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Analysis of Shelters for Disaster Evacuation Using a Network Modeling and GIS Approach

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Evacuation shelters play a critical role in disasters, providing a safe environment for evacuees. In this study, we analyze the suitability of evacuation shelters, in which potential shelters are assessed according to their accessibility and critical criteria within an evacuation network. The accessibility of evacuation shelters refers to their ease of approach for evacuees, whereas the criteria for evacuation shelters include the expected roles that they play in protecting evacuees during disasters. An illustrative case study was conducted.

Introduction

An evacuation shelter is a structural area that has the function of separating individuals from a hazard, threat, or disaster (Homeland Security, 2019). For shelters to be designated evacuation shelters, they must meet certain standards to ensure the survival and safety of affected people after disasters; nevertheless, the availability of such shelters tends to be found insufficient after the realities of evacuation after a disaster are observed (Vecere, et al., 2017; Kotani, 2020). Moreover, certain designated evacuation shelters have only a limited ability to accommodate evacuees. This study thus proposes a modeling framework that can analyze a set of potential sites to identify suitable evacuation shelters to improve evacuation performance in disasters.

Methodology

In this study, we analyze the suitability of potential shelters for evacuation using a network modeling and geographical information systems (GIS) approach.

In network modelling, an evacuation network k_n is constructed to represent the area where the topology of shelters is embedded, where n is the number of potential shelters. It is assumed that each potential shelter exhibits interdependency with other potential shelters over a link n_{ij} for $n_i, n_j \in k_n$, i.e., link n_{ij} represents the interdependence wherein a potential shelter n_i is connected with another potential shelter n_j in a path (Lam and Tai, 2018). Therefore, the evacuation diagram k_n is represented by a set of nodes (i.e., potential shelters) and links (i.e., interdependencies). The nodes are then analyzed by degree centrality. Degree centrality uses the node degree (in-degree and out-degree) to identify a node's direct interdependence to or from other nodes in the network, such that degree centrality represents how far other nodes can access a node in a network. The degree centrality of a node is the sum of the number of both types of interdependencies, i.e., $1/\sum_{i=1}^{N}(k_i^+ + k_i^-)/N$, where N is the total number of interdependencies and k_i^+ and k_i^- are the in-degree and out-degree values of the i-th node in the network, respectively. The higher the degree centrality of a node, the higher its node interdependency with other nodes and a high chance of accessibility from other nodes.

Additionally, the relative importance of the criteria for each node in the evacuation network is complementarily investigated using GIS. The criteria include (1) physical area, i.e., the occupied area (indoor area and/or indoor area), and (2) distance from potential disasters, which refers to the direct distances of the potential shelters as identified in GIS to the nearest potential disaster points (i.e., river, mountain, or sea).

The accessibility and criteria of shelters are then weighted, and the suitability of potential shelters for use as evacuation shelters are then analyzed.

Case study

To illustrate the modeling framework, a comparative study is conducted. The study area is Saijo, in Higashihiroshima City, Hiroshima Prefecture, Japan.

In the case study, an evacuation network with 2797 nodes and 2789 links was constructed in the study area. The accessibility of these 2797 nodes were analyzed according to their degree centrality. Of the 2797 nodes, 27 nodes were identified as potential shelters based on their accessibility. The physical characteristics of these 27 nodes are then further analyzed according to critical criteria deduced from referenced requirements. Each criterion was then quantified according to the characteristics of the potential shelters in terms of the properties and the GIS geospatial characteristics of the nodes in the network, such that the suitability of nodes as evacuation shelters were analyzed by the relative fulfillment of the requirements. The relative importance of the criteria was also investigated using GIS data and the information from the city, along with the hazard map of the study area. The results showed that nine nodes out of the 27 identified nodes are comparatively suitable to be the evacuation shelters, including the university, the schools, a government building, the community center, and a hotel; the schools and the community center are already accredited designated evacuation shelters in the study area. From the illustration, it is demonstrated that the modeling framework can systematically reveal the characteristics of shelters, which are used to analyze not only the suitability of existing accredited designated evacuation shelters but also other potential shelters as alternative evacuation shelters.

Discussion and Conclusion

The modeling approach in this study provides a systematic approach to determining alternative evacuation shelters and understanding the suitability of potential shelters as evacuation shelters. Moreover, the approach characterizing shelters in terms of accessibility and critical criteria of evacuation shelters, which is expected to be useful in decision making for evacuation planning, disaster preparedness and response, and post disaster activities in recovery and restoration.

This study exhibited a few limitations. Extensive and accurate data are required to quantify the characteristics of shelters. Although network analysis can be used to identify the characteristics of shelters in an evacuation network, modeling complexity can also be increased as the number of nodes and links increases, and looping in the evacuation paths can also induce infinite computation in the analysis. Future work in this area should involve increasing the sample size and variety of shelters examined, including more concise or disaster-oriented critical criteria from the requirements of evacuation shelters, covering multiple evacuation networks, and considering the ratio of evacuation shelters to the population in the evacuation network.

References

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