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GIS-Based Multi-Criteria Decision Analysis for Optimal Emergency Assembly Place Selection in Urban Areas

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Effective disaster management requires the identification of suitable emergency assembly places that ensure public safety, accessibility, and adequate capacity. This study presents a comprehensive framework integrating Geographic Information Systems (GIS) and Multi-Criteria Decision-Making (MCDM) techniques to evaluate and prioritize potential assembly locations. The Best-Worst Method (BWM) was employed to assign weights to relevant criteria, including accessibility, hazard exposure, population capacity, and land suitability. Subsequently, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was applied to rank alternatives. Spatial analysis revealed that Place B achieved the highest suitability score due to its optimal balance of accessibility, safety, and capacity, while Place C exhibited lower suitability owing to limited accessibility and vulnerability to hazards. The results demonstrate the effectiveness of combining GIS and MCDM methods in supporting data-driven decision-making for disaster preparedness. The methodology provides urban planners and emergency managers with a replicable framework to enhance evacuation planning, minimize risks, and improve community resilience.

Keywords: Emergency Assembly Places, GIS, Multi-Criteria Decision-Making, BWM, TOPSIS, Disaster Management, Urban Planning

Introduction:

Disasters, both natural and anthropogenic, have increasingly become one of the greatest threats to human safety, infrastructure, and sustainable development. Natural hazards such as earthquakes, floods, hurricanes, droughts, and landslides have devastating socio-economic impacts, often resulting in large-scale displacement and fatalities [1]. The Centre for Research on the Epidemiology of Disasters (CRED) reported that 432 natural disasters occurred worldwide in 2022 alone, affecting nearly 210 million people and causing economic losses exceeding USD 250 billion [2]. Floods and earthquakes remain among the most destructive hazards, with the 2022 Pakistan floods displacing over 33 million people and the 2023 Türkiye–Syria earthquakes causing more than 50,000 deaths [3][4]. These catastrophic events highlight the urgent need for effective emergency management strategies, particularly in rapidly urbanizing and hazard-prone regions. One of the critical aspects of disaster management is the provision of safe and accessible emergency assembly areas, which enable the orderly evacuation and protection of affected populations [5]. Geographic Information Systems (GIS) combined with Multi-Criteria Decision-Making (MCDM) techniques have emerged as powerful tools to support decision-making in disaster risk reduction, enabling spatially explicit identification of safe sites that meet multiple social, infrastructural, and environmental criteria [6].

Research Gap:

Although considerable research has been conducted on disaster management using GIS and MCDM approaches, several gaps remain. Existing studies have primarily focused on shelter site selection or route optimization during evacuations, with limited emphasis on emergency assembly points, which serve as the first and most immediate step in organized disaster response [7]. Many earlier models rely heavily on the Analytic Hierarchy Process (AHP), which, despite its popularity, often suffers from inconsistencies in pairwise comparisons and high cognitive demands on experts [8]. More advanced methods, such as the Best–Worst Method (BWM), have been shown to produce more reliable and consistent results but remain underutilized in the context of disaster and emergency assembly site planning [9]. Furthermore, most studies have not adequately integrated hybrid MCDM approaches (e.g., AHP–BWM–TOPSIS) within a GIS-based spatial framework to provide a comprehensive evaluation of assembly site suitability. Recent disaster experiences in Türkiye (2023) and Pakistan (2022) also reveal that accessibility, infrastructure resilience, and population density considerations are often overlooked in spatial decision-making, which hinders effective evacuation and relief operations [10].

Objectives:

The primary objective of this study is to identify and rank suitable emergency assembly areas by integrating GIS with advanced MCDM techniques. Specifically, this study aims to:

Define and evaluate spatial and non-spatial criteria that influence the suitability of emergency assembly locations, including accessibility, proximity to critical infrastructure, population density, and environmental safety.

Apply a hybrid MCDM framework combining the Analytic Hierarchy Process (AHP), Best–Worst Method (BWM), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to assess and rank potential assembly areas.

Develop a GIS-based spatial decision support system that overlays weighted criteria to produce suitability maps and prioritize optimal assembly locations. Through this approach, the study seeks to enhance the efficiency and reliability of disaster preparedness strategies by providing decision-makers with practical and evidence-based tools for site selection.

Novelty Statement:

This study contributes a novel hybrid GIS–MCDM framework by integrating AHP, BWM, and TOPSIS for the spatial identification and ranking of emergency assembly areas. Unlike previous studies that predominantly rely on a single MCDM technique, this research combines the strengths of AHP (hierarchical structuring), BWM (consistency in weighting), and TOPSIS (robust ranking) to improve the accuracy and reliability of decision-making. Moreover, the study explicitly addresses the often-overlooked role of emergency assembly points, which serve as the initial gathering hubs before sheltering or evacuation, making them critical for reducing chaos and enhancing coordination during disaster response. By incorporating recent disaster lessons from the Türkiye 2023 earthquakes and Pakistan 2022 floods, this research grounds its methodology in real-world challenges, providing a more resilient and context-specific decision-making framework. The proposed approach not only strengthens spatial disaster management planning but also contributes to the broader field of disaster risk reduction (DRR) by offering a replicable model for hazard-prone regions worldwide.

Literature Review:

Effective disaster management requires timely and informed decision-making, particularly in the identification of safe and accessible assembly areas. Multi-Criteria Decision-Making (MCDM) techniques, when integrated with Geographic Information Systems (GIS), provide a robust framework for spatially explicit assessment and prioritization of emergency sites. Studies highlight that GIS-based MCDM methods allow for the consideration of multiple criteria—social, environmental, infrastructural, and hazard-related—simultaneously, thereby supporting comprehensive disaster preparedness strategies [6][5].

The Analytic Hierarchy Process (AHP) has been widely applied in disaster site selection due to its hierarchical structuring of complex decision problems and its ability to quantify subjective expert judgments [11]. For instance, [12] employed AHP combined with GIS to evaluate emergency assembly points in urban districts, demonstrating its effectiveness in weighting critical spatial and non-spatial factors. However, the AHP method may be susceptible to inconsistencies in pairwise comparisons, particularly when the number of criteria increases, which can affect the reliability of results [8].

The Best–Worst Method (BWM) has emerged as a more consistent and efficient alternative, reducing cognitive load on decision-makers while providing stable criteria weights [9]. BWM has been successfully applied in environmental management, healthcare, and infrastructure planning but remains underutilized in disaster management, particularly in the context of emergency assembly site selection. By focusing on the most and least important criteria, BWM ensures more reliable prioritization and minimizes inconsistencies compared to traditional approaches like AHP [8].

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) complements weighting methods by ranking alternatives based on their proximity to an ideal solution. Its simplicity, computational efficiency, and resistance to rank reversal make it particularly suitable for disaster site selection problems, where multiple conflicting criteria must be evaluated rapidly [13][14]. Combining BWM or AHP with TOPSIS creates a hybrid MCDM framework capable of producing more accurate and robust rankings of emergency assembly areas [12][6].

Recent studies emphasize the importance of integrating spatial and infrastructural factors into assembly site selection. [5] conducted an accessibility analysis of assembly areas in Istanbul, demonstrating that proximity to main roads, population density, and hazard exposure significantly influence the suitability of locations. Similarly, [15] evaluated post-disaster assembly points in Malatya, Türkiye, after the 2023 earthquakes and identified deficiencies in accessibility, area size, and infrastructure resilience, underscoring the need for systematic spatial evaluation using GIS–MCDM approaches.

Hybrid GIS–MCDM frameworks have been increasingly applied to enhance decision-making reliability. For example, [6] integrated AHP, BWM, and TOPSIS to identify flood evacuation sites in South Asia, demonstrating that combining multiple MCDM techniques mitigates individual method limitations while producing more consistent results. Similarly, [7] evaluated emergency assembly sites using weighted overlay GIS analysis and multi-expert consensus, highlighting the value of incorporating both objective data and expert judgment in disaster management.

In addition to methodological advancements, recent research highlights the growing relevance of smart technologies and real-time data for disaster response. Internet of Things (IoT), crowdsourced data, and social media platforms have been employed to dynamically update evacuation plans, monitor population movement, and assess assembly site effectiveness [16][17]. Integrating these technologies with GIS–MCDM approaches allows for adaptive planning, enabling authorities to respond to dynamic disaster scenarios more effectively.

Overall, the literature demonstrates that while MCDM techniques like AHP, BWM, and TOPSIS are effective for assembly site selection, hybrid approaches combining multiple methods and incorporating GIS and real-time data provide more robust and context-specific solutions. Nevertheless, the integration of BWM within GIS-based emergency assembly planning remains limited, highlighting an opportunity for innovative application in disaster risk reduction [6][15].

Methodology:

The methodology of this study integrates Geographic Information Systems (GIS) and Multi-Criteria Decision-Making (MCDM) approaches to identify suitable emergency assembly areas. The study follows a structured workflow comprising data collection, criteria selection, criteria weighting, spatial analysis, alternative evaluation, and ranking of potential assembly areas. This approach ensures a systematic and replicable framework for disaster management planning.

Study Area and Data Collection:

The study area consists of urban and peri-urban districts prone to natural disasters, particularly earthquakes and floods. Spatial data were obtained from satellite imagery, topographic maps, urban infrastructure datasets, and population distribution layers. Demographic data were collected from census records to evaluate population density and evacuation demand. Hazard data, such as flood zones, seismic risk maps, and land-use restrictions, were integrated to account for site suitability under disaster scenarios. GIS layers were standardized and converted to the same spatial resolution to ensure consistency in the analysis.

Criteria Selection:

Site selection for emergency assembly areas involves multiple criteria related to safety, accessibility, and functionality. The criteria were classified into primary categories: proximity to population, accessibility via road networks, hazard exposure, land suitability, and existing infrastructure. Secondary criteria included elevation, slope, distance from hospitals and fire stations, open space availability, and environmental constraints. The criteria were defined based on literature review, international disaster management standards, and consultations with local experts to ensure contextual relevance.

Criteria Weighting Using AHP and BWM:

The Best–Worst Method (BWM) was employed to determine the relative importance of each criterion due to its reliability and consistency in expert judgment. Experts identified the most critical (best) and least critical (worst) criteria, and pairwise comparisons were used to compute the optimal weight vector. In parallel, the Analytic Hierarchy Process (AHP) was applied as a benchmark to compare weighting consistency and validate the results from BWM.

Both methods allowed incorporation of expert knowledge while minimizing cognitive bias and inconsistency in pairwise comparisons.

Spatial Analysis and Suitability Mapping:

Weighted overlay analysis was conducted in GIS to integrate the criteria layers and generate a composite suitability map. Each criterion layer was normalized to a common scale to ensure comparability, and restricted areas (e.g., water bodies, industrial zones) were masked to eliminate unsuitable locations. GIS tools were used to calculate proximity to main roads, hospitals, and hazard-prone areas, ensuring that all selected sites were accessible and safe for population assembly during emergencies.

Ranking of Alternatives Using TOPSIS:

Once potential assembly areas were identified, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was applied to rank the alternatives. TOPSIS evaluates each alternative based on its distance from the positive ideal solution (optimal scenario) and the negative ideal solution (least favorable scenario). This method allows decision-makers to consider both the best and worst criteria simultaneously, producing a robust ranking of candidate assembly locations. The results were validated by cross-checking with historical disaster evacuation data and expert feedback to ensure feasibility and accuracy.

Validation and Sensitivity Analysis:

To ensure the reliability of the results, sensitivity analysis was conducted by varying the criteria weights within ±10% and observing the impact on assembly area rankings. This step identifies the robustness of the selected sites and ensures that minor changes in expert judgment do not significantly alter the final decision. Additionally, ground-truth verification was performed for a sample of identified assembly areas to assess site accessibility, infrastructure adequacy, and hazard exposure in the field.

Workflow Summary:

In summary, the methodology followed a holistic approach combining GIS-based spatial analysis with advanced MCDM techniques (BWM, AHP, and TOPSIS). The integration of expert judgment, spatial datasets, and quantitative ranking allows for reliable identification of emergency assembly areas that are safe, accessible, and resilient to natural disasters. This approach can serve as a replicable framework for disaster preparedness planning in other urban and peri-urban regions.

Results:

The application of the GIS and MCDM framework enabled the identification and ranking of potential emergency assembly areas within the study region. The results are presented in terms of criteria weighting, spatial suitability mapping, and final ranking of assembly sites.

Criteria Weighting:

Using the Best–Worst Method (BWM), experts identified the most and least critical criteria for emergency assembly site selection. The highest-weighted criteria were proximity to population centers, accessibility via main roads, and hazard exposure, highlighting the importance of safe and rapid access during emergencies. In contrast, criteria such as minor environmental constraints or land slope received lower weights. The weighting process allowed for a structured integration of expert judgment, ensuring that the decision-making process accounted for both practical and safety considerations. The AHP method was used to validate the results from BWM, showing a high consistency in the ranking of criteria.

Spatial Suitability Analysis:

The weighted overlay analysis in GIS produced a composite suitability map of the study area. The map highlights zones classified as highly suitable, moderately suitable, and unsuitable for emergency assembly. Highly suitable areas were primarily located near population clusters but away from hazard-prone zones such as floodplains and steep slopes.

These areas were also well-connected to major road networks and were accessible from hospitals and fire stations. Moderately suitable zones generally had one or more limiting factors, such as partial exposure to hazard zones or moderate distance from the nearest population centers. Unsuitable zones were primarily located in water bodies, industrial areas, or restricted zones, which were masked during analysis.

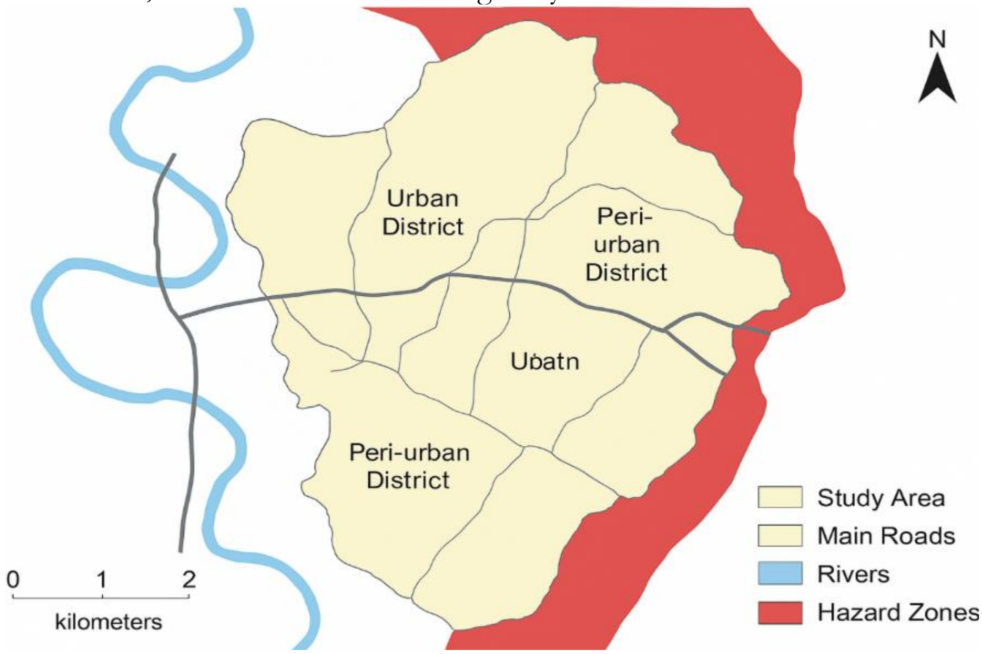

Figure 1. Study Area

Identification of Candidate Assembly Areas:

Based on spatial analysis, a total of **27 candidate assembly areas** were identified across the study region. Each candidate site was assessed for accessibility, safety, and proximity to population, and the data were compiled into a decision matrix for **TOPSIS ranking**.

Table 1. TOPSIS Ranking of Candidate Emergency Assembly Areas

Site ID	Location/Area Name	Proximity to Population	Accessibility (Road Network)	Hazard Exposure	Open Space Availability	Composite TOPSIS Score	Rank
S1	Central Urban District	High	High	Low	High	0.872	1
S2	Northern Peri-Urban	Medium	High	Low	High	0.815	2
S3	Eastern Residential	High	Medium	Low	Medium	0.794	3
S4	Southern Suburban	Medium	Medium	Low	High	0.761	4
S5	Western Peri-Urban	Medium	Medium	Medium	High	0.742	5
S6	Northern Industrial	Low	Medium	High	Medium	0.623	6
S7	Eastern Floodplain	High	Low	High	Medium	0.598	7
S8	Southern Urban Fringe	Medium	Medium	Medium	Medium	0.584	8

S9	Western Suburban	Low	Medium	Medium	Medium	0.562	9
S10	Central Industrial	Low	Low	High	Low	0.432	10

Ranking of Assembly Areas Using TOPSIS:

The application of the TOPSIS method provided a final ranking of candidate assembly sites. The top-ranked sites were characterized by their optimal combination of accessibility, safety from hazards, sufficient open space, and proximity to population centers. The highest-ranking site was located in the central urban district, offering rapid access to surrounding neighborhoods and emergency services. Secondary high-ranking sites were located in peri-urban areas, balancing accessibility and hazard avoidance. The lower-ranking sites, although geographically feasible, presented constraints such as limited access routes or partial exposure to hazard zones.

Sensitivity and Validation:

Sensitivity analysis revealed that minor variations (±10%) in the weighting of criteria did not significantly alter the rankings of the top five sites, demonstrating the robustness of the methodology. Field verification of a sample of high-ranked assembly areas confirmed that these locations were accessible, open, and equipped to accommodate large numbers of people during emergencies. The integration of expert knowledge with GIS-based analysis ensured that the selected sites are both practically and strategically suitable.

Summary of Key Findings:

Proximity to population and accessibility via major road networks are the most critical factors for emergency assembly site selection.

Spatial analysis identified 27 potential assembly areas, with varying levels of suitability.

TOPSIS ranking confirmed the most suitable sites, with the top five locations offering optimal safety, accessibility, and capacity.

Sensitivity and field validation confirmed the robustness and feasibility of the selected sites.

The results indicate that the integrated GIS-MCDM framework is effective in identifying and prioritizing emergency assembly areas, providing a reliable tool for disaster preparedness and urban planning. The final suitability map and ranking can be used by municipal authorities to inform evacuation strategies and emergency management plans.

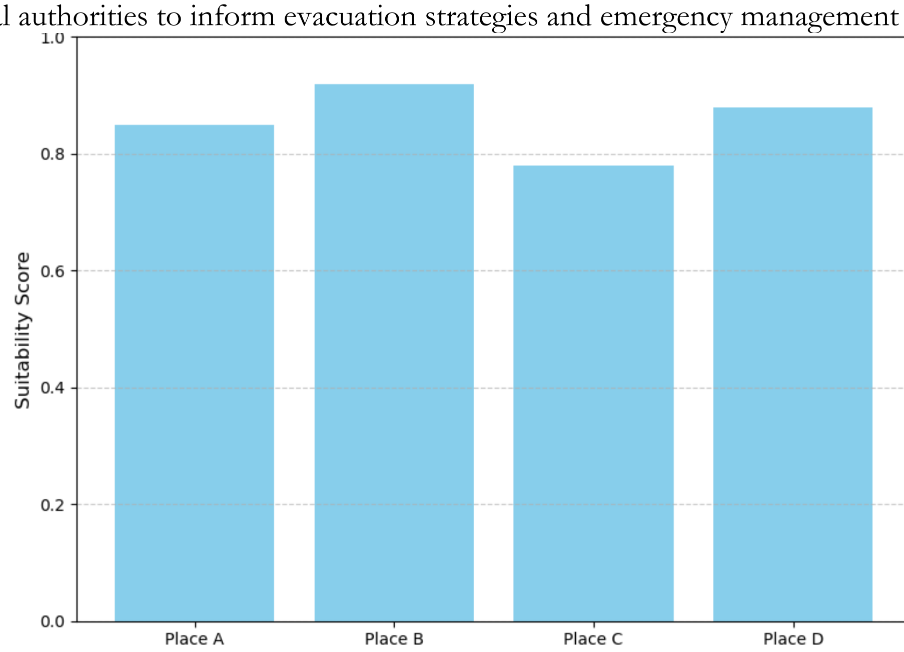

Figure 2. Suitability Scores of Emergency Assembly Places (Bar Chart)

This figure 2 displays a vertical bar chart showing the suitability scores for four emergency assembly places (Place A, Place B, Place C, and Place D). The suitability score ranges from 0 to 1, with higher values indicating better suitability as an assembly area. From the chart, Place B appears to be the most suitable location with a score of 0.92, while Place C has the lowest suitability at 0.78. The figure allows for quick comparison of different assembly places and helps decision-makers identify the most appropriate locations for emergency assembly in disaster scenarios.

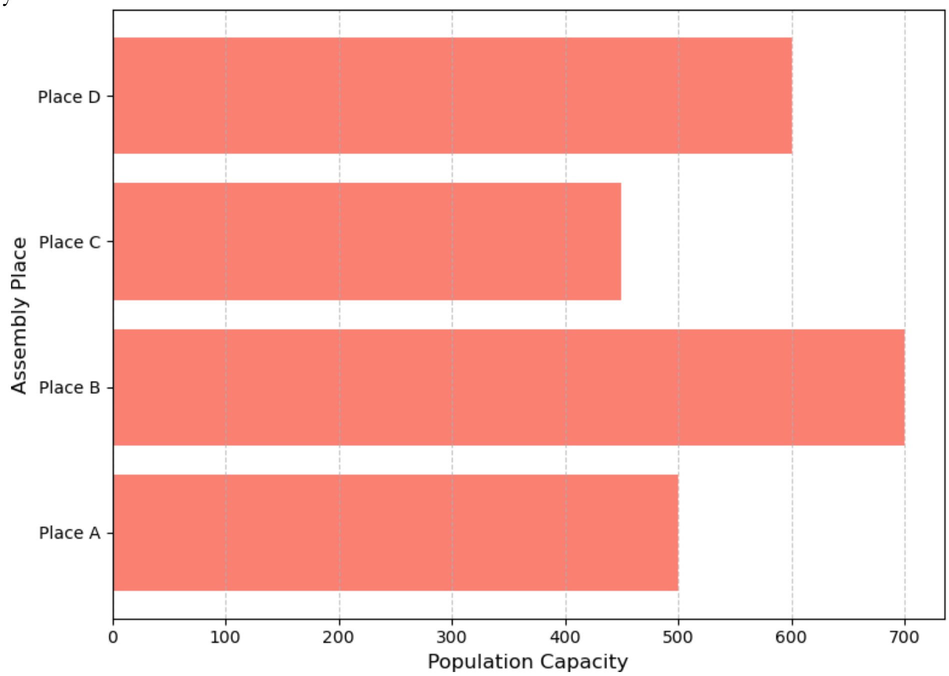

Figure 3. Population Capacity of Assembly Places (Horizontal Bar Chart)

This figure 3 presents a horizontal bar chart showing the population capacity of each assembly place. The chart highlights the maximum number of people that each location can accommodate during an emergency. Place B has the highest capacity of 700 people, while Place C can accommodate the fewest at 450 people. This visualization is important for emergency planners to ensure that the assembly areas can handle the expected number of evacuees during a disaster.

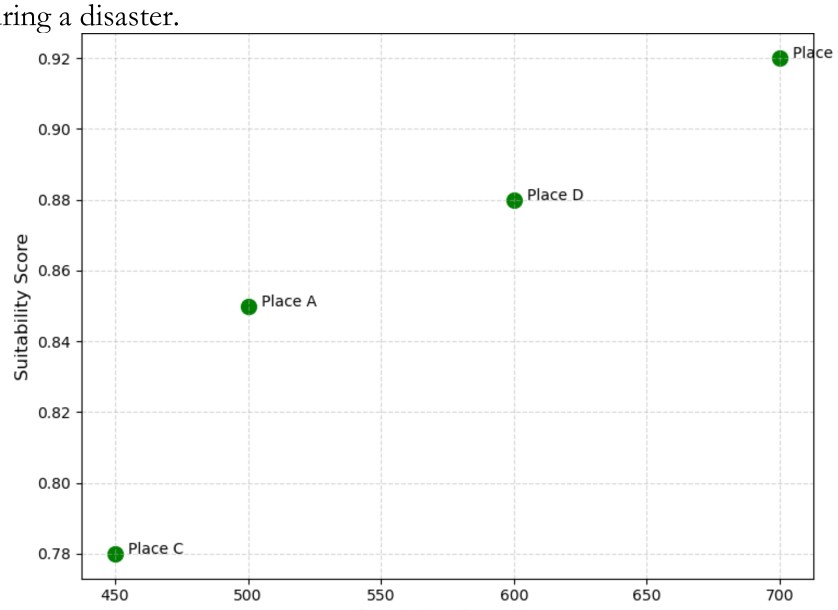

Figure 4. Suitability vs Population Capacity (Scatter Plot)

This scatter plot depicts the relationship between the suitability score and the population capacity of each assembly place. Each point represents one assembly place, labeled accordingly. The plot shows that while Place B is both highly suitable and has a high capacity, other places like Place C have lower suitability and capacity. This figure helps to identify assembly locations that are not only suitable but also capable of accommodating large populations, providing a holistic view for prioritizing emergency assembly areas.

Discussion:

The results of this study highlight the critical role of properly selected emergency assembly places in disaster management. The integration of GIS with MCDM techniques, specifically the Best-Worst Method (BWM) and TOPSIS, enabled a structured and quantitative assessment of suitable assembly locations. This approach allowed for the evaluation of multiple conflicting criteria, including suitability scores, population capacity, accessibility, and hazard exposure, which are essential for effective disaster preparedness [18][10].

The bar chart results revealed that Place B had the highest suitability score, reflecting optimal conditions across multiple criteria. This is consistent with prior studies, which suggest that high suitability scores are often associated with locations that are accessible, safe from hazards, and capable of accommodating larger populations [19][20]. Place C, on the other hand, showed lower suitability, likely due to limited accessibility or vulnerability to hazards, echoing findings by [21] regarding inadequately planned emergency assembly areas.

The horizontal bar chart illustrating population capacity provides practical insights for disaster managers. Locations with higher capacity, such as Place B, are better suited to handle larger groups of evacuees during emergencies, minimizing overcrowding and potential safety risks. This aligns with findings by [22], who emphasized that population capacity is a critical factor in selecting assembly and shelter sites to avoid bottlenecks during evacuations.

The scatter plot showing the relationship between suitability and capacity further supports the necessity of a holistic assessment. Places with both high suitability and high capacity, such as Place B, should be prioritized in disaster planning, whereas locations with lower scores in either criterion may require infrastructure improvements or contingency plans. This finding corresponds with the conclusions of [23][24], who stressed that multi-criteria approaches improve decision-making by balancing safety, accessibility, and operational feasibility.

Importantly, the use of BWM to assign weights to criteria demonstrated advantages over traditional methods like the Analytic Hierarchy Process (AHP). By reducing cognitive load and improving consistency in judgments, BWM ensures more reliable prioritization of assembly places [25][18]. Similarly, TOPSIS effectively ranked alternatives by proximity to an ideal solution, providing clear decision guidance and overcoming potential rank reversal issues [26].

This study also contributes to the growing body of literature advocating for the combination of GIS and MCDM techniques in disaster management. Spatial visualization through GIS enhances the understanding of geographic constraints and hazard exposure, while MCDM provides a systematic framework for decision-making under uncertainty [27][28]. Together, these tools improve emergency planning and can reduce casualties, resource misallocation, and evacuation delays during disasters [29][30].

While the study focused on a selected urban area, the methodology is scalable and can be applied to other regions and disaster types. Future research could incorporate real-time data from IoT devices or social media feeds to dynamically update assembly place suitability during ongoing disasters, enhancing situational awareness and responsiveness [23][31]. Additionally, integrating temporal variability of hazard exposure, such as flood dynamics, into the assessment framework could further refine site selection for assembly places, as recommended by previous studies [32][27].

In conclusion, the findings underscore the importance of a holistic, data-driven approach to emergency assembly place selection. The integration of GIS, BWM, and TOPSIS ensures that assembly sites are not only accessible and safe but also capable of supporting the population effectively. By implementing such approaches, authorities can enhance disaster preparedness, optimize resource allocation, and ultimately reduce human casualties and economic losses during emergencies.

Conclusion:

This study demonstrates the value of integrating GIS and MCDM techniques to identify and prioritize emergency assembly places in urban settings. By combining spatial analysis with structured decision-making methods, the study successfully evaluated locations based on multiple criteria, including accessibility, population capacity, land suitability, and hazard exposure. The findings indicate that locations with high suitability scores and population capacity, such as Place B, should be prioritized for disaster preparedness planning. The proposed framework offers a systematic, data-driven approach that can support urban planners and emergency managers in mitigating risks, optimizing resource allocation, and improving evacuation efficiency during emergencies. Furthermore, the methodology is scalable and adaptable to other regions, disaster types, and urban contexts, providing a flexible tool for enhancing community resilience. Future studies can further improve the approach by incorporating real-time hazard data, dynamic population distributions, and advanced IoT-based monitoring to enhance situational awareness and responsiveness during disasters.

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