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OPTIMISING EVACUATION ROUTES FOR RAPID ONSET HAZARDS AMIDST PANDEMICS USING NATURE-INSPIRED ALGORITHMS: AN APPLICATION OF THE CHARACTERISTICS OF NATURE-INSPIRED SOLUTIONS IN A WEIGHTED CENTRALITY-BASED EVACUATION STRATEGY

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ABSTRACT - This research manuscript aims to explore the use of nature-inspired methods to optimise the evacuation of vulnerable communities during rapid-onset hazards, especially considering pandemic situations and additional challenges posed by pandemics. Multi-hazard scenarios can be identified as potential threats to public safety, and economic and infrastructure functionality in cities, especially in densely populated urban areas. The current COVID-19 pandemic has amplified these issues as multi-hazard responses including evacuation of communities were never prepared for such compound incidents, especially for highly dynamic and changing circumstances. This research proposes the use of three nature-inspired algorithms to optimise evacuation planning and ensure the safety and efficiency of response operations during compound hazards. The characteristics in Particle Swarm Optimisation (PSO), Ant Colony Optimisation (ACO), and Artificial Bee Colony (ABC) Optimisation algorithms are used to propose a novel approach to minimising the total distance of evacuation routes while considering a dispersed evacuation strategy to ensure social distancing in shelter spaces and between evacuation zones. The optimisation characteristics have incorporated the pheromone information and heuristic information to determine the most suitable evacuation route and direction to shelter based on information such as integrated risk at vulnerable locations, time and distance estimation to a safe location, shelter location and service capacity. The application of nature-inspired optimisation to multi-hazard evacuation planning can be considered a promising approach to improve public safety, especially in the context of compound hazards amidst pandemics. The result of this research could provide transport planners as well as emergency managers with novel insights for planning adaptive and dynamic evacuation plans for changing circumstances.

Keywords: COVID-19; emergency management; nature-inspired solutions; rapid onset hazards; risk assessment.

1. INTRODUCTION

Natural disasters and pandemics pose significant threats to human life and livelihoods, with compounded hazards escalating disaster risks at exponential rates [1]. To address these challenges, disaster preparedness and response measures need systemic revisions to ensure the safety of vulnerable communities and infrastructure systems [2]. Optimizing evacuation and relief strategies is crucial to reduce evacuation time, congestion, and disease transmission risks during planning [3]. Conventional evacuation planning methods often rely on heuristic algorithms that lack consideration for real-world conditions, systemic risks, and constraints [4]. The COVID-19 pandemic has underscored the necessity of pandemic preparedness integration in evacuation planning, especially after attributing limited social distancing due to disaster response mobility and increased hospitalizations in disaster areas [5]. Nature-inspired algorithms like PSO, ACO, and ABC have shown success in optimizing transportation solutions in diverse contexts, yielding efficient routes and activities along transportation networks [6]. Centrality as an analytical method of connectivity

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represents the relevance and risk of a given node based on the geometric positioning and the weighted properties of the node [7]. This analysis can be widely adopted into the scenario evaluation of tsunami evacuation to assess the system-wide response for internal and external impacts. Accordingly, the centrality analysis can be identified as a common approach for both pandemic management and disaster evacuation planning disciplines [8]. As centrality analysis can capture the parameters of central and peripheral nodes, it can be combined with tsunami and pandemic risk elements in a weighted analysis to develop a clustered tsunami evacuation strategy [9]. In this light, the aim of this research is to develop an optimization model for multi-hazard evacuation planning using nature-inspired algorithms which determine the most efficient evacuation routes for rapid onset hazards amidst pandemics. In achieving this aim, the research has evaluated the usefulness and characteristics of PSO, ACO, and ABC algorithms in finding optimal evacuation routes.

2. MATERIALS AND METHODS

This study employed an integrative literature review to discern essential theories related to tsunami response, COVID-19 management, and nature-inspired solutions. Using PRISMA guidelines, databases like PubMed, Scopus, ScienceDirect, Web of Science, and Google Scholar were searched. Inclusion criteria encompassed disaster evacuation, contagious disease transmission, centrality analysis, nature-inspired solutions, and COVID-19. Literature before 2004 was excluded for increased relevance. The review aimed to address how rapid-onset disaster evacuations accelerate contagious disease transmission. Content analysis, based on expert opinions, identified key elements for tsunami evacuation planning during a pandemic. Analysis categorized results into three forms using degree analysis. Verified by relevant experts, these results formed a conceptual framework aiding pandemic risk analysis in evacuation, spanning risk identification, assessment, and mitigation phases.

3. RESULTS AND DISCUSSION

3.1. Key Phases of the Conceptual Framework for Nature Inspired Evacuation Path Optimisation

The risk identification phase consists of the elements of deterministic tsunami hazard identification, weighted centrality analysis, and COVID-19 transmission. The risk assessment phase consists of the scenarios identified from the weighted centrality analysis to characterize the probability and spatial hierarchy of contagious disease transmission across evacuation routes regarding varying disaster risk scenarios. The simulated result was used to identify the disease transmission routes and hotspots along the evacuation routes. Finally, the risk mitigation phase incorporated the evaluation of nature-inspired solutions indicating the use of distinguished characteristics of the PSO, ACO and ABC algorithms in terms of minimizing the risk of contagious disease transmission during a tsunami evacuation.

To enhance the risk mitigation phase of overall evacuation planning, incorporating pheromone information in all routes can improve awareness and communication during evacuation. Inspired by the ABC algorithm, which emulates bees exploring food sources, exposure and vulnerability assessments are crucial for securing future evacuation plans. Employing elements from the ACO algorithm, preparedness measures can be strategically implemented based on route density and frequency of use. Agents can then identify optimal routes using pheromone and heuristic information, considering distance and direction from the risk zone to the relief centre. The ACO algorithm's adaptability to environmental changes can be combined with PSO algorithm features, utilizing speed and acceleration as essential factors for finding the best solutions. Balancing exploitation and exploration, the algorithms capitalize on local agents' intuitive knowledge to learn from one another.

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Additionally, the ABC algorithm's capacity to target source capacity at the origin location proves effective in managing integrated tsunami and COVID-19 risks, providing secure routes for each community. The ACO algorithm also aids in planning rescue and relief operations, minimizing travel distance and time amid dynamic contexts. The risk assessment phase involves attaching pheromone information to potential routes, allowing for continuous updates and modifications based on new information. Safe locations are identified as agents explore the environment and evaluate fitness values, mimicking the foraging behaviour of bees and ants. Safe routes and exits are determined by calculating the total distance of selected routes, guiding evacuees to safe exits while maintaining social distancing to minimize disease transmission. Communication and warning systems are optimized by identifying optimal routes for information dissemination based on factors like distance, accessibility, and population distribution. Disease transmission is minimized by selecting routes with appropriate pheromone levels and incorporating disease-related constraints. Evacuation procedures, including rescue and relief operations, are optimized including adaptive and dynamic capacities by attaching pheromone information to each route.

4. CONCLUSION AND SUGGESTIONS

The integration of nature-inspired algorithms into multi-hazard evacuation planning shows promise in optimizing evacuation practices and minimizing the risks of infectious disease transmission during pandemics. By addressing these aspects, emergency management agencies can effectively leverage nature-inspired optimisation to bolster public safety and reduce disease transmission during evacuations by prioritising safe routes, avoiding high-risk areas, and facilitating social distancing in shelter spaces. This approach can lead to better-prepared and adaptive evacuation strategies, considering the challenges posed by pandemics and other rapid-onset hazards. Practitioners and policymakers can benefit by applying this approach to real-world evacuation planning scenarios. However, the study's limitations, including the need for validation in actual evacuation events and limited parameter tuning, must be acknowledged.

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