims to quantify social resilience indicators for flood management options in the Gorganrood watershed in Iran. Fuzzy sets are used to analyze vulnerability variables, and a hierarchical fuzzy system is developed for the quantification process. The study's novelty lies in employing a comprehensive set of vulnerability variables and utilizing a hierarchical fuzzy approach to quantify social resilience. Furthermore, the research enables the evaluation of both structural and non-structural flood management options by employing social response-recovery curves for floods with different return periods. In conclusion, this study emphasizes the importance of resilience in RBFM systems and proposes an algorithm for quantifying social resilience through fuzzy

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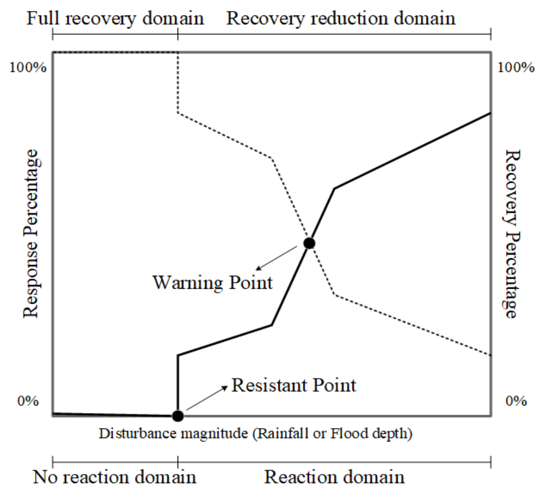

Fig. 1. Schematic of Response curve (solid line)-Recovery curve (dotted line)

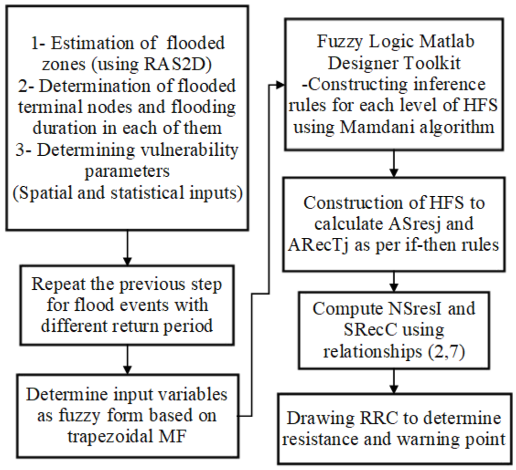

Fig. 2. Methodology for quantifying social resilience

sets and response-recovery curves. Enhancing the resilience of these systems can effectively mitigate flood impacts and improve overall flood management in vulnerable urban areas.

2- Materials and Methods

This study provides a case study on the assessment of social resilience indicators for flood management in the Gorganrood River basin, including both rural and urban areas with different land uses and a complex drainage system. The research focuses on evaluating the effectiveness of an algorithm for quantifying social resilience during flood events. The methodology employed in this study is depicted in Figure 2.

The study employs a RRC-based framework for social resilience indicators, consisting of three main components: social response, social recovery capability, and resilience point. The social response magnitude is determined using a Hierarchical Fuzzy System (HFS), considering the affected areas and node response within the RBFM system. Social recovery is evaluated by calculating the recovery time for flooded nodes using HFS and fuzzy sets, with recovery time intervals categorized (as shown in Table 1). The resilience point is identified by analyzing the maximum rainfall depth at which the response of the RBFM system reaches zero.

Table 1. Definition of fuzzy sets for social response and recovery duration (recompensing and subsidence)

Fuzzy set	Response	Recovery
very low	There are no damages and discomfort conditions	very fast
low	There is no damage and low discomfort conditions	fast
medium	Damages and discomfort conditions are probable	medium
high	Damages is probable and discomfort conditions are intolerable	slow

Vulnerability variables are evaluated using GIS data and 2D simulations, considering different flood management options and rainfall scenarios. Options such as earthen levee (EL), green belt (GB), warning systems (WS), diversion channels (DC), and retention reservoirs (RR) are examined, and their impact on vulnerability variables is assessed. The study also explores the quantification of social indicators using fuzzy membership functions. Normalized social indicators are calculated for various flood events and management options. Rainfall events with return periods of 5, 10, 25, 50, 100, and 200 years are analyzed to assess social resilience.

3- Results and Discussion

The findings reveal that the retention reservoirs (RR) option generally exhibits the lowest normalized response, except for the 200-year rainfall scenario where the green belt (GB) option performs better. However, compared to the status quo, the RR option reduces the expected social response by approximately 9%. Decision-makers may take this indicator into account when choosing flood management options, although cost considerations often influence the decision-making process.

Additionally, the study examines vulnerability variables related to recovery and calculates the fuzzy recovery indicator. It develops fuzzy systems for different levels and assigns variables, such as inundation recession duration, to fuzzy sets. The recovery capacity is normalized, and response-recovery curves are generated to assess the impact of management options on social resilience indicators.

Overall, the study provides valuable insights into the assessment of social resilience indicators for flood management. It underscores the importance of considering social response, recovery capability, and resilience points in the decision-making process. The findings contribute to a better understanding of the effectiveness of diverse flood management options in reducing vulnerability variables and fostering resilient communities.

4- Conclusion

This study focuses on the social aspects of flood management in river basins and defines resilience as the ability of the River Basin Flood Management (RBFM) system to effectively respond to riverine flood events and restore pre-disturbance conditions. It introduces an algorithm that quantifies social resilience indicators, including response, recovery, resistance point, and warning point. To address uncertainties and relative judgments in quantifying response and recovery, the algorithm incorporates a hierarchical fuzzy system.

A case study conducted in the Gorganrood River basin assesses these indicators for various flood management options. The results demonstrate that the social indicators facilitate the evaluation of the impacts of drainage options on the behavior of urban watersheds under diverse flood conditions. Generally, the Retention Reservoir option is found to be more advantageous, except for one scenario where the Green Belt option exhibits a lower social response.

The proposed algorithm provides a comprehensive approach to evaluating social resilience, considering the population, organizational, and physical characteristics of the RBFM system. It emphasizes the importance of incorporating social indicators into decision-making processes alongside economic and environmental factors. However, determining a single unique value for watershed resilience requires further research, as it involves integrating preferences and weights assigned by decision-makers and stakeholders.

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