A Statistical Approach to Modeling Induced Seismicity in Oklahoma Using Multiple Linear Regression

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Abstract

Compared to the years 1976-2007, Oklahoma has experienced a 40-fold increase from 2008-2013[2]. These earthquakes are associated with Underground Injection Control (UIC) Class II wells, which inject chemically treated water into porous subsurface rock formations [1]. Oklahoma has been particularly affected by these disposals: prior to 2008, OK experienced about one earthquake (M>3) per year, however, after 2008, the state saw hundreds of earthquakes per year as a result of increased wastewater disposal [5]. Using logistic regression, we took a statistical approach, similar to hydrogeological modeling, to project a probabilistic output for earthquake occurrence.

Model Parameters

Table 1: List of parameters inputted into the model and a description of their effect on causing earthquakes.

Rate of injection (barrels per month)	High rate injection wells are more likely to be associated with induced seismicity than lower rate injection wells.[4]	Pressure of injection	Similar to injection rate, high pressure injections cause more distress and are more likely to result in seismicity.[4]
Injection well distance to basement	Seismic moments are strongly correlated with the proximity of injection to the crystalline basement.[4]	Injection well drilled to basement	In wells drilled to the basement, wastewater is injected directly into the basement, reducing effective stress and possibly causing fault slip.[4]
Well distance to faults	For an earthquake to occur, a fault needs to be reached an activated. Therefore, wells closer to faults are more likely to set off an earthquake.[6]	Likelihood of fault slip relative to injection well	Since faults need to be activated for an earthquake to occur, wells located near faults that are likely to slip are more likely to cause earthquakes.[6]
Earthquake distance to faults	Earthquakes that occur in close proximity to other fault lines are capable of reactivating faults and causing them to slip.[6]	Likelihood of fault slip relative to earthquake	If an earthquake occurs near a fault that is likely to slip, a higher magnitude earthquake may follow as a result of fault slip.[6]

Output Equation = 1.54537 -1.50029 ED_earth.to.fault+ 0.05781 EA_earth.to.fault+ 4.67922 BBLs.month+ 2.27404 Pressure -7.81624 inj.dist.to.basement -4.45288 ED_inj.to.fault+ 0.11057 EA_inj.to.fault+ 0.40077 In_bedrock..Y.N

Regression Analysis

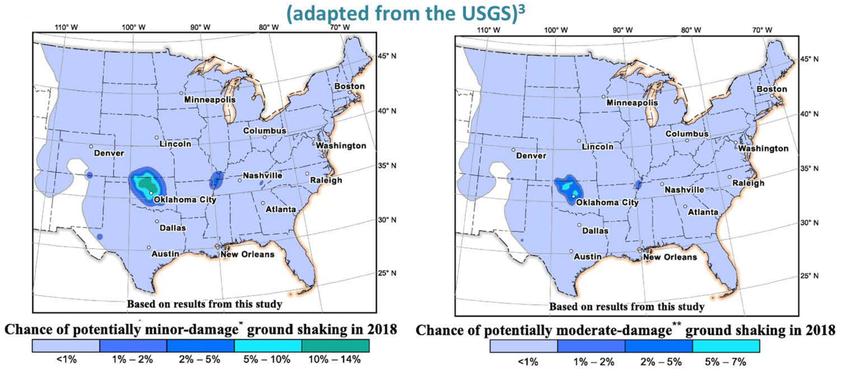
Parameter	Coefficients:	Std. Error	t-value	Pr(>|t|)
(Intercept)	1.54537	0.10357	14.921	< 2e-16 ***
BBLs.month	4.67922	0.13430	34.841	< 2e-16
ED_inj.to.fault	-4.45288	0.14971	-29.742	< 2e-16
Inj.dist.to.basement	-7.81624	0.29308	-26.669	< 2e-16
In_bedrock..Y.N	0.40077	0.03887	10.311	< 2e-16
ED_earth.to.fault	-1.50029	0.21362	-7.023	2.17e-12
Pressure	2.27404	0.10221	22.249	< 2e-16
EA_earth.to.fault	0.05781	0.04992	1.158	0.2468
EA_inj.to.fault	0.11057	0.05190	2.131	0.0331

Table 2. Parameters are ordered from greatest impact on earthquakes to least.. EA_earthquake. to. fault* is not significant ($\alpha > 0.05$) .

Null deviance: 36217 on 28711 degrees of freedom. Residual deviance: 26167 on 28703 degrees of freedom.

Compare to Other Models

2018 One-Year Seismic Hazard for Oklahoma (adapted from the USGS)[3]



Based on the average of horizontal spectral response acceleration for 1.0-s period and peak ground acceleration

Conclusions and Future Work

- The Probability Output map shows much more clearly defined regions of high and low probability than the USGS Hazard Map
- Of all the parameters, rate of wastewater injection (BBLs/month) correlated most strongly with causing earthquakes
- Some parameters were left out of the model and will be investigated in the future. These include:
  - Cumulative volume (BBLs)
  - Spatial/Temporal Clustering of Past Earthquakes
  - Porosity and Permeability of Lithology

*This model works under the assumptions of Binomial Distribution and Interpolation

Methodology

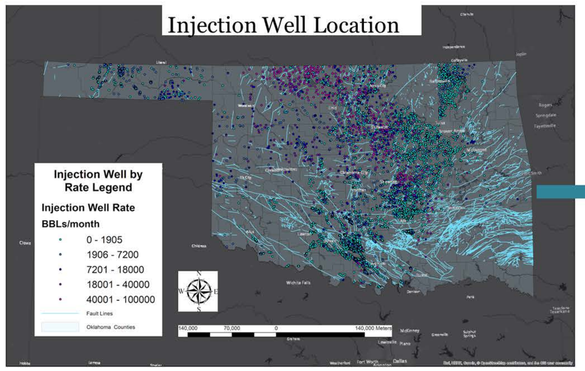


Figure 1: High rate injection wells are located to the north of the state, while low rate wells are toward the east.

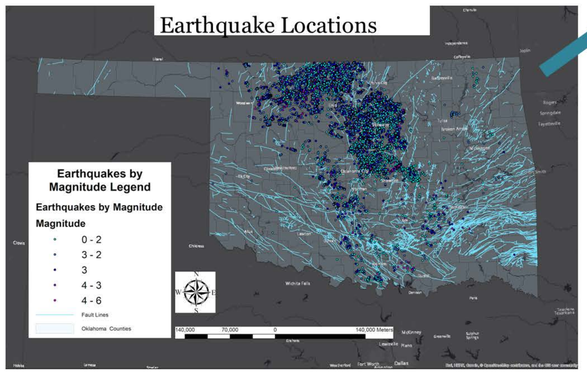


Figure 2: Earthquakes are located in similar areas to injection wells rather than on the fault lines. This indicates a correlation between the two.

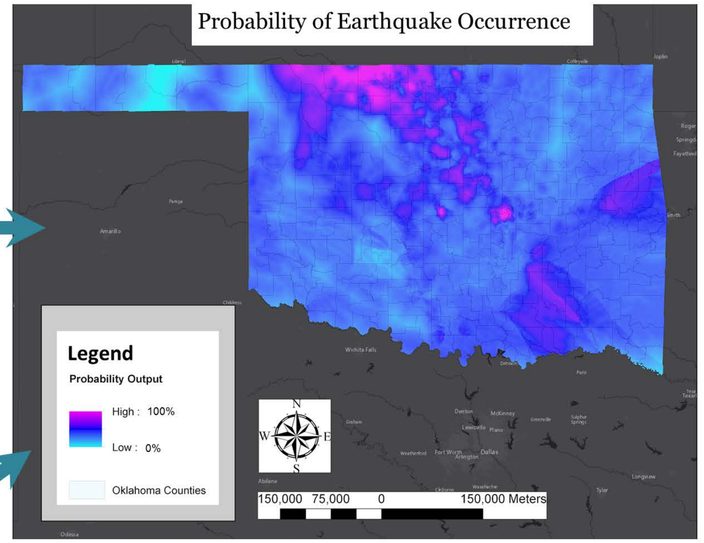
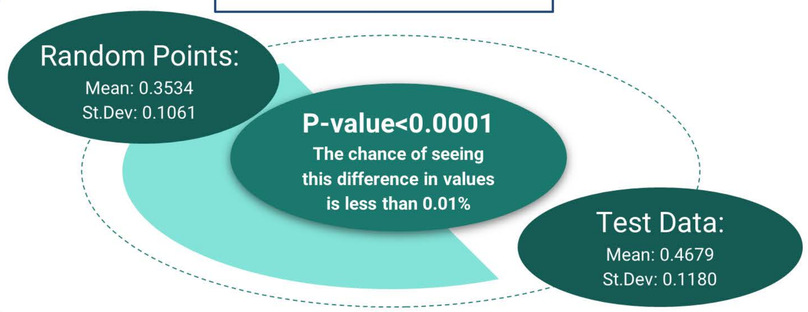


Figure 3: Future earthquakes are statistically most likely to occur in the purple regions, and least likely in the light blue regions.

Model Validation



References

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