Anthropogenic Seismology: Earthquakes and Fracking Activity in Oklahoma

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1. Introduction

Earthquake activity has markedly increased in frequency and magnitude in Oklahoma since 2009. More recently, activity has almost doubled in the past two years. In 2013, there were 109 M3+ earthquakes in Oklahoma. In 2014, there were 585 and then a stark jump to 907 in 2015. That's an astonishing 732% increase from 2013 to 2015. A quick google search reveals many perspectives as to its causes, associations as well as the associated damage to property and industry. Oklahoma is one of the top five oil producing states and boasts three of the nation's largest oil fields. Across the US, injecting wastewater from fracking into deep underground caverns is a common practice. There are many supportive data relating underground wastewater injection sites in the state to its increase in seismic activity. There have been large studies linking fracking activity, namely wastewater injection sites, and earthquakes. The induced seismic activity is known as aseismic slip. It is based upon the theory that high volumes of fracking brine solutions (highly toxic) are injected into the basement layers which cause slippage of faults deep within the earth.

This analysis focused uncovering any meaningful significance between the location of M3+ earthquakes in 2015 and underground injection wells in Oklahoma. More specifically, I was interested in finding out what the probability that the distribution of earthquakes is occurring due to random chance. Defining and testing whether earthquakes occurring at a certain depth, location and magnitude are related to fracking activity is out of scope of this analysis. However, determining preliminary pattern analysis using GIS is a prudent first step.

2. Analysis Tools

This analysis focused on finding patterns and relationships between earthquakes and fracking activity. As such, I chose to use various cluster analysis tools to reject my null hypothesis. First, I wanted to find out if various attributes of the earthquakes were significantly clustered or random. This analysis was not used to support a hypothesis which would point *directly* to a correlation between fracking activity and earthquakes but was useful to highlight correlations while rejecting null hypotheses.

The first analysis tool used was the Spatial Autocorrelation (Morans I) tool was used to measure autocorrelation based on feature locations and attribute value using the Global Moran's I statistic. Attributes tested against this tool were the depth and magnitude of Oklahoma earthquakes in 2015. The second tool used was the Average Nearest Neighbor tool. This tool was chosen to provide a positive indication between the clustering of wastewater injection wells, earthquakes as well as fracking wells. The third tool used was the optimized hotspot analysis on wastewater injection wells, earthquakes as well as fracking wells.

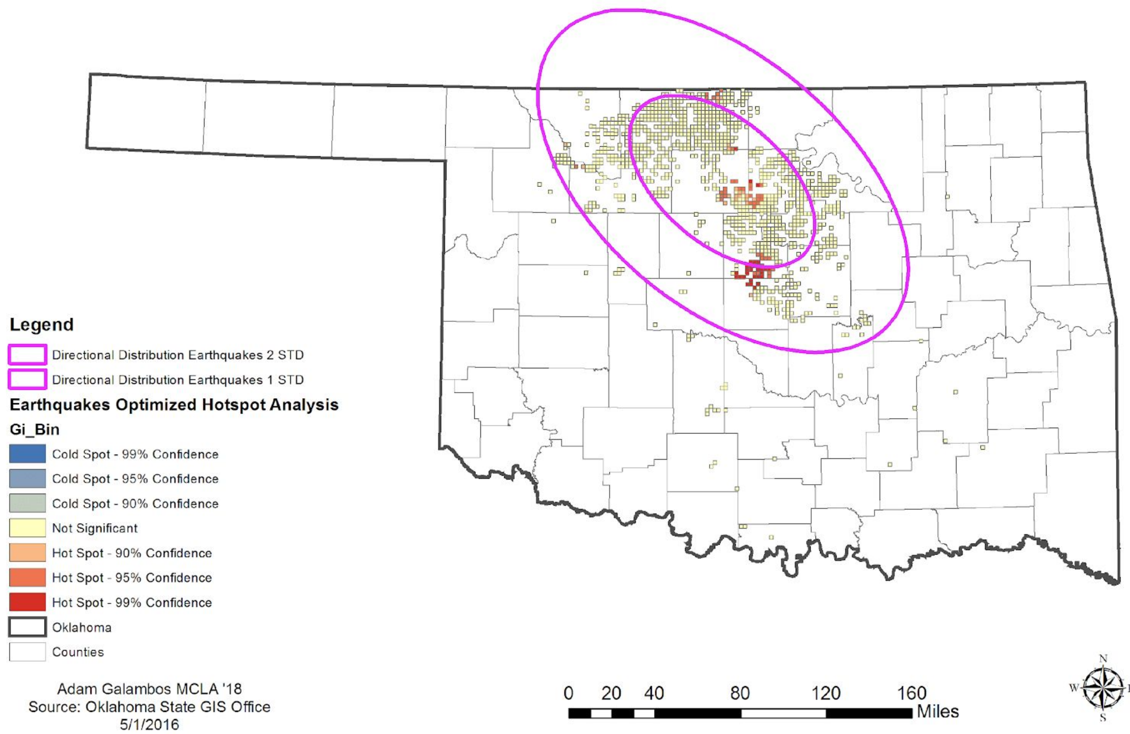
3. Results

The null hypothesis stating that the fracking activities and earthquakes are randomly distributed was rejected. All three data areas were proven to be clustered using three methods of statistical analysis. Although the areas with highest activity were in different locations, there were clear areas of clustering activity. First, the average nearest neighbor index was used on all three data points and provided a positive result on all three. For fracking wells, the nearest neighbor index was positively skewed right, indicating that it was clustered. The nearest neighbor ratio was 0.0502496 with a z-score of -36.836946, indicating that the data points were clustered. For wastewater injection wells, the average nearest neighbor ratio was 0.193963 with a z-score of -70.646739 and an observed mean distance of 732 meters. For earthquakes, the average nearest neighbor ratio was 0.22636 with a z-score of -113.267870 and an observed mean distance of 478 meters.

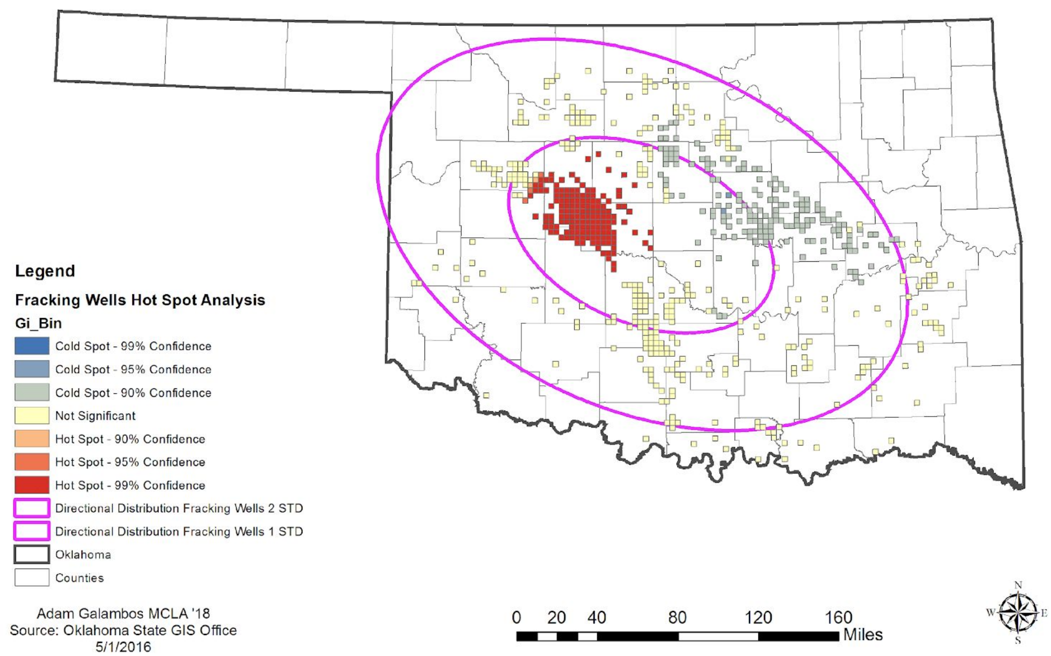
The next statistical tool used was spatial autocorrelation for two earthquake attributes which were unable to be processed and analyzed using average nearest neighbor or optimized hot spot analysis. Both earthquake depth and magnitude were autocorrelated to view determine if clustering existed in both these attributes. The results were significant, showing that the data was skewed left on each result, indicating positive clustering. The Global Moran's I Index for earthquake magnitude was 0.046545 with a z-score >2.58. This result indicated that there is less than a 1% chance that the earthquake magnitudes are randomly dispersed.

The third analysis tool used was the optimized hotspot analysis for each of the three datasets. There was positive hot spots indicated in the maps below.

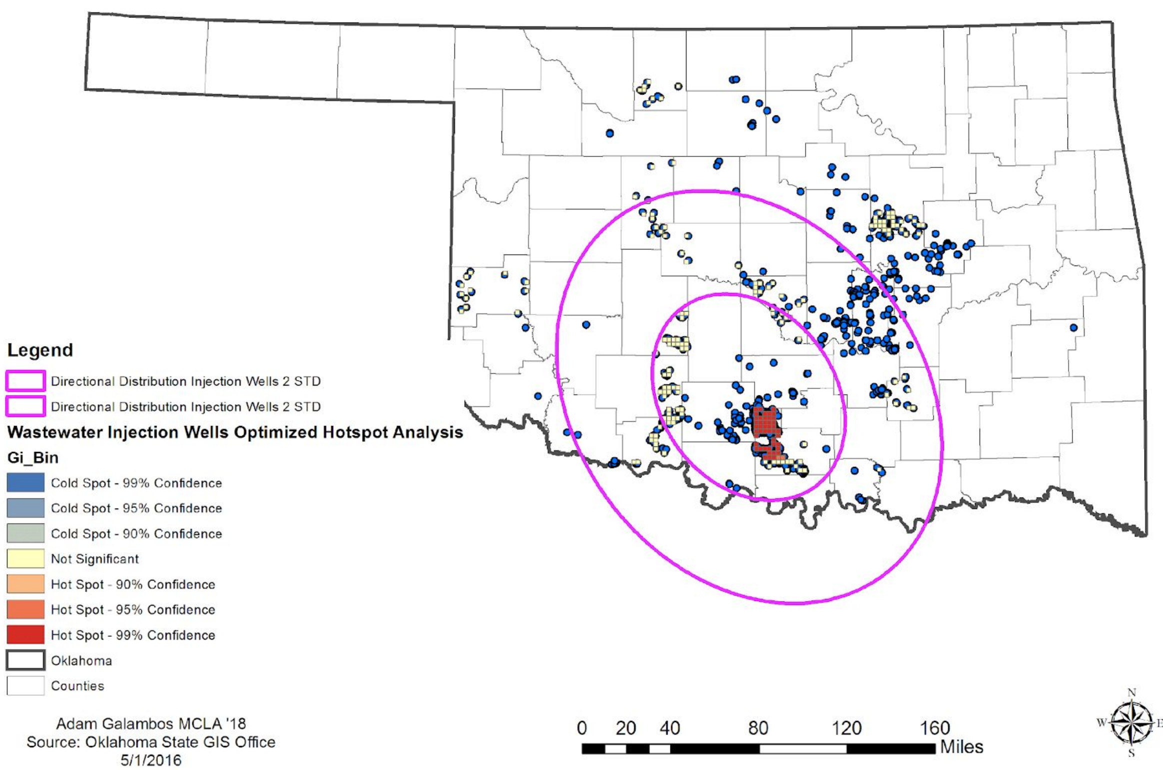
2015 Oklahoma Earthquakes - Optimized Hot Spot Analysis With Directional Distribution Ellipse



Oklahoma Fracking Wells - Optimized Hot Spot Analysis With Directional Distribution Ellipse

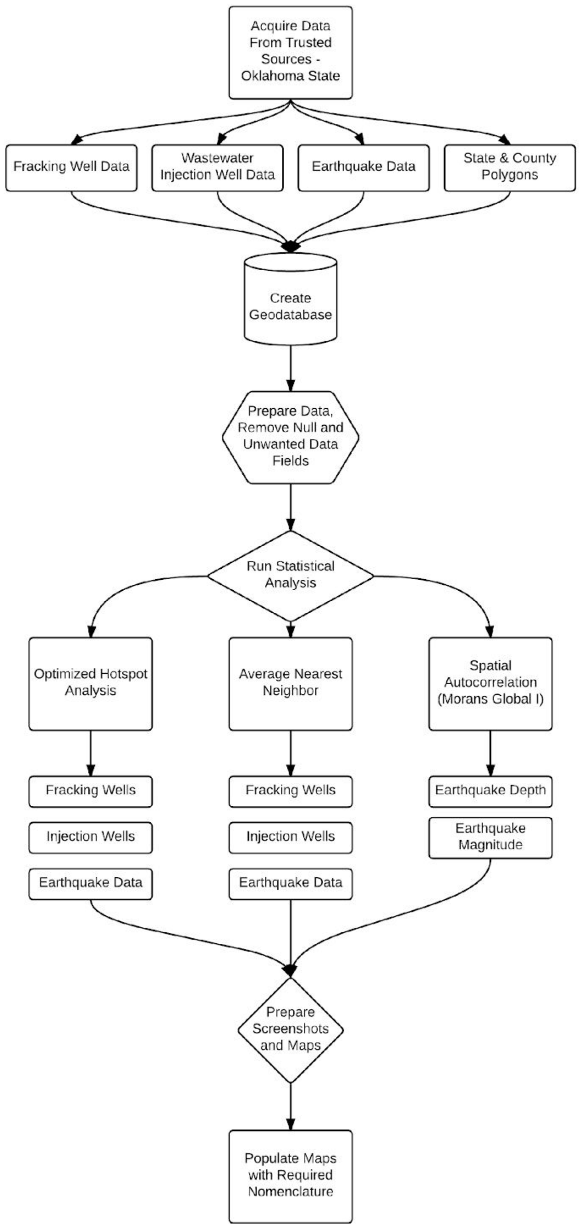


Oklahoma Wastewater Injection Wells - Optimized Hot Spot Analysis With Directional Distribution Ellipse



3. Workflow

Data from the Oklahoma state GIS department was extremely useful in this analysis. The ability to download files via FTP was quicker than http. The workflow follows the chart below.



4. Problems

Problems were faced in the beginning when I failed to compile and label all files inside the geodatabase. I was saving files in various locations and soon found that an analysis of this size is very difficult to keep track of. Good organization was practiced after that and was not an issue after. Another issue centered around the inability to know with certainty if certain analyses were compatible with certain datasets. For instance, I was trying to run spatial autocorrelation of my fracking and injection well data without having a field to weight them by. I tried to add a field and use object ID but it was unable to give me the result I desired. Instead, I used the other tools for those attributes and was successful.

5. Possible Addition and Improvements

I would extend this analysis to include more connection within the datasets. By establishing this baseline clustering knowledge and extending this project to include more of an in depth view as to how fault lines are tracking through and near the fracking sites as well as injection sites, a more vivid picture is provided as to the relationships contained. Also, more time spent of tracking data which was needed for this analysis would be indicated. Although data for this project was able to be located, I would have appreciated a source for directional fault line information in order to run a directional mean to predict where the next high probability areas are for earthquakes.

6. References

1. http://okmaps.onenet.net/digital_atlas.htm
2. Allen W, David. GIS Tutorial 2, Spatial Analysis Workbook. 2009 ESRI Press, Redlands CA.
3. https://earthquakes.ok.gov/