Probabilistic Seismic Hazard Assessment Associated with Induced Seismicity at Geothermal Sites in the Upper Rhine Graben

Manuel Hobiger[1], Aida Azari Sisi[1], Andreas Steinberg[1], Thomas Spies[1,2]

1 *Federal Institute for Geosciences and Natural Resources (BGR), Hanover, Germany (manuel.hobiger@bgr.de)*
2 *Clausthal University of Technology, Institute of Geotechnology and Mineral Resources, Clausthal-Zellerfeld, Germany*

Bundesanstalt für Geowissenschaften und Rohstoffe

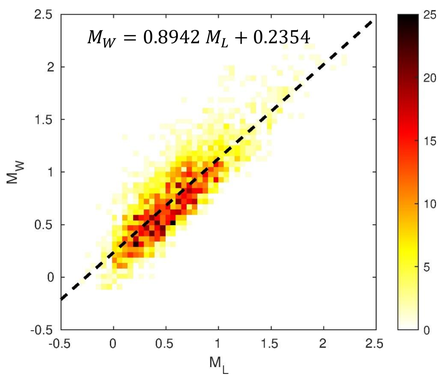
Summary

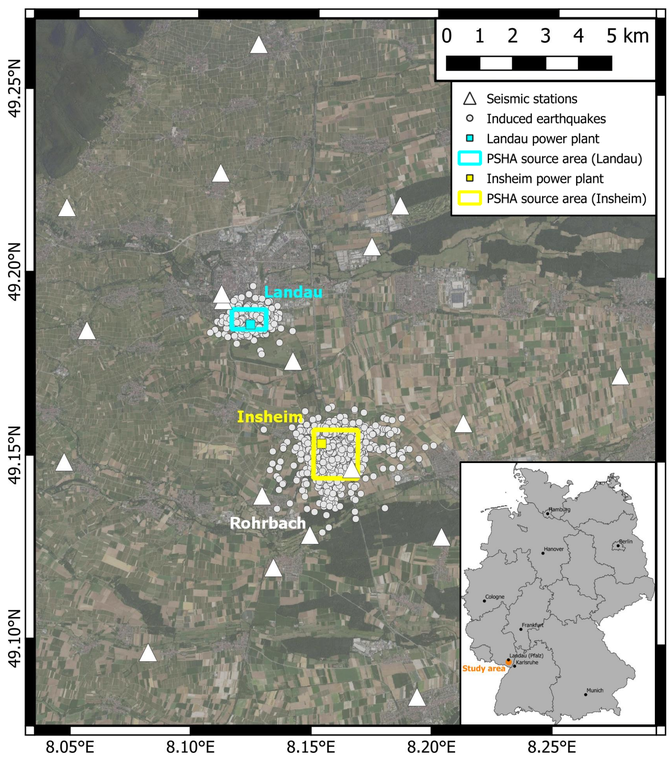
The two geothermal power plants of Landau and Insheim are located in the Upper Rhine Graben in Southwest Germany. A local seismic network consisting of 19 stations monitored the induced seismicity between 2012 and 2022, resulting in an earthquake catalog comprising 930 events for the Landau reservoir and 1985 events for the Insheim reservoir.
Changes of the extraction parameters, such as injection pressure and volume, lead to relatively large numbers of induced earthquakes. Using temporal subsets of the earthquake catalog, a probabilistic seismic hazard assessment (PSHA) is conducted for different time windows, showing larger expected peak ground velocities (PGV) in times of higher induced seismicity.
By performing passive seismic measurements in the area around the village of Rohrbach, shear-wave velocity profiles were obtained from the shallow surface down to several hundreds of meters. Large near-surface variations of the velocity profiles are found on small distances, affecting the local seismic hazard assessment considerably.

Earthquake catalog

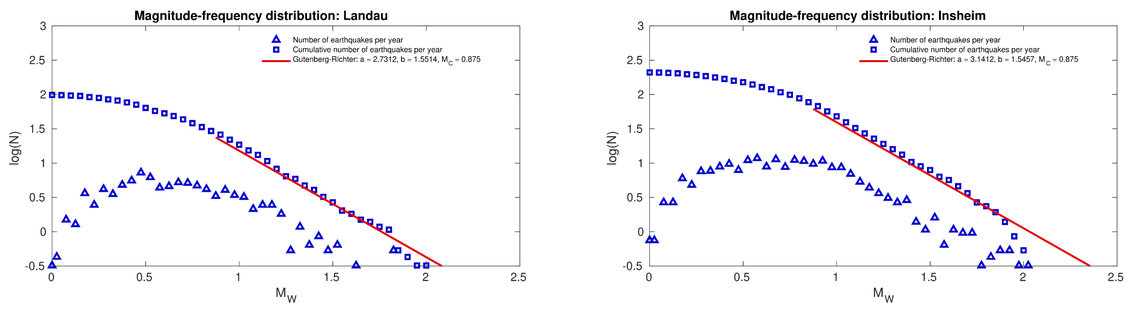
Steps in the compilation of the earthquake catalog:

- Denoising of the waveform data
- Detection of possible events (stacking detector / AI-based approach)
- Localization
- Determination of M_L and M_W





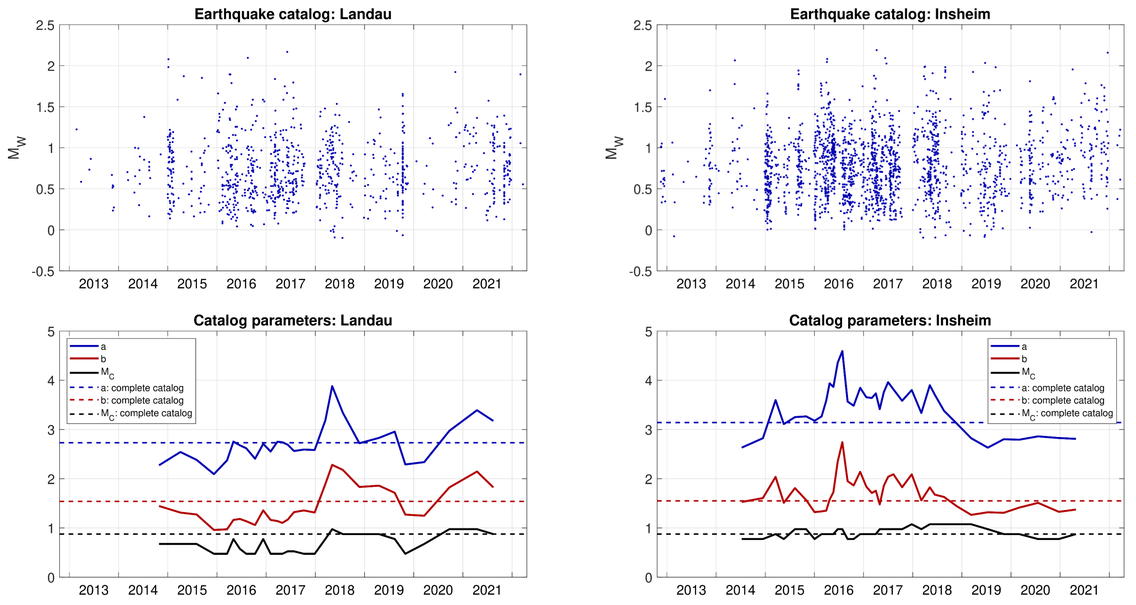
Magnitude-frequency distribution



The magnitude-frequency distributions for the earthquake catalogs for the two reservoirs in Landau (930 events) and Insheim (1985 events) give similar b values, but the a value for Insheim (3.14) is larger than for Landau (2.73), reflecting the larger number of induced earthquakes of the reservoir.

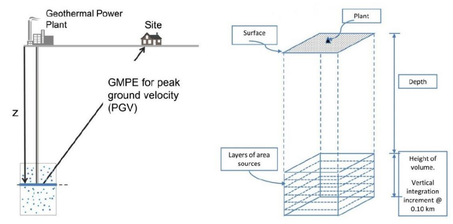
Temporal evolution of the earthquake catalog

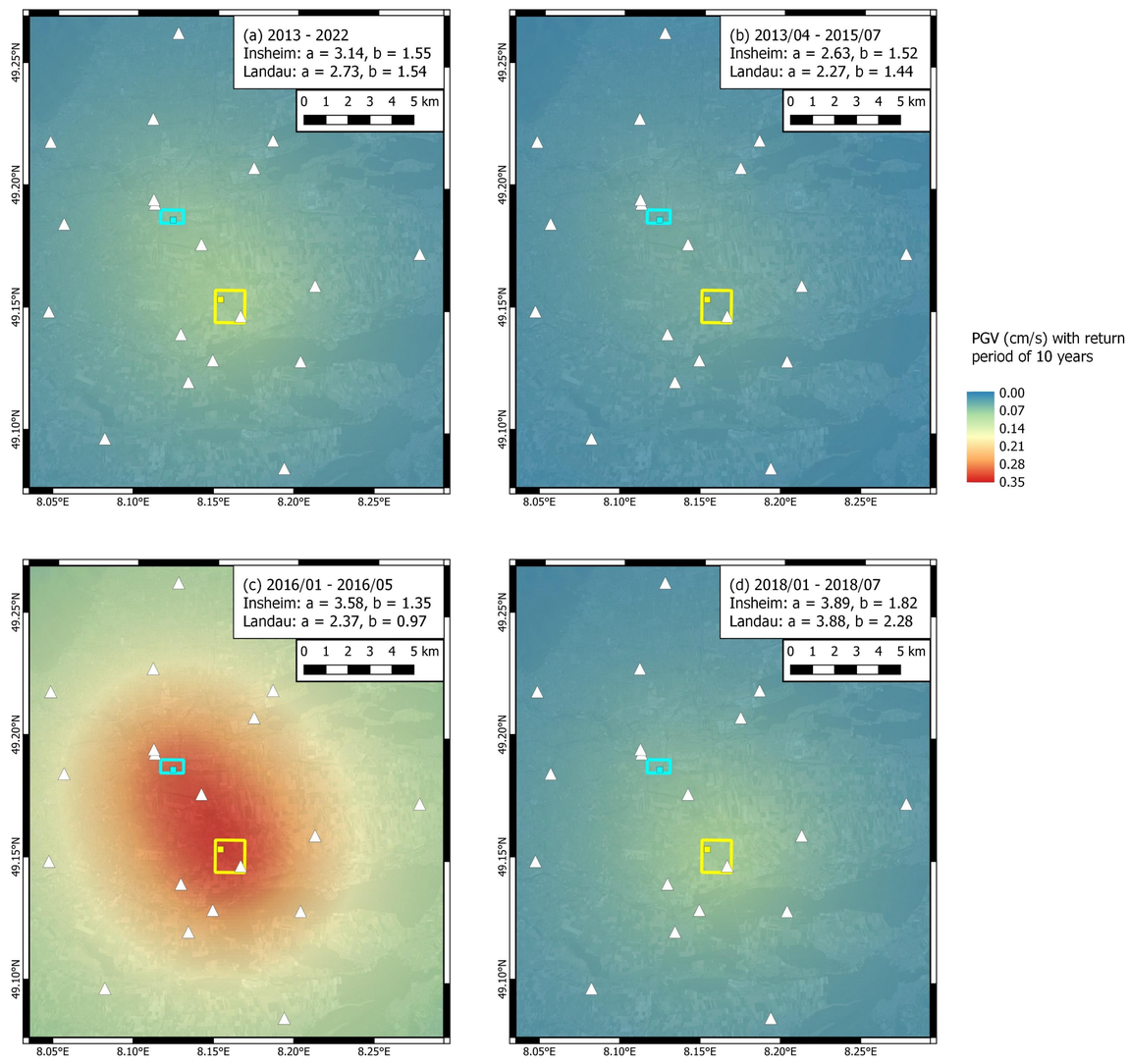
Both reservoirs show periods of increased seismicity and more quiet periods. Using subsets of the earthquake catalogs, the temporal evolution of the Gutenberg-Richter parameters is investigated. These subsets include 100 events for Landau and 200 events for Insheim with overlaps of 30 and 50 events, respectively. The number of events above M_C in the different subsets varies between 26 and 83 events for Landau and between 42 and 119 for Insheim. The clustering of the events results in a large variability of the a and b values with time.



Probabilistic seismic hazard assessment (PSHA)

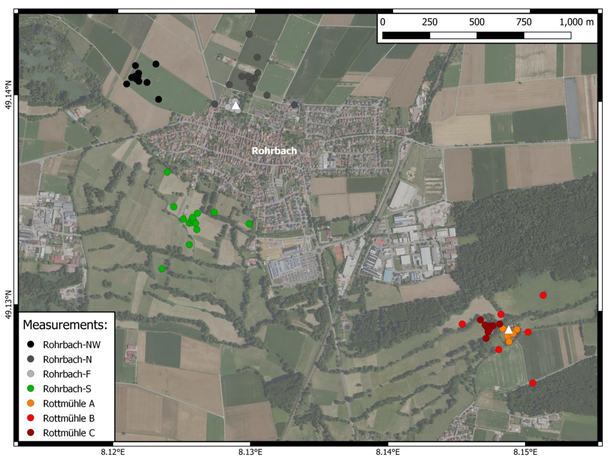
Time-dependent PSHA was performed using the EZ-FRISK software package. Taking appropriate GMPEs, a truncated exponential model with M_{min} = 0.5 and M_{max} = 3.5 was used.
The seismicity was attributed to the source areas (including 90 % of the earthquakes in each coordinate direction) with the respective Gutenberg-Richter parameters for the different time windows.

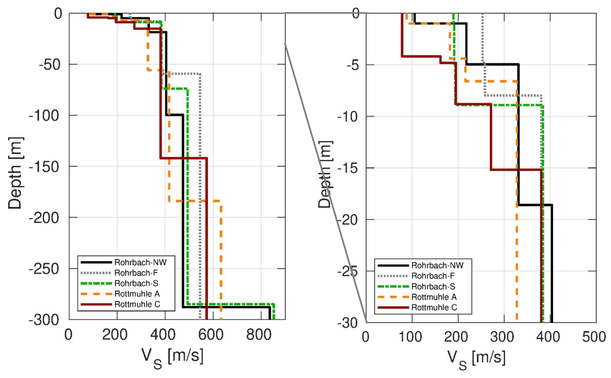




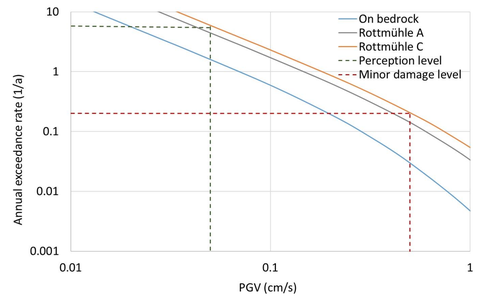
For the complete catalog (a), the maximum PGV of 0.09 cm/s is found above the Insheim reservoir. For the second time window (b), a smaller maximum PGV of 0.05 cm/s is found in the central part of the area. The third time window (c) corresponds to the highest seismic activity in the area. Here, a maximum PGV of 0.34 cm/s is found above the Insheim reservoir. The last analyzed time window (d) is very similar to (a), with a maximum PGV of 0.09 cm/s above the Insheim reservoir.

Site effects





Around the village of Rohrbach, several passive seismic array measurements were performed to retrieve shear-wave velocity profiles.
They show a large variability, especially in the near-surface parts, with V_{S30} values ranging from 214 m/s at Rottmühle C over 269 m/s at Rottmühle A to about 337 m/s at Rohrbach-F. The large difference between Rottmühle A and C is caused by a 4 m thick soft-sediment layer at Rottmühle C.
Taking this site effect into account, more than three induced earthquakes per year should be felt at Rottmühle C with the magnitude recurrence parameters of time window (c).



Further information and details:

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