JOWRM

Journal of Water Resources Management
Journal homepage: https://journal.water.gov.my

e-ISSN: 2811-3578

Estimation of Life Loss and Direct Damage Due to Flooding Using HEC-LifeSim Model

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Received 13 May 2025;
Accepted 08 June 2025;
Available online 28 June 2025

Abstract: This study simulates flood events with 10-, 50-, and 100-year return periods in Kota Belud, Sabah, to assess potential life loss and direct damage, with the goal of strengthening the local evacuation plan. As one of Sabah's most flood-prone regions, Kota Belud has experienced significant socio-economic impacts from past floods. Utilizing HEC-RAS and HEC-LifeSim, the analysis integrates hydraulic modeling with population and structural data sourced from tools such as Google Earth Pro, QGIS, and OpenStreetMap. Building characteristics, including geospatial coordinates, storeys, function, and construction details, were systematically compiled to support simulation inputs. Two preparedness scenarios were modeled over 2000 iterations: minimal awareness and early alert with high awareness. Results show higher population mobilization rates with improved preparedness (83.52%, 80.67%, 77.38%) compared to minimal preparation (72.67%, 70.17%, 67.20%), across increasing return periods. However, structural damage remained relatively consistent across both scenarios, with values of RM126,022.30, RM166,016.52, and RM204,856.40, respectively. The findings suggest current flood response measures are insufficient to prevent life loss, highlighting the need for revised land-use planning and improved resource allocation to emergency services.

Keywords: Flood risk assessment, HEC-LifeSim, agent-based modeling, evacuation planning, Kota Belud

1. Introduction

Floods are among the most devastating natural hazards globally, causing significant human casualties and economic disruption. In Malaysia, flooding is a recurring issue, particularly during the monsoon seasons. Kota Belud, a town in Sabah, has been identified as one of the most flood-prone areas in the region. Repeated flood events in this district have resulted in the displacement of communities, infrastructure damage, and substantial economic losses.

Despite ongoing efforts to manage flood risks, there is a pressing need for more sophisticated tools that can simulate flood events and support decision-making processes. Traditional flood assessments often fail to integrate life loss estimation and real-time emergency preparedness planning. As a result, many flood mitigation strategies lack the depth required to ensure public safety and effective resource allocation during emergencies.

To address this gap, this study employs two hydraulic and risk simulation models: HEC-RAS (Hydrologic Engineering Center's River Analysis System) and HEC-LifeSim (Life Safety Model). These tools provide a comprehensive framework for simulating flood scenarios, estimating potential casualties, and assessing structural damages under varying conditions of public preparedness and flood severity.

The primary aim of this study is to simulate 10-, 50-, and 100-year return period flood events in Kota Belud and evaluate their potential impacts on life and infrastructure. By incorporating demographic, structural, and geospatial data into the modeling process, the study seeks to generate accurate flood hazard and risk maps. Ultimately, the goal is to inform the development of an improved flood emergency preparedness plan that enhances community resilience and supports governmental response strategies.

2. Literature Review

Flood loss assessments aim to quantify economic and infrastructural damage resulting from flood events, often using hydrological models, indicator systems, and post-flood surveys [1]. These assessments are crucial for effective flood risk management and adaptation planning, which can reduce vulnerability and improve response strategies [2]. HEC-LifeSim estimates life loss using population and flood severity data, employing a distribution of life loss rates [3]. The model divides the population into subgroups based on vulnerability, estimating fatalities based on the flood zone and event severity. This method is applied to various types of floods, including those caused by dam failures, where gradual collapses allow for better data collection on flow rates and population density [4]. HEC-RAS is a widely used

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hydrodynamic model for assessing flood hazards, offering accurate evaluations of flow velocity and depth. Researchers have applied it to simulate dam breaks, estimate flood levels, and create floodplain maps by integrating it with tools like GIS, HEC-HMS, SWAT, and LiDAR data. Studies confirm its reliability and adaptability for various terrains and return periods.

HEC-LifeSim addresses a limitation of hydrodynamic models by focusing on human consequences such as life loss and structural damage. Developed by Aboelata and Bowles in 2005, it models human behavior during floods, allowing for detailed evacuation and fatality simulations as shown in case studies from Japan, Switzerland, and Brazil [5].

Alternative Agent-Based Models offer a flexible framework to model complex interactions among individuals and their environment. These models are ideal for simulating human behavior during disasters, with spatial context provided via GIS. Tools like HEC-LifeSim, HEC-FIA, and the Life Safety Model exemplify how agent-based methods can estimate life loss and inform emergency planning.

To date, there are no specific studies focused solely on flooding in Kota Belud, but existing literature provides relevant insights. A study by Osman *et al*. linked the area's low elevation to frequent flood threats, particularly impacting fisheries and local livelihoods [6]. The 2015 Mount Kinabalu earthquake has also altered the region's physical environment, exacerbating flood risks. Rasam *et al*. found that inadequate road drainage contributes to flooding and disrupts evacuation routes [7]. Additionally, Saleh *et al*. noted that mangrove destruction in Ambong Bay has left the shoreline vulnerable to tidal waves [8].

3. Methodology

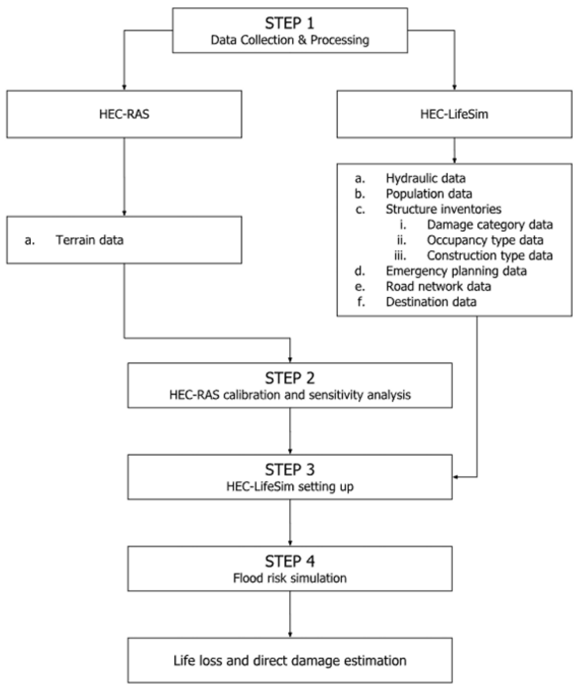

Fig. 1 – Methodology flowchart

4. Analysis and Discussion

Table 1 – Summarized output for life loss

Output	10-year (minimally prepared)	10-year (well-prepared)	50-year (minimally prepared)	50-year (well-prepared)	100-year (minimally prepared)	100-year (well-prepared)
Structures inundated	39	39	63	63	74	74
Average depth of structure	0.3306 m	0.3306 m	0.3549 m	0.3549 m	0.3991 m	0.3991 m
% of PAR warned	85.44%	85.44%	82.50%	82.50%	79.28%	79.28%
% of PAR mobilized	72.67%	83.52%	70.17%	80.67%	67.20%	77.38%
Life-loss in structure U65	7.0705	7.0915	7.109	7.1705	7.1685	7.2185
Life-loss in structure O65	1.4275	1.442	1.868	1.869	2.0765	2.076
Structure damage	126022.30	126022.30	166016.52	166016.52	204856.40	204856.40
Content damage	1475.35	1475.35	2002.02	2002.02	2391.35	2391.35

Across 10-, 50-, and 100-year flood events, 39, 63, and 74 structures were inundated, respectively, with average depths increasing from 0.33 m to 0.40 m. Due to the immobility of structures, warnings had limited effect on reducing structural exposure. Life loss varied slightly across events and preparedness levels. Under low preparedness, mobilization ranged from 67% to 73%, resulting in life losses of 7.07–7.17 (under 65) and 1.43–2.08 (over 65). Improved preparedness increased mobilization up to 83%, but life loss remained largely unchanged due to structural constraints.

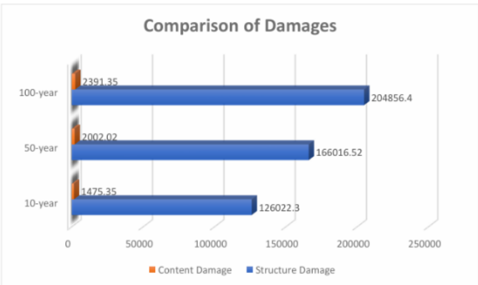

Fig. 2 – Comparison of the damage done by each flood return period

Structural and content damages from flooding remain consistent across preparedness levels but vary with flood severity. Damage increases with discharge flow, with the 10-year flood causing the least impact, followed by the 50-year event, while the 100-year flood results in the highest damage to structures and their contents.

Table 2 – Summarized output for structure inundations

Output	10-year	50-year	100-year
Average depth of structure	0.3306 m	0.3306 m	0.3549 m
Minimum depth of structure	0.0016 m	0.0107 m	0.0057 m
Maximum depth of structure	2.2642 m	2.7034 m	2.8841 m

Flood depths across return periods show increasing severity, with maximum inundation reaching 2.26 m, 2.70 m, and 2.84 m for the 10-, 50-, and 100-year floods respectively.

These depths explain both the extent of structural damage and the associated life loss.

The study highlights that although no prior analysis had quantified life loss and direct flood damage in Kota Belud, the HEC-LifeSim model effectively simulates flood impacts by incorporating human behavior, structural vulnerability, and emergency preparedness. The model demonstrates that while enhanced warning systems can improve evacuation rates, life loss remains relatively consistent across 10-, 50-, and 100-year flood scenarios, suggesting a critical vulnerability in the population's exposure and infrastructure. However, structural damage increases significantly with flood severity, underlining the importance of resilient land-use planning and targeted mitigation strategies. This emphasizes the need for improved urban planning, stricter building codes, and enhanced emergency response measures, particularly in areas with frequent flood hazards. Investments in robust drainage systems, early warning dissemination, and pre-identified evacuation routes can significantly reduce human and economic losses. Additionally, strengthening existing levees, constructing new flood defenses, and revising zoning regulations would support long-term flood resilience. This research supports a call to action for policymakers, urban planners, and emergency agencies to collaborate in implementing risk-informed decisions for sustainable and safer development.

5. Conclusion and Recommendation

This study affirms the value of agent-based models like HEC-LifeSim in urban flood risk assessment, particularly in supporting planning, policy-making, and emergency response. Despite data limitations typical of developing areas like Kota Belud, the model effectively simulated life loss and structural damage using available sources such as Google Earth, census data, and QGIS. Challenges included limited population and infrastructure data, as well as misaligned hydraulic data from HEC-RAS, which restricted simulation of road networks and evacuation routes. Nevertheless, the model provided critical insights into flood vulnerability and potential mitigation measures.

Recommendations emphasize the software's capacity for cost-effective flood simulation, with future studies encouraged to integrate additional parameters—such as road networks, evacuation centers, and accurate population counts—for improved realism. Exploring various structural mitigation strategies and increasing collaboration across disciplines are also advised to enhance model development and broader application. Sharing research through platforms like ResearchGate may foster global collaboration and innovation in flood risk reduction.

Acknowledgement

The authors would like to thank the Department of Irrigation and Drainage Sabah for providing essential hydrological data and technical support throughout this study.

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