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Incompatibility of anthropogenic seismicity with probabilistic models typically used in seismic hazard analysis: the case of Oklahoma earthquakes

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The exponential distribution model for magnitude arises from the Gutenberg-Richter magnitude-frequency relationship and the exponential model for interevent time is valid if the earthquake occurrences are governed by a homogeneous Poisson process. The Gutenberg-Richter rule for magnitudes and the Poisson process for earthquake occurrences are typically assumed in stationary earthquake hazard estimation although there are reports showing significant violations of these assumptions in both tectonic as well as anthropogenic seismicity cases. We use Anderson-Darling test to investigate validity of these assumptions for injection induced earthquake data from Oklahoma (Oklahoma Geological Survey, www.ou.edu/content/ogs/research/earthquakes/catalogs.html). The epicenters of analyzed events form two distinct spatial clusters, the one, A, in a north-western part of the study area and the second one, B, in a south-eastern part. The hypothesis that the magnitudes follow exponential distribution is rejected for the whole dataset and for cluster B. The hypothesis that the interevent times follow exponential distribution is rejected for the whole dataset and both spatial clusters. The side hypothesis that the occurrence process is an inhomogeneous Poisson process where interevent times follow a Weibull distribution, is also rejected for all three datasets. Neither an exponential distribution of magnitude nor a Poisson distribution of event rate can be used to assess the stationary seismic hazard due to the anthropogenic seismicity from Oklahoma. For the seismicity cases like in Oklahoma, we propose therefore a new method to approximate event rate distribution, based on estimation of interevent time distribution and computer simulation of event occurrences from this distribution estimate. Regarding magnitude, we replace the Gutenberg-Richter relation-led model with nonparametric estimates of the distribution functions. This approach is fully data-driven hence it reproduces correctly the distributions that underlay data. The differences between hazard estimates obtained with the use of the inappropriate probabilistic distributions: exponential for magnitude and Poisson for event rate, and attained from the proposed approach are significant. Our results indicate that in anthropogenic seismicity cases hazards assessments should be preceded by tests of conformity of the distribution models, which are to be used, with observations. When the tests turn down any of these models, the approach introduced here should be applied.
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