UNIVERSITY OF CALIFORNIA,
IRVINE

Barriers to Mitigating Induced Earthquakes in Areas of Low Natural Seismic Hazard

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Public Health

by

Georgia Halkia

Dissertation Committee:
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2021

DEDICATION

To

my daughter Vanessa for her unconditional love, my mentor mom Jessie, my sisters Dimitra and Victoria, and all my incredible mentors and professors who supported me during this endeavor.

And to my parents, Giannis and Sophia, who never got a chance to pursue their dreams. With only an elementary education, they raised three daughters, two of whom pursued graduate studies.

Finally, this dissertation is dedicated to the people of Pawnee and Cushing, Oklahoma, who trusted me and so generously opened their homes and their hearts.

Hope

I can't change the direction of the wind, but I can adjust my sails

to always reach my destination. - (Jimmy Dean)

And appreciation

Don’t hope that events will turn out the way you want, welcome events in whichever way they happen: this is the path to peace. - (From the Enchiridion of Epictetus)

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ABSTRACT OF THE DISSERTATION

Barriers to Mitigating Induced Earthquakes in Areas of Low Natural Seismic Hazard

By

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Doctor of Philosophy in Public Health

University of California, Irvine, 2021

Professor Lisa Grant Ludwig, Chair

In the last decade, the state of Oklahoma has quietly gone from a low natural seismic hazard area into one of the most seismic areas in the United States and the rest of the world. Seismologists have now reached a consensus that deep wastewater injection are the cause of Oklahoma's frequent, low- to moderate-magnitude seismicity. The M5.0 Cushing, OK, and M5.8 Pawnee events served to demonstrate the potential of injection-induced earthquakes.

The purpose of this dissertation was to use three separate research designs to investigate the current circumstances and perspectives of community members in and around the cities of Cushing and Pawnee. In the first study, we used a qualitative interview design supplemented by survey data to evaluate, detail, and discuss the earthquake preparedness of the community members, reflecting on possible solutions to the challenges they face. In the second study, we used an emic, ***in situ*** qualitative interview approach to generate detailed descriptions of the implications of induced earthquakes (IE) according to the experiences of the community members. In the third study, we used a qualitative interview design, also supplemented by survey

data, to identify, contextualize, and discuss community members' perspectives and opinions regarding the oil and gas industry and state government representatives.

The findings indicate an overall lack of earthquake preparedness and dissatisfaction with state government officials. Qualitative data analysis resulted in several themes and subthemes highlighting the complexity of induced earthquake outcomes: (a) IEs have a distinct sound and are incessant; (b) IEs cause repeated damages; (c) IEs result in multiple financial consequences; (d) residents face insurance challenges; (e) existing government and institutional support does not meet residents' needs; (f) community members desire greater involvement in decisions that affect their lives; (g) new fracking techniques and state legislation impact the rights and earnings of lessors; (h) possible wastewater spills result in environmental concerns; (i) residents feel a generalized neglect for rural areas in the U.S.; (j) simultaneous earthquake preparedness and extreme weather preparations is complex; and (k) there is a lack of understanding of earthquake response.

This study gave the opportunity for the voices of those impacted to be heard, which revealed several complex and unique issues for hazard experts to consider. The findings provide a foundation for assessing and customizing current interventions to improve earthquake mitigation outcomes for people living in areas of low natural seismic hazard and impacted by induced earthquakes.

CHAPTER 1

Introduction

Introduction

In the past decade, Oklahoma captured the attention of seismologists and related earth scientists as they were called to explain the state's sudden and unprecedented increase in seismicity. Historically, the state had only experienced two significant seismic events but their frequency was such that the United States Geological Survey (USGS) did not include the earthquakes in the annual seismic hazard maps (Ellsworth, 2013). By 2013, a total of 109 earthquakes were recorded from 2010 that were greater than magnitude 3 (>*M*3.0), surpassing the total number of seismic events experienced over the same period in California, one of the most seismic states in the nation (Ellsworth, 2013). By 2014, the total number of recorded earthquakes greater than *M*3.0 had increased to 585, more than quintupling within a single year (Hough, 2014). Initially, hydraulic fracturing, also called fracking, was suspected to be the sole cause of induced earthquakes (IE). In 2014, wastewater injection into the Earth's crust, a method of disposing the water-suspended by-products of hydraulic fracturing, was identified as the primary cause of IEs, though fracking is still considered a major origin (Delatte & Greer, 2018; Keranen et al., 2014a).

Earthquakes have the potential for catastrophic outcomes such as death, injury, mental morbidity, disruption of critical services, damaged municipal structures, and fires caused by broken gas lines. The cost of recovery can reach billions of dollars, with the potential to devastate the strongest economies. The 1994 *M*6.7 Northridge, CA earthquake is considered one of the costliest natural disasters in U.S. history. The total cost of damage reached $20 billion, with the total economic losses surpassing $49 billion (earthquakecountry.org). In the past quarter century, more than 530,000 have died from earthquakes globally (Alexander, 1996; Ramirez & Peek-Asa, 2005).

In this chapter, we first introduce and elaborate the issues inherent in induced seismicity in Oklahoma, distinguishing them from those of natural earthquakes. Next, we describe the overall aims and objectives of the study. We then discuss the historical and background information and research needed to understand the central problem of the study. Finally, we lay out the research problem, purpose, and questions, which is followed by discussions of the significance of the study, the study's limitations, and the overall structure of the dissertation.

Distinguishing Induced Earthquakes in Oklahoma from Natural Earthquakes

Oklahoma was, historically, classified as a low natural seismic hazard (LNSH) area. Now, researchers have estimated the maximum magnitude of an earthquake in the state to be *M*6 (McGarr, 2014). It is important to note that earthquakes of *M*4 or greater have the potential to cause major damage, especially in areas containing buildings and municipal structures not designed to withstand shaking (Delatte & Greer, 2018; Ellsworth et al., 2015). As such, Oklahoman IEs are not an insignificant hazard. The 2016 *M*5.0 Cushing, OK event resulted in three water main breaks, several road closures caused by debris, significant architectural damage to brick structures in the business district, and significant structural damage to houses (Taylor et al., 2017). Cushing is known as the Pipeline Crossroads of the World (see Figure 1.1 for Cushing's pipeline landmark monument) and approximately 66 million barrels of oil are stored underneath the city at any given time, putting the residents in extreme potential danger if the pipelines are severely damaged (Rogers, 2017).

Unlike tornadoes and other severe seasonal weather phenomena, earthquakes are unpredictable. Natural earthquakes (NE) can occur at any time in areas of high natural seismic hazard (HNSH), with their frequency depending upon the amount of stress built up in the Earth's crust (Abbott, 2014). When the stress reaches a certain level, rocks along faults move suddenly,

releasing energy in the form of waves that are felt as earthquakes or seismic activity. Injecting high volumes of wastewater into the ground and, to a lesser degree, the act of hydraulic fracturing can reactivate faults and cause persistent shaking (Ellsworth, 2013; Keranen et al., 2014; McGarr et al., 2015).

Figure 1.1

Cushing Oklahoma, the pipeline crossroads of the world landmark monument

Due to their differing natures, it is important to distinguish IEs from NEs both in terms of properties and in the human element. IEs differ significantly from NEs in terms of frequency of occurrence, with the former having the potential of becoming daily events depending on the degree and location of excavation or wastewater disposal activities. Those living in HNSH areas have had extensive experience with earthquakes and earthquake education, so anticipate the ever-present possibility of another seismic event. The well-known Great California ShakeOut drills began in 2008, with residents, organizations, and schools being given an annual state-wide opportunity to practice their responses and evaluate their current level of preparedness (Adams,

Karlin, et al., 2017a). Furthermore, California state building codes establish and enforce minimum standards required to protect life by preventing structural collapse, such that regulations exist to deem structures stable or unstable in the aftermath of a seismic event (Seismic Safety Commission, 2019). Yet in spite of the sharp increase in induced seismicity from 2010 onward, Oklahoma is lacking in coordinated earthquake education and preparation efforts. Nor has the state changed its building codes or provided opportunities to retrofit existing structures. As such, Oklahomans affected by IEs are lacking experience, education, and governance, which increase their vulnerability to property damage and physical harm (Becker et al., 2017; Dooley et al., 1992; Greer et al., 2020).

Earthquake hazard literature exhibits a significant gap of knowledge pertaining to the implications and challenges of low- to moderate-magnitude persistent induced seismicity in LNSH areas. At the date of writing this dissertation, there have been no formal assessments of the earthquake preparedness of Oklahomans living in IE impacted areas, despite the fact that more than 153,000 Oklahomans submitted earthquake reports through the USGS website (McNamara et al., 2015, p. 2742). There is also relatively little research into the perspectives of this population, including issues such as degree of resident support for deep wastewater injection, satisfaction with current leadership, and opinions on this novel human-induced hazard.

Due to these gaps, it can be said that existing earthquake hazard research is inadequate to address the needs of IE impacted communities. The public health field too, as a result, is ill-equipped in terms of offering guidelines and interventions that can sufficiently address the unique needs of these communities, as there is an overall lack of data on this emergent hazard. The implications are dire, as any proposed preparedness and mitigation actions which are not based on evidence have the potential to increase health inequities, as they may not meet the

needs of the communities in question (Glanz & Bishop, 2010; Kirkwood, 2004; MacDonald et al., 2016).

Background

History of Induced Earthquakes in Oklahoma

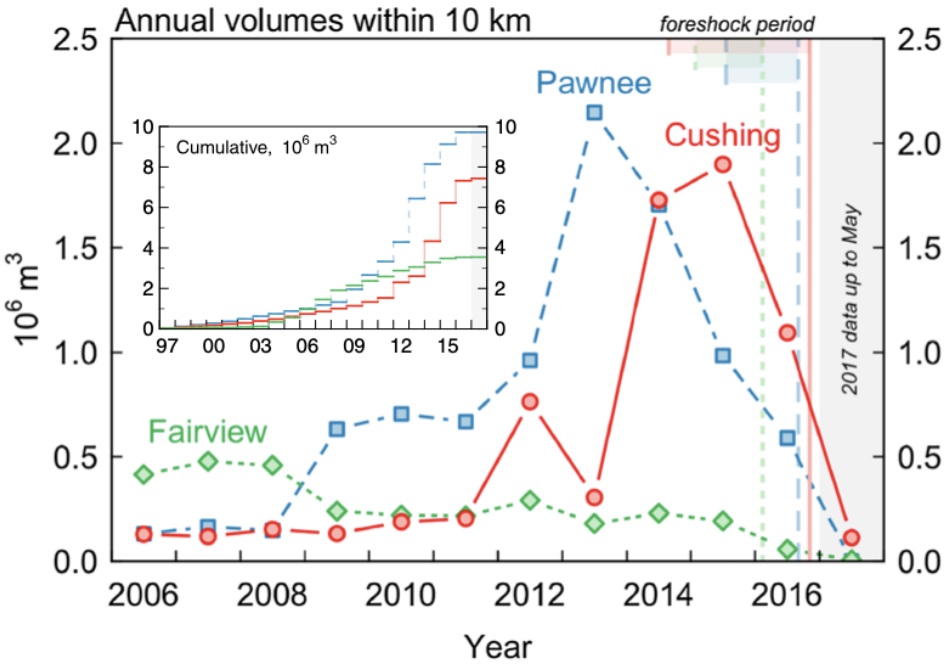
Seismic activity associated with fossil fuel extraction and byproduct disposal have significantly increased in the central and eastern United States beginning from approximately 2009 (Hough, 2014). At first, the exact causes were unknown. Ellsworth's (2013) research indicated that fracking typically only results in small earthquakes, with a growing body of research confirming that deep wastewater injection can indeed induce larger earthquakes (Keranen et al., 2013). As Figure 1.2 clearly captures, there exists a significant positive association between earthquake activity and the volume of wastewater injected in affected areas. Due to these findings, seismologists have begun investigating the potential strength of earthquakes induced by deep wastewater injection in order to calculate overall risk. Researchers developing new models of induced seismicity have determined that the maximum magnitudes for wastewater-injection-induced earthquakes may be no different from the maximum naturally occurring earthquake in a given region, which simultaneously confirmed that induced earthquakes can be quite significant in magnitude (Hough, 2014; Keranen et al., 2014).

In Oklahoma specifically, seismologists have delineated several faults that have been reactivated due to wastewater injection, which increases the overall earthquake risk in the surrounding areas, though the majority of earthquakes in Oklahoma have been fairly shallow (McNamara et al., 2015). Of special interest is the Wilzetta-Whitetail fault zone which is located directly beneath the Cushing Municipal Airport as well as Cushing's oil storage and

transportation facility, posing a significant risk to a major part of the nation's energy industry (McNamara et al., 2015).

Figure 1. 2

Annual volumes of wastewater injected



Note. The figure shows the cumulative injection history, in cubic meters for Pawnee, Cushing and Fairview, Oklahoma. On the top right corner, the three main shocks and the periods of foreshocks sequences are presented. (From *Wastewater Disposal and the Earthquake Sequences During 2016 Near Fairview, Pawnee, and Cushing, Oklahoma* by A. McGarr and A. J. Barbour, 2018, *Geophysical Research Letters, 44,* p. 9333). Copyright 2017 by The Authors.

USGS seismologists have been attempting to determine whether there is a cumulative effect within or fluid migration from high-rate disposal wells into nearby faults since the seismic

rate of certain regions are more diffuse than the geography suggests, appearing in different clusters which indicates a cascading reactivation of numerous faults surrounding an injection area (McGarr, 2014; Pei et al., 2018). The latest major estimates indicate that Oklahoma could experience up to a *M*6.5 earthquake, with the shallowness of the seismicity translating to more shaking from smaller earthquakes compared with areas with deeper seismicity (McNamara et al., 2015). IEs are particularly concerning to seismologists because they do not follow the statistical distribution of natural tectonic earthquakes, making it more difficult for them to apply existing theories and models, which are based on NEs, to calculate risk (McGarr, 2014; Pei et al., 2018).

Given the sudden emergence of induced seismicity and its history as a LNSH area, the state of Oklahoma was slow to respond to IEs and to take preventative action. It was not until 2015, over five years after the seismicity began, that the state government tacitly acknowledged that evidence does link deep wastewater injection to increased seismicity and committed to supporting researchers in examining the process by which this occurs (Darold et al., 2015; Oklahoma State Archives, 2021). Later that year, the Oklahoma Geological Survey (OGS) shifted their focus into estimating potential IE risks to begin determining the proper measures to curb damage (McNamara et al., 2014; Oklahoma Corporation Commission [OCC], 2017). The current consensus is that wastewater injection is directly linked to Oklahoma's induced seismicity (USGS, 2017).

State officials chose to work together with the oil industry and local scientists to find ways to decrease earthquake prevalence rates without impacting the OGI, as the industry supports a significant part of the state's economy. A key intervention put into effect was the *traffic light* protocol system, developed through a collaboration between the Oklahoma Corporation Commission (OCC) and the OGS as a means of regulating the amount of

wastewater injected per day (OCC, 2017). According to this protocol, companies in charge of injecting wastewater into wells are required to monitor seismic activity in areas proximal to injection sites. If an earthquake of M2.5 or greater occurs in an area, the Oil and Gas Conservation Division (OGCD) of the OCC is required to contact the designated OGS representative of injection operations within a 2km radius of the seismic event. If the magnitude of the event is greater than or equal to M3.0, then the operator must pause operations for at least 6 hours. A decision made through a technical conference between OGCD and OGS representatives will dictate whether activities will resume (OCC, 2017). For an event greater than or equal to M3.5, operators are required to suspend operations until OGCD staff and the respective OGS operator decide whether it is possible to change the injection protocol to better suit the area or to shut down operations in the area altogether (OCC, 2017).

Regardless of the implementation of the traffic light protocol, there is a lack of programming and intervention for residents. Not one of the reports released by the OCC or the OGCD up to the present date offer guidance—regarding preparation, communication, response, or recovery—to community members affected by the seismicity or to the local disaster managers.

The Earthquake Hazard

Over 500,000 earthquakes are recorded every year worldwide, with more than 530,000 total earthquake-related deaths in the past 25 years (Ramirez & Peek-Asa, 2005). Natural earthquakes are concentrated in regions where tectonic plates collide (Adams, 1990). Those living in HNSH areas face greater risks for both morbidity and mortality. These regions include the boundaries between certain continents (Himalayas to central Asia, Caucasus Mountains and the Mediterranean Sea), the Pacific Rim (e.g., the western border of South and North America), and along island chains such as Japan and the Aleutians (Simkin et al., 2006). Some of the

deadliest earthquakes ever recorded include: the 1556 *M*8 Shaanxi, China event with ~830,000 deaths; the 2010 *M*7 Port-au-Prince, Haiti event with ~316,000 deaths; and the 2004 *M*9 Sumatra, Indonesia event with ~227,899 deaths (Ritchie, 2018).

Earthquakes are unpredictable, but there are several variables that influence how catastrophic they can become. Some of those variables include the velocity of the secondary seismic waves[1] (which depends on the density and resistance to shearing of materials), the magnitude[2], fault rupture length (which influences earthquake magnitudes), and the density and quality of the built environment. Building design is extremely important in earthquake prone areas and it must account for acceleration[3] (Abbott, 2014).

Although earthquakes are more likely to cause greater numbers of casualties in urban communities, rural communities can be equally impacted though they may face different types of challenges. Urban centers have a higher concentration of people, higher structural density, and complex transportation and communication networks, which can influence the degree of damage incurred during and after a seismic event. In contrast, rural communities face the risk of isolation and have a higher likelihood of living in substandard homes not retrofitted to adequately survive seismicity (Adams, 1990). As such, earthquakes in general present multiple challenges for public health officials, as interventions designed to aid people in preparing for and mitigating the impact of disasters must be holistic and address the specific needs of the various communities (Adams, Rivard, et al., 2017).

[1] When a fault slips or there is an explosion, the earth releases energy in the form of seismic waves that pass through the whole body of the planet and called body waves. The two types of body waves are the primary and the secondary. Primary waves are the fastest and they reach the recording station first. Secondary waves are transverse waves that propagate by shearing or shaking particles.
[2] Estimate of the relative size or energy release of an earthquake.
[3] Acceleration is the rate of change of velocity as the seismic waves move the ground and buildings back and forth and up and down.

As stated previously, the earthquake magnitude is not the only indicator of how catastrophic an earthquake can be. The 2014 *M*5.1 La Habra, California earthquake caused the breaking of a dozen water mains while the overall damage to Orange County's public structures exceeded $12 million. The La Habra event occurred at a depth of approximately 5.85km (considered relatively shallow), which is similar to the earthquake depths occurring in much of Oklahoma (Donnellan et al., 2015; McGarr & Barbour, 2017). In contrast, the 2005 M7.6 Pakistan event (Naeem et al., 2011), the 2008 Wenchuan event (Cheng, Wang, Wen, & Shi, 2014), and the 2010 M8.8 Bío Bío event (Garfin et al., 2014) were high-magnitude earthquakes that resulted in significant deaths, injuries, and displacement, leading to high prevalence rates of posttraumatic stress disorder and other mental illnesses in victims.

The M5.8 Pawnee event, the largest earthquake in Oklahoman history, was far milder than these high-magnitude earthquakes, with no deaths, only minor injuries, no displacement, and relatively minor instances of small-scale damage to homes and buildings (Clayton et al., 2016). To our knowledge, no survey or interview research has been performed investigating the emotional implications of IEs on Oklahomans impacted by this newfound seismicity. One study involved using U.S. earthquake dates and magnitudes gathered from the Geologic Survey's Advanced National Seismic Comprehensive Catalog and using Google Health's application programming interface to gather the number of Oklahomans that initiated a search for anxiety (Casey et al., 2018). The results indicated that for each earthquake above the average prevalence of two events of M4 or greater per month, the proportion of Google searches for anxiety increased by 1.3%. For months with greater than two IEs of M4 or greater, the number of searches for anxiety increased by 5.8%, indicating a need for further investigation (Casey et al., 2018).

Health Implications of Earthquakes

The most direct and acute health implications of earthquakes are death and injury. Earthquakes can lead to death and injuries due to structural damage (Naghii, 2005; Ramirez & Peek-Asa, 2005). The most common cause of earthquake death is by being crushed from falling structural debris and can range from immediate mortality to delayed mortality (Naghii, 2005). The most common injuries are also from falling debris, with the majority being minor injuries for which medical attention is not sought. Injuries for which medical attention is sought, include lacerations, contusions, simple fractures, and combination injuries, as well as more severe injuries such as head trauma or spinal damage (Naghii, 2005). In more rural areas, those facing injuries may be isolated from response teams (Ramirez & Peek-Asa, 2005).

Health implications are not limited to mortality and injury, but can be psychological in nature, due to acute psychological trauma or factors associated with earthquake events such as financial trouble (Anwar et al., 2013; Beaglehole et al., 2019; Garfin, 2013; Garfin et al., 2015; Tang et al., 2018). Such psychological and psychiatric outcomes can be a result of or be mediated by a number of factors, including socioeconomic status, the nature of the earthquake experience, history of exposure to trauma, availability of social support, age, and gender (Anwar et al., 2013). Psychological and psychiatric outcomes originating from experiencing earthquakes include acute stress, depression, anxiety, and an increase in overall mental disorder prevalence (Beaglehole et al., 2019). Posttraumatic stress disorder (PTSD) is one of the most common psychiatric disorders that occur after earthquakes (Anwar et al., 2013). Furthermore, psychological comorbidities to PTSD and other earthquake related mental disorders are quite common, which can lead to ancillary outcomes such as sleep-disorders (Tang et al., 2018).

Earthquake Preparedness

Earthquake preparedness and response are major priorities for emergency public health due to unpredictability and the potential for catastrophic outcomes. The key to successful public health preparedness and response lies in effective coordination across multiple levels of government, including federal, state and local. The federal government can link funding to specific state responsibilities, thereby influencing and promoting preparedness (Alexander, 2016; Bernstein, 2012; Burnside-Lawry & Carvalho, 2016; Cromartie, 2018). For example, the federal government can set minimum building standards or provide funding for programs that provide hazard preparedness education to schools, organizations, and local disaster response agencies. In turn, state governments have the responsibility for assessing hazards and allocating the appropriate resources to local governments to prepare, respond, and recover from the disaster in question (Cromartie, 2018). Local governments are responsible for the actual implementation of preparation, response, and recovery activities, being at the forefront of the public response and responsible for coordinating disaster response (Burnside-Lawry & Carvalho, 2016). As such, it is necessary for local governments to continually update their preparedness to reflect current community threats (Kapur & Smith, 2010). Local governments are also responsible for providing information to the general public to give them an opportunity to prepare before an earthquake occurs (Paton, 2013; Paton et al., 2010; Rogers et al., 2016; Thornley et al., 2015).

Unlike extreme weather events like hurricanes, earthquakes cannot be predicted. Early earthquake warning systems[4] installed in HNSH areas such as Japan, Mexico, Taiwan, and California can provide people up to a minute of advance notice before the shaking begins,

[4] A rupturing fault sends out waves that can be captured by sensors. The earthquake early warning system consists of a series of seismometers installed along major fault lines. The sensors detect the fast-moving primary waves, which are the first to arrive before the secondary propagating waves and transmit the data to warning sirens within cities.

allowing them just that much time to evacuate structures or move to safer locations (Kapur & Smith, 2010). As such, public health messages can only be the primary means by which earthquake preparedness and response information can be communicated to the general public. The California Education Code, for example, requires all schools in California to participate regularly in earthquake drills, which teach students how to properly respond to seismic events. Government organizations such as fire departments also often disseminate earthquake preparation and response information, such as storing three days of food and water, preparing supplies that may be needed in emergencies, and knowing how to turn off a gas line.

Earthquakes directly impact structures, leading to a number of implications and complexities for preparatory, response, and recovery efforts. Retrofitting structures can be highly effective method for minimizing structural damage, injury, and loss of life during seismic events (Bommer et al., 2015). However, fatalistic attitudes, combined with efforts to minimize building expenses, continue to present major hurdles in persuading residents of earthquake-prone areas to invest in retrofitting (Baytiyeh & Naja, 2016; Comerio, 2004). Meanwhile, local governments are more likely to invest money on matters within their jurisdiction, such as transit, schools, and healthcare. Despite helping pay for earthquake damage recovery, the federal government does not play a regulatory role in earthquake matters and cannot mandate local communities to enforce risk reduction strategies such as stricter building codes.

Yet residential housing remains most vulnerable to damage in the face of seismicity. According to the Earthquake Engineering Research Institute [EERI] (2003), a single catastrophic earthquake in the United States can result in recovery costs exceeding $100 billion. Data gathered from earthquake recovery efforts around the world indicates that approximately 90% of structures damaged are residences, with most of these structures experiencing damage of up to

50% of their total value (Earthquake Engineering Research Institute, 2003; Najafi et al., 2014). Indeed, minimizing and mitigating structural damage is a critical aspect of earthquake preparation, one that may require regulatory measures (Comerio, 2004).

The response effort for major earthquakes is comprised of two phases. The first phase involves rescuing the trapped or injured, then providing medical care and supplies. The second phase involves providing shelter to displaced individuals, along with nutrition, safety, and sanitation (Najafi et al., 2014; Tavakkoli-Moghaddam et al., 2016). Successful recovery typically requires both community involvement, leadership, and economic resources (Robertson et al., 2021). Retrofitting older structures and updating building codes can have the greatest impact in reducing mortality and morbidity following strong seismic events (Bommer et al., 2015). In reality, many places around the world, including within the United States, such codes either do not exist or are not enforced. Most important to the scope of this study, historically LNSH areas facing IEs are likely at a greater risk than other areas because their public works and building regulations were not designed to protect against seismicity.

Earthquake preparedness also involves acknowledging and accounting for possible secondary disasters that earthquakes can trigger, such as fires, landslides, and dam breaks. The majority of those who died during the historic 1906 San Francisco earthquake died due to the fires fed by broken gas lines. Secondary disasters can also evolve into tertiary issues, such as the many individuals who decided to let their houses burn down in the aftermath of the 1906 event as insurance at the time provided coverage for fires, but not for earthquake damage (Scawthorn et al., 2006).

A final critical element to effective earthquake preparedness planning is assessing local vulnerability and adapting the plans to fit the unique needs of the community in question (Mishra & Mazumdar, 2015; Noriega & Ludwig, 2012).

Predictors of Earthquake Preparedness

Scholars have investigated many factors that predict for or mediate earthquake preparedness (Becker et al., 2012; Becker et al., 2013; Dooley et al., 1992; Kruger et al., 2020; Maryam et al., 2018; Mishra & Mazumdar, 2015). Quite numerous among these factors are unique individual characteristics, demographics, and traits. Mishra and Mazumdar (2015) outlined many confirmed traits predictive of earthquake preparedness that can be attributed to the individual, including age, sense of responsibility, personal resources, gender, trait anxiety, locus of control, self-efficacy, self-esteem, individual mastery, dependence proneness, risk perception, hazard anticipation, prior experience, knowledge of protective actions, information, place attachment, and community attachment.

Because of the sheer number of mediating factors and the multidisciplinary nature of examining these factors in the appropriate context, research into the predictors of disaster preparation is complex and varied, though findings tend to be insightful (Maryam et al., 2018; Mishra & Mazumdar, 2015). Individuals' awareness of local disasters is one of the most significant predictors of both preparedness and quality of preparedness, while confusion regarding how to plan for the unknown is one of the most significant barriers to preparedness (Kruger et al., 2020). Resource availability is another major factor, as the current capabilities of an individual will directly and indirectly influence ability to successfully prepare (Mishra & Mazumdar, 2015). Education about a natural disaster and how to prepare against it, which is

often considered a subfactor of resources, is also a consistent predictor of preparedness, though this is not always the case (Maryam et al., 2018; Mishra & Mazumdar, 2015).

Compounding the complexity of earthquake preparedness research, other environmental, social, and other external factors can also greatly mediate preparedness. Consider place attachment, which involves an individual's affective attachments—that are further strengthened through reciprocation by other people, groups, and the environment—which can mediate disaster preparedness in different ways (Mishra et al., 2010). A similar concept is community attachment, which focuses more upon reciprocated community bonds (Mishra & Mazumdar, 2015). Regardless of the concept, these combinations of individual and environmental factors can result in powerful outcomes that can either aid or hinder preparation at the individual, community, and group levels (Mishra & Mazumdar, 2015).

Earthquake Resilience

At the community and local levels, mediated largely by state and federal governmental organizations, is the concept of resilience. Community resilience is defined as the present and continually developing capacity for a community to both address its weaknesses and cultivate resources to (a) prevent, withstand, and mitigate the outcomes of a health incident such as an earthquake, (b) restore the community's self-sufficiency to the point of equivalent social and physical functioning as prior to the incident, and (c) use knowledge from past and present incidents to strengthen the community's ability to withstand and recover from future incidents (Chandra et al., 2011; Chandra et al., 2010; Choudhury et al., 2019). Community resilience is particularly salient to locations that experience IEs. Induced disasters have the potential for more catastrophic outcomes (Baum et al., 1983; Baum & Gatchel, 1981; Erikson, 1976). The frequency of occurrence of IEs, the relative lack of earthquake-resistant buildings, and the

absence of anticipatory services and governance for IE increase the vulnerability of communities impacted by IE (Becker et al., 2017; Delatte & Greer, 2018; Greer et al., 2020; Taylor et al., 2017).

Government leadership and organizations involved in earthquake preparedness must address four factors to establish and develop community resilience. First, it is important to encourage local government to become actively involved in the community regarding earthquake preparation, which will serve as a catalyst for residents to accept and engage in personal and community-wide preparedness measures (Burnside-Lawry & Carvalho, 2016; McComas et al., 2016). Second, any earthquake preparation intervention, communication regime, educational offering, or program must account for the local characteristics and circumstances of the target community (Adams, Karlin, et al., 2017a; Adams, Rivard, et al., 2017). Third, any acts of communication must be considered carefully with clear, consistent, honest, and considerate messages that build a reciprocal dialogue between community members and government representatives (Hanlon, 2017; Rogers et al., 2016). Finally, the foundation for institutional action should be building trust between the community and its leaders, which leads to greater preparatory actions and collaboration (Becker et al., 2020; Robertson et al., 2021).

The Public Health Issue

Oklahoma residents residing in non-retrofitted structures that are in proximity to deep wastewater injection sites are acutely affected by IEs (see Appendix D for images from Cushing and Pawnee, Oklahoma). This is documented in the 2016 EERI Earthquake Reconnaissance Team Report, which captured the aftermath of the *M*5.0 Cushing, OK event and demonstrated several vulnerabilities (Taylor et al., 2017). Though no official government statement of the cost of damage are extant for this event, the EERI engineers recorded three water main breaks,

multiple road closures, significant architectural damage to commercial buildings, and major architectural damage to homes. Interviews with local stakeholders revealed either a lack of appropriate earthquake insurance policies or the inability to pay the high deductibles of policies designed for losses following catastrophic events. According to Taylor et al. (2017) the majority of buildings in Oklahoma are not designed to withstand earthquake shaking, with building codes not accounting for the emergent IE hazard.

The problem motivating our study is that the implications of persistent, low- to moderate-magnitude induced earthquakes are not well understood. Though there is a large body of research on the effects of high-magnitude NEs and their outcomes, such research and the recommendations therein may not accurately reflect and inform investigation into IEs. Programs and interventions that are designed to address issues pertaining to single instances of high-magnitude seismic events (e.g. The Great ShakeOut, 2018) might not be effective in areas subject to IE. Oklahoma is not expected to experience earthquakes exceeding M6.5, though very frequent low- to moderate-magnitude seismicity remains a distinct possibility (McNamara et al., 2015). As such, Oklahoman seismicity is distinctive compared with what is typically addressed in earthquake research. Though Oklahoman earthquakes are milder in comparison with catastrophic events, the possible outcomes are not insignificant, including injury, structural damage, and irreparable financial harm (Clayton et al., 2016). Indeed, regardless of scale, exploratory research is necessary to better understand IEs and IE outcomes.

Aims and Objectives of This Study

Given the relative lack of research into IEs in LNSH areas, the aims of this study are to identify and evaluate the challenges inherent to living with induced seismicity and to assess the earthquake preparedness of participants in two Oklahoman municipalities heavily impacted by

IEs. We also investigated community members' views and opinions of the oil and gas industry (OGI) and of the Oklahoma state government representatives. These perspectives may provide a deeper understanding of what is important to the local population when addressing issues caused by IEs. We specifically set the following objectives:

1. Provide information on the earthquake preparedness of Oklahomans living in areas with continuous induced seismicity.
2. Capture the impacts of IEs as experienced by those living in areas with continuous induced seismicity.
3. Gain an insider's perspective on the role of the oil and gas industry in the affected communities.
4. Better understand the wants and needs of the population affected by IEs.
5. Assess the overall satisfaction of IE impacted residents with their state government representatives' handling of the IE issue.

Significance

In this study, we engaged in three independent yet interrelated research designs, each with a distinct significance to earthquake and public health research. The first study involved identifying the current state of earthquake preparedness of those affected by IEs. This may help researchers better understand the factors of preparation unique to those experiencing induced seismicity. This may also help refine interventions and programs to specifically address the idiosyncrasies of IE. The second study involved uncovering unique factors that residents of LNSH areas experiencing IEs face, including outcomes, challenges, and damage. This will help researchers better understand the circumstances and experiences of those living with induced seismicity. The third study involved participants' perspectives on the OGI and the state

government. This may help industry and government leaders to better approach future efforts in increasing the resilience of their workers and constituents.

Limitations

Although qualitative designs, particularly when supplemented by survey-derived descriptive statistics, are ideal for generating rich data to inform this research project, the primary limitation of relying heavily on interviewing a specific population is specificity to this sample. Though the study is limited by the geographic location of the participants, implications beyond the Pawnee, OK and Cushing, OK areas do exist, as other areas in the state and in other states face similar challenges with IEs in LNSH areas. A secondary limitation of the study, also due to reliance on qualitative interview data, is the probability of subjectivity and bias on the parts of both the researcher and the participants. Though unavoidable, it is also true that qualitative interviews performed with an emic approach are ideal for capturing complex issues

Structural Outline

In this chapter, the context of the study is introduced. The research aims, objectives, problem, and question have been identified, the significance of the study is established, and the limitations are discussed. In Chapter Two, the earthquake preparedness of Cushing, OK and Pawnee, OK are evaluated and discussed. Using a qualitative interview design supplemented by survey data, we identify factors that may be antecedents to preparedness actions. We also reflect on possible culturally-sensitive solutions to these challenges based on the interview data. In Chapter Three, a detailed description of the impacts of IE are presented. A qualitative design is used to gain insight into the lives of those impacted by IEs, including details that could not be accurately hypothesized without experience. In Chapter Four, the opinions and perspectives of Oklahoman residents regarding the OGI and state government are detailed. A qualitative

interview design, also supplemented by survey data, is used to explore participants' opinions and to gain context for their perspectives. Finally, Chapter Five contains a reflection and synthesis of the findings, detailing their significance and implications for disaster preparedness, public health, and policy.

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CHAPTER 2

Household Earthquake Preparedness in Oklahoma: A Study of Selected Municipalities

Introduction

Earthquake Prevalence in Oklahoma

The importance of earthquake preparation in areas in which hydraulic fracturing is practiced has been rising. As the use of this oil extraction technique has increased within the United States, the prevalence of seismic activities in these geographic areas has increased dramatically in the past decade (Delatte & Greer, 2018; Khosravikia et al., 2021). Prior to 2008, the state of Oklahoma was classified as an area of low natural seismic hazard (LNSH) with little to no seismic activity of significance (Ellsworth et al., 2015), such that the United States Geological Survey (USGS) did not include the state in its annual seismic hazard documentation. This classification has changed since 2010, when seismic activity sharply increased (Ellsworth, 2013). By 2015, the total number of earthquakes greater than magnitude 3 since 2010 had risen to 907 (Delatte & Greer, 2018). Oklahoma residents, who had previously rarely or never experienced earthquakes, experience rates of seismic activity exceeding that of residents of California (Petersen et al., 2016), mostly in the Pawnee, Cushing, and Fairview regions (McGarr et al., 2015b).

Induced earthquakes (IEs) in Oklahoma and other regions in the Central U.S. are secondary products of the hydraulic fracturing method of oil extraction, also called *fracking*, which involves injecting water, chemicals, and sand directly into low-permeability bedrock to create new fractures and facilitate gas or oil flow into wells (Ellsworth, 2013). The hydraulic fracturing method is not a primary cause of earthquakes of moderate intensity or magnitude 3 or greater, but leads to the inducement of earthquakes of very small magnitudes (Ellsworth, 2013). IEs of moderate or greater magnitude are the result of wastewater injection. Hydraulic fracturing

produces large volumes of toxic wastewater that can only be reinjected back into the earth's crust (Delatte & Greer, 2018; Keranen et al., 2014).

Human and Structural Outcomes of Induced Seismicity

A major concern for these areas with increased earthquake prevalence is the damage potential of earthquakes, particularly to structures built in areas of induced seismicity that were previously LNSH regions (Khosravikia et al., 2020; Petersen et al., 2016). Although the earthquakes of $M \leq 3$ can cause perceptible to imperceptible shaking, the $M \geq 3$ earthquakes that have increased in prevalence within Oklahoma can cause damage to architectural structures and their contents (Taylor et al., 2017). To exacerbate potential damages, induced seismicity tends to occur in areas with a history of insignificant seismic activity, for which structures are designed and constructed according to zero- to low-seismic requirements (Khosravikia et al., 2021). Indeed, Khosravikia et al. (2021) estimated that earthquakes of the maximum recorded magnitude of induced seismicity had the probability over 70% slight damage and over 25% moderate degree of damage to bridges in such areas.

In actual terms, IEs in Oklahoma have resulted in a combination of physical and financial damages. For example, the aftermath of 2016 *M*5.0 Cushing event included three water main breaks, road closures caused by debris, significant architectural damage to brick structures in the town's business district, and significant structural damage to houses (Taylor et al., 2017). Though the cost of these outcomes was not calculated, residents noted that many were not able to gain compensation because of a lack of insurance or due to the inability to pay deductibles (Taylor et al., 2017).

Induced seismicity also negatively affects the price of housing (Burnett & Mothorpe, 2021). Metz et al.'s (2017) investigations revealed that induced seismicity led to housing prices

being reduced from 3% to 5%, with an upper range of $6,660 total reduction in value in Oklahoma County. In an investigation of the same county, Ferreira et al. (2018) found that the 2011 seismic event in Prague led to a 2% reduction of housing prices post-event. In a study across Oklahoma, Cheung et al. (2018) likewise found a 3% to 4% decrease in the value of properties after a seismic event. In a meta-analysis of housing data from 2008 through 2018, Burnett and Mothorpe (2021) found an average 4.2%, or $8,8000, decline in property value due to the cumulative effect of earthquakes.

Another major concern in areas of induced seismicity is that of potential damage to personal wellness. Psychological stability and the safety of living environment are critical to personal and community wellness in terms of physical and mental health (Insel & Walton, 2014). Considering the structural damage to homes, lack of access to insurance, lowering house prices, and the challenges inherent in induced earthquakes, it is becoming increasingly clear that continuous seismicity may result in a cluster of psychological stressors to residents. Researchers of catastrophic earthquakes have found that seismicity can be a source of discrete and secondary psychological stressors that increases prevalence of mental disorders or functional impairment (Garfin et al., 2014). Similar studies have not been made of IEs, despite findings that many seismic events throughout the 20th century may have been manmade (Hough & Page, 2015; 2016). Oklahomans living in proximity to hydraulic fracturing operations and wastewater disposal wells may experience seismic activity of M3.0 or greater daily (Greer et al., 2020). Psychological stressors, particularly continuous stressors, have been widely associated with various forms of negative physical and mental health outcomes (Cohen et al., 2007).

Locations Affected

Although induced seismicity in Oklahoma is not ubiquitous, it is quite pervasive, albeit concentrated in locations in which the wastewater byproducts of hydraulic fracturing are injected back into deep sedimentary layers (Greer et al., 2020; Skoumal et al., 2018). Four earthquakes of magnitude 5 or greater have been documented in different locations throughout the state. The 2016 M5.0 Cushing event occurred in Payne County (Taylor et al., 2017), the 2016 *M*5.1 Fairview event occurred in Major County (Goebel et al., 2017), the 2011 *M*5.7 Prague event occurred in Lincoln County, and the *M*5.8 Pawnee even occurred in Pawnee County (Skoumal et al., 2018). Among these higher magnitude events, it should be noted that Pawnee, Payne, and Lincoln Counties are contiguous from north to south, respectively, while Major County is disconnected to the east of the three-county cluster.

Areas of induced seismicity are not limited to these areas that contained historically higher magnitude events nor do induced earthquakes occur only in areas directly adjacent to wastewater injection sites (Greer et al., 2020; Pei et al., 2018; Skoumal et al. 2018). With regards to general induced seismicity in Oklahoma, Pei et al. (2018) found that earthquakes were associated either with the geological boundaries that exist between differing rock formations or with regions of the upper crust that have strong material properties. The researchers suggest that although induced seismicity is initiated by injection of hydraulic fracturing waste, the locations are likely dictated by local geological properties (Pei et al., 2018). Earthquakes of $M \geq 5$ aside, induced seismicity has been consistently found in Tulsa, Creek, and Pottawatomie Counties (Greer et al., 2020) which, notably, are adjacent to Pawnee, Payne, and Lincoln Counties.

Other regions of Oklahoma are also affected by induced seismicity. Skoumal et al. (2018) examined areas not traditionally associated with wastewater disposal wells, but which exhibited

low to moderate magnitude seismicity in association with hydraulic fracturing or a combination of the two causes. Areas with continuous seismicity largely correlated with hydraulic fracturing included Love, Carter, McClain, Coal, and Stephens Counties. Areas with seismicity associated with both hydraulic fracturing and wastewater disposal, due to proximity of the Anadarko Platform included Kay, Kingfisher, and Major Counties. Finally, other areas with continuous seismicity associated with both hydraulic fracturing and wastewater injection included Woodward, Hughes, Blaine, Canadian, Marshall, Grady, Pittsburg, and Garvin Counties (Skoumal et al., 2018). In total, at least 22 of the 77 Oklahoman counties are subject to induced seismicity to varying degrees.

Properties of Induced Earthquakes

The need for novel methods or programs of earthquake preparation in areas like Oklahoma becomes evident when identifying the distinguishing properties of IEs. Induced earthquakes can occur in areas of LNSH with little to no history of seismicity, resulting in a population with lack of experience or preparation, as well as a community without existing governance or community process by which potential risks can be attenuated (Chang et al., 2018). In areas of LNSH, IEs occur more frequently than natural earthquakes and repeated low- to moderate-magnitude seismicity causes damage that is distinct from that of natural earthquakes (Delatte & Greer, 2018). Though increases in human-induced natural hazards such as IEs should result in risk reduction such as revised building codes (Tracy et al., 2021), structures in these areas are not designed to resist seismic forces, let alone high rates of seismic activity (Taylor et al., 2017). Of concern to residents, for example, is the gradual degradation of structures which can lead to major failures (Campbell et al., 2020).

Despite the risk of damage, Oklahoma residents lack the urgency or awareness to prepare by seeking insurance, nor are attractive policies available (Greer et al., 2020). Most available earthquake insurance does not meet the needs for structures in areas of induced seismicity as the policies are not optimized for damage associated with small-scale but frequent earthquakes (Campbell et al., 2020; Delatte & Greer, 2018). Two major problems inherent in existing policies include prohibitive costs due to premiums being a percentage of the insured property and endorsements only covering damage associated with catastrophic earthquakes (Taylor et al., 2017). Other complications may exist, such as the frequency of earthquakes making it impossible to determine the which event caused damage and the difficulties inherent in calculating the accumulation of small damages.

Contemporary Research on Earthquake Preparedness

Much contemporary research on earthquake preparedness is focused upon catastrophic natural earthquakes, in which the aim is to minimize deaths from rapid structural degradation while expediting recovery efforts following major seismic events (e.g., Adams et al., 2017; Ranjbar et al., 2018; Wu & Wu, 2020). To illustrate the scale of such earthquakes in an earthquake-prone nation like Iran, the 2003 M6.5 Bam even resulted in 26,796 total deaths and the 2017 M7.3 Kermanshah event resulted in 620 deaths (Ranjbar et al., 2018). Likewise, 650 million people in rural China live in areas prone to earthquakes equal to or greater than 6 in magnitude (Wu & Wu, 2020). The Great ShakeOut, the leading earthquake preparation drill in the United States, involves an earthquake scenario of M7.8 (Adams et al., 2017). Many states, including Oklahoma (Center, 2021), and several nations have adopted the ShakeOut model. As with most earthquake preparation efforts, these ShakeOut drills are focused on earthquakes of

large magnitude rather than those that are representative of Oklahoman seismicity (Center, 2021).

How well do conventional earthquake preparation efforts designed for catastrophic seismic events fit the needs of those who live in areas of lower magnitude induced earthquakes? The drop, cover, and hold methodology emblematic of the Great ShakeOut may be the most appropriate course of action in California, an area in which higher magnitude earthquakes can occur in unpredictable times and aftershocks may only occur for a limited number of days (Adams et al., 2017). Residents of Oklahoma who face continuous seismicity of low- to moderate-magnitude should not be expected to drop, cover, and hold daily or several times each day. Most of these earthquakes will not cause objects to fall or structures to collapse in any single event (Greer et al., 2020).

Although researchers have investigated risk appraisal (e.g., Greer et al., 2020) and preparedness adoption intent (e.g., Chang et al., 2018), the earthquake preparedness actions of individuals living in areas of continuous induced seismicity has not been addressed. The aim of this exploratory qualitative interview study, which is informed by survey data, is to investigate and evaluate earthquake preparedness of Oklahomans living in areas with nearly continuous induced seismicity, focusing on whether those who have experienced damages from earthquakes were more likely to prepare than those who have not. The investigation is enhanced through the use of an emic approach, in which survey and qualitative data are collected from a population in order to gain understanding of the participants, and factors that influence their preparedness actions.

Research Questions

We address two primary research questions (PRQ) and one secondary research question (SRQ).

PRQ1: Are people who experienced damages in Pawnee and Cushing Oklahoma better prepared for IEs than those who did not experience any damages?

SRQ1: What type of earthquake preparedness actions have the people living with IEs taken to protect themselves from seismic events?

PRQ2: What factors influence the earthquake preparedness decisions of people living with IEs in Oklahoma?

Methods

Research Method

To best answer our research questions Naturalistic Field Research (NFR) methods was combined with surveys to provide a deeper understanding of the IE problem (Curry & Nunez-Smith, 2015; Dowding, 2013; Vogt et al., 2012). By using multiple methods of inquiry, we were able to address the controversial topic of preparing for earthquakes that are induced by wastewater injection in a population that relies heavily on the oil and gas industry for employment. In addition to interviews, we used visual methods, such as observation and analysis of photographs (see Appendix D), to enhance the richness of our data and help with the interpretation of interview and survey data. The addition of visual methodologies in research adds validity and increases the breadth of understanding (Catalani & Minkler, 2010; Glaw et al., 2017). Following a multi-step coding approach, we used an inductive methodology to analyze and interpret data, allowing us to build a strong empirical foundation to understand the challenges impacted people face when dealing with IE in LNSH areas (Bailey, 2007; Breuer, 2010; Dellve et al., 2002).

Study Area and Recruitment Procedure

The principal investigator (PI) collected survey and qualitative data at areas in and surrounding Pawnee, OK and Cushing, OK. The sample was comprised of a combination of residents living inside the city areas and around the perimeter. Both rural municipalities experienced a sudden increase in seismic activity beginning in 2010 (Delatte & Greer, 2018). Seismicity increased in frequency and magnitude over the years until, in 2016, the residents felt the strongest earthquake ever recorded in the area. Specifically, Pawnee experienced a M5.8 earthquake on September 3rd, 2016, and Cushing was struck by a M5.0 earthquake on November 7th (Skoumal et al., 2018; Taylor et al., 2017). Cushing serves as one of the biggest oil hubs in the country, featuring large underground pipe systems that deliver oil and gas to most states. Both cities have a long history of participating in oil and gas exploration activities.

Purposive sampling techniques were used to recruit adult English-speaking participants. The majority of residents in both Pawnee and Cushing, Oklahoma, are non-Hispanic whites, according to the U.S. Census Bureau (2019). Specifically, 76% and 77.6% in Pawnee and Cushing, Oklahoma, respectively, are white non-Hispanic. American and Alaska Native is the second most predominant race in both cities (14% in Pawnee and 6% in Cushing). For the survey component, the PI determined a specific number of individuals to select ethnic groups based on the U.S. Census Bureau (2019) and collected data by respecting the ethnic quota. Purposive snowball sampling techniques are used when dealing with controversial issues, hard-to-reach populations, and we try to garner diverse perspectives. Snowball sampling is particularly appropriate when investigating sensitive issues that require special "insider access" to recruit participants. The researcher creates a network of participants by receiving recommendations for additional interview candidates from participants already interviewed. Since not all residents

were impacted equally by IE, it was necessary to seek participants that could share their experience and provide rich detail to illustrate the challenges of preparing for IE (Biernacki & Waldorf, 1981; Tracy, 2013, p.134; Vogt et al., 2012, pp. 219-222).

Snowball sampling is also preferred when a project will be enhanced by thick description by interviewing participants non-randomly but intentionally, with the aim of including people that will provide a rich narrative to meet research objectives (Biernacki & Waldorf, 1981; Vogt et al., 2012). Purposive snowball sampling was appropriate because not all residents are equally impacted by IE. It was important to specifically identify and interview participants who have experienced IE and were directly impacted by them. A random sample would have been unlikely to provide an adequate sample of individuals who both experienced and were impacted by IE.

Recruitment commenced on April 25th, 2019 through making contact with a member community member that I met inside the Pawnee County Historical Society Museum. The participant had ties to the Pawnee tribe as well as City Hall. The individual introduced me to city clerks, the mayor, and other important members of the community who, once I explained my research, communicated that they were willing to advocate my research efforts in their community. Some interview participants exhibited much skepticism and there were instances in which individuals felt more comfortable engaging in informal discussions than formal in-depth interviews.

As per snowball sampling procedures, once a referring member called a participant on my behalf, I followed up with specifics (namely informed consent, survey distribution, and interview scheduling) if potential participants agreed to participate. A former oil industry CEO that I was introduced to by a City Hall employee became essential to my sampling efforts. His extensive knowledge on the OGI and his ties to the community opened many doors. He was

well-respected because he had helped many residents with leasing their land to the OGI. As such, simply mentioning his name was enough for many community members to take the time and learn more about my research.

I disseminated the survey to all my interview participants, additionally inquiring whether they would be willing to ask other members of the community they know to complete the survey as well. I also was invited to attend service in a local church by one of the interview participants where I was also able to recruit more respondents to complete my survey. I attended the Pawnee Veterans Homecoming Powwow, during which two tribal leaders agreed to participate in my research if I participated in their celebratory dances. I agreed, and they not only permitted me to schedule interviews but introduced me to other members of the community.

Recruitment Challenges

My original recruitment plan, which included calling community members inside various organizations and sending them emails with explicit details about my research, was not successful. Instead, I found out that the only way community members in Pawnee and Cushing would participate in the study was if someone they respect made an introduction. This was not enough for some individuals. With such cases, I had to initiate several calls, then meet them informally in person, and they would only participate once they felt comfortable through the establishment of a certain degree of rapport.

Another challenge I was not prepared for was the weather. In the year that I arrived, Oklahoma was experiencing the most severe flood and tornado season in ten years. I was forced to leave Oklahoma on June 11th because many roads had been flooded and residents were dealing with the aftermath of the floods, precluding the ability to conduct any meaningful research. I

reentered the community from July 6th through August 25th and was able to conduct follow-up interviews with participants who I had previously interviewed.

Scheduling interviews also required a great deal of flexibility on my part. There were instances in which I arrived on time only to find the participant doing work and needing to cancel the interview. These cancelations were largely due to the weather: if rain was forecasted, participants were forced to complete their work before rainfall occurred. In one instance, I helped a participant mow his lawn. Having driven 45 miles to reach the participant, I was determined to do whatever it took to complete the interview. As he appreciated my gesture, the participant introduced me to two other families.

Data Collection

The PI administered surveys and interviews in and around both cities. Within Public Health hazard research, an interview data-based approach that integrates qualitative data and survey data can help to examine the complexity of IE, measure outcomes, and evaluate efficacy of existing interventions (Kelle, 2006). The PI collected data between April 25th, 2019 and June 11th, 2019, as well as between July 6th and August 25th of the same year. The study was reviewed and approved by the Institutional Review Board (IRB) at UCI prior to any data collection.

Surveys

Respondents submitted data via a self-administered structured paper survey given to residents in the Pawnee and Cushing areas. An ethnically stratified purposive sample of residents (N=112) agreed to participate, out of which 28 also agreed to participate in an in-depth interview. Participants were given the option to fill out the paper survey or complete the online version of the same survey hosted on UCI Qualtrics. The survey contained 42 items and took approximately 20 minutes to complete. The major topics covered in the questionnaire included

demographics, earthquake experience, IE exposure history, preparedness actions, a stress assessment, and IE damage (see Appendix A). All items were closed-ended and organized by city of residence.

Earthquake Preparedness Variable. To evaluate preparedness, we constructed a 9-item binary scale (Yes/No) variable. The topics included whether respondents made a family disaster preparedness plan, made copies of important documents, bought earthquake insurance coverage, prepared 3-days of food, prepared 3-days of water, had a first aid kit, knew how to turn off the main gas valve off, secured heavy furniture to the wall, and possessed a portable radio with spare batteries.

Earthquake Damages. The instrument for measuring IE damages had three possible responses, including (a) yes, (b) a few, and (c) no damage at all. Respondents were asked if and how they paid to fix those damages. The options included, (a) paid out of pocket, (b) earthquake insurance, (c) federal or state funds, and (d) did not fix the damages yet.

Demographic Variables. Key demographic variables included age, sex, race, income and education level. Participants were also asked about their current home ownership status (own/rent).

Interviews and Visual Observation

The PI conducted face-to-face, in situ interviews while simultaneously observing the immediate environment. Respondents who completed the survey were asked to participate in in-depth interviews. The majority of interviews took place in the participants' homes. A total of 28 participants consented to share their experiences with IE. Participants filled out the paper survey prior to being interviewed. The PI asked for permission to read the survey responses prior to proceeding with the interview. The interviews followed a semi-structured, open-ended question

format to allow for flexibility and to obtain the richest detail possible. The aim was to gain deep understanding of the factors influencing their earthquake preparedness decisions as well as to evaluate their reactions during an earthquake by inquiring about their immediate response following the most recent significant earthquake in their area. As a result, the length of each interview varied greatly and was fully dependent on the willingness of each participant to share information.

To ensure diversity of perspectives, the PI collaborated with local stakeholders, such as city council employees that helped identify participants with experiences of varied levels of IE damage and with varying degrees of personal involvement with the OGI. Participants were given pseudonyms to protect their identities.

Data Analyses

Survey Data. We conducted survey data analysis using SPSS V27. We cleaned the data to enable analysis and generated descriptive statistics. We calculated mean levels of agreement and the corresponding confidence limits (95%) for each questionnaire item.

Interview Data. We transcribed interviews verbatim and entered the transcripts into Atlas.ti V9 for analysis. We used the qualitative data analysis software to organize, manage and reconfigure the data to facilitate analysis. The software was not used as a tool to perform the actual analysis. We did not focus on word counting but rather on identifying key themes by performing several cycles of coding. During the primary coding cycles, we focused on categorizing the basic activities and processes in the data, rather than interpretation. Through constant comparison of identified processes, we moved to secondary-cycle coding with the aim of synthesizing and categorizing the primary codes into interpretive second-level codes (Bailey, 2007; Basit, 2003;

Tracy, 2010). Following this, we used the emergent themes to further synthesize and interpret the resultant codes.

Results

Survey Data Findings

A total of 112 respondents were included in this study. Considering that the estimated population of Cushing, OK is 7,615 and of Pawnee, OK is 2,106, this is not an insignificant sample size. Table 2.1 contains descriptive statistics of respondents. The average age was approximately 46 years (M = 46.43, SD = 13.65). Most of the sample were female (N = 61, 54.5%), earned $35-$49k in income (N = 27, 24.1%), were high school graduates (N = 39, 34.8%), White (N = 67, 59.8%), and were homeowners (N = 76, 67.9%). Table 2.2 captures the descriptive statistics for the earthquake preparedness questionnaire. Out of the 112 respondents 59.8% (N=67) experienced damages, 25.9% (N=29) paid out of pocket to fix them and 33.9% (N=38) did not fix the damages yet due to being unable to pay for them. Almost one-third of the sample (33.9%, N=38) stated that they have earthquake insurance, yet none of the respondents were compensated for earthquake damages by their home earthquake insurance company.

Earthquake Preparedness based on IE Damages

The results of independent samples t-test, comparing earthquake preparedness between those who experience IE damages and those with no damages at one point in time, are shown in Table 2.3. According to Table 2.3, those who experienced earthquake related damages (M = 20.43, SD = 2.14) did not score significantly differently in earthquake preparedness compared to those who did not experience any property loss (M = 20.27, SD = 1.78), $t_{(110)} = 0.43$, $p = .668$ while living in Cushing or Pawnee, OK during the time of increased earthquake activity. This finding suggests that experiencing IE related damages does not impact the earthquake

preparedness of those living in Cushing or Pawnee, OK during the time of increased earthquake activity.

Qualitative Data Findings: Factors Influencing IE Preparedness

Qualitative analysis of interviews yielded five primary themes explaining the factors that influenced their IE preparedness. Table 2.4 presents an organized representation of themes and subthemes. Of note is that participants expressed valid reasons that prevent them from preparing fully for earthquakes. Participants also communicated a general sense of resentment towards IE, which many expressed led them to reject taking action to improve preparedness.

Interview participants lacked knowledge about dealing with earthquakes. They were not aware of how to prepare and what to do during an earthquake. Some participants tried to find information by talking to others, searching online, reading the local news, and visiting the USGS website. Participants felt confused since their experience and what they read did not resemble what they have felt—almost daily multiple lower magnitude earthquakes with loud sounds and varying degrees of shakings. The themes and quotes presented below are indicative of the data collected.

Lack of earthquake experience. Interview participants had no prior experience with earthquakes. Participants stated that they know exactly how to deal with the extreme weather conditions characteristic of Oklahoma's climate. In contrast, they expressed not knowing the proper procedures for dealing with earthquakes. Based on the statements that follow, it can be inferred that interviewees rationalized their lack of earthquake preparedness knowledge upon the premise that Oklahoma is a low natural seismic hazard area. Interviewees often referred to California, a state known to have high seismicity.

I don't have much experience. I never lived outside of Oklahoma. —Betty

I don't have any. I didn't know what earthquakes felt like until we got them. Well, when I was in grade school, they kept telling me they had them in California. —Elie

Well, I have never felt an earthquake until I moved here (Pawnee)…Let's see, the big M5.8 earthquake was about, well, that was in September of 2016. I probably started feeling earthquakes a couple of years before that, 2014. —Nick

Lack of IE Preparedness Knowledge. Participants, including a first responder in a leadership position, did not know which actions were most appropriate for maximum safety during seismic events. Some expressed the belief that they could do nothing to truly prepare for earthquakes besides remembering to stand underneath a doorway or running outside a structure. Both actions can be highly dangerous during major earthquakes as they increase the chances of being injured

by flying objects (Adams et al, 2017; Petal, 2011). Instead dropping, covering, and holding on during a strong earthquake is the sequence of actions recommended by the Great Shakeout to minimize injuries and to protect vital organs (Adams et al., 2017). Also of note is that participants sought additional information through talking with other people, reading the local newspaper, visiting the USGS website, and listening to news broadcasts. Participants expressed, however, that they tended to ignore the resulting information due to lack of clarity.

Nothing really. There is nothing you can do about earthquakes. — Liam

I know what to do…I know how to get under the doorway. —Sarah

I try to listen to the news, read the local paper, we have a Facebook page, and make announcements there. I go to church and talk to people. No one knows for sure. They all got opinions. We are in the dark. I would like to hear someone in charge tell us what to do. —Betty

I do not know if there is anything you can do about our kind of earthquakes. I read a few things, but I am not very informed. I do not know what to do. What do you do when you have daily earthquakes? What are the recommendations? I could not find any. —Brianna

Go under the door or run outside if you can. Outside is the safest place to be, but are we going to run outside every time we feel one? —Mary

The information provided did not seem to "make sense" based on their experience. One interview participant questioned the helpfulness of the ShakeOut drill after I explained to him why we recommend to drop, cover and hold on. His response was

… and what do we do, drop, cover and hold on ten times per day? Does that make sense to you? —Steven

Challenges in Preparing for Multiple Hazards.

Preparing for both weather-related hazards and earthquakes presented unique challenges for participants. Interviewees were aware of weather-related prevention actions and most of them were sufficiently prepared. Regarding earthquake preparedness, we found overlap between their weather-related hazard preparations and recommended earthquake preparations. Participants were not prepared for situations specific to earthquake preparedness, but for justifiable reasons. The two following subthemes capture the primary reasons participants expressed that resulted in a lack of preparation for earthquakes.

Some Weather Hazard Preparedness Contradicts Earthquake Preparedness. Participants were confused and conflicted about the practical implications of earthquake preparedness. They expressed concern regarding how they may be able to prepare for earthquakes when their buildings and public works are designed to protect from extreme weather hazards such as

tornadoes or flooding. Many homes in the area have shelters made out of thick slabs of concrete. Many older homes in the area are made of stone while newer houses sit on top of concrete slabs designed to reduce flooding risk. Concrete does not dissipate energy well and it is prone to developing cracks, requiring costly repairs.

> *…you can't build for both earthquakes and tornadoes. What keeps you safe during a tornado is what it will kill you during an earthquake.* —Nick

> *You are better off living in a trailer home when there is an earthquake. They are not safe with tornadoes…We build homes in Oklahoma to withstand tornadoes. It is that rigidity that will keep you safe. We use a lot of cement and heavy roofs, so they won't fly away. I don't think all that rigidity goes well with earthquakes. There are cracks all over my floors, my laundry room separated from my kitchen, and my shelter got cracks because it was made out of cement. How do you prepare for both?* —Tina

> *…we build for 90 miles an hour sustained winds. This is what our code says. My house has a 28-feet peak, and we are coming up with ideas to attach it [the roof] to the ground with some post and that kind of thing…it is not cheap. Is it going to hold all that weight during an earthquake? I don't know... That's why we run outside. The roof won't fly away, but it will crash you during an earthquake.* —Frank

Some Earthquake Preparedness Actions Overlap with Weather Hazard Preparedness. Based on the Great ShakeOut, earthquake preparedness actions include having at least three days' worth of food and water for each person in the household, preparing a portable radio with extra batteries, knowledge to turn off the main gas valve, having a disaster preparedness plan, making copies of important documents, and having secured heavy items to the wall so they won't become airborne during an earthquake (Adams et al., 2017). Most earthquake injuries are from

falling objects rather than buildings (Petal, 2011). In analyzing the survey data, we discovered that a number of recommended actions and preparations for earthquakes, coincide with the extreme weather hazards for which Oklahomans must routinely prepare. For example, interviewees often explained that the risk of flooding is very high, and tornadoes are not uncommon. As a result, many individual households have their own generators and have at least a week of food stored at all times. Of note, Pawnee residents do not have access to many stores, having to commute to Stillwater to buy most of their groceries. They must stock up on essentials every time they visit the city.

> *Yes, we all keep a lot of food and all sorts of supplies at home. We get lots of floods around here, so it is not wise to drive.* —Connor
>
> *The weather here gets pretty bad fast, and we can go a day or two without electricity, so you need to have a generator, a flashlight, batteries, and a freezer full of food. I keep water in my car, my garage, and two large-capacity tanks with water.* —Simon
>
> *How many markets did you find on your way here? (laughter). Not that many, right? There is not much around here, so you need to drive to Stillwater to get anything decent. There they have a Walmart, a Target, even Whole Foods. With the weather being so unpredictable, we all drive there and stock up our pantries.* —Tina

Resentment. Participants expressed an overall sense of resentment toward being forced to invest their resources to improve their earthquake resilience. Interview participants expressed that they are used to the weather-related hazards and have accepted them as a natural part of living in Oklahoma. Earthquakes, however, are not historically common in Oklahoma and interviewees

expressed discontent in having to expend their resources in adapting to an induced hazard they were not responsible for creating.

> *I live in Oklahoma, not in California. Why should I prepare for earthquakes when we are not supposed to have any?* —Briana
>
> *This is Oklahoma we are talking about. I am prepared for all kinds of weather hazards. I do not need to prepare for earthquakes too.* —Rose
>
> *We are not supposed to have earthquakes here. They've been drilling for oil for over 100 years. We never had earthquakes before. Why now? This is not natural for Oklahoma.* —Violet

Damages from Induced Hazards Should be the Responsibility of Those Who Profit from Them. Participants expressed strong opposition to paying for damage caused by the OGI. Regardless of their ties to the OGI, interviewees believed that the damages should be addressed by the people or organizations who are responsible for the increase in seismic activity.

> *Why should I pay for something that was not God's doing but someone's greed?* —Sam
>
> *I know that someone is prospering from that activity at my expense. I detest the earthquakes, and it just goes right through me. Especially knowing how much damage was done to my house, my place, and my barn.* —Nick

Discussion

Discussion of Results

In the survey component of the study, we found that prior experience of property damage from IEs was not associated with earthquake preparedness. The findings are in contrast with research into preparation for major seismic events, which tend to find that prior experience is a useful indicator (Becker et al., 2017). This implies that other factors may mediate readiness.

Motivators of those prepared for disasters include increased likelihood of the disaster in question, information regarding the disasters, personal experience, discounted prices on basic supplies, knowledge about potential losses associated with disaster, and personal disposition toward preparedness (Kruger et al., 2020). Barriers include difficulty planning for the unknown, lack of finances, belief that preparation is unimportant at current residence, lack of knowledge of where to begin, and difficulty communicating to family (Kruger et al., 2020). Note also the distinctiveness of Oklahoman IE preparedness research compared to conventional earthquake preparation research, the latter which tends to focus on catastrophic events (Ardalan et al., 2020; Baytiyeh & Naja, 2016; Wu et al., 2020). That explains why the respondents who purchased earthquake insurance were not compensated for the damages caused by the IE. Earthquake insurance has high deductibles that are based on the value of the home. IEs lead to smaller but frequent damages that prevent homeowners from meeting their deductible from a single seismic event. The lack of precedent in IE preparedness research points to the need to investigate predictors and mediators of preparation unique to areas of induced continuous seismicity.

In this study, we identified a number of unique themes not found in contemporary earthquake preparedness literature. Residents are unaware of what to do during earthquakes due to lack of information and education pertaining specifically to induced earthquake hazard. On one hand, participants had not engaged in preparations specific to earthquakes, such as securing heavy items or enrolling in earthquake insurance. On the other hand, many of the preparations for conventional Oklahoman disasters—such as food, water, lights, first aid kits, and turning off the gas main—overlapped with that of earthquake preparation. Of particular note is that preparation for tornadoes and other climate-based natural disasters in Oklahoma can be, in critical aspects, contradictory and detrimental with respect to seismic events. As multiple

participants noted, the structural rigidity so advantageous during tornado and flood seasons may be dangerous during earthquakes. A final novel theme is the overall resentment that participants expressed toward having to prepare for hazards induced by a third party. The resentment also involved the need to address continually accumulating damage to property combined with the inability to find insurance products that met their needs.

Theoretical Implications

The participating residents of Pawnee, and Cushing Oklahoma were far better prepared for weather phenomena than earthquakes. This is consistent with findings that people are less likely to adequately prepare for human-induced hazards (Baum & Gatchel, 1981; Baum et al., 1983). Unlike natural hazards, induced hazards involve events that can be controlled and prevented, which is a critical difference (Erikson, 1976). However, as with natural hazards, they are just as difficult to predict, least of all because they were not intentional (Erikson, 1976). Participants expressed that they did not want to be responsible for damages they did not cause, particularly because they were not part of the overall decision-making process despite being stakeholders. This ties into McComas et al.'s (2016) findings that residents tend to believe IEs to be more acceptable if they believed that they had a voice in the decision-making process. Campbell et al.'s (2020) findings, that stakeholders viewed the damages caused by induced earthquakes as inconsequential, may seem contradictory with the findings of this research, but it must be noted that the researchers included participants who were stakeholders in the oil and gas industry (OGI) and did not reside in the highly impacted with IE areas. Furthermore, Campbell et al. (2020) noted that those who exhibited skepticism toward the potential for IE to cause substantial damage were often purchasers of earthquake insurance despite expressing these

opinions. It will be important, therefore, for future researchers to note attitudinal differences and nuances that can be attributed to the degree research participants are stakeholders to the OGI.

The findings also highlight the complexities inherent in residents' lack of understanding of the implications of earthquakes, their mistaken actions, and the actual implications of IE. As Patton et al. (2014) found, even experiences with earthquakes—such as the near-daily experiences of some of the participants—may not lead to preparatory action in the face of misinformation or conventional fallacies. Evidence suggests that formal modes of education are not as effective for generating meaningful preparative action compared to self-education and community-oriented education measures (Shaw et al., 2004). Likewise, Becker et al. (2017) found that disaster experiences create cognitions, conversations, and community interactions about preparation which, instead of creating a system of logical thought, creates a social context in which preparedness-related activities may occur. Extending Shaw et al.'s (2004) and Becker et al.'s (2017) findings may aid in understanding and addressing the lack of knowledge of Oklahoma residents regarding how to prepare for IE.

Public Health Implications and Recommendations

Induced earthquake preparedness presents challenges that differ from preparedness for large natural earthquakes (Bommer et al., 2015). Widely accepted and conventional earthquake readiness strategies such as those put forth by the Great Shakeout simply do not address the needs of people living in areas of induced seismicity. Unfortunately, current public policies neither protect the interests of residents or industries, instead allowing open opportunities for costly lawsuits against existing industries (Bulgarelli, 2017). Lack of knowledge and understanding of the most effective protective actions and precautions to take in the context of IEs can also be detrimental to the health and well-being of residents. This is important

considering that participants unanimously believed that running outside during a major earthquake was the most appropriate response, which is contrary to that of current recommendations. Meanwhile, given the type of construction used for many buildings in the affected areas, running outside might be a wiser option for people living in a single-story home made of stone. That is something that the preparedness community needs to examine, since it is not feasible for all the residents to rebuild their homes. According to the results, there are knowledge gaps in IE preparedness and overall community awareness and education efforts in areas impacted by IEs.

The lack of association between IE experience and preparation suggests that future research is needed to understand the motivators of preparative actions in populations experiencing IE. The results also show novel barriers not yet addressed, particularly of preparation measures that contradict that of other concurrent natural disasters in the area, such as rigid construction of structures. If ongoing research into the consequences of IEs confirm the severity of long-term and accumulative structural damage, this contradiction will be of major concern, as current Oklahoman building codes are designed for resistance to tornadoes and flooding rather than seismicity. It may be necessary for the government to reconcile these contradictory structural hazards through the formulation of new building codes and regulations.

Our research also revealed novel attitudes of residents toward induced seismicity, specifically that of resentment toward having to prepare for and deal with human-induced damage with inadequate information or insurance products. This can lead to litigation against the OGI which may result in unnecessary effort and expenses for both parties (Bulgarelli, 2017). These funds may be better spent by the OGI, for example, to help decrease insurance deductibles, pay for damages, or formulate insurance products more appropriate to IE. We

propose the establishment of an Induced Earthquake Restitution Fund. Another recommendation, which a private fund may facilitate, is for the government to direct funds to support retrofitting residences to meet earthquake resilience standards.

Finally, our results revealed lack of adequate intentional educational interventions for earthquake response and preparation. One participant felt that they only got "lip service" from those in charge and nothing more. As prior researchers have suggested, successful disaster education is not as simple as disseminating information but involves encouraging individuals to engage in cognitive and social ways (Becker et al., 2017). We recommend researchers and public health workers to begin formulating programs and strategies unique to areas affected by IE, as strategies promoted by conventional programs like the Great Shakeout are not readily applicable.

Conclusion

There are two key points that emerge from this study. First, current earthquake preparedness guidelines do not adequately address the unique risks associated with induced seismicity. Earthquake recommendations should account for the type of buildings and public works in the area, the knowledge level of the target audience, and characteristics of the geography and climate. Second, there is a need for efforts to educate and involve communities affected by this novel seismic hazard, to reduce the potential for misinformation and resentment about preparedness. As hydraulic fracking continues in usage and popularity, public health interventions for seismic hazards must be expanded to address the needs of communities affected by the outcomes.

Table 2. 1

Respondent Characteristics

Variable (N = 112)	*Frequency*	*%*
Sex		
Male	51	45.5
Female	61	54.5
Income		
Less than $25,000	14	12.5
$25,000-34,999	28	25.0
$35,000-49,000	27	24.1
$50,000-74,999	25	22.3
$75,000-99,999	6	5.4
$100,000+	3	2.7
Prefer not to answer	9	8.0
Education		
Less than high school	8	7.1
High school graduate	39	34.8
Some college	28	25.0
2-year degree	17	15.2
4-year degree	16	14.3
Professional degree	4	3.6
Race		
White	67	59.8
Hispanic or Latino	13	11.6
American Indian or Alaskan Native	17	15.2
Asian	7	6.3
Black or African American	7	6.3
Other	1	0.8
Home ownership		
I own my home	76	67.9
I am renting	36	32.1

Table 2. 2

Earthquake Preparedness Actions

Variable (N = 112)	*Frequency*	*%*
Have a family disaster plan		
Yes	51	45.5
No	61	54.5
Copied important documents for safekeeping		
Yes	17	38.4
No	95	66.1
Have earthquake insurance		
Yes	38	33.9
No	74	66.1
Have three days' worth of food		
Yes	81	72.3
No	31	27.7
Have three days' worth of water		
Yes	71	63.4
No	41	36.6
Know how to turn off the main gas valve		
Yes	71	63.4
No	41	36.6
Have a portable radio and spare batteries		
Yes	74	66.1
No	38	33.9
Secured heavy furniture to the wall		
Yes	5	4.5
No	107	95.5
Have a first aid kit		
Yes	88	78.6
No	24	21.4

Table 2. 3

Independent samples t-test comparing earthquake preparedness between those who experienced earthquake related damages and those who have not (N = 112).

Item	Experience	*n*	*M*	*SD*	*t*	*df*	*p*
Earthquake related damages?	Yes	67	20.43	2.14	0.43	110	.668
	No	45	20.27	1.78			

Table 2. 4

Factors influencing IE preparedness

- Lack of Earthquake Experience
- Lack of IE Preparedness Knowledge
- Challenges Preparing for Multiple Hazards
  - *Contradictory Preparations*
  - *Overlapping Preparations*
- Resentment
- IE Damage Not Residents' Responsibility

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CHAPTER 3

Shaking up Oklahoma: A Qualitative Study of the Effects of Induced Earthquakes on Pawnee and Cushing Residents

Introduction

How does environmental hazard affect individuals and communities? Sudden onset of earthquakes in Oklahoma, USA, provides an opportunity to address this question in an area with relatively low natural seismic hazard (LNSH). Until 2008, very few residents of Oklahoma had experienced an earthquake (Ellsworth et al., 2015; Petersen, Zeng, et al., 2014). This period of seismic quiescence changed abruptly with the occurrence of non-natural earthquakes induced by injection of wastewater from oil and gas production activities (Keranen et al., 2014). Wastewater is a byproduct of oil and gas production, and when injected in large volumes under high pressure, leads to induced earthquakes (IE). By 2010 the State of Oklahoma experienced an unprecedented increase in the occurrence of low to moderate magnitude earthquakes (Ellsworth, 2013; Ellsworth et al., 2015; Petersen et al., 2015). Low magnitude earthquakes ($M \leq 3$) can cause perceptible shaking, and moderate magnitude earthquakes ($3 < M < 6$) can cause damage to buildings and their contents. In 2014, the total number of earthquakes with magnitude $M \geq 3$ reached 585, more than quintupling within a single year. In 2015 the number of $M \geq 3$ earthquakes increased to a shocking 907, nearly doubling the previous year's total (Delatte & Greer, 2018; Hough, 2014; Earthquakes in Oklahoma, 2018). By 2016, IE had caused considerable damage in Pawnee, Cushing, and Fairview, Oklahoma (McGarr et al., 2018). In less than a decade (2008-2016) many Oklahoma residents experienced earthquake shaking for the first time and suffered damages. How were they affected?

Much research has focused on understanding the cause of IE and their potential for damages. Researchers only recently started to examine the social and behavioral impacts of IE. Greer et al. (2020) used mail-in surveys to compare data on the perceived threat and coping appraisal between the residents of two communities in Oklahoma with different IE exposure.

They found that earthquake risk perception and mitigation adoption intentions are significantly higher among people living in the area impacted most by IE. The study did not measure actual adjustment to the IE (Greer et al., 2020). Another study showed that regardless of IE's community impacts, Oklahoma government officials have not taken measures to protect the affected communities (Chang et al., 2018).

The oil and gas industry (OGI) provides an economic lifeline for many Oklahomans, and is also responsible for the increase in seismicity. Research on IE hazards indicates that the benefits of OGI activities influence how people view the risks associated with those activities. McComas et al. (2016) examined factors that affect people's acceptance of induced hazards. They found that when people are involved in decisions that impact them, they are more likely to accept IE's effects. The study participants were U.S. adults and not necessarily from states affected by IE. A qualitative study conducted in Oklahoma by Campbell et al. (2020) examined benefits and opportunities derived from OGI activities and how they may affect people's risk perception. Campbell et al. (2020) interviewed various stakeholders within the state and found that the economic benefits of the OGI play an essential role in Oklahoma. The interviewees did not include household participants of the highly impacted areas in Oklahoma.

In addition to abrupt onset, there may be differences between IE and natural earthquakes with respect to their impact on residents. IE can occur anywhere wastewater injection activities are taking place. Therefore, IEs can and do impact communities not previously designed to withstand earthquake shaking. IEs may also differ in characteristics that affect people. For example, many IE occur at shallower depths[5], and therefore closer to humans, than natural

[5] Earthquakes occur in various depths between the upper mantle and the crust. The strength of earthquake shaking increases with decreasing distance from the source. Therefore, an earthquake that occurs at 500km deep will be less than if the same earthquake had occurred at a depth of 20km.

tectonic earthquakes. Some areas in Oklahoma experience multiple daily swarms (Oklahoma Geological Survey, 2021). Natural earthquakes affect specific regions independent of human activities, and occur in relationship to natural tectonic processes, typically with long periods of seismic quiescence. The total number of states and people affected by IE has increased in recent years due to human activities. Arkansas, Colorado, Kansas, and Ohio also experience IE, with Oklahoma leading in the prevalence (Hough, 2014).

Oklahoman IEs provide an opportunity to examine how frequent, low- to moderate-magnitude earthquakes impact individuals and communities and how their experiences differ from those following a catastrophic natural earthquake. A community-centered understanding of this new hazard can help disaster preparedness planners and Public Health policymakers to revise and adapt mitigation and earthquake preparedness actions to fit the needs of people affected by IE.

Research Questions

This study aims to understand the impact of IE and present the experiences of those impacted the most to inform current earthquake preparedness and mitigation plans.

We address the following Primary Research Question (PRQ) and Secondary Research Questions (SRQ):

PRQ: What are the experiences of people living with IEs in areas of LNSH in Oklahoma?

SRQ1: In what ways do IE affect residents' lives?

SQR2: How do residents react to the IE hazard?

SQR3: What resources are available to help residents, and to what extent do those resources meet their needs?

Methods

Research Method

We used the qualitative methods of Naturalistic Field Research to provide an emic (insider's) understanding of the IE problem (Bailey, 2007; Pope & Mays, 1995; Shortell, 1999). An emic approach will provide an insider's perspective to understand IE. We conducted *in situ* in-depth interviews with impacted residents and local stakeholders to provide rich detail on the experiences, values, and challenges faced by those communities (Erikson, 1976; Lofland et al., 2006; Siedman, 2013). We utilized visual methods, such as observation and analysis of photographs, to enhance the richness of our data. The addition of visual methodologies in qualitative research adds validity and increases the breadth of understanding (Catalani & Minkler, 2010; Glaw et al., 2017). Following a multi-step approach to coding, we used an inductive methodology to collect, analyze and interpret data, allowing us to build a strong empirical foundation to understand the IE problem in LNSH areas (Bailey, 2007; Dellve et al., 2002; Mruck & Mey, 2019). The coding approach emphasizes the field under study and the data instead of theoretical assumptions (Flick, 1998).

Study Area and Recruitment Procedure

We used purposive sampling to recruit adult English-speaking participants for interviews as it is optimal for hard-to-reach communities and controversial issues (Heckathorn, 2011). We adapted our methodology to respect the needs and privacy of the participants while maintaining the required rigor through detailed note-taking, cross-referencing, and voice recordings when permitted. We sought interviews with residents from varied backgrounds, ranging from local government representatives, first responders, and people working for the oil industry. Prominent community members provided names, phone numbers, and in some instances, telephoned other

participants and advocated on the behalf of the principal investigator to facilitate the sampling process. IRB approval was obtained from the University of California, Irvine.

We selected Pawnee and Cushing, Oklahoma as sites to conduct the interviews. Pawnee, in addition to having daily seismic swarms, was the site of one of the strongest earthquakes (M5.8) in the state of Oklahoma, which occurred on September 3rd, 2016 (Skoumal et al., 2018). On November 7th of the same year, Cushing Oklahoma was struck by a M5.0 earthquake (Taylor et al., 2017). Despite having a significantly lower magnitude, the Cushing event got more attention than the Pawnee event because it is located on one of the largest oil hubs in the Country. In Cushing, any earthquake of $M \geq 4$ has the potential of becoming a national-scale disaster, posing a significant risk since it is a major part of the nation's energy infrastructure (McNamara et al., 2015). Both Pawnee and Cushing are classified as cities, with some people residing in the center and others around the perimeter, the latter which more resembles a rural society than an urban environment. The architectural and structural[6] situation of each participant was taken into close consideration during the interview and analysis processes.

Interviews

The principal investigator conducted *in situ* interviews during two spans of time in 2019, from April 25th to June 11th and from July 6th to August 25th. I was forced to leave the area from June 11th through July 6th because extreme weather conditions precluded data collection, with Oklahomans experiencing the most severe flooding and tornado season in the past decade. We conducted follow up interviews with some participants if clarifications were required (Wengraf,

[6] The earthquake intensity value at any given location depends on several variables: 1) earthquake magnitude; 2) distance from the epicenter; 3) type of rock sediment; 4) building style, design, height, and kind of building materials; 5) duration of earthquake. All these factors must be considered when assessing the earthquake threat for any location. Rigid and short buildings amplify high-frequency P and S waves, increasing the overall threat substantially.

2001). Interview length varied by participant and ranged from 45 to 120 minutes. We also held many informal discussions with some participants. The primary investigator resided locally for the majority of the data collection period which further increased rapport with the local communities of Pawnee and Cushing.

The interviews took place primarily in the participants' homes. Exceptions included a few individuals requesting to meet in their offices or in Stillwater, a nearby city, at a local coffee shop. A common reason for this exception was to avoid being seen participating in the study because they had active lawsuits against the oil industry.

Interview Guide and Experience

We developed and used a semi-structured interview guide (see Appendix B) with open-ended questions to allow participants to share their unique experience (Kvale, 2015; Seidman, 1991). The interview questions contained inquiries into the experiences, feelings and opinions of the participants. Participants were asked questions about their overall experience with earthquakes, including whether the events were natural and induced, how they reacted, and how they felt. They were asked to describe their experience in as much detail as possible and to provide visual examples if able, such as photos of damage or by showing us current examples of damage. The interviewees were prompted to share their views about the OGI, wastewater injection, concerns about the practice, and how they have been affected. Participants were also asked to reflect on any interventions or resources they were provided to help them adapt to the IE hazard. The interview questions were adapted to fit the nature of each interview, and the number of follow up questions varied by participant. Because the primary focus was to understand the impact of IE, the interviewees' willingness to share their experiences determined the amount of

time spent with each participant. The homes and immediate environment were treated as important experiential components of the study.

Analysis

Professional transcription services were used to transcribe all recorded interviews into digital written formats. All notes made by the principal investigator, if not already typed, were also transcribed into digital written formats. We coded the transcripts using Atlas.ti software (Version 9). Several rounds of second-level axial coding followed the first level of coding and memoing until no further themes emerged (Bailey, 2007; Lofland et al., 2006; Tracy, 2010). Themes and representative quotes were discussed among the research team members, to verify information.

Results

Demographics

The participants (*N*=28) had a mean age of 55.2 (*SD*=14.9) ranging from 33 to 90 years old. The majority of participants identified as White Non-Hispanics, (53.6%, *n*=15); 25% as "Native American or Alaskan Native" (*n*=7); 10.7% as Hispanic or Latino (*n*=3); 7.1% as Black or African American (*n*=2); and 3.6% as Asian (*n*=1). Table 3.1 contains the breakdown of participants classified by their role, including insiders, who we define as professionals with extensive knowledge of IE (e.g., oil industry executive, city employees, etc.). All participants were assigned pseudonyms to protect their identities and to comply with IRB approval guidelines. Insiders are defined as those who expressed their views and opinions based on local government and/or OGI experience.

Table 3. 1

Participant breakdown (N=28)

Category	Number of Participants[c]
Elected Official[a]	2
City Employee[a]	4
Other Public Servant	2
First Responder[a]	2
Oil Industry Executive/CEO[a,b]	1
Oil Industry employee[a,b]	2
Insurance Provider	1
PTA Representative	1
Business Owner	2
Community Member	11
Total	28

Note. [a] Participants categorized as insiders.
[b] The Oil Industry employees shared their experience and expertise. Their interviews do not represent the views of the OGI.
[c] Individuals that participated through informal discussions are not included.

Qualitative Findings: Experiences and Effects of IE

Many participants began their narratives from similar perspectives, articulating that IE are not natural and they should not happen in Oklahoma. Regardless of their ties to the OGI, participants appeared resentful towards induced hazards. However, they argued that the OGI activities should remain, and that IEs need not be eliminated as a consequence of those activities. Although the people of Pawnee and Cushing have a long history of fracking, they did not experience IE until relatively recently. As a result, some speculated that there must be a reason for this newfound seismicity that can be addressed.

The following results were organized to present the participants' perspectives on nine different themes that emerged from analysis: the features and characteristics of IE, financial

impact of IE, earthquake insurance challenges, inability to make sustainable repairs, emotional strain, inadequate government and institutional support, reduced income from leasing their lands to the OGI, environmental and safety concerns, and generalized neglect of rural areas in the U.S. Figure 3.1 illustrates themes and subthemes that emerged from interviews, in no order of significance, as well as participant comments, concerns, and thoughts. Figure 3.2 is a conceptual model built from these themes. We first describe each major theme, then present evidence of subthemes that comprise each theme. Themes are directly or indirectly related to IE, as described below.

Features and Characteristics of IE

IE Had Peculiar Sounds

IEs were experienced as rolling movements, accompanied by loud screeching sounds. As Liam, a business owner close to retirement in his mid-60s, described:

> *It starts off with distant thunder, thunder that you could hear it coming…It sounded like lightning which created a boom, and that boom is over here, and then the noise rolls from the thunder. The thunder would roll, as the earthquake would roll through the house, from one side to the other. They would come and go.*

The distinct sounds made them stand out in the minds of the people. Brianna described her experience:

> *... [an IE] can be long ways away and just make a little noise or you can be right up on top of it. When they first started, you would hear little rumbles and say, what was that? Sunshine and thunder don't go together.*

Frank, a middle-aged structural consultant recalled hearing and sensing IEs:

Sometimes you only hear those. The bigger they are the louder… I was in a golf course in Perkins one day. It shook pretty good, and you could just feel it. It feels like there is water under your feet. The ground ripples.

Incessant IE

Participants described IE as frequent daily events. According to Liam:

Before the September earthquake, the frequency would be as many as 10 earthquakes a day.

Sam, an older Native American man who lives inside the Pawnee Nation reservation and leases his land to the OGI for oil extraction, shared a unique negative consequence of IEs:

As I told you, my dog noticed the earthquakes first. He started to bark before we even heard the sound. We would hear this weird rambling noise and we did not know what it was. They became so frequent, that the dog would not shut up. I was like, Nelson you better get used to it.

Feeling Varied Earthquake Intensities

Although the great majority of IE were of lower magnitude and were not listed in the USGS website, participants stated that they felt them. Frank, a middle-aged structural consultant, stated:

Oh, yes, you can feel the little ones (a M<2), but it is a quick little something.

Brianna was able to detect IEs far away and mentioned that her sensitivity to IE was higher at particular times:

I want to say that I felt them earlier in the morning and late at night.

IEs of higher magnitude were more noticeable and disturbing. The following quotes from Sarah capture her experience with IE and provide a glimpse of what happened on the day of the M5.8 Pawnee event, the largest recorded earthquake in Oklahoma.

> *A lot of shaking and rumbling noises. It was weird…The noise intensified and started to sound like a freight train was going through the house… I was asleep during the big one, and it woke me up. I heard a roar and got louder and louder. It seemed to go on for a while. Longer than I remember in Northridge [10-20 secs]. This one broke more things.*

Confusion. A subtheme that emerged when participants described their experience with IE was confusion. Earthquakes were not a hazard Oklahomans were used to deal with, let alone become a part of their daily lives. The constant shaking, loud noises, and feeling varied magnitudes confused participants. Interviewees reported that IEs do not resemble anything like the earthquakes seen on the news or movies. As the frequency of IEs gradually increased, the booming sounds likewise increased in frequency. Participants reported shaking becoming increasingly noticeable and lasting for longer periods of time.

> *The first time I felt an earthquake, I did not know it was an earthquake. It shook for a second and it stopped. I heard a noise first, and then it was boom, this intense shaking that if it would last, it would cause damages.* - Neil

> *I felt puzzled. The noise was like a sonic boom, and the shaking was very brief. I did not think it was an earthquake. When you think of an earthquake, you think the earth will open up, and buildings are tumbling down. This was different. When I heard people talking about earthquakes in Oklahoma, I thought they were crazy.* - Beatrice

I was caught unprepared since I did not expect to get an earthquake in Oklahoma. A tornado yes, flooding is very possible, but an earthquake, never! - Sarah

Financial Impact of IE

Property Damages.

Types of property damage varied greatly, with participants experiencing anywhere from minor cracks on their walls to major fractures to cement basements and exterior stone sidings (See Figures 3.2a & 3.2b, and 3.3a & 3.3b). One pair of participants, a couple living in Pawnee, experienced damage extensive enough to warrant moving out of the property. Their house was rendered unsafe and cracks throughout the structure became infested with insects, rodents, and snakes. At the time of the interview, Ken and Katherine had been living inside their barn and were in the process of building their new home. Figures 3.2a and 3.3a capture the exterior and interior damages they described. Figure 3.4 shows Katherine in front of her newly built foundation. Katherine did not receive any assistance from the state and had an active lawsuit against the OGI. Ken described the aftermath of the "big one" as follows:

This place was a mess after the big earthquake…we had to foot the whole bill and rebuild when there is no insurance. The house was so bad that could probably spend $100,000 to $200,000 to fix it. We had mice infestation and insects. Snakes. We had snakes in our house. The walls were damaged beyond repair.

Figure 3.2a & 3.2b

Exterior damages after the M5.8 IE in Pawnee, Oklahoma

Figure 3.3a & 3.3b

Interior damages after the M5.8 IE in Pawnee, Oklahoma

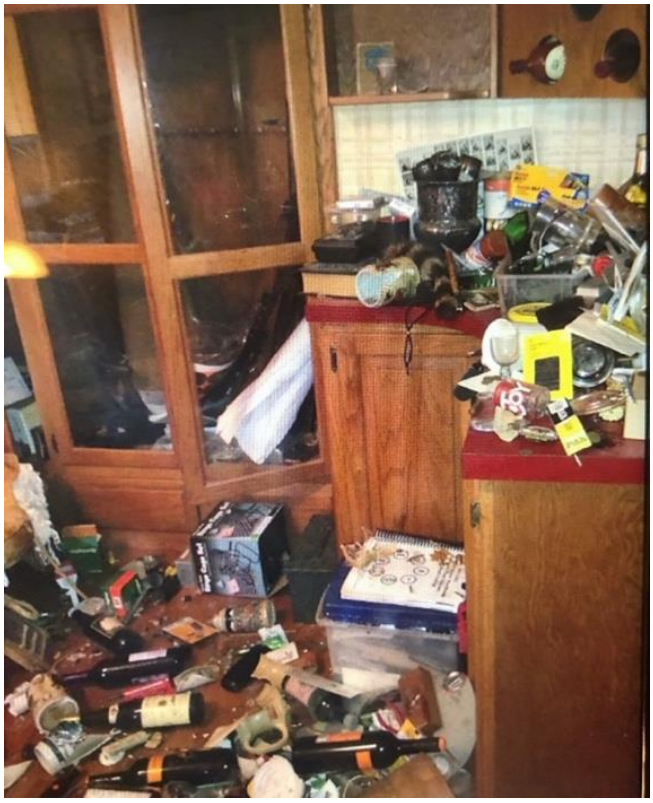


Figure 3.4

Construction of replacement home following the 2016 M5.8 IE

Loss of Personal Belongings

Some participants experienced damage of personal belonging during the M5.8 Pawnee event. Smaller IEs produced uneven damage, with some community members affected more than others due to their proximity to the wastewater injection site or due to other factors unique to each property.

Nick, who worked for the OGI, had built a brand-new house in the Pawnee area to retire. According to his account, he spared no expense and tried to build to the highest standards of the state. His wife hired an interior designer and invested a great deal of money decorating the home. Many personal items—including china, glassware, memorabilia, collectibles, and others —became airborne during the big earthquake and were broken. The earthquake also resulted in a fire, damaging expensive equipment. The participant described that day:

...I got a call from my then wife and was hysteric. I drove 95 miles an hour to get here too. Then I got another call when she said the barn was on fire. I had over $100,000 worth of equipment inside that barn. The barn was two years old, and it cost me a lot of money to build. My house was a mess. The fire chief asked me to startup my dozer and go ahead and push my barn in and completely finish off my barn so they wouldn't spread any more, but everything was off the walls and on the floor. Vases were broken and glass everything out of the cabinets, all the dishes, and everything. The cabinet had fallen out. It just looked like a tornado had hit the house."

Caddo, a middle-aged Native American living inside the Pawnee reservation, described the IE as incessant. He claimed that the Pawnee reservation experienced some of the worst damage due to the age of the houses and structures. His account:

...I felt them every day. Once they started, they never stopped. Some days were worse than others. Probably they injected more that day… [describing the big one] I heard a loud roar, and I woke up. The house started to shake pretty bad. Everything started to fall on the floor. My TV broke, my air conditioner came off the window, and every picture that was hanging shuttered. I run outside, to protect myself. When I came back in, it was a mess. I had to throw everything out.

Earthquake Insurance Challenges

The number of people who had earthquake insurance was limited prior to the onset of IEs. The idea of purchasing earthquake insurance in tornado country was thought to be justifiably unwise. Once induced seismicity began to increase in frequency, obtaining appropriate coverage became nearly impossible and those with existing policies were unable to make claims to get compensated for damages. The following subthemes were the primary reasons for the challenges residents faced.

IE Insurance Coverage Limitations

Earthquake insurance coverage was originally designed to provide coverage for natural earthquakes. At the onset of seismicity in Oklahoma, there was debate whether the earthquakes were natural or induced, leading to insurers refusing to underwrite policies in the state. The Oklahoman government was slow to respond as they waited for scientists to find conclusive evidence. It was not until 2014 that the state intervened and made it illegal to deny coverage due to the earthquakes being induced. The new legislation did not address a major caveat, however, in which insurance companies required homeowners to go 60 days without any earthquakes before they could obtain coverage.

A structural consultant, who had interacted with many homeowners that experienced earthquake-related damages in his area told us the following:

> *You have to go 60 days without a sign of an earthquake before the insurance company will talk to you. Nobody could ever find that window…We found, here, that some of them [people with earthquake insurance] weren't happy that had been paying for this insurance, and it really didn't treat them the way they expected it to. As I know, insurance companies, you got to fight for your money, anyway, after you've paid them for years.* - Frank

High Deductibles

The demand for insurance increased as the IE became more frequent. As a result, the claims began to accumulate, requiring agencies to adapt. Insurance agencies originally offered high deductible packages, but such high deductibles were not appropriate to the type of low-cost damage caused by IEs. In response, insurance companies began offering policies with lower deductibles. For a few years, agencies offered policies with deductibles as low as 5% of the value

of the home. These policies became unsustainable, however, leading some companies to either increase deductibles or raise premiums.

Simon, a middle-aged farmer stated the rationale for not purchasing an earthquake insurance policy:

> *…no, we did not think we needed earthquake insurance. We live in Oklahoma, not in California…even the people who had it, most of them got nothing…you never going to meet your deductible, so it is a waste of your money.*

Tina, whose house was damaged during the Pawnee event, stated the following:

> *My girlfriend had earthquake insurance and they got nothing. It's too expensive, the deductible is too high, so it is useless. She got the run around that the earthquakes were not natural, so go figure. When we ask what to do, they tell us go sue the oil industry. Who has money for that? And who can fight them?*

Beatrice shared her experience of the futility of having earthquake insurance in Oklahoma, even after the M5.8 event:

> *… [earthquake insurance] is useless … we got nothing after the big earthquake. We did not meet the deductible, and back then, damages from induced earthquakes were not covered. I think they changed that now, but still, it is not a good deal. I only keep it because I got a good deal when I signed, and God forbid we get a really big one, we will be covered, but there is nothing you can do for the smaller earthquakes. We are on our own for those.* -Beatrice

Inability to Make Sustainable Repairs

Frequent Nature of IE Leads to Repeated Damage

Although daily quakes do not cause immediate visible damage, some participants began to notice cracks on their walls as the time went by. This led to participants questioning whether they should be concerned about cumulative damage. Furthermore, the IEs that did cause immediate visible damage were frequent enough that repairs were unsustainable (see Figure 3.5 and 3.6).

> *I can't see inside my walls. I live in an old house. They were some cracks before but how can you tell which crack is from which earthquake when you get so many?* – Wendy

Some of this damage was not static, but would worsen over time. Other damage would occur even if repairs were made:

> *You see that crack above the door? Well, I can't remember if it was there or not before the earthquakes started. I never noticed. I do know that now that I keep looking at it, it has gotten bigger. If I call the insurance, how I can prove which earthquake caused what damage? If I pay to fix it, it will come up with the next one. That's what happened with the Tag Agency. The insurance paid to fix the damages the first time, but then we got another one, and the siding fell again. They paid to fix it and then it came down again. You can't be fixing things if they going to break again and again. It doesn't matter who pays for it.* - Liam

Summers are extremely hot in Oklahoma so many rely on portable air conditioners to stay cool. Neil, a first responder, claimed his income does not allow him to make the repairs that would improve his family's safety. During the M5.8 event, his window-mounted air conditioner became airborne and almost hurt his four-year-old son:

> *...I could not afford to buy another [window-mounted air conditioner], and the possibility of getting hurt is not worth it.*

Buildings and Public Works Not Designed for IE

Oklahomans are experienced with extreme weather. Many have insurance coverage for flooding and tornados. When it comes to IEs, however, participants questioned admonitions to prepare. Nick, who built his new home adhering to the highest safety standards for tornadoes said:

> *...you can't build for both, earthquakes and tornadoes. What keeps you safe during a tornado is what it will kill you during an earthquake.*

Figure 3.5

The Pawnee Tag Agency is housed inside a historic building. The damage shown occurred during a smaller magnitude earthquake after the owner paid to rebuild the stonework following the M5.8 earthquake on September 3rd, 2016.

Figure 3.6
Damage shown has been repeatedly fixed by the owner but it keeps returning with each >M4 IE

Frank, who recently purchased a new home, shared that he had been investing a significant amount of money to make his roof heavier so it won't fly away during a tornado. He placed extra support beams to hold the roof to protect against extreme winds, but is now worried they might collapse during an earthquake:

> *…we build for 90 miles an hour sustained winds. This is what our code says. My house has a 28-feet peak, and we are coming up with ideas to attach it [the roof] to the ground with some post and that kind of thing…it is not cheap. Is it going to hold all that weight during an earthquake? I don't know... That's why we run outside. The roof won't fly away but it will crush you during an earthquake.*

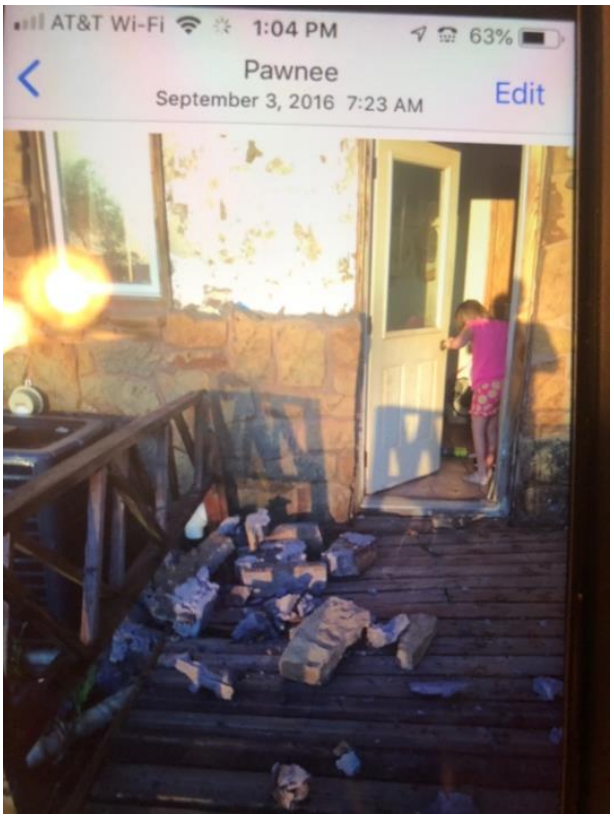
Emotional Strain of IE

Although participants communicated that IEs are now an integral part of their lives and that they try to ignore them, they also admitted that the constant seismicity is something they have not been able to become accustomed to. They indicated that the constant seismicity added

one more thing to worry about. Additionally, people living in older homes are afraid of having friends and family members visit because they fear a possible stronger IE that can cause their house to collapse. Specifically, one of the respondents stated that her grandchild is no longer allowed to stay overnight following the 2016 Pawnee earthquake. That morning, her granddaughter, who has Down Syndrome, was sitting on the couch near the fireplace when the entire mantle collapsed in front of her. She managed to escape with minor injuries from falling debris, but the grandmother stated that luck does not strike twice, so she won't allow her to stay overnight anymore (See Figure 3.7) The following subthemes encompass the various factors related to IEs that cause emotional strain.

Figure 3.7

Image of a participant's grandchild entering her home following the 2016 Pawnee IE



Inability to Get Used to Frequent Shaking and Sounds of IE

Most IEs are low magnitude. The USGS uses the Modified Mercalli Intensity Scale to measure the intensity felt by individuals and is a better indicator of the effects of IEs on humans than magnitude alone (Khosravikia et al., 2020). The intensity of an earthquake is simply the effect of an earthquake on the Earth's surface. But what is felt by human beings can vary greatly, being influenced by several factors such as proximity to the epicenter, depth, underlying soil, and building characteristics.

Katherine of Pawnee captured the variability of what was felt by comparing her experience to that of her neighbors five miles away:

> *…no, they were not strong, but you notice them. I notice them. My friend who lives five miles from here, she says she did not feel the shaking, just the booming and the rumbling. I felt them. My walls were shaken. Nothing broke with the little ones, but the house was shaken.*

Betty described her experience as follows:

> *A year or two before the big one, that is when I started to feel them. I think there were more during the evening. You would be in your bed, and you felt the shakes…they were strong enough to shake the bed…you try to ignore them, but you don't get used to them.*

Fear of Uncertainty and the Possibility of Experiencing a Larger Magnitude IE

Participants' concerns regarding IEs derived from the overall uncertainty surrounding earthquakes, as well as the possibility of experiencing another larger and catastrophic seismic event in the future:

> *I am concerned, and I don't want to say that I am terrified, but I should not sound heartless because I did not get the worst damages. I am concerned about the recent increase in earthquakes. I've lived here all my life and never experienced earthquakes before. Now all of a sudden, we are having earthquakes…what is*

causing them, and are we going to have more like the big one? Does it ever end, or this is how it is going to be? - Violet

They come out of nowhere and you have no idea how strong they will be. The unpredictability makes me very nervous, although I know we will never get earthquakes like the ones you get in California. - Beatrice

Loss of Sentimental, Irreplaceable Personal Belongings

Participants experienced different degrees of losing their personal belongings. Regardless of the value of the items involved, the source of the grief was the irreplaceable nature of what was lost. Katherine and Ken, in particular, not only lost their home but a lifetime of memories.

I lost my china. 50 years old. We'd gotten it when we'd gotten married. I've lost so much, just countless. We'd go to New Mexico every year and I would buy the Indian pottery, the hand-made pottery, and all that shattered. I mean shattered…We filled ten 50-pound feed sacks full of broken glass.

Inadequate Government Protective Actions

Participants shared an overall dissatisfaction with how the issue of induced seismicity was handled at the state and federal government levels. Though local government representatives stated that they tried to reach out for both state and federal financial aid after the two major earthquakes that caused considerable damage to their communities in 2016, they did not receive any help. According to the statements of local government insiders, no resources were provided to help the local government address this new hazard nor was any financial assistance given to help local families.

Government Response did Not Translate to Addressing the Economic Losses of the People Affected

According to Frank, a Cushing city employee, any financial assistance requests they made were declined due to not meeting some kind of criteria.

> *We had everybody come. We had FEMA. I'm not going to be able to name all the organizations. I chauffeured them around. Our goal was to find financial help. We did not qualify for one dime of financial help…Enough people didn't die. I don't mean it that way…We had some injuries; porch fell off a house and hit a girl on the shoulder. She's lucky…She shouldn't have been there. It happened, and it was the earthquake. Whose fault is it? … I had the FEMA group, state group, an insurance group, and we all went through. We had to lose, I think, 15 structures and one death before we qualify for something. Now, had the hotel fell, which is now section 8 housing, it would have not only killed 40 people, but it would have covered us on that.*

A Pawnee city employee was forced to deal with furious homeowners that demanded to be compensated for their losses, but he was not able to provide any financial assistance:

> *I went everywhere, met with people, made phone calls, but we did not get a dime. We tried to help the people with what we have, but this is a rural town, and we don't have a lot of resources. The ones who got a lot of damages were advised to sue the OGI. The ones with the smaller damages got nothing… you can't just give the money [referring to city funds] you have to anyone. The rest of the people want to see actions, such as new roads. They don't want us to spend the money to fix people's houses.*

Lack of Communication Led to Frustration and Misinformation

Neil, a first responder, stated that he never received any training for dealing with earthquakes. He was under the impression that there is nothing one can do to prepare for seismic hazards compared to tornadoes and flooding. The principal investigator asked him to share his knowledge about earthquake preparedness and response, to which he replied:

> *…run outside since there is nothing you can do to prepare for an earthquake…is there? I mean, what do you do in California?...We received a bunch of paper work to fill out after the big one, I wish I can show you that. They did not tell us what to do, they just had us fill out paperwork…People came here but they did not talk to us.*

Violet, a city clerk, comes in contact with several residents on a daily basis and expressed that she would actively distribute information if she had any to share:

> *…again, this is my opinion. I don't feel like that the information has been put out there…I hate to say it but more information probably should be put out there so people know what to do, when to do it, how to go about it, how to react, where to get resources, who to contact…we are as small town here. We would probably put something in the newspaper, but it only comes out once a week. I would say attack it in several different ways. The newspaper, social media…flyers here at the City Hall, at the library, in places that you know a lot of people come in contact. Make sure the information is there, even if they don't need it.*

Reduced Income from Leasing Their Land to the OGI

The economic impacts of IE are multiple and recurring. Lease contracts with the OGI, for example, were once highly profitable endeavors for many landowners, some who inherited both land and contracts, but no longer yield the same profits. With decreased annual earnings, homeowners felt unable to fix the costly repeated damages caused by the induced seismicity.

Horizontal Drilling Techniques Result in Lower Earnings for Some Landowners

Horizontal wells begin at the surface just like a vertical well, but they provide the ability to move in any direction once the target rock is reached. Instead of drilling several vertical wells, OGI operations can drill one well which, once underground, can be directed to drill in any direction. Contracts, however, often do not stipulate provisions for the newer horizontal drilling techniques despite the possibility that oil can be taken directly from the landowner lands without direct vertical drilling. As a result, some who lease their lands are no longer getting paid for having a well on their property. Division of royalties is also a complex issue and varies by state. Ostensibly, the person who has the horizontal well on their land is to be paid the greatest amount. However, the OGI can choose to place the well into land with an owner with the least amount of acreage, allowing companies to give a lesser payout to the rest of the parcel owners under whose land is drilled underground and horizontally.

Nick, who worked his entire life for the OGI and who negotiated such deals on the behalf of the OGI, shared the following:

> *…They [the OGI] select a small piece of land to place their well and negotiate a low price with an unaware small landowner who does not know the real value.*

Rose, a city clerk, inherited from her father land with a multiyear lease contract with the OGI that dates back 40 years. The lease provided a steady income for her family, but with the advent of horizontal drilling techniques she had been witnessing a gradual decline of payment. She expressed worry that the OGI would break the lease while continuing to gain resources from within her land and without her permission:

… it is a trust issue with them. How do we know they aren't on our land, to begin with, without our knowledge? … I know, we have to have oil and gas, that's a given…I just hope it's done properly and to the law.

State Approved "Statutory Land Pooling" Limits the Rights of Landowners

The state of Oklahoma allows statutory land pooling: if landowners decline to lease their land to the OGI, their land can be forced into a land pool because mineral resources exist to be extracted. The practice further decreases landlords' profits because compensation per acre of land is based on the negotiatory power of the landowner hosting the horizontal well. Parcel owners who own thousands of acres may have the resources and industry knowledge to negotiate higher prices. But parcel owners with a small acreage and little knowledge of the oil industry may lease their land for far less money, which then dictates the prices that the OGI must pay nearby owners if they are force-pooled.

Nick, who worked for the OGI and lives in a 180-acre lot, was contacted by the OGI because they had an interest in his land. Though he declined because he did not want anyone to drill underneath his property, he was worried that they would force-pool him into an unprofitable deal that will damage his land:

…this is what I mean. I already told them [OGI] that I am not interested. This land is my respite. I bought this land to retire and get away from the city. I have plans to create a place where people can come and relax. I don't want anyone drilling underneath my land. They can force-pool me by involving the Oklahoma Corporation Commission and claim they need to extract mineral resources. Imagine if they can do this me, that I worked for them [OGI] all my life, what they can do to someone who has no clue how they operate.

Environmental and Safety Concerns

When questioned about other concerns they have about IEs, many participants stated that wastewater injection and horizontal drilling practices likely impact the environment in ways that are not well understood or that have not been studied. Many also stated the belief that there is no true oversight to drilling operations, that it is simply the OGI. The Oklahoma Corporation Commission (OCC) officially regulates the OGI, but many participants questioned whether the commission has the people's best interest at heart. The interviewees felt that you could not put a price on the environment. Protecting the environment from toxic hazards is far more important than increased earnings from horizontal drilling techniques. They would choose regulation of the OGI over increased profits if it meant that current oil and gas extracting practices do not pollute their water sources or contaminate their lands.

Safety Concerns from Lack of State Oversight to Ensure OGI Maintains Old Wells and Pipes

Nick, an OGI employee who previously had a leading role within the industry, stated that in most disputes between the OGI and residents that was mediated by the commission:

> *... nine out of ten times I got what I needed from the OCC.*

The participant expressed safety concerns, though he emphasized that if there is any wrongdoing, it is not intentional. For example, many of the tubing and casings that go through freshwater zones were installed several decades ago. Nick explained:

> *...think what can happen, from time to time you get a casing leak on a well and you're required to go in and fix it... Well, think about how old and how rusty some of these wells must be now that were drilled back in the 20s, 30s, 40s, 50s. Think about, some of these are 70 years old. Think about, how old and how brittle some of those cement jobs and that old steel, how rusty and think about how rigid and vulnerable those things are right now.*

Water Contamination Concerns from Wastewater Disposal

A major concern for the interviewees is the possible contamination of fresh water sources. Participants unilaterally agreed that safety is more important than profitable oil and gas activities. John, who has both water and oil wells on his property, shared:

> *My dad got his wells up there, was running 20-30 years ago. It had a film on it and I couldn't use it. We had to drive another well in there to get water…but those kinds of environmental things happening with these damn oil companies. They said fracking is safe, but when you frack you open that ground up… My neighbor over here, he became an advisor [got certified], because he could not trust them.*

Connor, a city employee from Pawnee expressed his concern by referring to a past incident in which a local lake was contaminated. The participant stated that the OGI in Oklahoma has a long history of violations that resulted in harm to local families.

> *They say [the OGI] that wastewater [injection] is safe, and fracking is safe. They say that they inject at deeper levels. Again, they might be right, but is anyone checking? How do we know there are no leaks? We don't. We hope they are doing the right thing. If we look at past events, it paints a different picture. They contaminated the lake many years ago, they left wells open after they got the oil out, and a toddler fell in…there is evidence of negligence. How do we know our water is safe? Do we just trust them [the OGI]?*

Concerns of Illegal Wastewater Disposal

Several participants stated that that despite OCC restrictions on the amount of wastewater injected per day, there have been many sightings of illegal wastewater disposal. Betty, a store owner in Pawnee who converses with many people, shared:

You hear about injecting during the night, about trucks emptying their tanks while driving on the streets. I mean that staff is toxic, and it goes on our fields.

The building evaluator independently corroborated such sightings:

I have people telling me the lights were on during the night. They heard noises. They inject during the night. They haven't stopped producing, so think about it. Where all that water goes? They say they load trucks, and they release the wastewater while driving. It's hard to prove, but if it is true, we are going to have a problem.

Katherine strongly argued that illegal wastewater disposal was undoubtedly occurring. She based her reasoning on the fact that OGI operations in states, such as Arkansas, that no longer allow wastewater injecters to ship their wastewater to Oklahoma for disposal. According to the participant's argument, if production of oil in other states has continued and if out-of-state operations ship their wastewater to Oklahoma, it would be possible to stay within the OCC wastewater injection limits set for their state. Katherine shared:

We have become the country's dumping ground…I think the oil companies push the limit and go further than the limit as far as environmental protection. A friend was following a disposal water truck…they said the vacuum opened, and the water was just seeping all the way down the road.

Neglect and Exploitation of Rural Areas

Interviews contained overall feelings of disappointment among the participants when they spoke about urban people vising their rural cities to conduct business or vacation. Many communicated that they felt used and forgotten. According to some, lack of sufficient funding forced the local medical center to close, which was clear example of overall neglect. Following the M5.8 Pawnee event, gas lines in front of a school broke and were never repaired, despite the

fact that the school also serves as a shelter. Tina, a PTA representative, shared locals have been trying to raise money to fix the gas lines for two years prior to the interviews to no avail.

The Needs of Rural Populations Not Understood or Met by Business People, Researchers and Politicians

Participants expressed anger towards politicians, researchers, and urban people who visit the area. "Forgotten Oklahoma" t-shirts sold at the local Pawnee museum were considered a powerful throwback to the past, marked by participants' reminiscence of the glorious olden days when cities like Pawnee were booming with business and activity. Now, participants felt that their cities were like old towns forgotten by history. Participants claimed that "outsiders" often visit to do business, but that such individuals did not have the people's best interest at heart.

Nick, who liked to call Californians *"fruits and nuts,"* believed that people in the big cities are *"brainwashed,"* and they have *"misconceptions and do not understand the needs of rural America."* He continued:

> *… I don't want someone in California telling me how to do my business because I think California does a lot of things in the most ridiculous manner... think about what they did when natural gas was at a premium. You are probably too young to remember. They set a limit on the (gas) price… they end up not having enough natural gas to power everything, and their companies would sell their gas to other states for more money… so no, I do not want an outsider making decisions for us... Scientists get a degree, and they think they know everything. They don't live here, and they don't understand our needs and they don't care about us. Why do they get to make decisions without having spent a day in rural Oklahoma?*

Steven, a 55-year-old farmer, laughed at the idea of "outsiders" understanding the needs of rural Oklahoma:

> *I see those kids from the University, they come here with their professors, they follow them like ducks and go out in the fields and put seismometers here and there. You ask them a question and they know their science, but they know nothing about us, our history, our lives. They look at us like we're stupid, and we won't understand what they have to say… they probably think we deserve it because we lease our lands for money, but that ain't true.*

Katherine raised her voice during the interview when she was asked to describe the resources they were provided or the information communicated to them following the onset of IE:

> *… the response was horrid. They gave us lip service. That's what we got. When we had the big one, everyone knew about it. We made it to the news, so they [government officials] showed and gave interviews and smiled pretty for the pictures. Then they left. They did nothing. We are expendable.*

Views of Outsiders

Participants felt stereotyped as lacking in intelligence and education from outsiders visiting their areas. They felt misunderstood and neglected.

> *I would like to see more of our government to care about the people they serve, instead of caring about Russia and Korea… They only come when there is money to make or for publicity. Do you know who came? Erin Brockovich came a couple of years ago about the water issue, and now you... Still, we are not worth their time… I would like someone to listen to me, for at least once. I am not stupid. I was*

up in the 95% in intelligence, and I can't stand when they treat me like I am an idiot because I don't live in a big city. - Sarah

Betty, a store owner, shared several stories from interacting with tourists visiting their town. Her overall conclusion was that urban people have many misconceptions about rural people and that they do not appreciate the contributions of rural communities.

They don't care too much about rural Oklahoma. If you live in a city like Tulsa, you don't think there's any intelligent life outside the city.

Beatrice, who was employed in the OGI, shared the following:

A lot of people visit or do business here. They don't spend the time to get to know the locals. I see it now. They look at us in a way that makes you feel like you are not smart enough or you are uneducated ... I used to be one of them. I lived in Oklahoma City and drove here almost every day. I bought this home five years ago because I was tired of commuting. Over the years, I have met many unassumingly bright people and changed the way I view things.

Discussion

The primary goal of this study is to develop a structured understanding of the ways IEs affect residents of LNSH areas in Oklahoma. The aim is to provide critical insight into the complex nature of the induced hazard with both positive and negative impacts. Oklahoma's economy depends a great deal on the OGI and participants often responded to questions about IE by describing concerns about OGI activities. As such, any suggestion for future policy should be sensitive and accommodating to the interests of those affected (Mileti, 2000). The interviews revealed many obstacles faced by the people residing in LNSH areas once exposed to IEs.

Participants communicated the frustration and damage that could have been prevented if they had more experience and knowledge of how to prepare and respond to earthquake hazards in Oklahoma. Findings were aligned with prior research, including property damage, decreased valuation of real estate property, and the introduction of mental stressors (Burnett & Mothorpe, 2020; Garfin et al., 2014; Taylor et al., 2017).

Property damage and loss of sentimental belongings is the usual outcome of earthquakes whether they are natural or induced (Becker et al., 2017; Nakagawa, 2015). Unique to IEs are how they are induced—such as through fracking or wastewater injection (Keranen et al., 2014a)—which results in the possibility of causing other environmental risks such as water and land contamination (Aczel, 2017). Some participants viewed the consistent, sometimes daily, seismic events as ever-present reminders that a catastrophic earthquake may occur at any time, which may be classified as a constant low-level stressor. Though the chances of higher magnitude earthquakes occurring depend on controllable factors such as amount of wastewater injected and the length of time an injection site is used (Bulgarelli, 2017), these were not factors residents cancontrol. The limited and delayed government (e.g., the OCC) and institutional (e.g., the OGI or insurance companies) response further hindered participants' abilities to protect themselves, their families, and their property. The interviews contained a strong overall dissatisfaction with how the IE hazard was communicated and handled by public and private people in power.

Analysis of interviews also reveals a complexity inherent in IE preparation and consequences that remain unaddressed in current literature. Though participants continued to make attempts to adapt to the constant seismicity, the unpredictability of IE prevalence and magnitude led to confusion and controversy regarding what measures must be taken to maximize

safety and minimize risk of damage. In structural engineering, the term *building fatigue* is used to describe the cumulative damage that a structure accumulates as it is subject to continuous shaking (Pnevmatikos et al., 2018; Vayas et al., 2003). The frequent low magnitude earthquakes did not cause visible damage at first, but participants witnessed cumulative effects accruing. These effects may constitute building fatigue, though the topic of building fatigue and IEs has not yet been fully investigated. Interviews also revealed that insurance remained a complex issue. Typical earthquake policies only cover damage that could be attributed to a single causal seismic event. Complicating matters further, multiple companies inject wastewater which makes it difficult, if not impossible, to accurately identify which company is responsible for each earthquake.

New drilling techniques have made it possible for companies to extract gas and oil from areas previously thought impossible. The U.S. is producing enough oil that it no longer depends on other countries for its growing national energy requirements (Bulgarelli, 2017; Campbell et al., 2020). Yet the very techniques that allow this increasing energy independence are partially responsible for the increase in IEs (Bulgarelli, 2017). According to the interview data, many who have been leasing their lands to the OGI have not been made aware of the possible implications of newer oil extraction techniques. Furthermore, use of horizontal drilling led to reduced earnings despite the landowner's oil being extracted and forced pooling is permitted, which simultaneously reduces the rights of owners and makes it less appealing for them to lease land to the OGI.

Also of significance is that three of the nine themes are indirectly related to IEs: (a) reduced income from leasing land to the OGI, (b) environmental and safety concerns, and (c) neglect and exploitation of rural areas. Of interest is that these themes consistently emerged from

participant responses despite the PI's inquiry being focused specifically on IEs. There are several reasons why participants may have consistently communicated outcomes indirectly related to IE. First, new drilling techniques, such as horizontal drilling, increases wastewater, which leads to more wastewater injection and higher IE prevalence. Second, the decrease in income may disincentivize residents from supporting the OGI as IE prevalence increases. Third, participants do not want to harm the environment, particularly farmland, and many expressed the willingness to reduce profits to ensure the safety of the ecosystem.

A fundamental concept that links these three themes, as well as the other 6 themes, is resentment (see Figure 3.2) of the residents regarding the inability for them to address IE and issues originating from the OGI. Participants consistently mentioned neglect because many believed that big cities would have had state policymakers and politicians addressing the issues immediately. Politicians do not live near or around Cushing or Pawnee, so participants believed that these officials did not feel urgency to address IEs or to enforce OGI accountability. Finally, rural areas lack the media coverage and attention that urban areas naturally accumulate, making it easy to hide the negative impacts of IEs.

Finally, it is important to note that participant responses reveal a dilemma that residents face in Oklahoma. Participants expressed that they are unable to leave their homes, they cannot fully repair the damages, insurance is unavailable, current legislation allows the OGI to exploit their resources, they are unable to push legislation that would hold the OGI responsible, they do not feel heard or understood by leaders, and they do not know how to best respond to IEs. In all, this study reveals that residents are stuck in a catch-22 situation that they are unable to address.

Public Health Implications

This study contributes significant insights regarding the complex consequences of IEs. Individuals are less likely to accept induced hazards unless they have rights to their management (McComas et al., 2016). Though many Oklahoman landowners have leased their lands to the OGI, they did not agree to excessive wastewater injection nor its consequences. Statutory pooling laws have removed their right to decline to participate in the OGI's energy exploration and production activities within their land. Some participants shared that the new horizontal drilling techniques may generate increased amounts of wastewater though, unsurprisingly, others were not aware of this possibility.

Other studies into the IE hazard in Oklahoma involved surveys and theories designed to capture data following catastrophic natural earthquakes rather than events that were artificially induced (Chang et al., 2018; Greer et al., 2020). The findings of this study suggest that these instruments and theories may not be appropriate for the investigation of IEs. It may be expedient to revise and adapt existing measure and theories to accommodate the indirect challenges presented by induced hazards, which include residents' inability to protect themselves without the proper knowledge and lack of ability to access suitable interventions. A great deal of hazard research relies on the premise that people will adjust or prepare for natural hazards (Becker et al., 2012; Becker et al., 2013; Lindell & Perry, 2000). However, a Korean study investigating individuals' willingness to pay for retrofitting indicated that people were less likely to prepare if they believed earthquakes were induced (Moon et al., 2020). Existing research on human-induced hazards is neither detailed nor specific enough to allow for practical application or program development. The topic of induced hazards is in need of further investigation. Classifying and treating IEs as conventional earthquakes disregards the unique challenges and

needs of the communities affected. This also prevents public health policy from moving forward and providing actionable solutions to this ongoing issue.

The characteristics and consequences of IEs may differ from natural seismic events. The prevalence of IE shaking experienced by residents is notable. This frequent shaking appears to be associated with many concerns reported by interviewees. Oklahoma experienced more earthquakes than California, a state with an established history of earthquake hazards (Ellsworth et al., 2015). Building codes in areas with high natural seismicity have been adapted to protect people from building collapse and damage from earthquakes. Policies in these areas have been established to help people retrofit their houses to protect from natural earthquakes (City of LA Department of Building and Safety, 2021). Oklahomans do not have such provisions for earthquakes, although they do have codes and policies for annual extreme weather hazards. Furthermore, many participants shared that the measures that keep them safe during tornados might kill them during earthquakes.

Limitations and Future Directions

The study's qualitative design and methodology allowed collection of rich data that was analyzed to illuminate the challenges faced by residents affected by IE in areas of LNSH in Oklahoma. Although the study is limited by the specific geographic location of participants, the findings have implications beyond Pawnee and Cushing. These accounts may be representative of other LNSH areas experiencing IEs. Furthermore, Oklahoma is not the only state engaging in fracking or other new techniques that generate large amounts of wastewater. Documenting similar experiences in other locations with IE prevalence would strengthen our findings and help lead to policy change.

This study could be extended through interviews of state and federal officials that can provide insights into the challenges faced by the non-local government during significant Oklahoman earthquakes. IE is a new hazard, and acting to preserve the OGI that serves as a significant economic lifeline to their state is a justifiable policy. Most who declined to be formally included in the study but who agreed to engage in informal discussions feared that their disclosures might impact the very industry that puts food on their tables. There is a possibility that state representatives dealt with similar or novel dilemmas of which we are not yet aware.

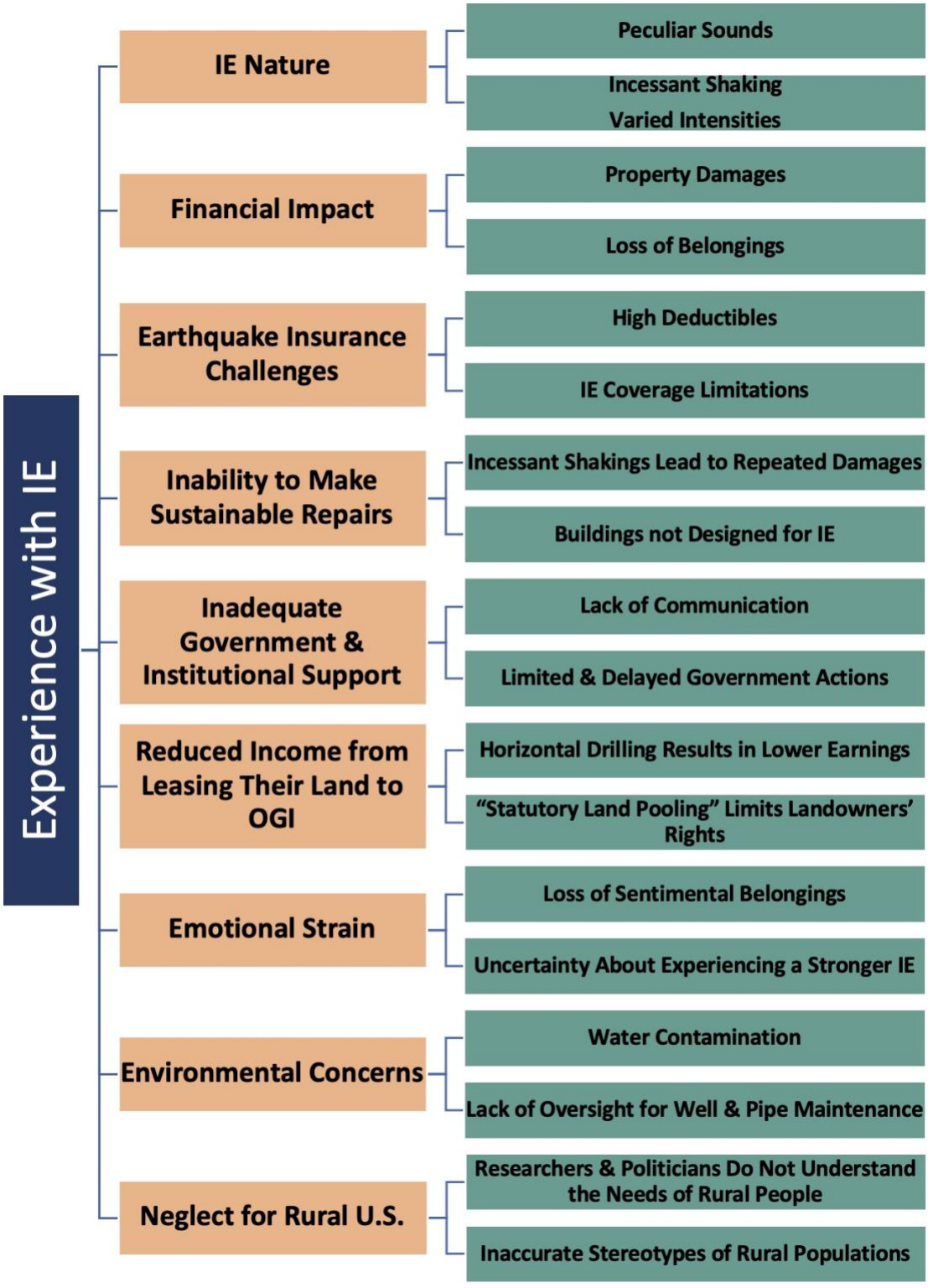
Researchers may choose to investigate other affected states to further enhance our understanding of IE and form a solid theoretical foundation. Qualitative research can suggest research questions and hypotheses to be examined with quantitative methods. By interviewing leading government representatives and people from other states who are also affected by IE, we can learn how their experiences align with the findings from Oklahoma.

Induced seismicity primarily affects working-class people dwelling in rural areas (Campbell et al., 2020). Recovery following a disaster is related to both cultural factors and resource availability (Hoffman, 2003; Hoffman, 2015). Natural earthquakes are relatively rare events in comparison to IEs but have the potential for catastrophic magnitude. As the interview data confirms, meeting FEMA requirements for financial assistance is more likely for natural rather than induced earthquakes. Implementation of new FEMA criteria for IEs may be a solution. OGI involvement and participation may also provide an opportunity for possible private- or public-sector solutions. For example, OGI companies might create a fund to be used for the recovery of local damage. Such a fund could possibly prevent costly lawsuits that only benefit those with the resources to sue the OGI. How public and private parties deal with this new community health risk will pave the road for future public health policy. As such, efforts to

increase awareness regarding IEs may set the stage for regulation, preventive actions, and actionable interventions resulting in increased safety, more appropriate policies, better communication between stakeholders, and overall conditions that promote mutual benefits.

Figure 3. 1

Thematic map showing the challenges stemming from IE in areas of LNSH in Oklahoma



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CHAPTER 4

Induced Earthquake Resiliency in Low Natural Seismic Hazard Areas

Introduction

Community resilience is defined as the ongoing and developing capacity of a community to account for its vulnerabilities and develop capabilities that aid that community in (1) preventing, withstanding, and mitigating the stress of a health incident; (2) recovering in a way that restores the community to a state of self-sufficiency and to at least the equivalent level of health and social functioning as prior to the incident; and (3) using knowledge from a past response to strengthen the community's ability to withstand the next health incident (Chandra et al., 2011; Chandra et al., 2010). Though education is a critical component of community resilience, it alone cannot compensate for lack of resources, engagement, and self-sufficiency (HHS, n.d.). Community resilience is typically a capacity that local and state governments develop in local populations according to the potential risk of health incidents in that region (Burnside-Lawry & Carvalho, 2016; Choudhury et al., 2019). A goal of Health People 2030 for Emergency Preparedness is to improve emergency preparedness and response by building community resilience (Office of Disease Prevention and Health Promotion [ODPHP], n.d.). In the case of induced hazards like induced earthquakes (IE), building community resilience is more crucial than in natural hazards since disasters resulting from human activities are not expected, though history proves that they have the potential to be more catastrophic than natural hazards (Baum et al., 1983; Baum & Gatchel, 1981; Erikson, 1976).

Induced Seismicity in Oklahoma and Low Natural Seismic Hazard Areas

Oklahoma is one of several states in the United States that experiences IE and hosts oil & gas extractive activities that have the potential to initiate potentially catastrophic disasters. The 2016 M5.8 earthquake in Pawnee, OK was the biggest seismic event recorded in the history of the state, although the United States Geological Survey (USGS) considered Oklahoma a low

natural seismic hazard area (LNSH) prior to 2014 (Petersen, Moschetti, et al., 2014). On November 7th the same year, Cushing, OK was struck by a M5.0 earthquake. Despite the lower magnitude, the Cushing event gained more publicity because it is located on one of the largest oil hubs in the nation. Considering that any earthquake of $M \geq 4$ can cause significant damage, induced seismicity in Oklahoma has the potential to cause nationally catastrophic outcomes in oil and gas distribution if critical pipelines are incapacitated due to extreme pressure breaks in a seismic event (Taylor et al., 2017).

Research on Induced Earthquake Resilience

As an emergent hazard, IEs pose challenges for the application of existing theories and models of seismic resilience developed largely from studies of catastrophic natural earthquakes. In an editorial review of disaster prevention and management, Alexander (2016) found that existing theories and models must be revised to account for a more sophisticated collection of variables, including changes over time that may have augmented levels of risk, vulnerability, and impact of natural hazards. IEs are emergent hazards of which models and theories, for both the events themselves as well as for preparation and recovery, are currently based on those of natural earthquakes, which may not fully address the needs of impacted communities (McGarr, 2014; McGarr et al., 2015a; Petersen et al., 2016; Petersen et al., 2015).

The public works, commercial structures, and residential buildings in LNSH areas such as Oklahoma are not designed for earthquakes, nor have they been revised for the damage represented by induced seismicity (Bommer et al., 2015; Bulgarelli, 2017; Delatte & Greer, 2018). Several issues and gaps regarding Oklahoman seismicity remain unaddressed, as described in Chapters Two and Three. According to forecasts based on 2016 and 2017 data, Oklahoma has the same probability of earthquake-caused damage as San Francisco, despite

equivalent preparatory and infrastructural measures lacking at nearly all levels (Chang et al., 2018; Delatte & Greer, 2018). Oklahomans lack adequate earthquake insurance (Taylor et al., 2017), as well as the knowledge necessary to successfully prepare for seismic events, to ensure the safety of their homes, and to recover from earthquakes (Murphy et al., 2018). Finally, although Oklahomans may have experience preparing for extreme weather hazards (Delatte & Greer, 2018), such preparations can increase the risk of catastrophic damage from IEs, as revealed in the previous two chapters.

Factors in Building Community Resilience

In light of the limited research in IE preparedness, policy, and practice, it is important for policymakers to consider whether Oklahoma's rural communities, which are most affected by IEs, are resilient to these emergent hazards and are able to adapt and recover from these new seismic events. Community resilience has significant practical implications, as this concept determines the ability for people to successfully prepare for, withstand, and rebuild from a natural disaster (Choudhury et al., 2019). Here, we examine four components essential for government leadership to build community resilience: (a) local government involvement, (b) community-specific resource and solution provision, (c) clear communication, and (d) trust-building.

Involving and engaging with community members is essential in helping to build community resilience (Burnside-Lawry & Carvalho, 2016). Not only does public participation encouraged by the local government strengthen a community's resilience against natural disasters, it reduces vulnerability to risks (Burnside-Lawry & Carvalho, 2016). Official leadership engaging with residents may be especially relevant to induced hazards, for which people are far more likely to accept and engage in preparedness actions if they are given

opportunities to participate in decision-making that affects their local communities (McComas et al., 2016). Effective leadership requires contextual intelligence, which is highest at the level of local leadership (Burnside-Lawry & Carvalho, 2016; Choudhury et al., 2019). The United Nations Office of Disaster Risk Reduction's (UNDRR) Sendai Framework supports these assertions, as it prescribes greater local government involvement through increased interaction with residents (UNDRR, 2015).

It is also important for policymakers and government leadership to account for the local characteristics and circumstances of the population in question. Adams, Karlin, et al. (2017a), in an investigation of the largest earthquake drill in the nations, found evidence supporting the need for preparedness solutions customized for the needs of the people and areas in question. As the researchers found, participation levels vary significantly according to participants' location of residence and their personal characteristics (Adams, Karlin et al., 2017). Likewise, in a study on community resilience in Los Angeles, researchers found that sociodemographic characteristics had a significant relationship to both disaster preparedness and resilience behavior (Adams, Rivard, et al., 2017). Community resilience followed distinct patterns that varied according to a population's characteristics (Adams, Rivard et al., 2017).

Communication is also critical, as it is the only way in which information can flow between government leaders and community members (McComas, 2006; Robertson et al., 2021; Rogers et al., 2016). When it comes to communicating information about hazards, messages must be clear, honest and consistent to build trust between community members and government representatives (Hanlon, 2017). In disaster preparation, proper communication is inextricably linked to both successful collaboration and effective disaster resilience (Rogers et al., 2016). However, disaster researchers have yet to create a framework by which the importance of

building community resilience to environmental hazards can be most effectively communicated (Rogers et al., 2016).

Finally, it is important for government leadership to build trust, as it is a fundamental to successful collaboration (Robertson et al., 2021). When the people trust their government representatives, they are more likely to comply with guidelines and recommendations (Becker et al., 2020; Comfort, 2016; Hanlon, 2017; McComas, 2006; Slovic, 1987). Without trusted contacts, relationships, and means of communication, successfully organizing community resilience efforts become difficult, even if community members make active efforts to build their own individual resilience strategies (Robertson et al., 2021).

Purpose

In the case of Oklahoma, researchers have primarily focused on evaluating risk perceptions and earthquake preparedness intentions (Chang et al., 2018; Greer et al., 2020). Neither form of inquiry provides insight into the topic of community resilience, which is a critical aspect of hazard preparation, mitigation, recovery, and overall resilience (Chandra, 2010; 2011). It is important to note Taylor et al. (2017) discovered several vulnerabilities following the Cushing earthquake of 2016, which indicate that affected communities do not have the capacity to sustain, deal with, or recover from IE.

The purpose of this qualitative study is to examine the factors that mediate the fundamental criteria of community resilience as applied to IE in Oklahoma. Drawing from the criteria of resilience described above, factors may include satisfaction with state and local government response, approval of quality of government communication with affected communities, and satisfaction with current provision of sufficient disaster preparedness information. High levels of approval of the government and its communication efforts are

indicators of trust in official leadership, which increases the likelihood of compliance with regulations and guidelines (McComas, 2006; Slovic, 1987).

The aim of this study is twofold. The first is to clarify the role of the OGI in the areas of Oklahoma that experience frequent IEs. The second is to understand participants' expectations from their government representatives. We also examine the type of resources provided to residents and community leaders to manage IE outcomes, as well as their ability to access these resources (Cui et al., 2018; Gil-Rivas & Kilmer, 2016). As the oil and gas industry (OGI) plays an important role in Oklahoma's economy (Howell et al., 2017; Lindell & Perry, 2000; McComas et al., 2016), we investigate participant viewpoints and expectations of the OGI in relation to induced seismicity. Finally, we investigate participants' assessments of whether their buildings are able to withstand IEs.

Research Questions

PRQ1: What are the opinions of those living in areas with IEs regarding the oil and gas industry?

SRQ1: How satisfied were participants regarding how the sudden increase in IEs was handled by their government representatives?

SRQ2: What types of communication did they receive regarding IEs?

PRQ2: How and to what degree were affected communities involved in the decision-making process in responding to IEs and what type of government support did they receive?

Methods

Study Area

The principal investigator (PI) conducted the study in Cushing, OK and Pawnee, OK, including the surrounding areas, because they were two of the primary locations that experienced increased seismicity from 2010 onward (Earthquakes in Oklahoma, 2018). Both cities have long

histories of hosting OGI activities. As alluded to above, Cushing is one of the primary hubs of oil and gas in the nation, with systems of underground pipes that deliver to all states. Prevalence and magnitude of IE activity have progressively increased in and around the two cities, culminating in the 2016 *M*5.8 Pawnee event and the 2016 *M*5.0 Cushing event, two of the strongest IEs in the history of the state (Skoumal et al., 2018; Taylor et al., 2017). The sample population includes residents living within and around city boundaries, encompassing both more populated and isolated regions.

Data Collection

Following a qualitative interview methodology informed by survey data, the PI collected data via surveys and interviews. Often used in hazard research in the discipline of public health, such designs are ideal for investigating hazard complexity, determining outcomes, and evaluating current interventions (Bailey, 2007; Padgett, 2012). Data collection was performed in two periods in 2019, from April 25th to June 11th and from July 6th to August 25th. The study was approved by the University of California, Irvine IRB.

Surveys

The PI distributed self-administered surveys (see Appendix A) to a sample of respondents (N=112) among Pawnee and Cushing residents. Considering that the estimated population of Cushing, OK is 7,615 and of Pawnee, OK is 2,106, this is not an insignificant sample size. Respondents chose between paper copies or online UCI Qualtrics links to the survey. The instrument included 42 items with a completion time of approximately 20 minutes. Items in the instrument were designed to be closed-ended and were customized according to respondents' city of residence. Factors investigated in the questionnaire included demographics, history of

exposure to IEs, experience with earthquakes, personal preparedness actions, damages incurred from induced seismicity, and participant perspective of OGI activities.

Participant Perspectives of OGI Activities, Responsibility, and Government Involvement

Apart from the demographical questions, 5 of the 42 items were relevant to this study, focusing upon respondents' perspective regarding OGI activities, responsibility for IEs, government response, and readiness of infrastructure. We constructed these items with a 6-point Likert-type scale: "1=Strongly agree", "2=Somewhat agree", "3=Neither agree nor disagree", "4=Somewhat disagree", "5=Strongly disagree", and "6=Not applicable." Respondents were asked to rate their agreement with the following five statements: "The governor of Oklahoma responded promptly to the induced earthquake problem," "My representatives did their best to provide information on how to prepare for earthquakes," "I am confident that our infrastructure can withstand multiple earthquakes," "The oil industry is responsible for the increased number of earthquakes," and "The oil industry is beneficial to our state's economy."

Demographic Variables

Key demographic variables relevant to this study include age, sex, race, income and education level. Also relevant is current home ownership status, namely whether respondents own or rent the property they are living on.

Qualitative Interviews

As stated in Chapters 2 and 3, the PI conducted in-person interviews with 28 participants. The PI noted observations of the immediate physical environment during each interview. We conducted most interviews in participants' residences, though a minority chose to speak in public locations (e.g., a coffee shop). Participants completed the surveys, online or on paper, prior to each interview. We planned interviews to follow a semi-structured, open-ended format to allow

for flexibility and high levels of detail. (To view the semi-structured interview guide see Appendix B). The primary goal was to gather as much information as possible regarding participant perspectives on the OGI, community resilience factors, and government involvement. Interview lengths were nonstandard and varied greatly depending on the participant's openness.

As described in Chapter 2, to gather a suitably diverse sample of participants, the PI worked with the help of local stakeholders to gather participants with varying degrees and types of experiences with IEs and the OGI. The name of every participant was replaced by a pseudonym.

Data Analyses

Survey Data

As with Chapter 2 and three, we used SPSS v27 to generate descriptive statistics results after cleaning and formatting the data. Additional calculations included mean levels of agreement and confidence limits (95%) for each item.

Qualitative Data

After transcribing all interviews into written electronic documents, we entered the data into Atlas.ti v9 for qualitative analysis. It should be noted that we used the qualitative data analysis software to facilitate the organization, management, and reconfiguration of the large amount of data represented in the interview transcripts, rather than as a total replacement for the human effort necessary for adequate categorization, coding, and thematic analysis. Instead of focusing on word counting, for example, we engaged in identifying individual themes over the course of several coding cycles. Primary coding cycles involved categorizing phrases in terms of activities and processes, rather than interpreting the data. Next, we synthesized and categorized primary codes to generate secondary codes through interpretive analysis, noting the various types

of information, such as perspectives, opinions, events, and fact-statements. The final level of coding involved identifying emergent themes and generating cohesive categories through further synthesis and interpretation.

Results

Survey Data from Pawnee and Cushing Residents

112 people responded to the survey, with an average age of 46 years (M = 46.43, SD = 13.65). Table 4.1 includes the descriptive statistics output for respondent demographic characteristics. Most respondents were female (N = 61, 54.5%), were in the $35-$49k income bracket (N = 27, 24.1%), graduated high school (N = 39, 34.8%), White (N = 67, 59.8%), and owned their homes (N = 76, 67.9%).

Respondent Perspective on the OGI and OGI Responsibility

Table 4.2 contains the results of the survey (to view the survey instrument, see Appendix A). The majority of respondents (N= 53, 47%) somewhat agreed that the OGI is responsible for the sudden increase in seismic activity. Only a small percent (N=9, 8%) somewhat disagreed with this statement. A greater percentage strongly agreed (N=75, 67%) that the OGI is beneficial to their state's economy. Only two people (<2%) strongly disagreed with the statement.

Readiness to Withstand Induced Seismicity

84% (N=94) of respondents did not believe their infrastructure is ready to withstand multiple earthquakes, with 36% (N=40) strongly disagreeing and 48% (N=54) somewhat disagreeing.

Government Response to Induced Seismicity

Respondents expressed overall dissatisfaction in the governor and representatives' response to increased seismicity in Oklahoma. Only 5% (N=6) and 8% (N=9) strongly agreed

and somewhat agreed, respectively, that their then-governor responded promptly to the induced earthquake issue. Likewise, only 4% (N=5) and 10% (N=11) agreed or somewhat agreed that their representatives did their best to provide them with information on how to prepare for earthquakes.

Qualitative Data from Pawnee and Cushing Residents

Results from qualitative analysis largely corroborated our survey findings while providing richer details about participant experiences, perspectives, and opinions. As questions centered upon community resilience, it is no surprise that the results yielded themes and subthemes that detailed factors directly mediating community resilience. In general, the results suggest that participants have very little satisfaction or trust toward the government and government officials. It should be noted, however, that participants were simultaneously outspoken about the importance of the OGI to their local economy. Due to a lack of diverse industries providing employment in the state of Oklahoma, participants stated that residents are highly dependent on the OGI. Over the coding process, we identified five primary themes, including (a) the OGI provides economic benefits through job creation, (b) oil extraction methods like fracking can be done safely, (c) the OGI should be held accountable for damage, (d) there is inadequate government and institutional support, and (e) there is a lack of information and community involvement.

Qualitative Data Analysis Themes

OGI as Oklahoma's Primary Economic Lifeline

Participants stated that the primary reason that the OGI is supported by Oklahoman residents is job creation. According to many participants, there would be no communities if not for the OGI, as this is one of the few industries left in the state that provide consistent

employment opportunities. Some spoke of a need for the state to diversify the types of industries that drive its economy in order to improve the number of employment opportunities available to residents. These participants expressed fear that depending solely upon a single industry makes residents and the state economy vulnerable. Others expressed approval of the OGI, noting that the industry ushered in Oklahoma's first economic boom in the early 1900s. These participants argued that the current OGI has established a strong foundation for further development and job creation. Halting or obstructing the OGI's activities in these areas would bring a swift end to their rural communities because people would have to migrate to other states for employment. In sum, participants agreed that the OGI is Oklahoma's primary economic lifeline. As Wendy expressed, residents acknowledge that the OGI creates employment:

> *Jobs! The oil industry employs a lot of people in the state. All kinds of jobs, and some of them are good, high-paying jobs. I know people that make $350,000 per year, and the cost of living in Oklahoma is cheap. They also employ people that nobody else wants to give them a job. They hire ex-cons and people with no skills, and they train them. The smart ones get ahead. We also have some companies that donate goods and give back to the community. They are not all bad.*

Participants also expressed that these employment opportunities were likely the reason why residents refuse to act against the OGI:

> *They are probably the top employer in Oklahoma, so jobs. That is why so many Oklahomans don't want to let go of fracking. That is their bread and butter. If you shut them down, then what are people going to do? They bring money to the state. We don't have anything else to replace them.* – Tessa

Jobs. That's about it. Some people are very wealthy because of the oil industry. – Betty

The oil industry provides jobs, all kind of jobs. Hence you won't find too many people talking against the oil industry. – Brianna

They provide a lot of jobs, and some of those jobs pay really well. - Eric

Neil shared that the OGI does contribute to community wellness, responding to earthquake damage in a way that the government did not:

Jobs and I'm sure some local oil companies here in town often help us with equipment. They helped us to clean up after the big one (M5.8 Pawnee earthquake in 2016). They brought front-end loaders, truck hoes, backhoes, and that kind of thing, helping clean the town up and get it operational down here, where we could get around good, that kind of thing. I can't say the same for the government.

Yet Mary expressed that the monopolized nature of the OGI has perpetuated a power imbalance among the OGI (which wields the most power), the government, and the people:

We need to have some competition. They have monopolized this state, and as a result, they have too much control. They control our government. Don't take me wrong. All of us who live here are thankful because, without the oil industry, we would not be able to continue living here, and you don't have to have a well in your yard to be dependent on them. Even if you are a teacher, you teach kids from families that work for the oil and gas industry. We are interdependent if that

makes sense. So, I will not sit here and trash them because many rural areas would have been abandoned if it weren't for the oil and gas industry.

Fracking Can Be Performed Safely

Interview participants, as well of others who engaged in informal discussions, believed that IEs are a result of greed, rather than simply fracking activities. Older residents in their late adulthood who grew up in the area stated that they did not remember experiencing any earthquakes throughout their lives until the recent increase in seismicity. Pawnee and Cushing are older cities with a rich history, and their development was based solely upon oil extraction. These participants all expressed degrees of bewilderment as to why earthquakes were occurring now, considering hydraulic fracturing is not a new oil extraction technique:

They need to go back to what they used to do. We did not have earthquakes ten years ago. Why now? – Penny

I've been in this business all my life; my dad was working for the oil industry. You can frack, and you don't have to have earthquakes. There are ways to do it safely, but someone will have to make a little less money. Why inject the wastewater? Why not recycle it? It will cost more per barrel, but we won't have earthquakes anymore. – Nick

Others, such as Betty and Zowie, did not have an explanation for IEs, not attributing the seismicity necessarily to the OGI:

I do not remember having earthquakes growing up. Why now? – Betty

Maybe it is God's will. I do not know what to tell you. We never had earthquakes before, and I lived here all my life. I am a 29 model; do you know what that is? [laughter]. I've been around for a while. – Zowie

The OGI Should Be Held Accountable for Damage

Though residents supported the OGI, they did call for accountability. They expressed that they did not want fracking practices to end, but that the parties responsible for the resultant damage ought to acknowledge and address mistakes, paying to fix damage they caused due to oil extraction activities. Participants questioned the Oklahoman government's willingness to regulate such a powerful industry that finances the campaigns of its officials. Some expressed that the government has, historically, not represented the interests of the people, especially considering the amount of money that has been made through the OGI combined with high poverty rates in the areas. Frank noted a lack of representation for Oklahoman residents:

> *It seems to me that someone did not do a very good job negotiating on our behalf. If the government would tax the oil industry even a cent on every barrel of oil produced here, then we would have no problems. But they don't, and they won't.*

Many participants openly called for the OGI to be held expressly accountable for the seismic consequences of their drilling and waste disposal activities:

> *Pay for the damages. They make plenty of money, so why shouldn't they pay? Why do I have to go to court to get the money they owe us for the damages they caused. If you ask anyone in charge, that is what they tell you. Sue them, which means what? You are on your own. Good luck winning the oil industry.* – Betty

> *They provide jobs, but since they make money here, then they should be held accountable if they violate any regulations.* – Brianna

> *Well, if you go to someone's house and you break something, aren't you going to offer to pay or replace what you broke? Well, they caused the*

earthquakes, and our homes got cracks, and we lost things. Isn't it fair to pay for the damages they caused? I think it is fair. – Wendy

If someone is doing something they are not supposed to, then they should pay. – Penny

Well, I believe they are responsible. Not everyone around here shares the same belief. I did my research, and they are definitely at fault, so they should pay up. – Mary

Sarah shared that some regulations efforts had resulted in the reduction of seismicity:

Well, they say, if it walks like a duck, swims like a duck, and quacks like a duck, then it must be a duck. When they regulated them, the earthquakes decreased. They caused the problem, so they should pay to fix the damages.

Inadequate Government & Institutional Support

Participants were not satisfied with their government officials, confirming the survey results. Qualitative analysis yielded participants' explanations regarding why they were dissatisfied, largely due to a general lack of any action to protect the interests of residents over that of the OGI. The two subthemes were miscommunication and inadequate oversight of OGI activities.

Miscommunication. We identified three main types of miscommunication in coding the interview data. First, the government and OGI lacked accountability in communicating the IE situation.

They were people that believed that this was the Second Coming or punishment from God. I guess it was the only reasonable explanation since our

state officials and scientists told us at the beginning that the oil industry is not responsible. – Steven

… the response was horrid. They gave us lip service. That's what we got. – Katherine

Second, the government, OGI, and scientists were inadequate in communicating either facts or meaningful information:

It depends on who you asked; you got a different answer. Not even the scientists spoke the truth. You know about the professor at the University of Oklahoma who said about injecting too much wastewater. They fired her. She lost her job for telling the truth, but back then, she was the bad guy. Nobody wanted to hear the truth. They were protecting the oil industry instead of the people. – Tina

Third was the prevalence of false information and lies being communicated to the public by the government, the OGI, and scientists:

People came from all over and talked, but nobody knew anything. Everyone came after the big one, including scientists, but they told us to wait and see until they figure out the cause. They waited until the earthquakes got out of control to speak the truth and could not hide anymore. So, we were not just misinformed; they lied to us. – Sarah

I am not against it, but we were lied to. They (government and the oil industry) told us that they had nothing to do with the earthquakes, and it took them five years to admit the truth. I think the oil industry still doesn't admit it. People who make the big bucks from them don't admit it. – Sarah

Inadequate Oversight of OGI Activities. Participants stated that the state does not hold the OGI accountable in spite of a long history of well-known violations. Interviewees communicated an overall sentiment that politicians are hesitant to take action against the OGI because they receive financial support from the industry. Some participants described violations in the past decades that resulted in fatal accidents. In Pawnee, for example, a child fell inside an oil well that was not plugged in after emptying. Despite this accident, over a decade passed before the state government took action for these open wells. Participants also reported observing instances of illegal wastewater injection and disposal, such as companies injecting more than their daily permitted volume or trucks intentionally releasing wastewater while driving. As a result, toxic water can seep into farmland used for raising crops or cattle.

> *We have become the country's dumping ground…I think the oil companies push the limit and go further than the limit as far as environmental protection. A friend was following a disposal water truck…they said the vacuum opened, and the water was just seeping all the way down the road.* – Katherine

> *You hear about injecting during the night, about trucks emptying their tanks while driving on the streets. I mean that stuff is toxic, and it goes on our fields.* – Betty

> *I have people telling me the lights were on during the night. They heard noises. They inject during the night. They haven't stopped producing, so think about it. Where all that water goes? They say they load trucks, and they release the wastewater while driving. It's hard to prove, but if it is true, we are going to have a problem.* – Frank

They should be keeping an eye on private businesses, like the oil industry and the wastewater companies, so they don't do what they don't suppose to. Better oversight, I guess. – Brianna

Lack of Information Resources and Community Involvement

Considering their negative attitudes toward and disapproval of IEs, many participants stated that they would gladly welcome any services that would help them deal with seismicity and the resultant problems. Many were perplexed at how to adapt to IEs, not knowing the most effective actions they should take. Community members that were particularly impacted by the earthquakes had reached out to their local government but were unable to gain any assistance.

One participant, a high-level public servant, made it clear that the local government is not able to support their communities' needs because the state did not provide them with the necessary resources or simply increased their funding to compensate for incurred losses. Every interviewee that was a city employee confirmed that local representatives reached out for aid. However, such efforts were ultimately futile, as they were invariably recommended to advise residents to sue the OGI as a possible solution to recuperate losses. Many participants did not have the resources to sue the OGI, though four participants did have active individual lawsuits. In contrast, the Pawnee tribe had filed class-action lawsuit during the time of the interview. Many buildings within the Pawnee tribe are older structures and tribal land experienced more damage than the rest of the area during the 2016 *M*5.8 event.

City employees shared that they did not know how to respond to community members asking for answers. City employees were not provided any information or educational resources with which to learn about the situation and communicate to residents effectively. Participants stated that most scientists who visited the areas following major earthquakes did not spend time

with locals. Likewise, FEMA and Oklahoma state officials who visited the areas did not organize public gatherings to inform residents.

> *… the response was horrid. They gave us lip service. That's what we got. When we had the big one, everyone knew about it. We made it to the news, so they [government officials] showed and gave interviews and smiled pretty for the pictures. Then they left. They did nothing. We are expendable.* – Katherine

> *They did nothing. No one will listen to us… I would like to see many things change, but it is not going to happen. This is Oklahoma.* – Elie

> *…again, this is my opinion. I don't feel like that the information has been put out there…I hate to say it but more information probably should be put out there so people know what to do, when to do it, how to go about it, how to react, where to get resources, who to contact…we are as small town here. We would probably put something in the newspaper, but it only comes out once a week. I would say attack it in several different ways. The newspaper, social media…flyers here at the City Hall, at the library, in places that you know a lot of people come in contact. Make sure the information is there, even if they don't need it*. – Violet

> *I went everywhere, met with people, made phone calls, but we did not get a dime. We tried to help the people with what we have, but this is a rural town, and we don't have a lot of resources. The ones who got a lot of damages were advised to sue the OGI. The ones with the smaller damages got nothing.* – Steven

> *We had everybody come. We had FEMA. I'm not going to be able to name all the organizations. I chauffeured them around. Our goal was to find financial help. We did not qualify for one dime of financial help.* – Frank

I went everywhere. I reached out to politicians, and I happen to know many of them because of my position. Do you know what they told me? Sue them to get your money back. We got nothing. I have the money to sue them, and I did sue them, but how about the people who don't have the means? What are they supposed to do? Why do we have government officials then if they are not going to advocate for the people they serve? – Nick

The mayor tried to help with the damages, but the state did not give him any money. Nice guy, but he doesn't get much help from the state….at least they should have town meeting and tell us what is happening. People were not informed. I would like someone to listen to me, for at least once. I am not stupid. I was up in the 95% in intelligence, and I can't stand when they treat me like I am an idiot. – Sarah

Discussion

Induced seismicity is a novel environmental hazard for which appropriate response and recovery protocols have not yet been standardized. The goal of this study is to use a qualitative interview design informed by descriptive statistics from a survey to evaluate the community resilience of residents in Pawnee, OK and Cushing OK, two areas heavily affected by IEs. Analysis yielded themes and statistics that illuminate specific details regarding factors that may mediate community resilience in areas experiencing induced seismicity. These findings suggest key elements necessary to building community resilience and adaptive capacity in such areas.

Discussion of Findings

Oklahoma was one of the first states to engage in hydraulic fracturing and had done so safely for many decades before 2010, when cases of IE first began (Delatte & Greer, 2018).

According to older participants, rural communities were thriving at the time, with residents either leasing their lands for oil and gas extraction or through employment with the OGI. The onset of IE was a dramatic change for residents, making these communities vulnerable by causing damage to houses and public works (Chang et al., 2018). Considering the seriousness of many of the vulnerabilities and outcomes presented in Chapter 2, the advent of induced seismicity has clearly been a damaging paradigm shift for many residents in the Pawnee and Cushing areas.

According to the data, community members appreciate and value the OGI. Participants expressed the desire to support fracking but with the caveat that they believe it can be done safely, as was the case in prior decades. They emphasized that their economy is highly dependent on the OGI and that any efforts to terminate oil extraction would be highly detrimental to their community. Some suggested that economic diversification would be welcome, though they also believed that this could only occur with active government involvement.

Participants expressed a clear lack of trust and faith toward their state-level representatives. Including those that were city employees and public servants, participants expressed the belief that Oklahoman officials do not look after the needs of their constituency. Some expressed that this was either due to fear of facing a powerful industrial power or because the OGI contributed to their campaigns.

Community involvement is one of the most significant factors that enable governments and public institutions to strengthen and enable their communities to become self-reliant in responding to disasters (Bajayo, 2012; Beck & Purcell, 2020; Burnside-Lawry & Carvalho, 2016; Cinderby et al., 2016; Cui et al., 2018; Moore et al., 2013; Poortinga, 2012). Our findings suggest that the state government engaged in no community involvement during either the onset or aftermath of IEs, despite major damage to community members and impacts in public works.

Through qualitative analysis of interview data, we found that participants did not believe that their state representatives did their best to address issues stemming from induced seismicity. Instead, participants expressed disappointment, with one participant stating that the government gave no more than "lip service" to affected Oklahomans.

Most interviewees did not recall being invited to participate as a part of the community, nor were city employees given information to share with residents. According to interview data, information sharing only occurred through informal sources, such as speaking with other community members, reading the local newspaper, and watching the news. Participants expressed that these sources were inadequate. Conflicting messages, combined with the state's initial and now-debunked position that there was no relationship between increased seismicity and the OGI, caused confusion and created controversy within the community among those negatively affected by IEs and those who feared that actions taken against the OGI would lead to job losses.

Participants believed their city's buildings and public works were not suitable to adequately sustain frequent seismicity. As such, they expressed the want of greater government oversight of OGI activities, including enforced accountability of violations. Residents wanted to be included in the decision-making process, as many decisions they had no power to influence resulted in significant alterations in their daily lives. Some stated the opinion that the government was responsible for providing them with the resources necessary to overcome the effects of IEs, though they did not believe such aid would actually be given. Others suggested that the government tax the OGI, with the funds being put toward supporting communities affected by induced seismicity. In all, despite the strong belief that it is the government's place to protect the

needs of local communities, all participants—including public servants and local government employees—doubted such aid would be provided in the state of Oklahoma.

Practical Impact and Public Health Implications

To determine the impact of the findings of this study, it is important to contrast these areas experiencing IEs with community resilience efforts that state and local governments engage in areas suffering from natural seismicity. Natural earthquakes have the potential to devastate communities. Loss of life, human suffering, negative emotional and physical health outcomes, structural collapse, power outages, fires, and water contamination are a short list of the undesirable outcomes of strong seismic events (Adhikari et al., 2017; Anwar et al., 2013; Arvidson, 1969; Beaglehole et al., 2019; Garfin et al., 2014; Li et al., 2017; M. R. Naghii, 2005). Natural earthquakes, which occur in high seismic hazard (HSH) areas, have been studied from multiple disciplinary perspectives. Preparedness, recovery, and resiliency interventions of HSH areas have also been examined. Beyond research, governments in HSH areas, such as California, Mexico and Japan, have invested in retrofitting buildings and public works to withstand strong and frequent seismicity, while implementing educational measures and installing early earthquake warning systems ("2012 Great California ShakeOut," 2012; Collins, 2009; *Disaster risk reduction : community resilience and responses*, 2019; Mileti, 1985; Mulilis, 2007). Furthermore, people living in HSH areas have extensive experience with earthquakes, have regular opportunities to participate in earthquake drills, and have several options when purchasing earthquake insurance, including higher or lower deductibles and higher or lower monthly premiums (Boissonnade & Shah, 1984; Collins, 2009; Jones et al., 2008; Keith; Orchiston et al., 2013; Perry, 2013; Petal, 2011; Porter et al., 2011; Shaw et al., 2004; Showstack, 2012). Destructive natural earthquakes, however, are not daily events. When they do

occur, they can cause severe damages. Existing earthquake interventions, though they are appropriate for natural earthquakes, may not meet the needs of people and areas affected by IEs.

It is important to contextualize the perspectives of Oklahomans affected by induced seismicity. IEs are unpredictable and the severity of any given event can depend on factors such as proximity to the wastewater injection site as well as the amount injected (Keranen et al., 2014a; McGarr, 2014). Those affected by IEs live in communities that were not designed to withstand seismic activity and many buildings are old (Taylor et al., 2017). Current insurance products do not meet their needs as policies are not designed for constant, low- to mid-magnitude seismicity. The state has not taken adequate measures to provide them with the resources they need to retrofit and strengthen their communities, nor has the government invested time in educating its residents. IEs should be viewed as a determinant of health for the impacted communities because it affects their homes and emotional wellbeing (Casey et al., 2018; Cheung et al., 2018). As such, earthquake policy and research must evolve not only to incorporate IE but also in developing customized solutions that respect local customs and meet community needs.

Limitations

This study's qualitative design, which was supplemented bysurveys, made it possible to gather a variety of data that we used to provide details about the perspectives of Cushing and Pawnee residents regarding the OGI, their government representatives, and overall governance. The study is limited by the participants' geographic location, their local sociodemographic breakdown, and local customs. However, it is possible to draw implications that can be applied beyond the Pawnee and Cushing area. First, our findings may be applicable to residents of other areas in Oklahoma affected by induced seismicity. Second, there are other states with IEs caused by OGI wastewater injection.

Implications for Future Research and Policy

Our findings are consistent with findings in earthquake preparedness and community resilience literature. Policymakers and researchers are advised to consider the unique geographic and seismic circumstances of those living in areas with IEs to maximize participation in potential interventions, as per the recommendations of Adams, Karlin, et al. (2017a). Policymakers and researchers are also advised to consider the personal characteristics of the target population. Recall Adams, Riverd et al.'s (2017) study, which confirms the mediating effect of sociodemographic characteristics on resilience factors. In effect, potential IE preparedness programs must account for the idiosyncrasies of the target population (e.g., rural Oklahomans) to maximize preparedness and resilience. Our findings, particularly the themes explicating the barriers to resilience, may serve as a foundation for studies involving program development or preparedness education.

Gil-Rivas and Kilmer (2016) suggested that an ecological framework should be used to build community capacity and foster resilience to hazards. The demographics of rural Oklahoma differ from those of California, the state simultaneously most vulnerable to natural earthquakes and most prepared. As such, it cannot be assumed that resilience-building efforts constructed for Californians would apply directly to Oklahomans. To promote wellness in the most effective way possible, it is necessary to address inequities, promote diversity, and support community-specific disaster preparedness, response and recovery interventions in ways that are grounded in collaboration and in the empowerment of those communities (Gil-Rivas & Kilmer, 2016).

Our results also highlighted the importance and impact of communication, particularly when communication fails. Participants' accounts confirmed that, during the first years of increased seismicity, leadership had conflicting, contradictory, and even false information, which

are contrary to Hanlon's (2017) recommendations for communicating with clarity and honesty. Finally, the results make it clear that participants do not trust their state representatives. As trust is one of the foundations for building successful community resilience (Robertson et al., 2021), this is an important issue to be addressed for rural Oklahoman communities experiencing IEs.

A final factor we found in the data was an overall lack of structures and public works capable of withstanding IEs. Important to improving community resilience is investing in earthquake resistance structures and retrofitting older buildings (Bajayo, 2012; Burton et al., 2016). The state of Oklahoma has not updated its public works to account for seismic threats, nor have residents engaged in maintenance or retrofitting to meet current seismic building codes. Furthermore, the disruption of even a single public works lifeline can disrupt recovery efforts following a major earthquake event. In the case of Cushing and Oklahoma, several roads, bridges and pipelines were compromised following the two most significant earthquakes in 2016 (Taylor et al., 2017). The interview participants did not trust their state or local governance, which may be indicative of the degree to which rural Oklahoma is prepared for potential future seismic disasters. As such, researchers are recommended to investigate the elements of public works and governance that are most prone to failing in the advent of IEs in LNSH areas.

Table 4. 1

Respondent Characteristics

Variable (N = 112)	*Frequency*	*%*
Sex		
Male	51	45
Female	61	55
Income		
Less than $25,000	14	13
$25,000-34,999	28	25
$35,000-49,000	27	24
$50,000-74,999	25	22
$75,000-99,999	6	5
$100,000+	3	3
Education		
Less than high school	8	7
High school graduate	39	35
Some college	28	25
2-year degree	17	15
4-year degree	16	14
Professional degree	4	4
Race		
White	67	60
Hispanic or Latino	13	12
American Indian or Alaskan Native	17	15
Asian	7	6
Black or African American	7	6
Other	1	1
Home ownership		
I own my home	76	68
I am renting	36	32

Table 4. 2

Views about the Oil & Gas Industry, infrastructure readiness, and government response to IE

Variable (N = 112)	*Frequency*	*%*
Oil industry is responsible for the IE		
Strongly agree	27	24
Somewhat agree	53	47
Neither agree nor disagree	23	21
Somewhat agree	9	8
Oil industry is beneficial to state's economy		
Strongly agree	75	67
Somewhat agree	34	30
Somewhat disagree	1	1
Strongly disagree	2	2
Infrastructure can withstand IE		
Somewhat agree	4	4
Neither agree nor disagree	14	13
Somewhat disagree	54	48
Strongly disagree	40	36
Governor of Oklahoma responded promptly to IE		
Strongly agree	6	5
Somewhat agree	9	8
Neither agree nor disagree	31	28
Somewhat disagree	41	37
Strongly disagree	25	22
Representatives did their best to provide information		
Strongly agree	5	4
Somewhat agree	11	10
Neither agree nor disagree	31	28
Somewhat disagree	40	36
Strongly disagree	25	22

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CHAPTER 5

Discussion and Conclusion

Conclusion

The purpose of this study is to gain insight into the impact of IEs on those living in areas of LNSH. The recent surge of IEs in rural Oklahoma in the past decade provided an ideal setting to investigate the objectives outlined in the introduction. We chose a qualitative interview-driven strategy, supplemented by descriptive statistics drawn from surveying the target population, to examine the needs of the impacted population from multiple perspectives (Almalki, 2016; Curry & Nunez-Smith, 2015; Kelle, 2006; Padgett, 2012). Using an emic approach, the PI entered the Pawnee, OK and Cushing, OK communities and built rapport with community members, integrating the community's distinct elements to examine its preparedness and resilience against the IE hazard (Bailey, 2007). Residents in the affected areas of Pawnee and Cushing became the primary actors of this study, providing real-world experience and context (Bailey, 2007; Goertz & Mahoney, 2012; Kelle, 2006; Padgett, 2012). With this insight, it is possible to close the gap that exists between general research and the need to find solutions that are tailored to the specific environment and community (Dowding, 2013; Jones, 1995). As has been consistently confirmed in resilience research, impacted individuals must have a voice in matters that directly impact their health and well-being to best promote community independence and improve resilience (Bajayo, 2012; Beck & Purcell, 2020; Comfort, 2016; Moore et al., 2013).

Discussion of Findings

Analysis of both survey and interview data yielded sufficient information to meet research objectives. Together, the descriptive statistics and interview-derived themes revealed numerous factors regarding the current state of those experiencing IEs in LNSH communities of Pawnee and Cushing, particularly of their vulnerability and lack of resilience. The interviews captured the experiences and reactions of many participants from the onset of induced seismicity,

through the years as they adjusted to this new reality, and to their current situations. Many participants were still surprised and perplexed as they work to understand and adapt to this new environmental hazard.

Participant Experiences and Outcomes of Induced Seismicity

The vast majority of survey respondents and interview participants were born and raised in Oklahoma. As the state has historically been a LNSH area but with a history of extreme weather, residents had not expected to experience a single earthquake prior to the increased seismicity, let alone have IEs become a part of their daily lives. Nearly all aspects of earthquakes were considered puzzling, including the peculiar sounds to the actual experience of seismic waves, as participants' experiences did not match how seismic events are depicted in books or in the media.

Qualitative data analysis revealed two outcomes not extensively discussed in current literature. The first is the concept of building fatigue, in which damage can accumulate in structures experiencing frequent low- to moderate-magnitude seismicity. Considering that buildings in LNSH areas do not account for seismicity, the scale to which building fatigue can result in harm is yet unknown. The second is that reinforcements made to increase the resilience of structures to extreme weather hazards can lead to greater risk of damage during seismic events. Increasing the rigidity of structures to endure storms, flooding, and tornadoes may have made them more vulnerable to even moderate seismicity.

Importance of the Oil and Gas Industry for the Local and State Economy

Those with extensive ties to the OGI were hesitant to blame this industry, as it provides many of them income and is the largest contributor to the state's economy. Those with ties to the OGI who were directly impacted did not hesitate to express their concerns, particularly their

disapproval of how the IE hazard has been handled by state representatives. But participants also acknowledged the need for the OGI to support their economy.

Greer et al. (2020) employed protection motivation theory (PMT) to investigate the role cognitive processes play when adjusting to IE hazards. PMT posits the existence of two cognitive processes that influence individuals to adjust to hazards: threat appraisals and coping appraisals. Threat appraisals are an individual's perceived estimation of the probability and severity of a threat or hazard, while coping appraisals included an individual's perceived estimation of the effectiveness of response, the cost of response, and self-efficacy (Greer et al., 2020). The researchers found that, while both mechanisms were related to intent to adjust, coping appraisals had more explanatory power for how people respond and adjust to IE hazards than threat appraisals alone (Greer et al., 2020). This has been confirmed by prior research, that the ability for people to cope is strongly influenced by their ability to recover financially following a hazard (Ajzen et al., 2004; Baum & Gatchel, 1981; Becker et al., 2012; Davis, 1990; Shaw et al., 2004). Our findings complement these findings, providing further support that the ability for the participants to adjust and recover from a seismic event was not related with fear or in feeling threatened by the hazard. Instead, we consistently found evidence that financial coping abilities, access to resources, local customs, and individual characteristics influenced preparedness and resilience, factors that should not be overlooked.

Information and Knowledge of IEs, Preparation, Response, and Recovery

Participants expressed the opinion that the information and notices they received were both insufficient and confusing. The prolonged debate between scientists regarding whether hydraulic fracturing or wastewater injection causes IEs, combined with the state and local government officials' fear of regulating its most important industry, led to residents losing trust

in both earthquake experts and government representatives. Residents expressed the opinion that they were left to deal with this new hazard by themselves, with no aid.

Both our qualitative and survey data suggest an overall disapproval of how IE were handled by state officials. Yet participants also recognized that the state of Oklahoma is vulnerable to financial instability due to heavy reliance upon the OGI to sustain their economy. In fact, many residents refused to participate due to unwillingness to potentially harm the OGI through their cooperation with the research. Participants did not want the OGI to move their operations, but instead expressed the need to be better informed about decisions that directly affect their well-being. Furthermore, many demanded greater oversight of OGI activities from their state representatives. This aligns with findings that confirm that transparent, clear, culturally sensitive, and consistent communication is the foundation of building trust between government representatives, stakeholders, experts, and community members (Bajayo, 2012; Bandura, 2001; Beck & Purcell, 2020; Boudet et al., 2014; Burby et al., 1999; Cretney, 2016; McComas, 2006; McComas et al., 2016; Slovic, 1987).

Participants expressed willingness to accept and adapt to IE, with the condition that all parties involved and responsible are held accountable. Participants particularly embraced the idea of what we named an Induced Earthquake Restitution Fund into which the OGI can contribute for the purpose of aiding impacted families and communities coping with IEs. Participants did not want to rely on costly and lengthy lawsuits, which also leave room for unequal access to potential compensation, which are the primary means currently available to keep the OGI accountable.

Information and educational resources that could help residents prepare and increase community resilience were unavailable. This is particularly true considering that the many

preparatory and resilience measures for extreme Oklahoman weather hazards, which are widely understood and applied, can be contradictory to measures for seismicity. Local public servants and local government employees stated that they would gladly and actively disseminate information about IE preparedness and resilience if they had access to such materials.

Our findings on residents' preparedness are consistent with those of Chang et al. (2018), who also investigated how Oklahomans adjust to newfound induced seismicity though, rather than community members, the researchers interviewed state and local stakeholders, emergency managers, and OGI representatives. Their findings suggested that emergency managers in Oklahoma rely on anticipatory resilience strategies for known or obvious threats, which do not necessarily include IEs. The state continues to focus primarily on preparing for and managing weather-related hazards while earthquakes remain largely overlooked despite having impacted several cities and communities (Chang et al., 2018; Greer et al., 2020; Pei et al., 2018; Skoumal et al., 2018). Chang et al.'s (2018) findings clearly suggest that Oklahoma has not yet accepted induced seismicity as part of the hazards it must prepare for. This is interesting considering that Oklahomans may feel more earthquakes than Californians, a state with a long history of seismic activity (Ellsworth, 2013; Hough, 2014).

Degrees of Preparation and Resilience

Our findings also suggest that participants remain unprepared, despite years of constant seismic activity and incidents of significant seismic events. The survey results show that residents in Pawnee and Cushing have not consciously made preparations for earthquakes. Another significant finding is that earthquake preparedness is not associated with prior property damage from IEs. The few preparatory activities that somewhat indicate preparedness were

incidental to preparations for extreme weather, such as flooding and tornadoes, rather than explicitly for earthquakes.

The qualitative data indicate the need to educate Oklahoman residents about earthquakes. Both lay participants and community first responders consistently expressed inaccurate knowledge of how to prepare for and respond to earthquakes. Shockingly, all participants communicated that they ran outdoors or stood under a door frame during earthquakes. These are two actions that are considered highly dangerous due to the elevated likelihood of injury from objects becoming airborne during seismic activity.

This lack of seemingly inconsequential earthquake response knowledge isimportant. A specific example is drawn from an interview with a young mother of two children as she described her experience during the M5.8 Pawnee event, the largest earthquake in the history of Oklahoma. She stressed that this memory was permanently imprinted in her mind, that it is proof that intervention and education regarding earthquakes is necessary for Oklahomans. The participant recalled yelling as loud as she could to wake her children who were sleeping upstairs. The family was living in a two-story home built in the 1920s of mostly stone which was not retrofitted. The children came running down the stairs, losing their balance several times due to the shaking, with sounds of objects falling and breaking being heard throughout. She had promoted these actions because she believed that running outside would be the safest course.

Running outside during an earthquake is contrary to accepted earthquake protocol. Indeed, several participants have been hurt from falling furnishings, flying objects, and broken glassware as they rushed outside their homes. When asked, none of the participant had learned about dropping in place and covering their heads to protect the body’s vitals. They were not

aware that they should identify areas in their homes that were safe from falling debris. Participants were also unaware of the need to secure furniture and heavy objects to walls.

Few participants owned earthquake insurance. Most believed that buying a policy against earthquakes was useless because the packages offered in the area do no provide coverage for the types of frequent but less expensive damage they experience. There is no coverage available for the long-term damage, building fatigue, that may accumulate as seismicity continues.

In sum, residents living in LNSH areas experiencing newfound induced seismicity are not prepared for earthquakes. The structures, communities, and public works are not designed or equipped to resist frequent seismicity, nor are there any programs to increase the overall resilience of residents to earthquakes. No insurance policies appropriate to their situation are available. Finally, there is a lack of accurate earthquake preparedness and response information which prevents residents from being able to address the hazards resulting from IEs.

Recommendations

IE prevalence continues to rise, as hydraulic fracturing wells and wastewater injection rates increase. Induced seismicity has affected at least 22 of Oklahoma's 77 counties as well as areas in other states in the central United States that host OGI extractive activities (Greer et al., 2020; Pei et al., 2018; Skoumal et al., 2018). As long as the OGI continues its current operating procedures, the risk of damage to people, structures, and public works will continue, necessitating measures to educate and prepare residents so they can achieve an acceptable degree of resilience.

The interview data suggests a recommendation for government leadership to begin addressing the issues caused by induced seismicity. Interview participants suggested a number of different policy approaches can be taken, including enforcing regulations on the OGI, holding

the industry accountable, educating residents, or creating a system of governance to promote resilience. Regardless of the actual approach or approaches taken, participants unilaterally expressed a desire for state leadership to take measures to minimize or eliminate the potential harms that can result from IEs.

State government, or industry-backed interventions need not require excessive resources or harm the OGI. Programs to educate residents and help retrofit existing structures might be adapted to the idiosyncracies of Oklahoma from those that have been implemented for decades in California. As participants shared that it is possible to engage in hydraulic fracturing and wastewater disposal without seismicity, leadership may be able to broker a solution that may end IEs altogether without harming OGI interests. Likewise, a system of accountability or a restitution fund set up by the OGI may prove to be more efficient than managing lawsuits from residents affected by induced seismicity. Finally, it may be possible to implement FEMA criteria specifically for IEs.

The interview data also confirms number of factors can augment the effectiveness of any IE intervention, which we recommend industry, community, or policy-level leaders to consider. It is clear from current resilience research (McComas et al., 2016) as well as from our interview data that people will be more likely to comply with guidelines if they are made part of the decision-making process. Furthermore, it is important for all proposed interventions to be sensitive to the target community and to have room for customization (Adams, Karlin, et al., 2017a; Adams, Rivard, et al., 2017). Diversity considerations should not be excluded in disaster preparation interventions. Interviewees nearly unanimously expressed a need to be heard and understood; those living in rural areas particularly expressed that they felt forgotten and neglected. Considering that rural communities make up a substantial part of the United States

population, it is important to recognize their value and provide them with the resources they need to thrive. Though Oklahoma's demographic makeup is not as ethnically diverse as other states, this does not mean that their local customs should be ignored nor does it preclude the fact that they make up a unique population. It is vital to create and promote a public health disaster preparedness platform allowing all people to express their needs and contribute to the collective effort in improving their lives and well-being.

We identified a pressing need for accurate earthquake preparedness information to be disseminated to those affected by induced seismicity. Consider that even basic information taught regularly in the state of California, for example, could have prevented the injuries incurred by the participants and perhaps have prevented more severe physical harm. Our interview data confirmed that local government departments lack knowledge and resources to educate their constituents. Local emergency managers and first responders also lacked information and training for earthquake preparedness, response, or recovery.

These local government and emergency workers also represent an effective channel by which accurate information about earthquake preparation, response, and recovery can be disseminated. Participants working in such capacity expressed willingness to distribute accurate and consistent information, acknowledging that they are ideally placed to influence the community. We recommend experts and state-level leaders to consider the potential synergy of working directly with local public servants to disseminate accurate information, education, and future programs or interventions that may be developed. We also recommend fostering an environment where scientists are trusted and can express their opinions without fear of repercussions.

We recommend that disaster preparation scholars investigate predictors and mediators of preparation for IEs and other induced hazards. Considering that our survey data analysis indicates that having experienced actual damage from IEs is not associated with earthquake preparedness, there may be other factors that are better indicators of preparatory behaviors. These factors, in turn, may be leveraged to formulate more effective interventions designed to improve disaster preparation actions.

We recommend scholars to take into account local weather hazards when performing future research on IE preparedness and resilience. Oklahoman structures and public works have already been established around resilience against heavy rain, storms, flooding, and tornadoes, which are all common in the state. Our interviews also indicated that many have constructed or reinforced their structures specifically to be resilient to these hazards. Yet these very measures so ideal for extreme weather conditions may lead to greater risks during seismic events. As such, we also recommend engineers to examine the implications of frequent low- to medium-magnitude seismicity for buildings and public works in affected areas of Oklahoma. In the scenario in which IEs continue in prevalence, building codes must be revised to account for seismic conditions. Likewise, seismologists and scientists from related fields may need to develop new scales, theories, and models that account for the unique circumstances by which IEs are caused, particularly considering that the extreme frequency of induced seismicity is a highly distinct challenge these areas face.

Contribution to Knowledge

My dissertation enhances existing knowledge in public health, disaster research, and induced seismicity, providing detailed information about experiences of Oklahomans living in LNSH areas impacted by IEs. The findings confirm existing research findings about disaster

preparedness, mitigation, and recovery. Such confirmation includes the need for customized interventions, support for the factors mediating community resilience, and the need for proper disaster education.

We also revealed gaps in the body of IE knowledge that our findings may help address. That commonly accepted structural reinforcements for extreme weather hazards is contradictory to that for seismicity is not an issue that has yet gained traction in current literature. Likewise, we confirmed a gap between conventional earthquake insurance policies and the cumulative building fatigue damage in structures that experience frequent seismicity. We also found that much earthquake research involves evaluating the aftermath of catastrophic seismic events using scales and theories proposed before scholars accepted the possibility of IEs in LNSH areas.

The study is unique in IE research. The PI's personal immersion into the communities affected by IEs gave her first-hand experience of induced seismicity, as well as in-person observations of the affected areas and the damage incurred. This personal immersion into the communities also allowed for increased rapport with participants, who expressed distrust in scientists and researchers due to prior experiences, lending further credence to our qualitative data. The photos (see Appendix D) captured throughout the interviews also demonstrate the distinct types of damage in rural residences. The photos also capture the unique challenges residents face when attempting to balance extreme weather and earthquake preparations. It is hoped that our qualitative interview design, which was supplemented with descriptive statistics from survey design and which was combined with immersive interviewing techniques, is a useful and insightful contribution to the current body of public health and disaster research.

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APPENDIX A: Survey Measures

General Household and Org/K12

Start of Block: Default Question Block

Thank you for taking the time to participate in this study on the effects of persistent low-magnitude, high-frequency earthquakes, experienced in your state. The purpose of this study is to better understand how frequent low magnitude earthquakes impact individual households and communities. Your participation is completely voluntary. We expect this survey to take 10-15 minutes to complete. You will be asked a series of questions using a scale provided with each question. If you are uncomfortable answering any questions, you may, of course, skip it, and you may stop participating at any time. Any information you give us will be extremely helpful.

Please read the questions carefully and answer them as honestly and completely as you can. There is no right or wrong answer, so choose what you feel is right.

As a token of appreciation, you will be entered in a raffle for a chance to win one of five $100.00 Amazon gift cards. Please provide us with your contact information if you would like to participate in the raffle.

Thank you, again, for your help!

Georgia Halkia, MPH, Ph.D. (ABD)

This project has been reviewed and approved by the Institutional Review Board of the University of California, Irvine (01-11-2019 | APP# 12904 | HS# 2018-4766). If you have any questions, you may contact Georgia Halkia, Program in Public Health, University of California, Irvine (ghalkia@uci.edu) or Dr. Grant Ludwig, Program in Public Health, University of California, Irvine (lgrant@uci.edu).

End of Block: Default Question Block

Start of Block: Verification Block

Q2 Please select the county WHERE you or your business/organization is located.

- ○ Pawnee County
- ○ Payne
- ○ Lincoln County
- ○ Oklahoma County
- ○ Noble County
- ○ Choctaw County
- ○ Other

Q3 On this survey I will be responding on behalf of:

- ○ Myself and my household
- ○ An Organization (health, community groups, faith-based)
- ○ A Private business
- ○ A K-12 Education Institution

End of Block: Verification Block

Start of Block: Business and schools

Q4 How many people work in your organization/business or school?

_____

Q5 Has your organization/business or school been impacted by any earthquakes in the past six months?

- Definitely yes
- Probably yes
- Might or might not
- Probably not
- Definitely not

Q6 How would you describe the earthquake activity in your area for the past six months?

- ○ Definitely increased
- ○ Probably increased
- ○ Stayed the same
- ○ Probably decreased
- ○ Definitely decreased

Q7 Does your organization/business or school have an earthquake preparedness plan?

- ○ Yes
- ○ No
- ○ I am not sure

Q8 Does your building meet all the current earthquake safety standards?

- ○ Yes
- ○ No
- ○ I am not sure

Q9 Does your organization/business or school provide staff training or education about earthquake preparedness?

- ○ Yes
- ○ No
- ○ I am not sure

Q10

Does your organization/business or school have an alternate work site for continuity of services in case of a disaster?

- ○ Yes
- ○ No
- ○ I am not sure

Q11 Are heavy furnishings secured to a wall?

- ○ Yes
- ○ No
- ○ I am not sure

Q12 Does your organization/business or school participate in the annual ShakeOut drill?

- ○ Yes
- ○ No
- ○ I am not sure

End of Block: Business and schools

Start of Block: The next few questions are about your earthquake PREPAREDNESS PLANS.

Start of Block: Individual Earthquake Preparedness

Q13

Do you have a family disaster plan?

- Yes
- No

Q14 Do you have an evacuation bag ready?

- Yes
- No

Q15 Did you identify safe spots in every room?

- Yes
- No

Q16 Have you copied important documents for safekeeping?

- Yes
- No

Q17

Do you have earthquake insurance coverage?

- Yes
- No

Q18 Do you store at least 3 days of food at home?

- Yes
- No

Q19 Do you store at least 3 days of water at home?

- ○ Yes
- ○ No

Q20 Do you have a first aid kit?

- ○ Yes
- ○ No

Q21 Do you know how to turn off the main gas valve?

- ○ Yes
- ○ No

Q22 Do you have a portable radio and spare batteries?

- Yes
- No

Q23 Did you talk to an expert to evaluate your building's earthquake risk?

- Yes
- No

Q24 Did you secure heavy furniture to the wall?

- Yes
- No

Q25 Did you try to find information about earthquake preparedness?

- Yes
- No

Q26 You stated Yes on the previous questions. Can you tell me how much effort did you put to find information about how to remain safe during an earthquake?

- ○ Far above average
- ○ Somewhat above average
- ○ Average
- ○ Somewhat below average
- ○ Far below average
- ○ I did not put any effort

Q27 What resources did you use to find earthquake preparedness information? Select all that apply.

- ☐ Government websites, such as FEMA
- ☐ U.S. Geological Survey
- ☐ Television news
- ☐ Newspapers (online or print)
- ☐ Social Media, such as Twitter and Facebook
- ☐ Local administration announcements

☐ Local school announcements

☐ Friends and family

☐ Other

Q28 Have you ever participated in the ShakeOut?

○ Yes

○ No

End of Block: Individual Earthquake Preparedness

Start of Block: Earthquake experience

The next few questions are about your EARTHQUAKE EXPERIENCE.

Q29 Have you felt an earthquake in the last six months?

○ Yes

○ No

Q30 How many earthquakes did you feel in the last six months? (Your Best estimate)

- ○ 2 or less
- ○ 3 to 5
- ○ 6 to 8
- ○ 9 to 11
- ○ More than I can remember
- ○ I did not feel any earthquakes

Q31 Have you experienced any earthquake-related damages in recent years? (last 5 years)

- ○ Yes
- ○ A few
- ○ No

Q32 How did you pay for the damages?

- ○ Paid out of pocket
- ○ Earthquake insurance
- ○ Federal or state funds
- ○ I/We did not fix the damages yet

Q33 Try to think of the STRONGEST earthquake you felt in your location in recent years (last 5 years).

How would you describe the intensity of that earthquake?

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
I barely felt it	○	○	○	○	○
A few objects flew off the shelves	○	○	○	○	○
Frightened, and walked unsteadily	○	○	○	○	○
Cracks appeared on my walls	○	○	○	○	○
Window and/or door frames were damaged	○	○	○	○	○

Q34 How would you describe the earthquake activity in your area in the past six months?

- ○ Definitely increased
- ○ Probably increased
- ○ Stayed the same
- ○ Probably decreased
- ○ Definitely decreased

End of Block: Earthquake experience

Start of Block: Perceived Stress Scale (PSS-10) - Matrix #4,#5,#7,#8 reversed coded

The following series of questions are about your feelings and thoughts during THE LAST MONTH. In each case, please select the answer that best reflects how often you felt a certain way.

Q35	Never	Almost never	Sometimes	Fairly Often	Often	Very Often
How often have you been upset because of something that happened unexpectedly?	○	○	○	○	○	○
How often have you felt that you were unable to control the important things in your life?	○	○	○	○	○	○
How often have you felt nervous and "stressed"?	○	○	○	○	○	○
How often have you felt confident about your ability to handle your personal problems?	○	○	○	○	○	○

How often have you felt that things were going your way?	○	○	○	○	○	○
How often have you found that you could not cope with all the things that you had to do?	○	○	○	○	○	○
How often have you been able to control irritations in your life?	○	○	○	○	○	○
How often have you felt that you were on top of things?	○	○	○	○	○	○
How often have you been angered because of things that were outside your control?	○	○	○	○	○	○

How often have you felt difficulties were piling up so high that you could not overcome them?	○	○	○	○	○	○

End of Block: Perceived Stress Scale (PSS-10) - Matrix #4,#5,#7,#8 reversed coded

Start of Block: Health Related Information

Now I would like to ask you a few questions about your health.

Q36 In general, would you say your health is: (**Select one answer only**.)

○ Excellent

○ Very Good

○ Good

○ Fair

○ Poor

Q37 Did a doctor or health care professional ever diagnose you with ...

	Yes	No
High blood pressure?	○	○
Heart problems such as heart attack, heart failure, or arrhythmia?	○	○
A stroke?	○	○
Depression?	○	○
Anxiety or panic disorder?	○	○

Q38 You answered yes to one of the previous conditions. How many years ago did you receive your diagnosis?

- ○ Less than a year ago
- ○ 1 to 2 years ago
- ○ 3 to 4 years ago
- ○ 5 to 6 years ago
- ○ 7 to 8 years ago
- ○ More than 9 years ago
- ○ I do not remember

Q39 In the last month, how much of the time has your PHYSICAL HEALTH ...

	None of the time	Some of the time	All of the time
Interfered with your social activities (like visiting with friends, relatives, etc.)?	○	○	○
Made it difficult for you to perform your work or other regular daily activities (e.g., it took extra effort)?	○	○	○

Q40 In the last month, how much of the time has your EMOTIONAL HEALTH ...

	None of the time	Some of the time	All of the time
Interfered with your social activities (like visiting with friends, relatives, etc.)?	○	○	○
Made it difficult for you to perform your work or other regular daily activities (e.g., it took extra effort)?	○	○	○

End of Block: Health Related Information

Start of Block: Government support and the oil industry

Below is a list of statements regarding human-induced earthquakes. Please respond to each comment by indicating how much you agree with each one of them.

Q41	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
The Governor of Oklahoma responded promptly to the induced earthquake problem	○	○	○	○	○
My representatives did their best to provide information on how to prepare for earthquakes	○	○	○	○	○

I am confident that our infrastructure can withstand multiple earthquakes	○	○	○	○	○
The oil industry is responsible for the increased number of earthquakes	○	○	○	○	○
The oil industry is beneficial to our state's economy	○	○	○	○	○

Start of Block: Please describe yourself by answering the remaining questions.

Start of Block: Demographics

Q42

I am:

- ○ Male
- ○ Female
- ○ Prefer not to say

Q43

What racial/ethnic group best describes you? If you belong to more than one ethnic group, select all that apply.

- [ ] White
- [ ] Hispanic/Latino
- [ ] Native American or Alaskan Native
- [ ] Black or African American
- [ ] Asian
- [ ] Native Hawaiian or Pacific Islander
- [ ] Other

Q44 How old are you?

_____

Q45

What is your educational status?

- ○ Less than high school
- ○ High school graduate
- ○ Some college
- ○ 2-year degree
- ○ 4-year degree
- ○ Professional degree
- ○ Doctorate

Q46 What is your employment status?

- ○ Employed for wages
- ○ Self-employed
- ○ Local business owner
- ○ Non-local business owner
- ○ Out of work
- ○ Student
- ○ Retired
- ○ Unable to work
- ○ Stay-at-home parent

Q47 What is your marital status?

- ○ Married
- ○ Widowed
- ○ Divorced
- ○ Separated
- ○ Single

Q48 Do you own or rent your home?

- ○ I own my home
- ○ I am renting

Q49 Do you have any children living with you?

- ○ Yes
- ○ No

Q50 What was your total household income before taxes during the past 12 months?

- Less than $25,000
- $25,000-34,999
- $35,000-49,000
- $50,000-74,999
- $75,000-99,999
- $100,000-149,999
- $150,000-199,999
- $200,000 or more
- Prefer not to answer

Q51 We would also like to invite you to participate in an in-person interview. Any information you share with us will remain anonymous and confidential.

If you are interested, please indicate the way you would like me to contact you.

_____

Q52 Would you like to be entered in the raffle for a chance to win 1 out of 5, $100.00 Amazon gift card?

- Yes
- No

Q53 Please provide us with either your email address or your phone number so we can contact in case you are one of the 5 possible raffle winners.

_____

End of Block: Demographics

APPENDIX B: Semi-structured Interview Guide

Semi-structured Qualitative Interview Question Guide

First, I would like to introduce myself and my study. My name is Georgia Halkia, and I am a Public Health Ph.D. Candidate at the University of California, Irvine. My research area of interest is disaster preparedness, and specifically, earthquakes, whether natural or human-induced.

Before we start our interview, I have to read you the informed consent. If you accept, we can proceed with the interview questions.

This interview session is expected to last approximately 60 minutes. The online survey that follows should take 10 additional minutes of your time. Your feedback is really important, and it will provide us with a greater understanding of any issues that may arise from frequent shakings caused by deep-wastewater injection. Understanding the people's needs is a crucial step before we create any Public Health earthquake preparedness interventions.

As a small token of appreciation, you will be automatically enrolled in a raffle for a chance to win one of five $100.00 Amazon gift cards. Your chances of winning will vary depending on the total number of people who will participate in this study, but it will be no less than one in fifteen.

The research procedures involve audio-taping the interview. If you do not feel comfortable with audio recording, then I would like to take detailed notes during this meeting.

Your participation is entirely voluntary, and what you share will be used for analysis, and it will not compromise your identity. You can withdraw at any time.

Do you have any questions at this time?

Interview Guide

1) How long have you lived in this area?

    - Probes

        A. When did you move to Pawnee/Cushing?

        B. Where else did you live?

2) Please tell me about your living situation.

    - Probes

        A. Do any other people live with you?

3) Tell me about your general experience with earthquakes.

    - Probes

        A. When was the first time you felt an earthquake?

        B. Can you describe how it felt?

4) Please describe what happened the first time you felt an earthquake in this location?

    - Probes

        A. Ask for details as to what did they feel?

        B. Can you describe the earthquakes you felt in as much detail as possible?

        C. Can you describe in as much detail as possible what was your reaction?

        D. How did your family react? Can you provide more details of their reactions?

5) How about the big earthquake you had on (Cushing: November 7th, 2016/ Pawnee: September 3rd, 2016)? Where were you at that time?

    A. Can you describe what happened that day?

    B. What did you do next?

6) Have you experienced any damages in your home following the big earthquake? If yes, then:

- Probes

    A. Can you describe the damages?

    B. Can you show me? (if interview takes place in their home)

7) How about noticing any damages in your home following the smaller shakings? Did you notice any damages later on, and not immediately after the smaller earthquakes?

- Probes

    A. Please describe any changes or damages you witnessed following the frequent shakings?

    B. Tell me about any damages you noticed in your home following the increase of earthquake activity.

8) Please tell me how are you planning to fix the damages?

- Probes

    A. Asking for more details regarding the cost involved, the possibility of replacing items, source of paying for the damages.

9) Do you have earthquake insurance?

If yes, then:

- Probes

A. Did you contact the insurance company? If yes, then:

ii. Can you describe the process of contacting your earthquake insurance?

iii. Please tell me about how the insurance company handled the issue.

B. If not, then why?

10) Can you tell me how many earthquakes would you say you felt the past year and how would you describe them?

- Probes

i. Can you describe any earthquakes you felt this past year?

ii. Can you provide me with details of how strong they were?

11) Can you tell me how do earthquakes compare to tornadoes?

- Probes

A. Ask to provide specific examples

B. Tell me what you know about earthquakes and how it compares to what you experienced?

C. In a scale one to five, with one being Not scared at all, and five being Completely terrified, how would you rate your fear of earthquakes?

D. Can you explain why?

12) Now let's talk about earthquake preparedness. Can you describe what you need to do to prepare for an earthquake?

- Probes

    A. Can you tell me what you supposed to do during an earthquake?

    B. Can you tell me how can you prepare your home for an earthquake?

    C. Can you share any resources you used to prepare?

13) Can you tell me if you or someone in your household took any actions to prepare for earthquakes?

- Probes

    A. After the big earthquake tell me if you took any measures to prevent future damages in case of another one? Please describe in as much detail as possible.

14) Can you tell me how you and your family manage living with the earthquakes?

- Probes

    A. Can you describe anything that you do differently since the earthquakes started?

    B. Can you tell me how your reaction to frequent earthquakes changed over time?

    C. Can you describe your feelings and any actions you took to manage what you felt?

15) Can you tell me if the school that your daughter/son is going to, have contacted you about the issue? Or, Can you tell me if your local schools have made announcements about the increased earthquake activity?

- Probes
    A. Tell me more about your child's school. How did the school respond to the increase of earthquake activity in your area?
    B. Can you describe some of the information they communicated to you?
    C. Can you describe any changes your school made to prepare for the earthquakes?
    D. Do you know if your local schools have been retrofitted or they adhere to the latest earthquake safety building code?

16) Can you tell me if you heard of the ShakeOut, and if yes what do you know about it?

- Probes
    A. The ShakeOut is an earthquake drill. Can you tell me what you know about it?
    B. How about your school. Would you know if they participate in the ShakeOut?

17) How do you feel about the recent increase in earthquakes in your state?

- Probes
    A. Tell me about your reactions when you found out that your state started to have earthquakes.

B. Describe what went through your mind when you learned about earthquakes being a new hazard for your community.

C. What concerns you most?

18) Can you tell me how satisfied are you with your government representatives and how they dealt with the issue?

- Probes

A. Please describe how your local and state government dealt with the issue?

B. Please describe in as much detail as possible some of the actions they took.

C. Describe what you felt in response to their actions.

19) Can you tell me how they informed the community about the increase in earthquake activity?

- Probes

A. Please describe if anyone visited your town and talked to you about the induced earthquakes?

B. Please describe in as much detail as possible about any type of information that was communicated to you about the induced earthquakes.

20) Can you tell me how can your representatives better serve you?

- Probes

A. Can you tell me what specific actions could your local or state government have taken to satisfy you?

B. Can you tell me if there is anything you would like to see change? Please describe.

C. How about the federal government? Should they get involved or is this a local issue?

21) Can you tell me how you feel about the oil industry?

- Probes

A. Can you describe how the oil industry reacted to the increased seismicity?

B. Please tell me how you reacted to their response.

C. Can you tell me how would you like the oil industry deal with the issue?

22) What are your thoughts on the oil exploration and production activities in your state?

- Probes

A. Can you describe some of the benefits that oil production and exploration activities contribute to your state?

B. Can you also tell me about any drawback?

23) Is there anything else would you like to share with me that I didn't ask you about?

Thank you so much for your time! Here's my contact information. Please feel free to contact me if you have any concerns or you would like to add something more to your interview. I will be in your city for the next 30 days. If you want to talk to me again, we can schedule another meeting. After I leave, you can always reach me through my phone or my email address.

It's been a pleasure talking to you!
Thank you!

APPENDIX C: Qualitative Data — Theme Table

Themes	Representative Quotes
Nature of IE	It starts off with distant thunder, thunder that you could hear it coming…It sounded like lightning which created a boom, and that boom is over here, and then the noise rolls from the thunder. The thunder would roll, as the earthquake would roll through the house, from one side to the other. They would come and go. – Liam ... [an IE] can be long ways away and just make a little noise or you can be right up on top of it. When they first started, you would hear little rumbles and say, what was that? Sunshine and thunder don't go together. – Brianna Sometimes you only hear those. The bigger they are the louder…I was in a golf course in Perkins one day. It shook pretty good, and you could just feel it. It feels like there is water under your feet. The ground ripples. – Frank As I told you, my dog noticed the earthquakes first. He started to bark before we even heard the sound. We would hear this weird rambling noise and we did not know what it was. They became so frequent, that the dog would not shut up. I was like, Nelson you better get used to it. – Sam

	A lot of shaking and rumbling noises. It was weird…The noise intensified and started to sound like a freight train was going through the house… I was asleep during the big one, and it woke me up. I heard a roar and got louder and louder. It seemed to go on for a while. Longer than I remember in Northridge [10-20 secs]. This one broke more things. – Brianna
Lack of earthquake experience	I don't have much experience. I never lived outside of Oklahoma. – Betty.
	I don't have any. I didn't know what earthquakes felt like until we got them. Well, when I was in grade school, they kept telling me they had them in California. –Elie.
	Well, I have never felt an earthquake until I moved here (Pawnee)…Let's see, the big M5.8 earthquake was about, well, that was in September of 2016. I probably started feeling earthquakes a couple of years before that, 2014. –Nick.
	When I lived in Kentucky, many years ago, we had a M6.4 earthquake. I was also in California during the Northridge [M6.7] earthquake. I was caught unprepared since I did not expect to get an

earthquake in Oklahoma. A tornado yes, flooding is very possible, but an earthquake, never! – Sarah

Inaccurate knowledge

Nothing really. There is nothing you can do about earthquakes. – Liam.

I know what to do…I know how to get under the doorway. – Sarah.

I try to listen to the news, read the local paper, have a Facebook page, and make announcements there. I go to church and talk to people. No one knows for sure. They all got opinions. We are in the dark. I would like to hear someone in charge tell us what to do. – Betty.

I do not know if there is anything you can do about our kind of earthquakes. I read a few things, but I am not very informed. I do not know what to do. What do you do when you have daily earthquakes? What are the recommendations? I could not find any. – Brianna.

Go under the door or run outside if you can. Outside is the safest place to be, but are we going to run outside every time we feel one? – Mary.

… the response was horrid. They gave us lip service. That's what we got. When we had the big one, everyone knew about it. We made it to

	the news, so they [government officials] showed and gave interviews and smiled pretty for the pictures. Then they left. They did nothing. – Katherine.
Challenging in preparing for multiple hazards	…you can't build for both earthquakes and tornadoes. What keeps you safe during a tornado is what it will kill you during an earthquake. – Nick.
	You are better off living in a trailer home when there is an earthquake. They are not safe with tornadoes…We build homes in Oklahoma to withstand tornadoes. It is that rigidity that will keep you safe. We use a lot of cement and heavy roofs, so they won't fly away. I don't think all that rigidity goes well with earthquakes. There are cracks all over my floors, my laundry room separated from my kitchen, and my shelter got cracks because it was made out of cement. How do you prepare for both? – Tina.
	…we build for 90 miles an hour sustained winds. This is what our code says. My house has a 28-feet peak, and we are coming up with ideas to attach it [the roof] to the ground with some post and that kind of thing…it is not cheap. Is it going to hold all that weight during an earthquake? I don't know... That's why we run outside. The roof won't fly away, but it will crash you during an earthquake. –Frank.

Yes, we all keep a lot of food and all sorts of supplies at home. We get lots of floods around here, so it is not wise to drive. – Connor.

The weather here gets pretty bad fast, and we can go a day or two without electricity, so you need to have a generator, a flashlight, batteries, and a freezer full of food. I keep water in my car, my garage, and two large-capacity tanks with water. –Simon.

How many markets did you find on your way here? (laughter). Not that many, right? There is not much around here, so you need to drive to Stillwater to get anything decent. There they have a Walmart, a Target, even Whole Foods. With the weather being so unpredictable, we all drive there and stock up our pantries. – Tina

Views on preparing for IE

I live in Oklahoma, not in California. Why should I prepare for earthquakes when we are not supposed to have any? – Briana.

This is Oklahoma we are talking about. I am prepared for all kinds of weather hazards. I do not need to prepare for earthquakes too. – Rose.

We are not supposed to have earthquakes here. They've been drilling for oil for over 100 years. We never had earthquakes before. Why now? This is not natural for Oklahoma. – Violet.

Why should I pay for something that was not God's doing but someone's greed? – Sam.

I know that someone is prospering from that activity at my expense. I detest the earthquakes, and it just goes right through me. Especially knowing how much damage was done to my house, my place, and my barn. – Nick.

Financial Impact of IE

This place was a mess after the big earthquake…we had to foot the whole bill and rebuild when there is no insurance. The house was so bad that could probably spend $100,000 to $200,000 to fix it. We had mice infestation and insects. Snakes. We had snakes in our house. The walls were damaged beyond repair. – Katherine

…I got a call from my then wife and was hysteric. I drove 95 miles an hour to get here too. Then I got another call when she said the barn was on fire. I had over $100,000 worth of equipment inside that barn. The barn was two years old, and it cost me a lot of money to build. My house was a mess. The fire chief asked me to startup my dozer and go

ahead and push my barn in and completely finish off my barn so they wouldn't spread any more, but everything was off the walls and on the floor. Vases were broken and glass everything out of the cabinets, all the dishes, and everything. The cabinet had fallen out. It just looked like a tornado had hit the house. – Nick

…I felt them every day. Once they started, they never stopped. Some days were worse than others. Probably they injected more that day… [describing the big one] I heard a loud roar, and I woke up. The house started to shake pretty bad. Everything started to fall on the floor. My TV broke, my air conditioner came off the window, and every picture that was hanging shuttered. I run outside, to protect myself. When I came back in, it was a mess. I had to throw everything out. – Caddo

Earthquake insurance challenges

You have to go 60 days without a sign of an earthquake before the insurance company will talk to you. Nobody could ever find that window…We found, here, that some of them [people with earthquake insurance] weren't happy that had been paying for this insurance, and it really didn't treat them the way they expected it to. As I know, insurance companies, you got to fight for your money, anyway, after you've paid them for years. – Frank

…no, we did not think we needed earthquake insurance. We live in Oklahoma, not in California…even the people who had it, most of

	them got nothing…you never going to meet your deductible, so it is a waste of your money. – Simon
	My girlfriend had earthquake insurance and they got nothing. It's too expensive, the deductible is too high, so it is useless. She got the run around that the earthquakes were not natural, so go figure. When we ask what to do, they tell us go sue the oil industry. Who has money for that? And who can fight them? – Tina
Inability to make sustainable repairs	I can't see inside my walls. I live in an old house. They were some cracks before but how can you tell which crack is from which earthquake when you get so many. – Wendy
	You see that crack above the door? Well, I can't remember if it was there or not before the earthquakes started. I never noticed. I do know that now that I keep looking at it, it has gotten bigger. If I call the insurance, how I can prove which earthquake caused what damage? If I pay to fix it, it will come up with the next one. That's what happened with the Tag Agency. The insurance paid to fix the damages the first time, but then we got another one, and the siding fell again. They paid to fix it and then it came down again. You can't be fixing things if they going to break again and again. It doesn't matter who pays for it. – Liam

	…I could not afford to buy another [window-mounted air conditioner], and the possibility of getting hurt is not worth it. – Neil
Infrastructure is not designed for IE	…you can't build for both, earthquakes and tornadoes. What keeps you safe during a tornado is what it will kill you during an earthquake. – Nick
	…we build for 90 miles an hour sustained winds. This is what our code says. My house has a 28-feet peak, and we are coming up with ideas to attach it [the roof] to the ground with some post and that kind of thing…it is not cheap. Is it going to hold all that weight during an earthquake? I don't know... That's why we run outside. The roof won't fly away but it will crash you during an earthquake. – Frank
Emotional strain	…no, they were not strong, but you notice them. I notice them. My friend who lives five miles from here, she says she did not feel the shaking, just the booming and the rumbling. I felt them. My walls were shaken. Nothing broke with the little ones, but the house was shaken. – Katherine

A year or two before the big one, that is when I started to feel them. I think there were more during the evening. You would be in your bed, and you felt the shakes…they were strong enough to shake the bed…you try to ignore them, but you don't get used to them. – Betty

I am concerned, and I don't want to say that I am terrified, but I should not sound heartless because I did not get the worst damages. I am concerned about the recent increase in earthquakes. I've lived here all my life and never experienced earthquakes before. Now all of a sudden, we are having earthquakes…what is causing them, and are we going to have more like the big one? Does it ever end, or this is how it is going to be?- Violet

I lost my china. 50 years old. We'd gotten it when we'd gotten married. I've lost so much, just countless. We'd go to New Mexico every year and I would buy the Indian pottery, the hand-made pottery, and all that shattered. I mean shattered…We filled ten 50-pound feed sacks full of broken glass. – Katherine

Inadequate government protective actions

We had everybody come. We had FEMA. I'm not going to be able to name all the organizations. I chauffeured them around. Our goal was to find financial help. We did not qualify for one dime of financial help…Enough people didn't die. I don't mean it that way…We had

	some injuries; porch fell off a house and hit a girl on the shoulder. She's lucky…She shouldn't have been there. It happened, and it was the earthquake. Whose fault is it? ... I had the FEMA group, state group, an insurance group, and we all went through. We had to lose, I think, 15 structures and one death before we qualify for something. Now, had the hotel fell, which is now section 8 housing, it would have not only killed 40 people, but it would have covered us on that. – Frank
	I went everywhere, met with people, made phone calls, but we did not get a dime. We tried to help the people with what we have, but this is a rural town, and we don't have a lot of resources. The ones who got a lot of damages were advised to sue the OGI. The ones with the smaller damages got nothing… you can't just give the money [referring to city funds] you have to anyone. The rest of the people want to see actions, such as new roads. They don't want us to spend the money to fix people's houses. – Stephen
Lack of communication led to frustration and miscommunication	…run outside since there is nothing you can do to prepare for an earthquake…is there? I mean, what do you do in California?...We received a bunch of paper work to fill out after the big one, I wish I can show you that. They did not tell us what to do, they just had us fill out paperwork…People came here but they did not talk to us. – Neil

	…again, this is my opinion. I don't feel like that the information has been put out there…I hate to say it but more information probably should be put out there so people know what to do, when to do it, how to go about it, how to react, where to get resources, who to contact…we are as small town here. We would probably put something in the newspaper, but it only comes out once a week. I would say attack it in several different ways. The newspaper, social media…flyers here at the City Hall, at the library, in places that you know a lot of people come in contact. Make sure the information is there, even if they don't need it. – Violet
	…we were lied to. They (government and the oil industry) told us that they had nothing to do with the earthquakes, and it took them five years to admit the truth. I think the oil industry still doesn't admit it. People who make the big bucks from them don't admit it. – Sarah
Reduced Income from leasing their land to the OGI	…They [the OGI] select a small piece of land to place their well and negotiate a low price with an unaware small landowner who does not know the real value. – Nick
	… it is a trust issue with them. How do we know they aren't on our land, to begin with, without our knowledge? … I know, we have to

have oil and gas, that's a given…I just hope it's done properly and to the law. – Rose

…this is what I mean. I already told them [OGI] that I am not interested. This land is my respite. I bought this land to retire and get away from the city. I have plans to create a place where people can come and relax. I don't want anyone drilling underneath my land. They can force-pool me by involving the Oklahoma Corporation Commission and claim they need to extract mineral resources. Imagine if they can do this me, that I worked for them [OGI] all my life, what they can do to someone who has no clue how they operate. – Nick

Environmental safety concerns

…think what can happen, from time to time you get a casing leak on a well and you're required to go in and fix it... Well, think about how old and how rusty some of these wells must be now that were drilled back in the 20s, 30s, 40s, 50s. Think about, some of these are 70 years old. Think about, how old and how brittle some of those cement jobs and that old steel, how rusty and think about how rigid and vulnerable those things are right now. – Nick

My dad got his wells up there, was running 20-30 years ago. It had a film on it and I couldn't use it. We had to drive another well in there to get water…but those kinds of environmental things happening with

these damn oil companies. They said fracking is safe, but when you frack you open that ground up… My neighbor over here, he became an advisor, because he could not trust them. – John

They say [the OGI] that wastewater [injection] is safe, and fracking is safe. They say that they inject at deeper levels. Again, they might be right, but is anyone checking? How do we know there are no leaks? We don't. We hope they are doing the right thing. If we look at past events, it paints a different picture. They contaminated the lake many years ago, they left wells open after they got the oil out, and a toddler fell in…there is evidence of negligence. How do we know our water is safe? Do we just trust them [the OGI]? – Connor

You hear about injecting during the night, about trucks emptying their tanks while driving on the streets. I mean that staff is toxic, and it goes on our fields. – Betty

I have people telling me the lights were on during the night. They heard noises. They inject during the night. They haven't stopped producing, so think about it. Where all that water goes? They say they load trucks, and they release the wastewater while driving. It's hard to prove, but if it is true, we are going to have a problem. – Frank

	We have become the country's dumping ground…I think the oil companies push the limit and go further than the limit as far as environmental protection. A friend was following a disposal water truck…they said the vacuum opened, and the water was just seeping all the way down the road. – Katherine
Neglect and exploitation of rural areas in the U.S.	… I don't want someone in California telling me how to do my business because I think California does a lot of things in the most ridiculous manner...think about what they did when natural gas was at a premium. You are probably too young to remember. They set a limit on the (gas) price…they end up not having enough natural gas to power everything, and their companies would sell their gas to other states for more money…so no, I do not want an outsider making decisions for us... Scientists get a degree, and they think they know everything. They don't live here, and they don't understand our needs and they don't care about us. Why do they get to make decisions without having spent a day in rural Oklahoma? - Nick
	I see those kids from the University, they come here with their professors, they follow them like ducks and go out in the fields and put seismometers here and there. You ask them a question and they know their science, but they know nothing about us, our history, our lives. They look at us like we're stupid, and we won't understand what they

have to say…they probably think we deserve it because we lease our lands for money, but that ain't true. – Steven

… the response was horrid. They gave us lip service. That's what we got. When we had the big one, everyone knew about it. We made it to the news, so they [government officials] showed and gave interviews and smiled pretty for the pictures. Then they left. They did nothing. We are expendable. – Katherine

I would like to see more of our government to care about the people they serve, instead of caring about Russia and Korea…They only come when there is money to make or for publicity. Do you know who came? Erin Brockovich came a couple of years ago about the water issue, and now you... Still, we are not worth their time… I would like someone to listen to me, for at least once. I am not stupid. I was up in the 95% in intelligence, and I can't stand when they treat me like I am an idiot because I don't live in a big city. – Sarah

They don't care too much about rural Oklahoma. If you live in a city like Tulsa, you don't think there's any intelligent life outside the city. – Betty

A lot of people visit or do business here. They don't spend the time to get to know the locals. I see it now. They look at us in a way that

	makes you feel like you are not smart enough or you are uneducated ... I used to be one of them. I lived in Oklahoma City and drove here almost every day. I bought this home five years ago because I was tired of commuting. Over the years, I have met many unassumingly bright people and changed the way I view things. – Beatrice
OGI is Oklahoma's primary economic lifeline	Jobs! The oil industry employs a lot of people in the state. All kinds of jobs, and some of them are good, high-paying jobs. I know people that make $350,000 per year, and the cost of living in Oklahoma is cheap. They also employ people that nobody else wants to give them a job. They hire ex-cons and people with no skills, and they train them. The smart ones get ahead. We also have some companies that donate goods and give back to the community. They are not all bad. – Wendy
	They are probably the top employer in Oklahoma, so jobs. That is why so many Oklahomans don't want to let go of fracking. That is their bread and butter. If you shut them down, then what are people going to do? They bring money to the state. We don't have anything else to replace them. – Tessa,
	Jobs. That's about it. Some people are very wealthy because of the oil industry. – Betty

The oil industry provides jobs, all kind of jobs. Hence you won't find too many people talking against the oil industry." – Brianna

"They provide a lot of jobs, and some of those jobs pay really well. – Eric

Jobs and I'm sure some local oil companies here in town often help us with equipment. They helped us to clean up after the big one (M5.8 Pawnee earthquake in 2016). They brought front-end loaders, truck hoes, backhoes, and that kind of thing, helping clean the town up and get it operational down here, where we could get around good, that kind of thing. I can't say the same for the government. – Neil

We need to have some competition. They have monopolized this state, and as a result, they have too much control. They control our government. Don't take me wrong. All of us who live here are thankful because, without the oil industry, we would not be able to continue living here, and you don't have to have a well in your yard to be dependent on them. Even if you are a teacher, you teach kids from families that work for the oil and gas industry. We are interdependent if that makes sense. So, I will not sit here and trash them because many rural areas would have been abandoned if it weren't for the oil and gas industry. – Mary

Fracking can be done safely	They need to go back to what they used to do. We did not have earthquakes ten years ago. Why now? – Penny
	I've been in this business all my life; my dad was working for the oil industry. You can frack, and you don't have to have earthquakes. There are ways to do it safely, but someone will have to make a little less money. Why inject the wastewater? Why not recycle it? It will cost more per barrel, but we won't have earthquakes anymore. – Nick
	I do not remember having earthquakes growing up. Why now? – Betty
	Maybe it is God's will. I do not know what to tell you. We never had earthquakes before, and I lived here all my life. I am a 29 model; do you know what that is? [laughter]. I've been around for a while. – Zowie
OGI should be held accountable for damages	It seems to me that someone did not do a very good job negotiating on our behalf. If the government would tax the oil industry even a cent on every barrel of oil produced here, then we would have no problems. But they don't, and they won't. – Frank

Pay for the damages. They make plenty of money, so why shouldn't they pay?...If you ask anyone in charge, that is what they tell you. Sue them, which means what? You are on your own. Good luck winning the oil industry. – Betty

They provide jobs, but since they make money here, then they should be held accountable if they violate any regulations." (Brianna, community member)

… Well, they caused the earthquakes, and our homes got cracks, and we lost things. Isn't it fair to pay for the damages they caused? I think it is fair. – Wendy

If someone is doing something they are not supposed to, then they should pay. – Penny

Well, I believe they are responsible. Not everyone around here shares the same belief. I did my research, and they are definitely at fault, so they should pay up. – Mary

Well, they say, if it walks like a duck, swims like a duck, and quacks like a duck, then it must be a duck. When they regulated them, the

earthquakes decreased. They caused the problem, so they should pay to fix the damages. – Sarah

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APPENDIX D: Images from Pawnee and Cushing, Oklahoma

Figure 6. 1

Pawnee, Oklahoma - Tag agency—The damages shown are after a M4.1 earthquake a year following the big Pawnee earthquake. The owners paid to fix the damages the first time but the repairs did not last.

Figure 6. 2

Pawnee, Oklahoma - Tag House; A side view of the damages.

Figure 6. 3

The two photos below were taken from a participant's phone capturing the damages inside the Pawnee City Hall

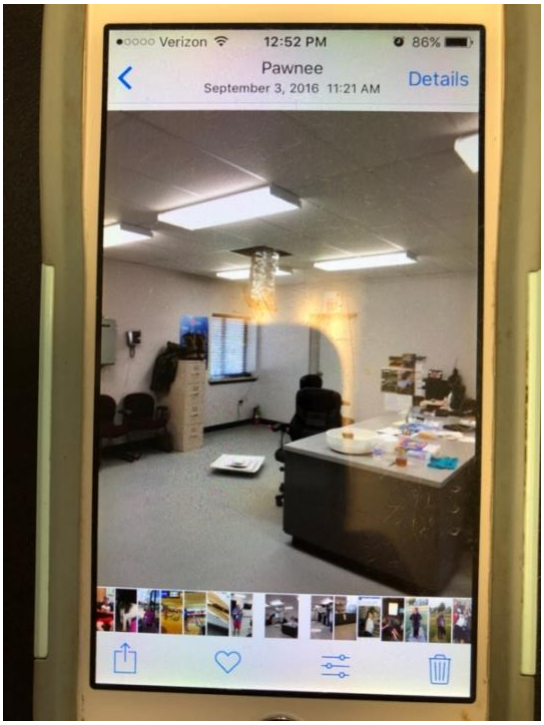


Figure 6. 4

The images below capture damages in Cushing, Oklahoma, following the 2016 earthquake. The photos are courtesy of the Cushing City Hall.

Figure 6. 5

Shown are the interior damages of an office building in Cushing. The photos are courtesy of the Cushing City Hall.

Figure 6. 6

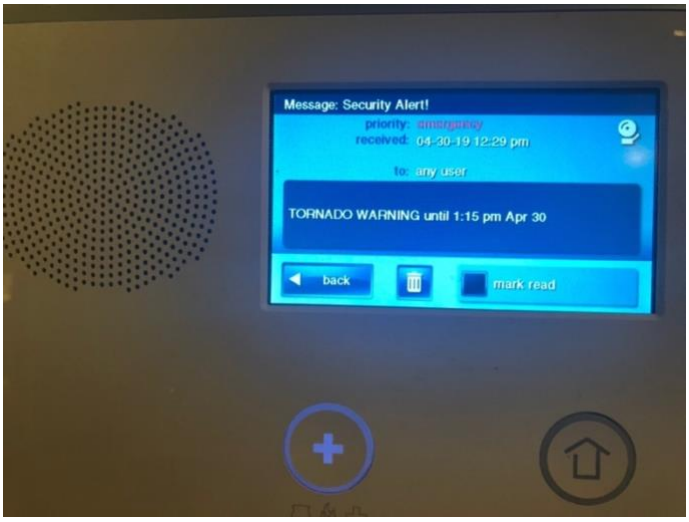
S*hown below are the interior and exterior damages of a home in Cushing, Oklahoma.*

Figure 6. 7

Damages from the 2016 IE in a farmhouse in Pawnee, Oklahoma.

Figure 6. 8

Extreme weather examples taken during my fieldwork; Multiple daily tornado warnings



Note. After the flooding in the Arkansas River, you can see only the top of the tree.

For reference, I used to sit under that tree when I first arrived in Tulsa, Oklahoma.

Figure 6. 9

Headline news during the time I was collecting data.

Note. The year 2019, was marked as one of the worst weather Oklahomans experienced the last ten years.

Figure 6. 0

The commute to Pawnee and Cushing proved to be challenging. Poor road conditions and daily rains translated to getting stuck in the mud or being unable to drive for several hours.

Figure 6. 11

The people of Pawnee created a t-shirt to honor Pawnee native Chester Gould (known as the creator of the Dick Tracy comic strip) and capture the unexpected 2016 IE