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A Simplified Methodology for Tsunami Casualty Estimation Using Geospatial Analysis and Numerical Simulation

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INTRODUCTION & AIM

Tsunami hazard assessments commonly combine numerical inundation models with geospatial demographic datasets to estimate exposed population and economic losses. However, evacuation dynamics, which play a critical role in determining casualties, are often simplified or omitted due to the computational cost of detailed agent-based evacuation models (ABMs) [1,2].

This study introduces a computationally efficient evacuation estimation framework that reduces population impact assessment time.

The aims of the study are:

- To integrate TUNAMI-N2 tsunami inundation simulations with a simplified, geospatially informed evacuation model.
- To estimate potentially injured, and fatality counts using fragility functions [3] for multiple tsunami scenarios in Central Peru.
- To evaluate the influence of key evacuation parameters—moving speed and response time—on impact outcomes.

The study area covers the Chorrillos and Villa El Salvador districts in Lima, Peru.

METHOD

Tsunami Modeling: Several tsunami scenarios were simulated with the TUNAMI-N2 model, generating inundation-depth and arrival-time maps for seismic sources along the Central Peru subduction zone.

Population: Census data were aggregated at the block level.

Evacuation Model: Evacuation shelters were placed outside the inundation zone based on the worst-case scenario. Shortest-path analysis was used to derive evacuation routes from each urban block, producing minute-by-minute movement trajectories.

Impact Estimation: Affected, injured, and fatality counts were estimated by comparing evacuation travel times with tsunami arrival times and applying a depth-dependent tsunami-casualty fragility function. Sensitivity analyses evaluated variations in moving speed (Ms) and reaction time (Rt).

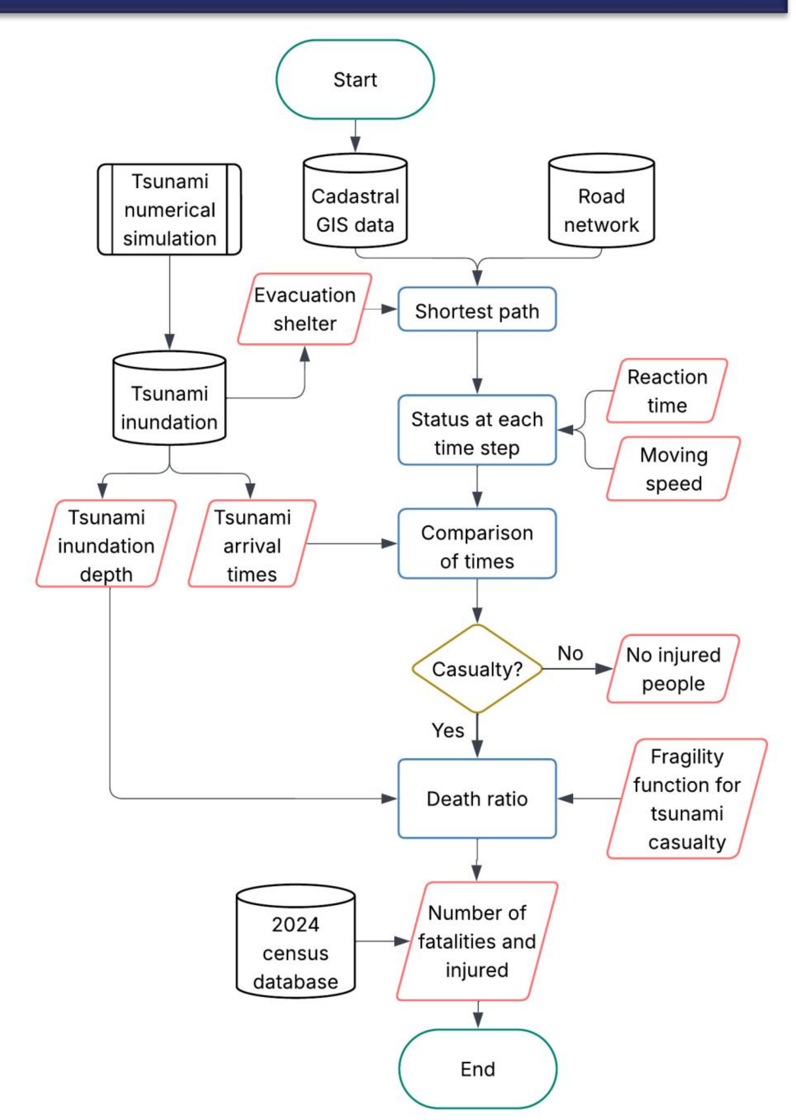
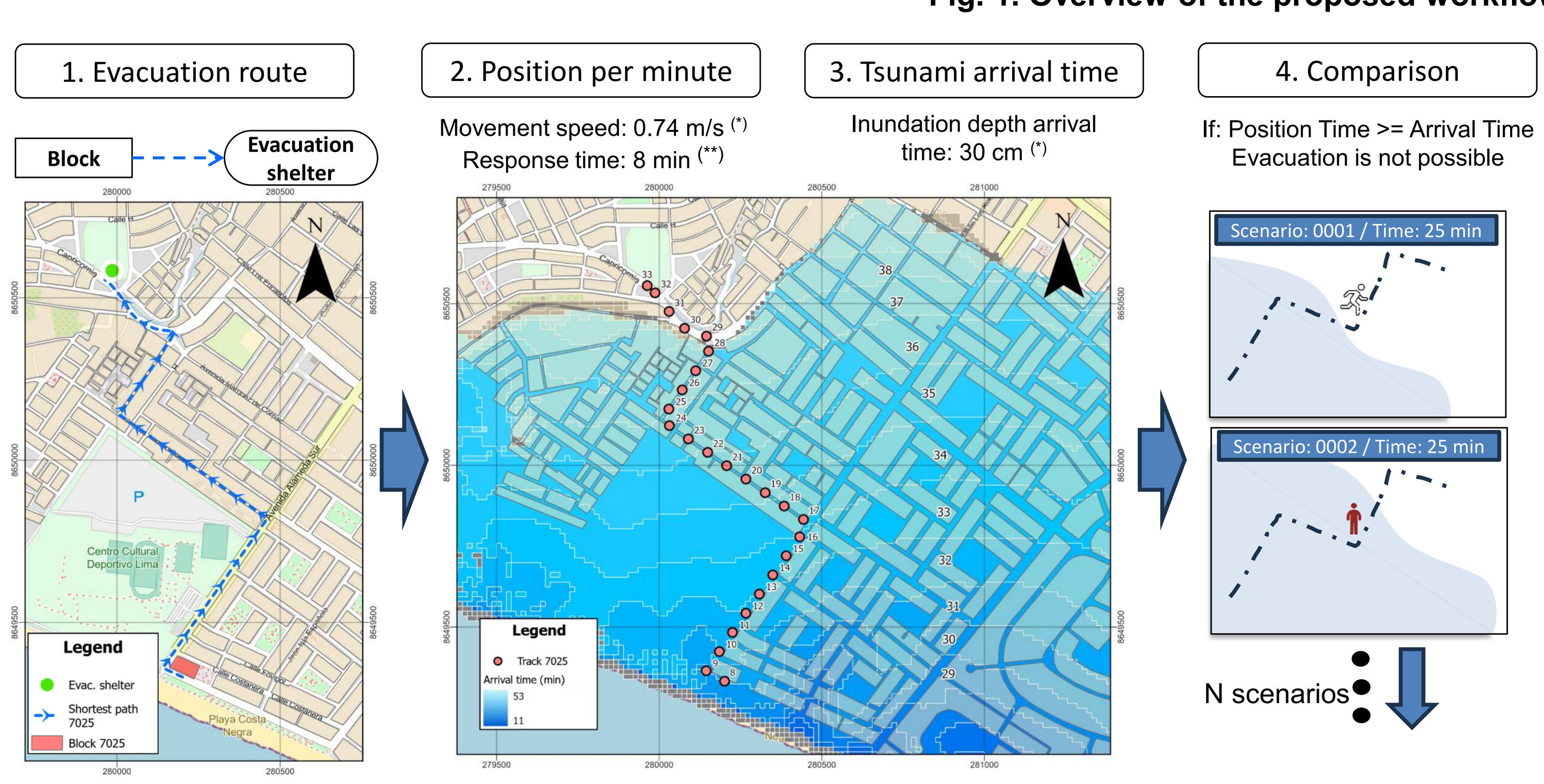


Fig. 1. Overview of the proposed workflow.



(*) Ministry of Land, Infrastructure, Transport and Tourism (MLIT). (2012). *Guide to Determining the Potential Tsunami Inundation*

(**) National Institute of Civil Defense (INDECI): *Standard Operating Procedures*

Fig. 2. Representation of evacuation routes and tsunami arrival times on GIS maps.

RESULTS & DISCUSSION

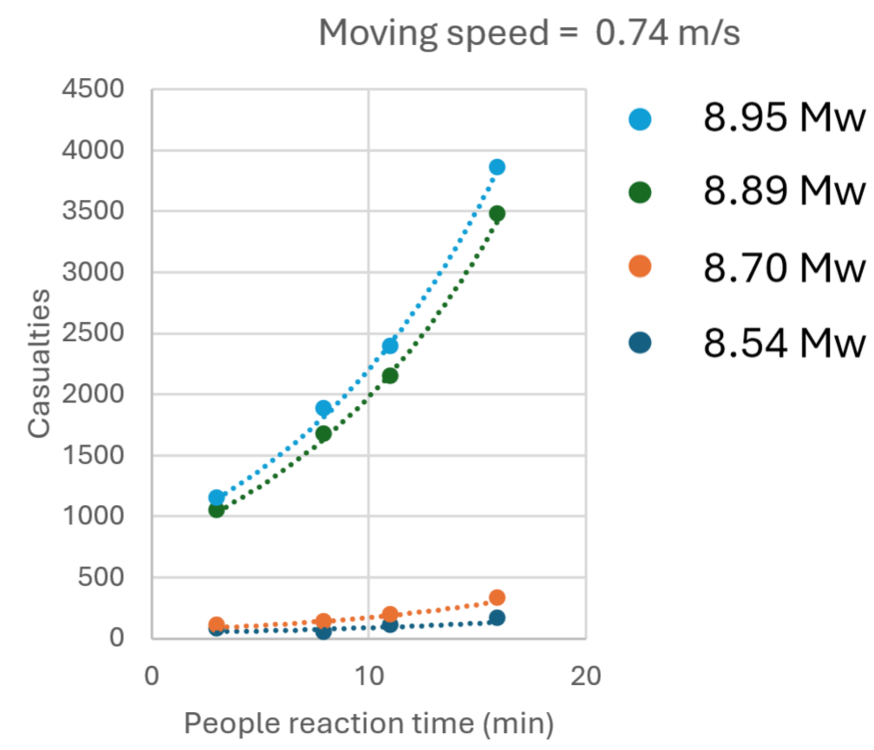


Fig. 3. Casualty estimation (Rt: var., Ms: const.)

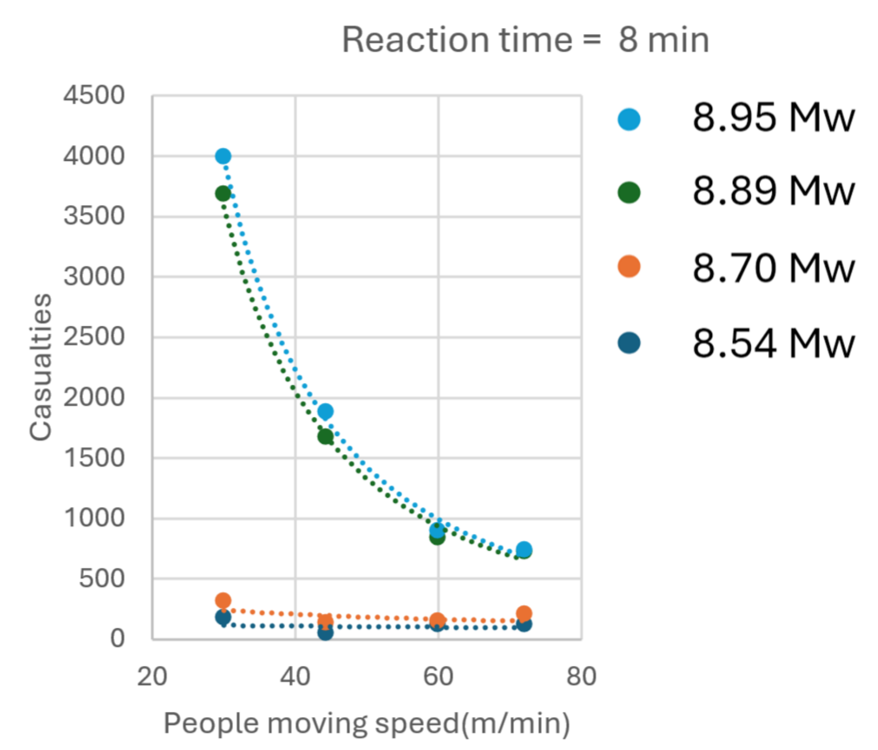


Fig. 4. Casualty estimation (Rt: const., Ms: var.)

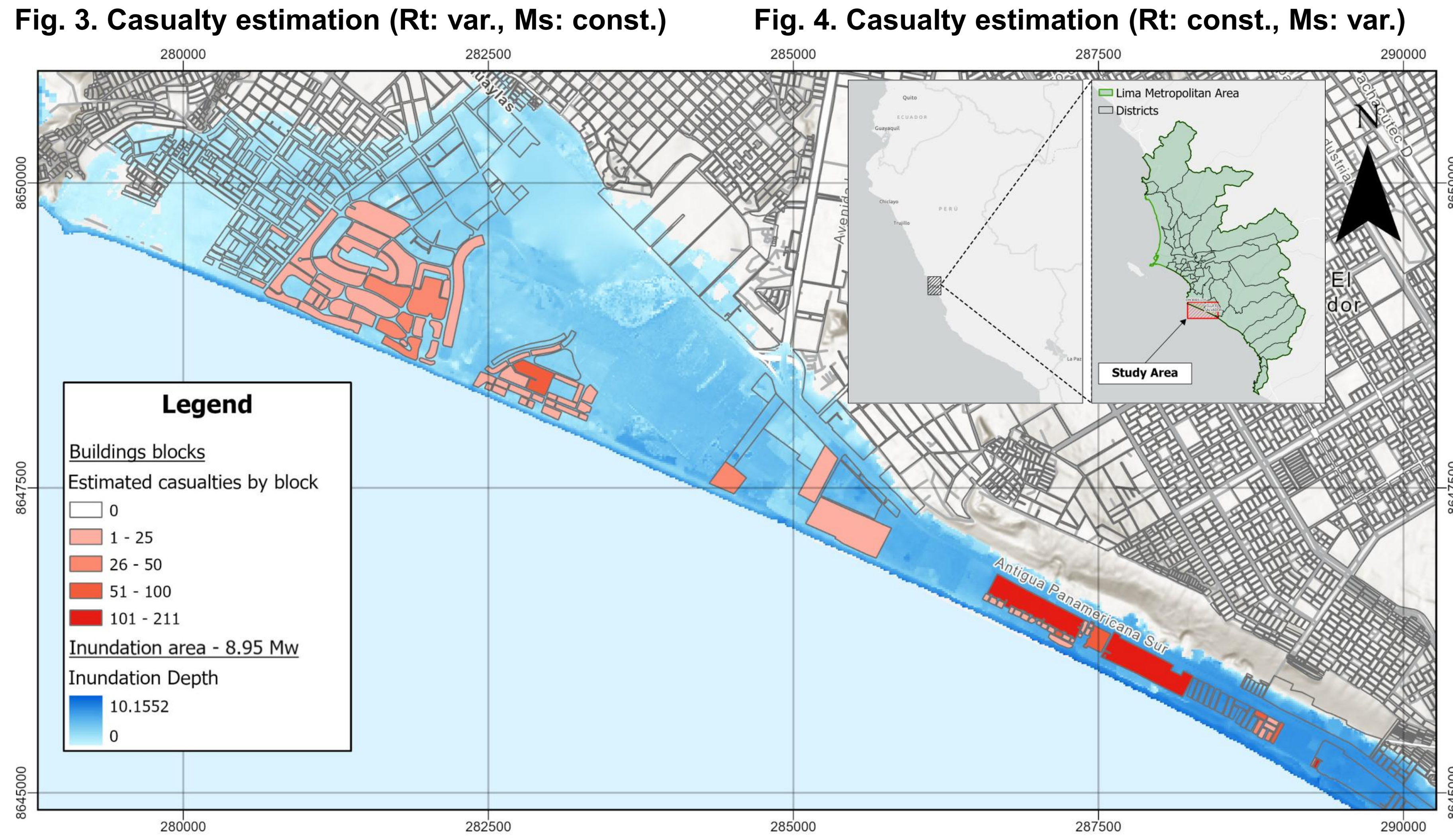


Fig. 5. Map showing inundation depth and estimated casualties by urban block.

The casualty estimates for four tsunami inundation scenarios generated from different seismic sources are presented in Figure 3 (varying reaction times with constant moving speed) and Figure 4 (varying moving speeds with constant reaction time).

Figure 5 displays a spatial distribution map of estimated casualties per census block for the scenario associated with the Mw 8.95 seismic source [4], highlighting in red intense the areas where evacuation could not be completed before tsunami arrival.

Although the approach relies on generalized population and mobility data, it effectively identifies areas with limited evacuation capacity, underscoring the need for targeted disaster mitigation measures in these high-risk locations..

CONCLUSION

The proposed methodology demonstrates that evacuation and casualty estimation can be performed with low computational demand, enabling the identification of zones with limited evacuation feasibility and supporting the strategic planning of disaster risk reduction measures, such as the placement of safe evacuation areas.

While the generalized datasets and simplified representation of human behavior limit the precision of fatality estimates, the method remains a useful, efficient, and scalable tool for recognizing critical areas where evacuation challenges arise due to road network availability and accessibility.

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