A rapid decision-support tool to assess flood-induced accessibility disruptions

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Abstract

Ensuring a functional road network during disasters, one that is robust and redundant enough to maintain connectivity in urgent situations, particularly to hospitals, is crucial for minimizing societal disruptions and protecting community wellbeing. In this study, we present an automated and scalable decision-support tool to identify critical road segments in terms of accessibility and connectivity to essential public services and infrastructure. To exemplify our approach, we evaluate population accessibility to healthcare facilities via the road network under nationwide flood scenarios in Georgia. The results provide valuable insights for policymakers on the impact of hazards on road network accessibility from a community vulnerability perspective, rather than focusing solely on economic impacts. These insights are essential to better guide budget allocation and prioritization from an equity perspective.

Keywords: accessibility; road network; flood impact; decision-support tool

Introduction

Timely and equitable access to some critical destinations is a fundamental social right, as delays can lead to severe consequences (Al-Worafi, 2023). This issue becomes even more critical during natural hazard events, when disruptions to mobility exacerbate existing vulnerabilities and restrict access to hospitals, shelters, evacuation routes and other vital social infrastructure (Balomenos et al., 2019). Recent studies highlight the importance of quantifying healthcare accessibility (Weiss et al., 2020) and its disruption under hazard scenarios (Tariverdi et al., 2023; Petricola et al., 2022).

In this study, we present a decision-support tool to assess the impact of potential hazards on access to essential destinations and the resulting non-financial losses. This approach helps policymakers to evaluate hazard impacts from a societal perspective. The workflow enables a rapid yet robust assessment of access vulnerabilities under hazard conditions, producing results that are clear and actionable for decision-making. To exemplify the workflow, we analyze the impact of floods on vehicle access from population areas to hospitals in Georgia.

Methodology

The scalable decision-support tool that is developed here automates data acquisition for the country of interest, including road networks, population distribution, and destination points (e.g., healthcare facilities, airports or ports), then cleans the data, models transportation networks as a diagraph. Simulates flood scenarios, and an adjustable threshold water level is applied to identify road segments blocked by inundation. For each simulated event, the affected road segments are removed, and network analysis is performed on the damaged system. The resulting loss metric, defined as travel time under free-flow conditions, is computed using the Dijkstra algorithm (Dijkstra, 1959). Changes in accessibility are then quantified by comparing disrupted travel times with baseline conditions. The tool is designed and developed as Python code that will be publicly available on GitHub.

Population data are collected from WorldPop, a global open-source initiative providing high resolution population distribution datasets. Road network data and the destination data points are sourced from the OpenStreetMap (OSM) database, a collaborative mapping platform that offers detailed geospatial data for roads and infrastructure.

To demonstrate the application of this workflow, here we present the assessment of vehicle accessibility of population to the health facilities in Georgia under several flood scenarios. Georgia is a country located at the intersection of Eastern Europe and Western Asia, with a population of approximately 3.8 million. Health facility data (hospitals and clinics) are derived from OSM. To represent disruptions, single-hazard event sets are created using basin and subnational geometries from the HydroSHEDS project (Lehner et al., 2013). Flood depths for these basins are derived from the latest Fathom flood hazard maps (Fathom Global, 2022), The threshold for water level is set to 25 cm due to the average height of air inlets of regular vehicles and falls within a commutable range studied by Pregnolato et al. (2017). Considering there is no standard 'golden time' applicable to all situations, different policymakers might have different requirements, we present the results of the loss in access time as curves. This curve is plotted versus time thresholds to make the results interpretable and adaptable for diverse needs.

Results and discussion

In figure 1, panel A shows the healthcare access time under normal conditions. Panel B shows the total affected population in each basin, where each basin represents the location of a fluvial flood event. Panel C shows the critical road segments impacted by the top ten flood events in terms of the number of affected people.

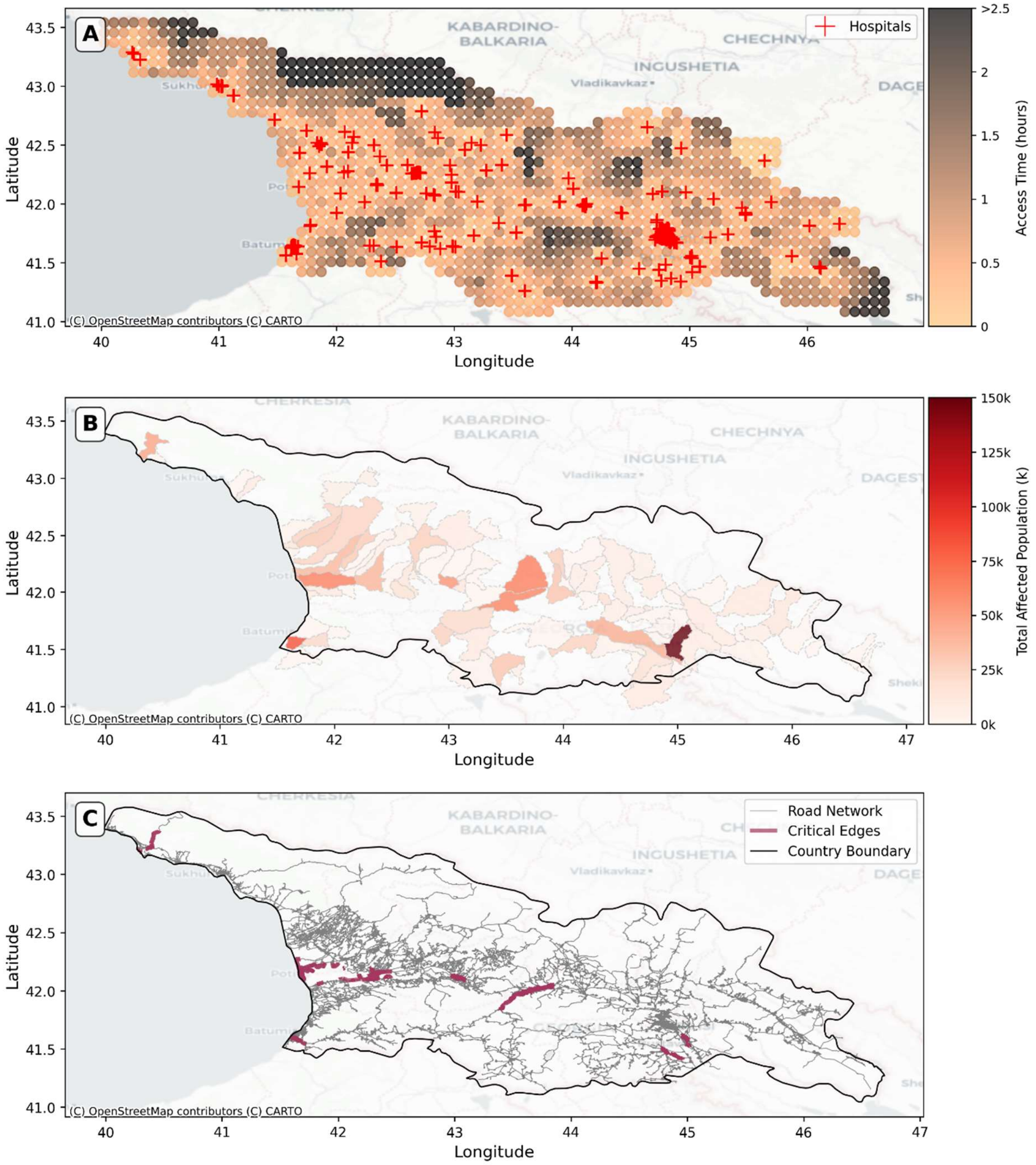

Figure 1. A) The access time to the closest health facilities under normal conditions B) The total affected population by each created flood event. C) the critical road segments damaged by flood events that led to the highest number of affected populations.

Figure 2 shows an example of loss modeling and the results for one of the fluvial flood events of this study. The total affected population by this event is about 75,000 people. Panel A shows the damaged road segments by the flood and Panel B illustrates the states of access to healthcare in the pre- and post-event conditions. In this event, a portion of the population completely lost access without an alternative route; therefore, the curve for the post-event condition will not reach 100% of the population until the road blockages are restored.

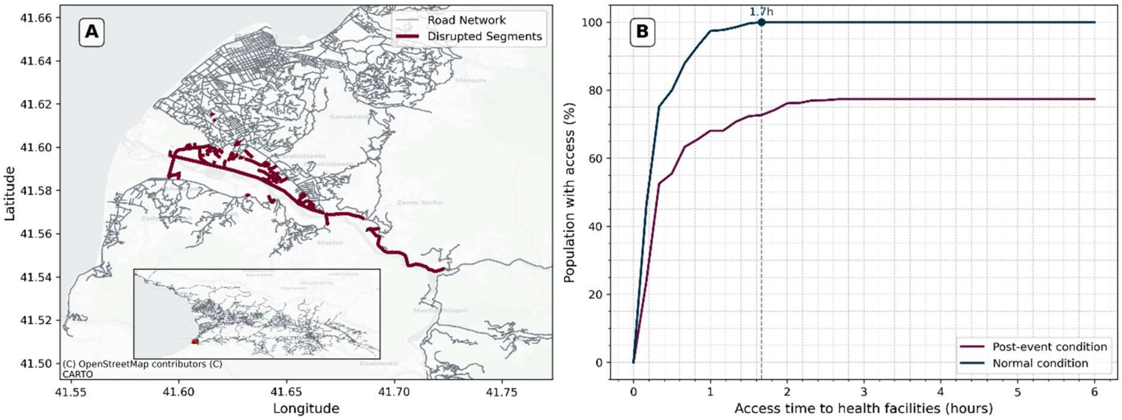

Figure 2. A) The road segments impacted by a flood event. B) The access curve shows the percentage of the population who could reach the health center within several time thresholds under normal and flooded conditions. It highlights what percentage of the population, within any defined time threshold (golden time), has access to their closest health facilities.

Conclusions

This paper presented a sample application of the developed scalable automated decision support tool, focusing on vehicle access to health facilities in Georgia. By using publicly available databases, the workflow is applicable even in data-scarce areas. The loss modeling results provide a general but clear overview of vulnerabilities in access to important destinations under flood conditions, highlighting critical road segments based on their social impact and the number of affected populations rather than just economic impact. These insights are valuable for policymakers in allocating and prioritizing budgets for developing effective risk mitigation strategies.

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