

# Impact of fault modeling assumptions on regional seismic risk assessment: A case study of the 1963 Skopje earthquake, North Macedonia

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## The study area

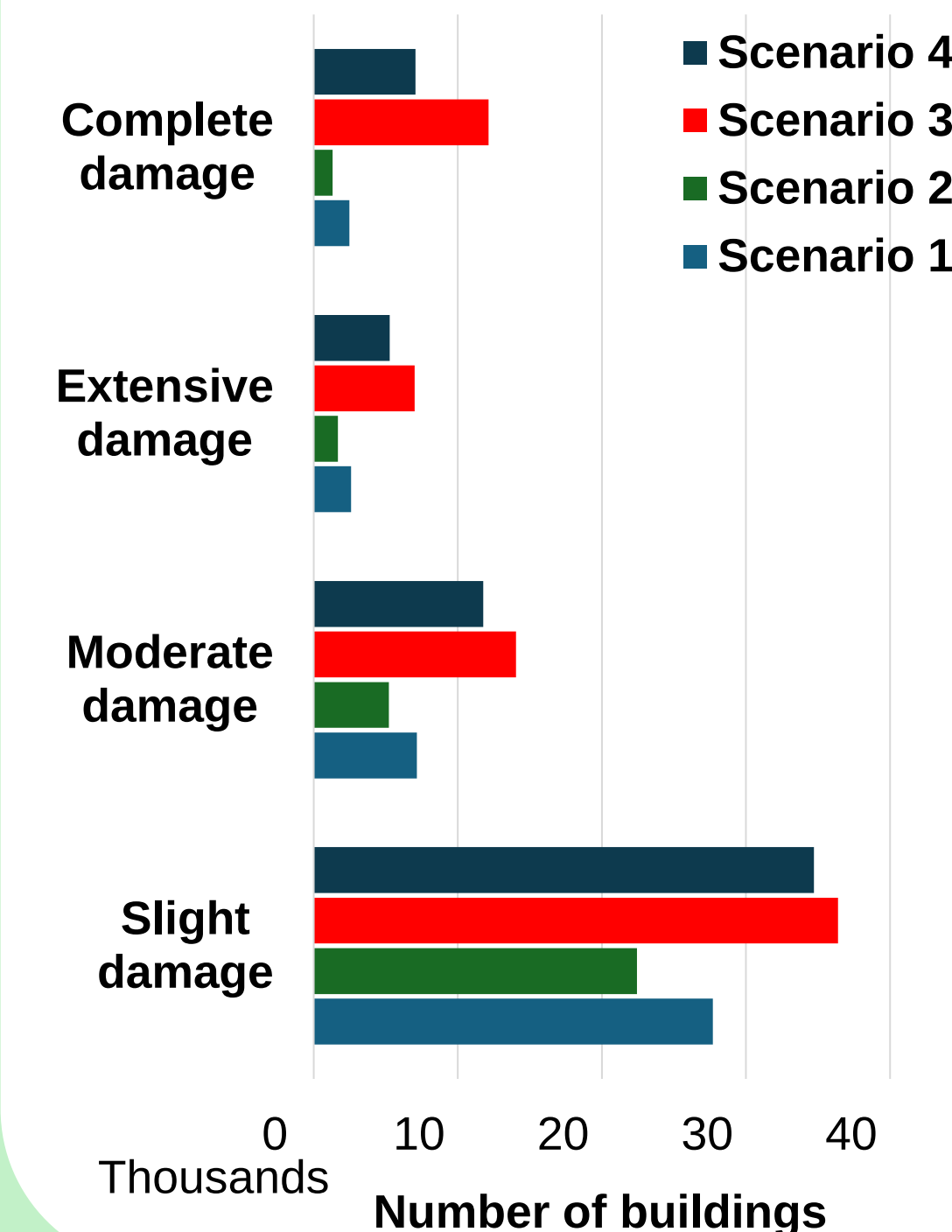
North Macedonia lies near the boundary between the Eurasian and African tectonic plates, whose movement causes frequent moderate to strong earthquakes, making the Balkan region among the most seismically active in the Mediterranean.

The Skopje region is the most densely populated among the eight regions of North Macedonia. It comprises 17 municipalities (9 urban and 8 rural), and it accommodates approximately one-third (607K) of the country's total population, highlighting the critical importance of seismic risk assessment in this area.

The **Skopje earthquake of July 26, 1963**, was one of the most destructive and devastating events, causing significant damage and losses to the region's building inventory.



## Scenario damages



## Vulnerability and exposure models

North Macedonia is one of the 44 countries included in ESRM20. Its exposure model, based on data from the State Statistical Office, comprises 446,231 residential, 12,051 industrial, and 35,545 commercial buildings. The **ESRM20 exposure model** (Crowley et al., 2020) was adopted in this research.

Similarly, the **ESRM20 fragility and vulnerability models** (Crowley et al., 2021) are used to characterise building response and estimate scenario damages and losses.

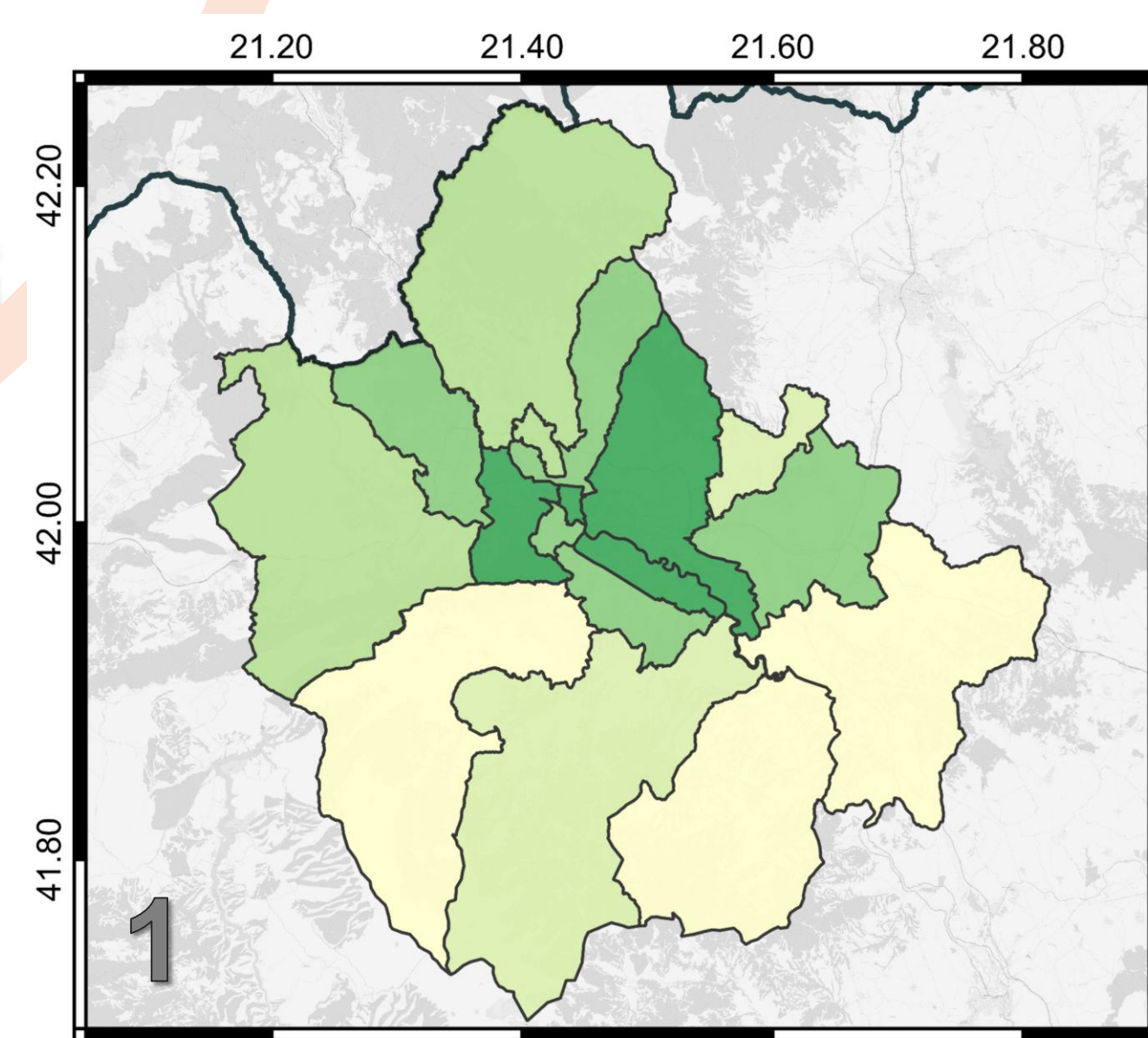
## Skopje 1963 Earthquake: Scenarios Modeling

Despite being studied extensively, the 1963 Skopje earthquake is modeled with varying input parameters (i.e., **depth, magnitude, fault kinematics**) in different sources, revealing inconsistencies in the seismic hazard characterization of the region.

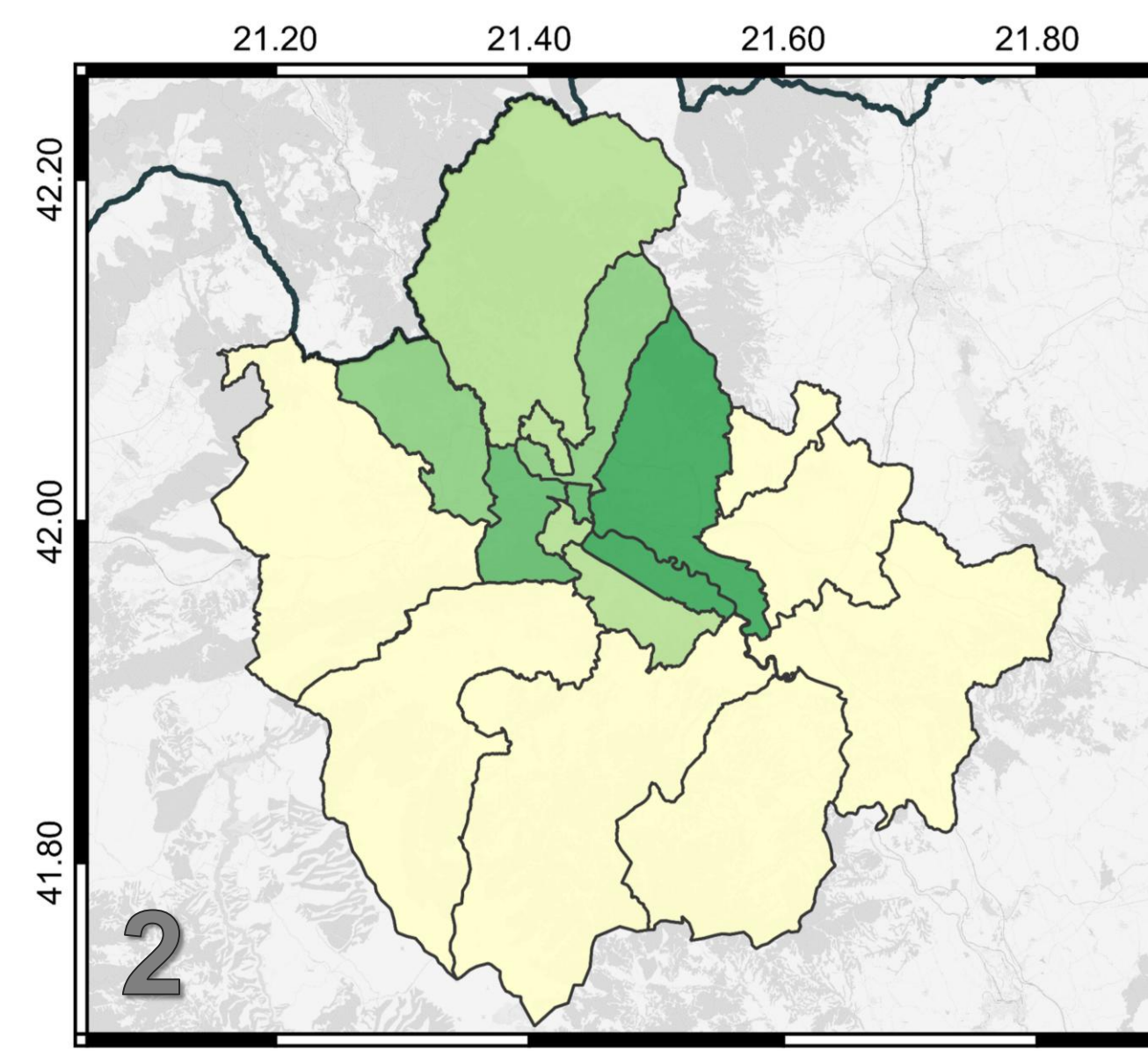
Given its influence on ground motion and seismic risk, the careful selection of input parameters is crucial in scenario modelling, which serves as the primary motivation for this work

|   | Reference                    | strike | dip | rake | depth | M <sub>w</sub> | Kin. |
|---|------------------------------|--------|-----|------|-------|----------------|------|
| 1 | Drogreshka (2018)            | 303    | 77  | -1   | 15    | 6.01           | SS   |
| 2 | Anderson and Jackson (1987)  | 303    | 74  | -21  | 5     | 5.30           | SS   |
| 3 | Suhadolc et al. (2004)       | 298    | 79  | 22   | 9     | 5.90           | SS   |
| 4 | ESHM20, Danciu et al. (2021) | 209    | 70  | -55  | 10    | 5.96           | NF   |

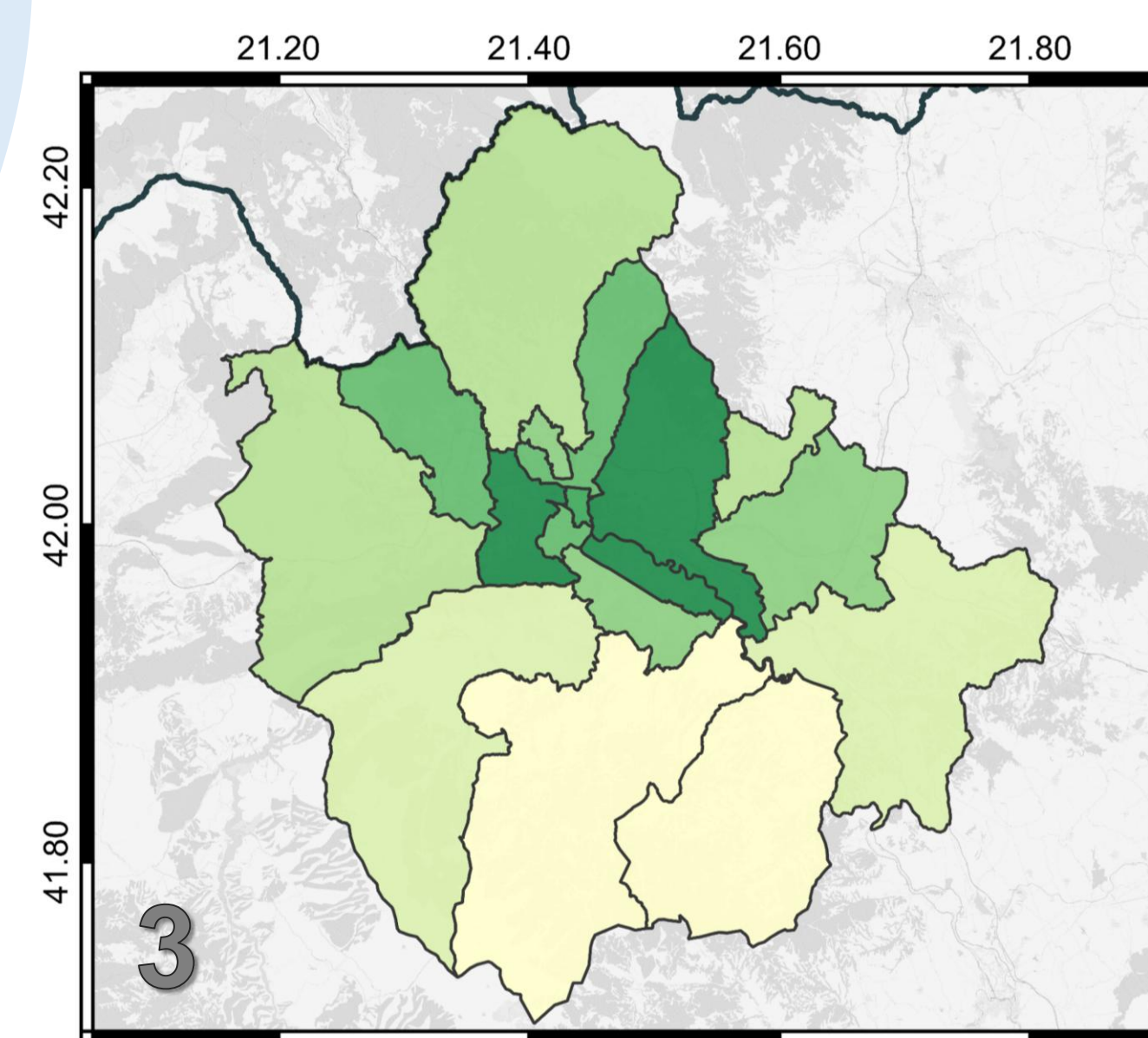
## Scenario losses



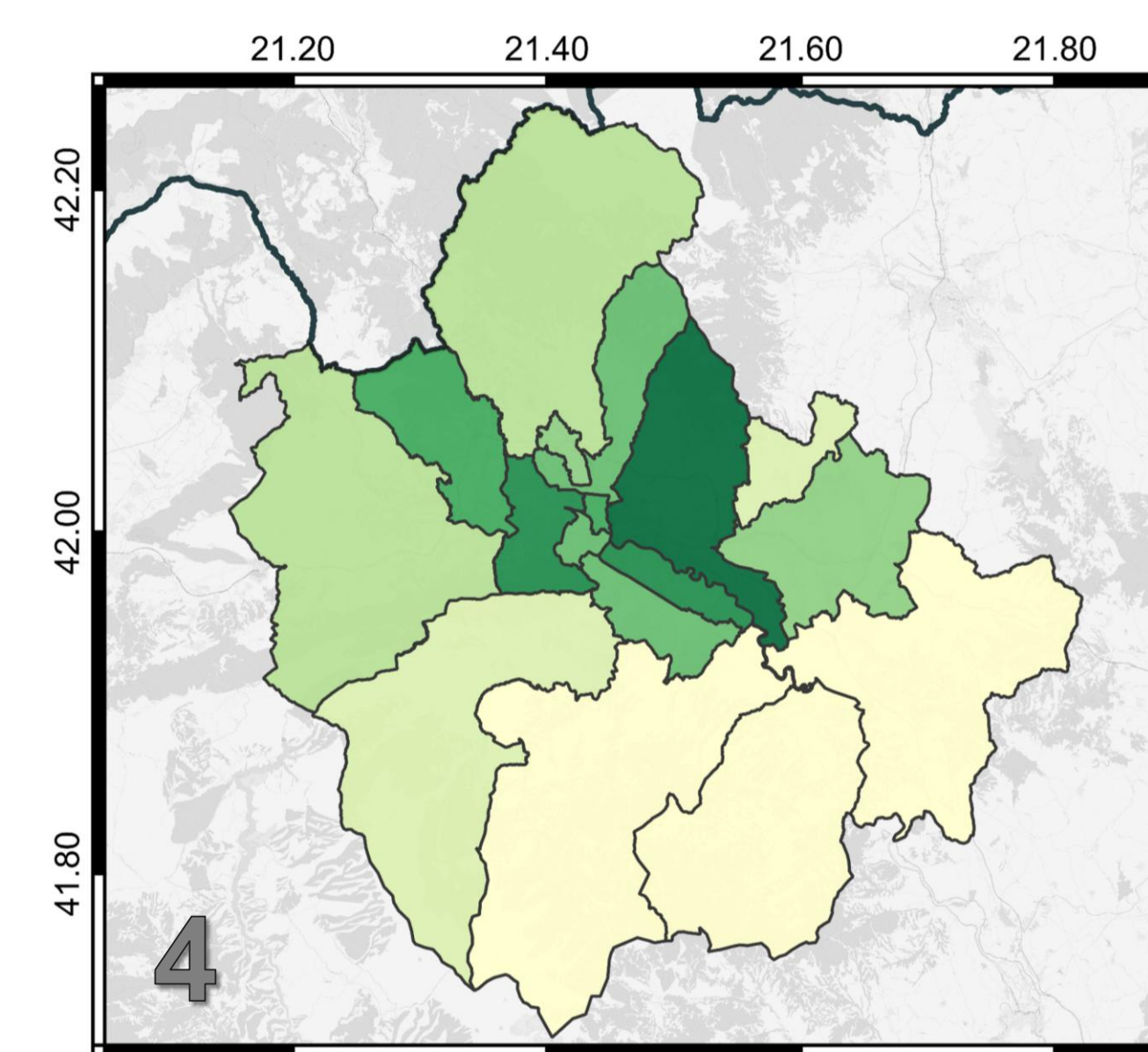
Structural loss: **1,041,483,840.0€**  
Loss extent: 7% of total building area  
Fatalities: **76**



Structural loss: **431,285,300.0€**  
Loss extent: 3% of total building area  
Fatalities: **29**

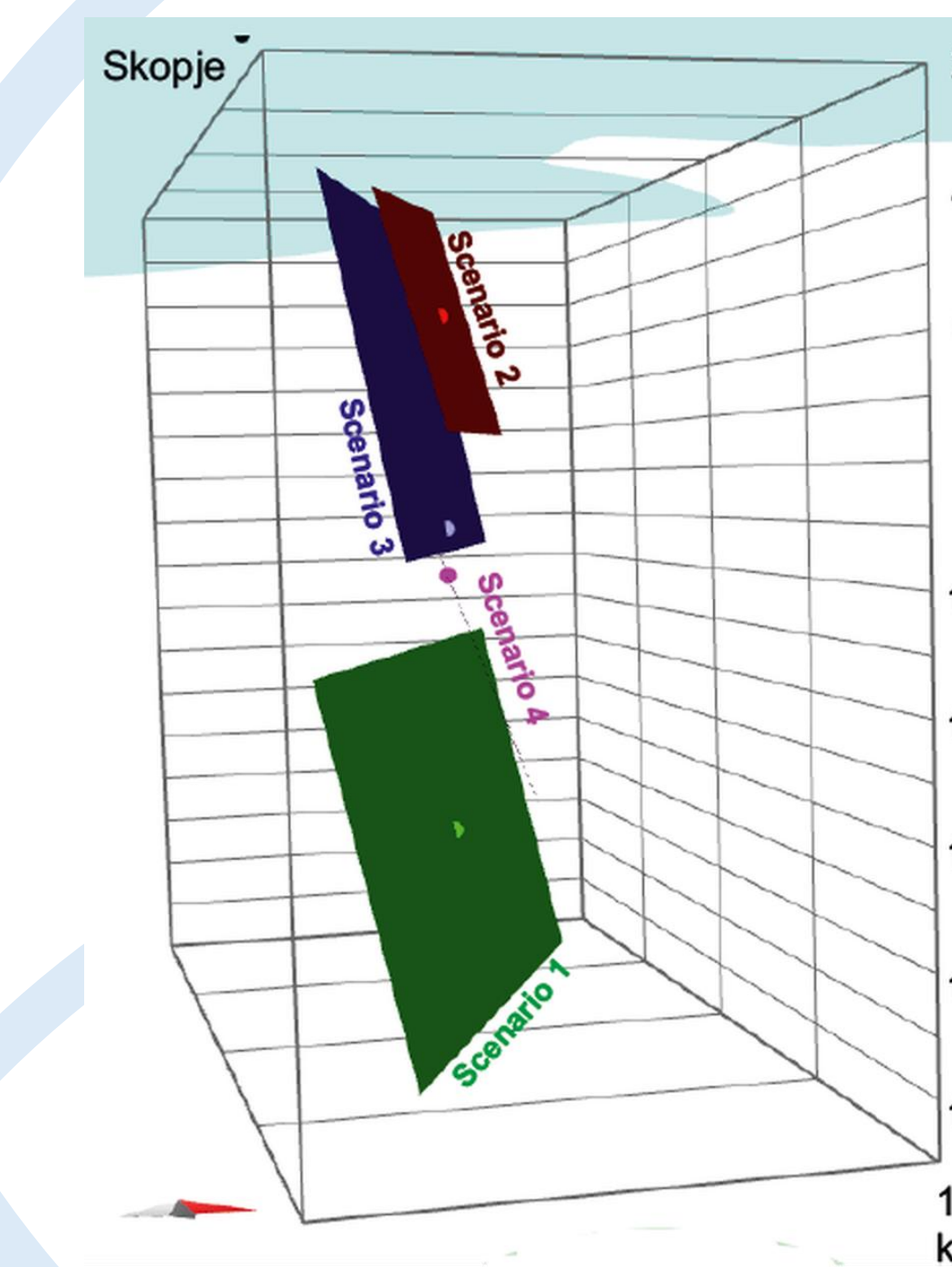


Structural loss: **2,447,831,600.0€**  
Loss extent: 17% of total building area  
Fatalities: **308**



Structural loss: **1,993,928,000.0€**  
Loss extent: 14% of total building area  
Life loss: **192**

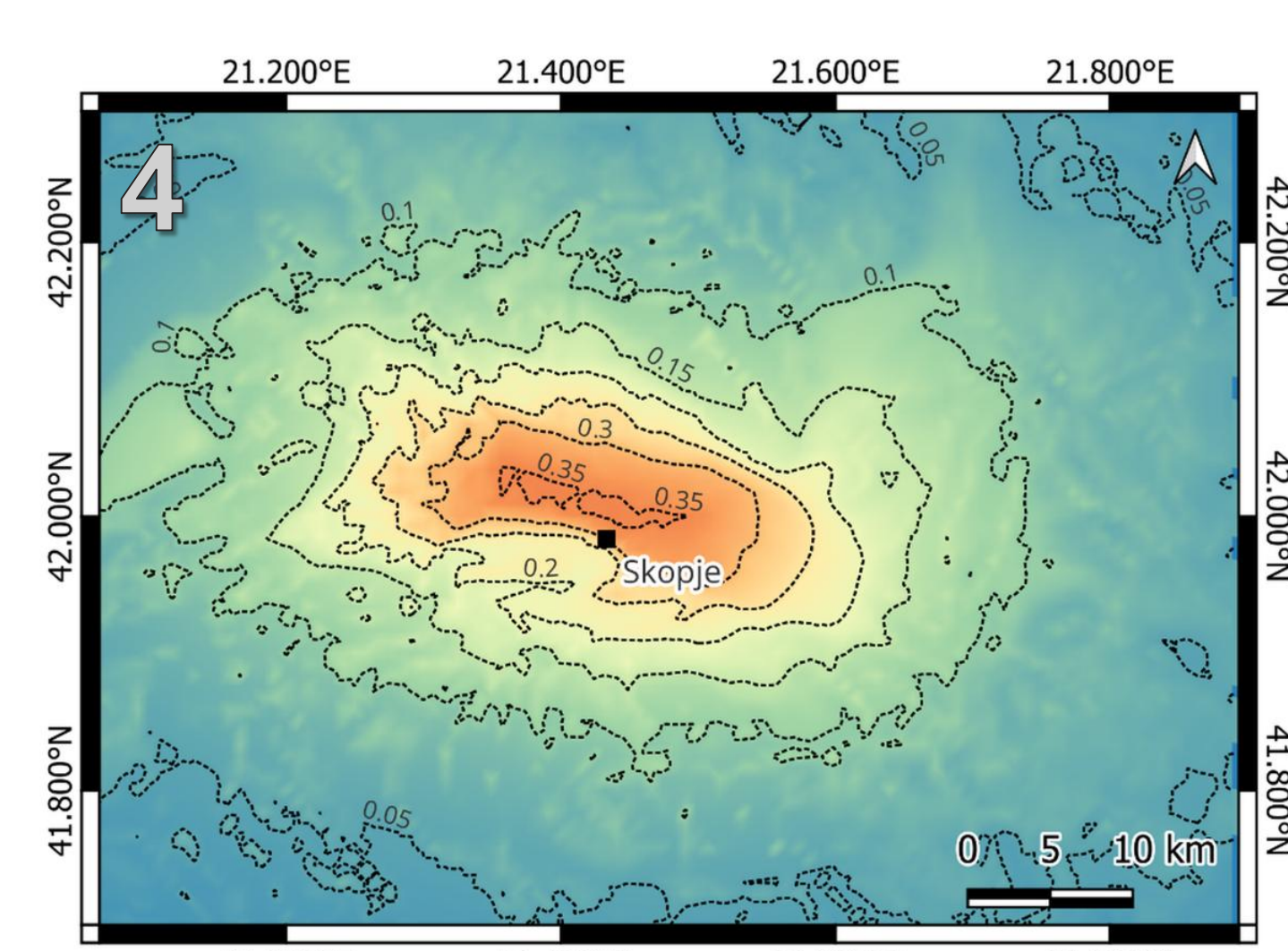
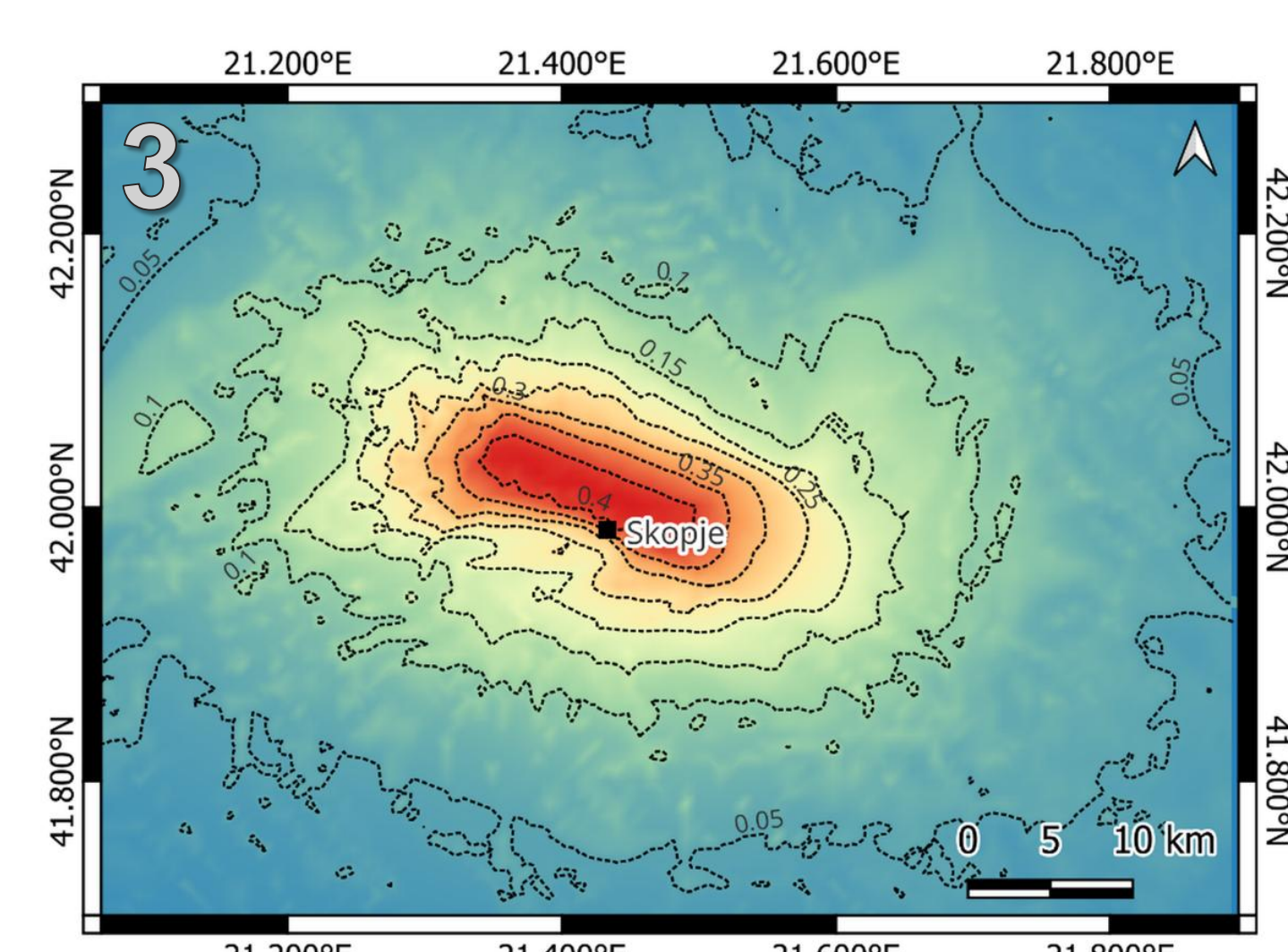
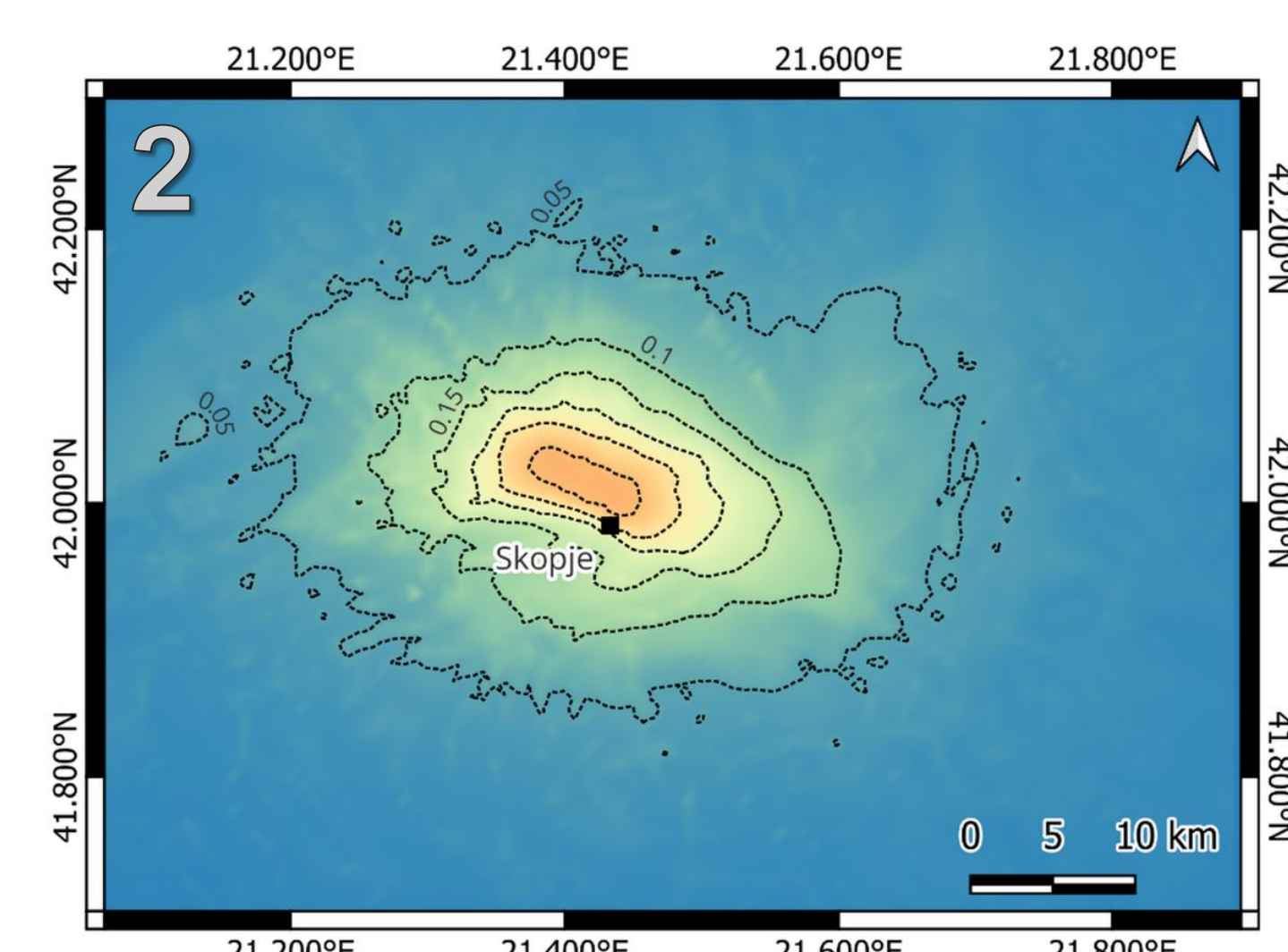
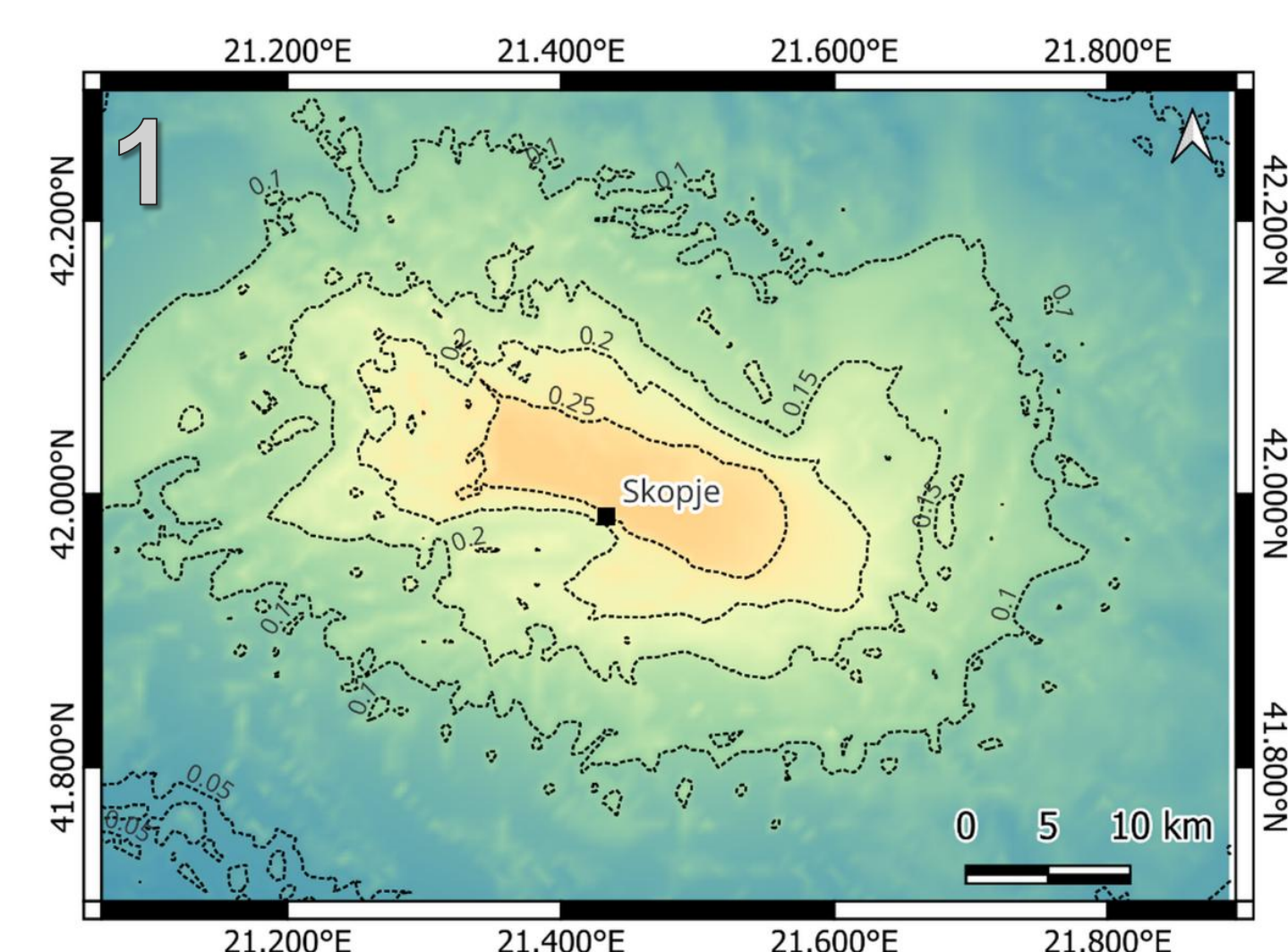
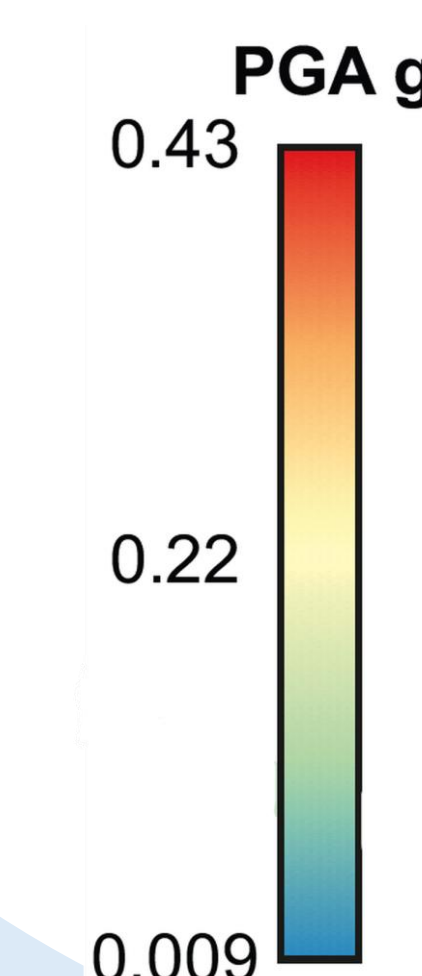
## Scenario Hazard



Each rupture scenario was modelled, and its impact on ground shaking was evaluated in terms of **Peak Ground Acceleration (PGA)**. The analysis were conducted using the OpenQuake engine (Pagani et al., 2014).

To effectively visualize the impact of different rupture depths and geometries, the GMM by **Chiou and Young (2014)** was utilized. This model incorporates rupture distance (*R*) to scale ground motion intensity relative to moment magnitude (*M<sub>w</sub>*), as well as the rupture's depth and its distance from the site. Additional rupture parameters considered in the analysis include dip angle and rake.

To account for site response (*V<sub>s30</sub>*), site parameters were considered based on the **USGS database** (Heath et al., 2020).



## Conclusions

- This study assessed how seismic hazard input parameters affect ground motion and consequently the seismic risk in Skopje, North Macedonia.
- Four literature-based hazard scenarios were modelled, revealing significant variability in ground motion and resulting building damage.
- The discrepancy between current loss estimates and the actual 1963 earthquake impact is due to post-earthquake improvements, including building retrofits and the introduction of two new seismic codes.
- A sensitivity analysis will be carried out in the future to identify the most critical parameters in scenario modeling in the scope of a regional seismic risk assessment.