Institute for Sustainable Solutions
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# [Draft] Interim EJ Review: Assessing Social Vulnerability to Earthquake-Induced Hazards at Fuel Storage Facilities

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**Purpose**

This report presents the results of an Environmental Justice (EJ) review using a social vulnerability assessment model for Columbia, Lane, and Multnomah Counties in Oregon. The Geographic Information System (GIS) based assessment aimed to identify areas of social vulnerability in communities surrounding the fuel storage facilities that may be affected by earthquake damage. Using Census Block Group (CBG) as the unit of analysis, this work categorizes neighborhoods into different social vulnerability statuses based on a set of seven indicators. In addition, the report examined the increased hazard risk within a 4-mile radius of the facilities and conducted a regional desk analysis covering a 50-mile radius to assess both nearby and more distant consequences.

**Background**

This report is part of a study conducted on behalf of the Oregon Department of Environmental Quality (DEQ) to support their rulemaking efforts for Oregon Senate Bill 1567, which requires fuel storage facility owners or operators to submit to the DEQ a comprehensive seismic vulnerability assessment (Oregon State Legislature, 2022). In the case of a mega-earthquake, the intense shaking can cause soil to lose its strength and behave like a liquid, a phenomenon known as liquefaction (Seed & Idriss, 1971). Thus, DEQ is concerned with understanding the community characteristics of those who will be most affected by earthquake-induced fuel spills and cascading disasters at terminals regulated by SB1567. Given the potential risk to public health and safety, it is important to understand the concerns of communities living near these facilities and to assess their social vulnerability to the impacts of an earthquake-induced fuel spill and cascading disasters.

Past natural disasters have highlighted the negative impact of insufficient preparation and planning on marginalized communities, underscoring the importance of understanding social vulnerability in developing plans and programs to mitigate, prepare for, respond to, and recover from hazardous events (Fothergill & Peek, 2004). The potential consequences of an earthquake include damage to infrastructure, loss of life and property, displacement, and disruptions to critical services and supplies. To be better prepared for such events, it is crucial to gain a more nuanced understanding of environmental injustice. This is where a social vulnerability model, such as SOVI, can be helpful (Cutter et al. 2003). Social Vulnerability Index provides a more comprehensive and holistic assessment of the potential impacts of an earthquake on socially and economically vulnerable communities. The model is already being utilized by numerous federal and state agencies to gain insights into environmental injustice (CDC; CPUC; Environmental Protection Agency; FBRACE)

**Methodology**

The study adapted the social vulnerability model originally developed by Cutter et al. (2003) to understand social vulnerability to environmental hazards. Cutter et al. (2003) defined social vulnerability as, "the susceptibility of given social groups to the deleterious effects of environmental or technological hazards, as well as to the stress resulting from social, economic, and political factors." The model is widely accepted in the field of environmental disaster research and has been used in various studies to understand and address social vulnerability to environmental hazards (Flanagan et al. 2011; Chang et al. 2021). The definition emphasizes that social vulnerability is not solely determined by physical factors like exposure to hazards but also by social factors like poverty, race, ethnicity, and age. Thus, social vulnerability is a multifaceted and intricate concept that encompasses both social and physical dimensions. Thus, the model used for this report incorporated various socioeconomic variables (Table 1) to create an index that measures social vulnerability. The index was built based on the relationship of each variable to vulnerability, which could be either positive or negative. By using this model, the study aimed to identify areas with high social vulnerability so emergency management strategies can be developed to mitigate potential impacts on these communities.

We selected census block groups (CBGs) as our unit of analysis because they are the smallest geographic unit for which the Census Bureau publishes data. The Census Bureau defines a census block group (CBG) as a geographic area that generally contains between 600 and 3,000 people. All the social vulnerability variable data was sourced from the American Community Survey of 2020 (U.S. Census Bureau, 2021). The variables used in this study are listed in Table 1 with corresponding vulnerability rationale. To facilitate the analysis, the variables were normalized using a standard min-max normalization technique (Eq 1 and Eq 2), ensuring that all variables were transformed to a standardized range of 0 to 1 before they were combined (Chang et al. 2021). The quantile classification method was then used to classify the normalized values into four distinct categories: "minimal," "low," "medium," and "high." The ranking was based on the normalized values falling within the defined ranges of 0-25%, 25-50%, 50-75%, and 75-100%, respectively. The normalized and ranked values for all variables were then combined to determine the overall vulnerability.

$$x' = (x - \min(x)) / (\max(x) - \min(x))$$
(Eq 1 used for positive relationship with vulnerability, see Table 1)

$$x' = (\max(x) - x) / (\max(x) - \min(x))$$
(Eq 2 used for negative relationship with vulnerability, see Table 1)

where:
$x$ is the original value of the variable
$x'$ is the normalized value of the variable
$\min(x)$ is the minimum value of $x$ in the dataset
$\max(x)$ is the maximum value of $x$ in the dataset
This formula scales the variable $x$ to a range between 0 and 1, where 0 represents the minimum value and 1 represents the maximum value in the dataset.

As part of the study, past fuel storage-related incidents from around the world were reviewed (Table 2), and an average radius of 4 miles was identified (Hinzen, 2007; Lam & Culbertson, 2014; Murthy, 2014). Within this buffer, there may be facilities that are critical from a social vulnerability or emergency management perspective that need further consideration, hence we called this buffer increased hazard risk area. The study identified certain facilities within this area (Table 3, 4, & 5) that may inform emergency management strategies and mitigate potential impacts on the communities located within the buffer zone.

**Preliminary Results**

The spatial analysis of social vulnerability revealed that there were varying patterns across different areas. Demographic factors such as non-white population, elderly population, renter population as well as poverty, language ability, high school education, and overall population density were all found to have played a significant role in driving social vulnerability in these areas. In Multnomah County, the census block groups that are located between multiple fuel facilities, especially those directly adjacent to industrial areas in northwest Portland and the Portland airport, are of particular concern. These areas (CBGs) are situated in the center of these two fuel storage facilities, and they contain numerous socially vulnerable neighborhoods (Figure 1). Notably, certain facilities located within the increased risk hazard area of Multnomah and Washington Counties are of significant concern. For instance, approximately 32% of all child daycare centers in these counties are situated within this 4-mile radius area, as are 38% of all nursing homes. Furthermore, 32% of all places of worship (including several minority and immigrant places of worship) in the county were also located in this radius. (Table 3).

In Lane County, the area around the fuel storage facility exhibits high social vulnerability (Figure 3), and it is the only county where a greater proportion of socially vulnerable neighborhoods were found within a 4-mile radius (Table 6). In this county, more than 28% of senior homes, as well as about 31% of child daycare centers, were situated within the increased hazard risk area (Table 5).

Compared to the other two counties, Columbia County had no critical facilities from a social vulnerability standpoint that were situated within the increased hazard risk area (Table 4). However, the CBGs in and around the facility displayed a relatively higher social vulnerability within the county.

The statewide analysis also revealed that 4 out of 8 high volume terminals were located in a CBG with higher social vulnerability, where as all of the 8 high volume terminals had adjacent neighborhoods with relatively higher social vulnerability (Figure 4; Table 7).

**Limitations of GIS**

Although GIS is a useful tool, it has certain limitations. One such limitation is that when aggregating sociodemographic data at the neighborhood scale, finer scale variations may be lost in the aggregation process. Additionally, the GIS workflow relies on geographic boundaries, which are not always applicable to ecological and technological disasters. While GIS can help identify spatial patterns, its findings must be supplemented with qualitative insights for a more comprehensive understanding of the issue at hand. There are also limitations in terms of data application, availability, and quality.

**Recommendations**

To gain a more comprehensive understanding of the issue, this environmental justice review will conduct focus group studies with members of the local communities who have a stake in the outcomes. Moreover, this report recommends considering issues that cannot be captured using traditional GIS methods due to limitations in data quality (e.g., coarse resolution of air pollution data) and availability (e.g., private industrial warehouses), as well as concerns related to privacy and ethics (e.g., unhoused population).  For example, the constantly changing presence of the unhoused population cannot be accurately captured using traditional GIS methods. However, it should still be considered for a more comprehensive understanding of the groups that may be socially vulnerable. Likewise, it is important to consider ecological impacts on water quality, fish population, and downstream effects on tribal communities for a more comprehensive understanding of the issue. Additionally, it will be useful to consider health impacts on urban communities as well. The regional analysis, a separate desk analysis, will create multiple buffers (x-mile each, varies by county) to summarize and recommend major issues to consider regionally at various buffer scales.

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**Appendix**

**Table 1. Based on Social Vulnerability Index developed by Cutter et al. 2003**

| Variable | Vulnerability Rationale | Used by |
|---|---|---|
| Population density (+) | Require more resources prior to, during, and after a hazard event | Cutter (2003) |
| % Population > 65 years of age (+) | Require more assistance during and after a hazard event | CDC, EPA |
| % Non-White Population (+) | Have less ability to recover after a disaster due to lack of resources | CDC, EPA |
| % Population with no high school diploma (+) | Have less access to information and resources | CDC, EPA |
| % Housing units occupied by renters (+) | Have less resources to recover after a hazard event | CDC, Ma and Smith (2020) |
| Median Household Income (US$) (-) | Have less resources before, during, and after a hazard event | CDC, EPA |
| % Households with limited English (+) | Require more assistance/outreach before, during, and after a hazard event | CDC, EPA |

(+) Higher the variable, higher the vulnerability

(-) Higher the variable, lower the vulnerability

**Table 2. Defining an increased hazard risk area for social vulnerability**

| Incident | Major Impact Radius | Reference |
|---|---|---|
| Toxic Train Accident in Raymond, Minnesota | 0.5 mile | CNN, 2023 |
| Toxic Train Accident in East Palestine, Ohio | 1 - 2 miles | Governor of Ohio, 2023 |
| Gas leak in Bhopal, India | 4.5 miles | Murthy, 2014 |
| Fuel tank explosion in London, UK | 3 miles | Hinzen, 2007 |
| Wildland/Urban fires in California, USA | 1.5 miles | Radeloff et al. 2005 |
| Aliso Canyon Gas Leak | 3 miles | Assessment Report, 2016 |
| San Juanico disaster | 3 - 4 miles | Arturson, 1987 |
| Beirut explosion | 6 miles | USA Today, 2020 |

**Table 3. Critical facilities to consider within 4-mile buffer Multnomah and Washington counties.**

| Facility | Total count within the 4-mile buffer | Total count within the counties | Data source |
|---|---|---|---|
| Basic Earthquake Emergency Communication Nodes (BEECNs) | Data pending | Data pending | County via special arrangement |
| Community centers | 19 | 293 | Metro via PSU |
| Daycare centers | 237 | 732 | HIFLD |
| Hospitals | 10 | 16 | HIFLD |
| Homeless camps | Data pending | Data pending | County via special arrangement |
| Places of worship | 332 | 1,025 | HIFLD |
| Public schools | 195 | 733 | HIFLD |
| Senior homes/Nursing homes | 34 | 186 | HIFLD |
| Supermarkets | 59 | 156 (Multnomah only) | Portland Open Data |
| Warehouses | Data not available | Data not available | |

**Table 4. Critical facilities to consider within 4-mile buffer Columbia county**

| Facility | Total count within the 4-mile buffer | Total count within the county | Data source |
|---|---|---|---|
| Basic Earthquake Emergency Communication Nodes (BEECNs) | NA | NA | |
| Community centers | NA | NA | Metro |
| Daycare centers | 0 | 23 | HIFLD |
| Hospitals | 0 | 0 | HIFLD |
| Homeless camps | NA | NA | County |
| Places of worship | 0 | 40 | HIFLD |
| Public schools | 0 | 24 | HIFLD |
| Senior homes/Nursing homes | 0 | 7 | HIFLD |
| Supermarkets | NA | NA | |
| Warehouses | NA | NA | |

NA = Not available

### Table 5. Critical facilities to consider within 4-mile buffer Lane county

| Facility | Total count within the 4-mile buffer | Total count within the county | Data source |
|---|---|---|---|
| Basic Earthquake Emergency Communication Nodes (BEECNs) | NA | NA | |
| Community centers | NA | NA | Metro |
| Daycare centers | 47 | 154 | HIFLD |
| Hospitals | 0 | 6 | HIFLD |
| Homeless camps | NA | NA | County |
| Places of worship | 80 | 299 | HIFLD |
| Public schools | 27 | 117 | HIFLD |
| Senior homes/Nursing homes | 15 | 53 | HIFLD |
| Supermarkets | NA | NA | |
| Warehouses | NA | NA | |

NA = Not available

**Table 6. Distribution of vulnerable neighborhood counts at different scales based on a quantile classification**

| Scale | Minimal | Low | Medium | High |
|---|---|---|---|---|
| 4-mile radius<br>Columbia county<br>(n = 3) | 0 | 0 | 2 | 1 |
| Columbia county<br>(n = 10) | 10 | 9 | 10 | 11 |
| 4-mile radius<br>Lane county<br>(n = 87) | 19 | 20 | 20 | 28 |
| Lane county<br>(n = 282) | 71 | 71 | 69 | 71 |
| 4-mile radius<br>Multnomah and Washington counties<br>(n = 310) | 94 | 68 | 81 | 67 |
| Multnomah and Washington counties<br>(n = 981) | 246 | 245 | 245 | 245 |
| Oregon<br>(n = 2956) | 739 | 739 | 739 | 739 |

**Table 7. High Volume Facilities and Status of the Census Block Group they are located in (State CBG scale)**

| Facility ID | County | Relative Social Vulnerability in the CBG | Whether has higher vulnerability in surrounding CBs |
|---|---|---|---|
| 6812 | Columbia | Minimal | Yes |
| 119622 | Columbia | Minimal | Yes |
| 87271 | Coos | High | Yes |
| 53107 | Jackson | Medium | Yes |
| 7988 | Jefferson | Medium | Yes |
| 1945 | Klamath | High | Yes |
| 18911 | Lane | Low | Yes |
| 18585 | Umatilla | Low | Yes |

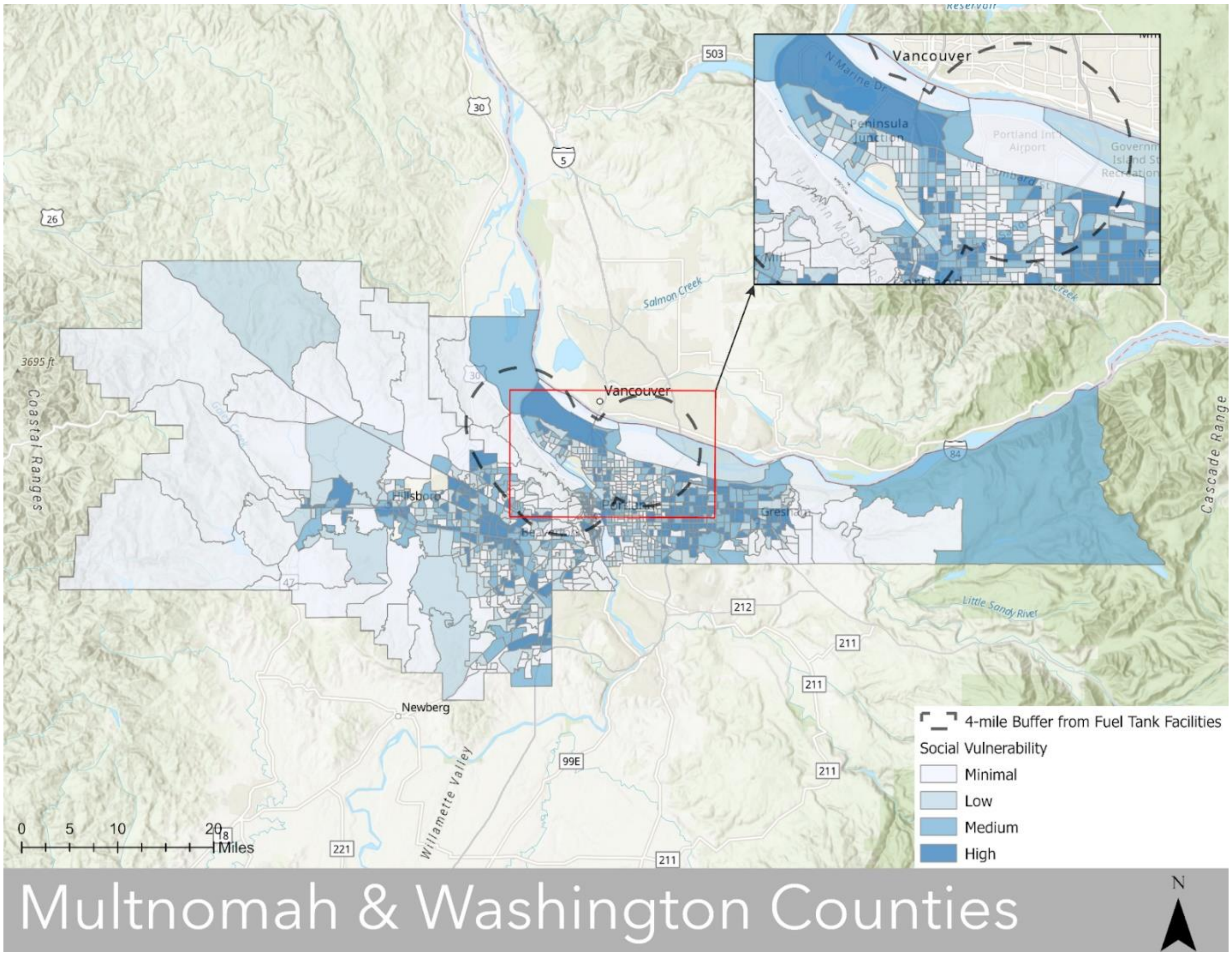


**Figure 1. Social Vulnerability (Census Block Group scale) of Multnomah and Washington Counties**

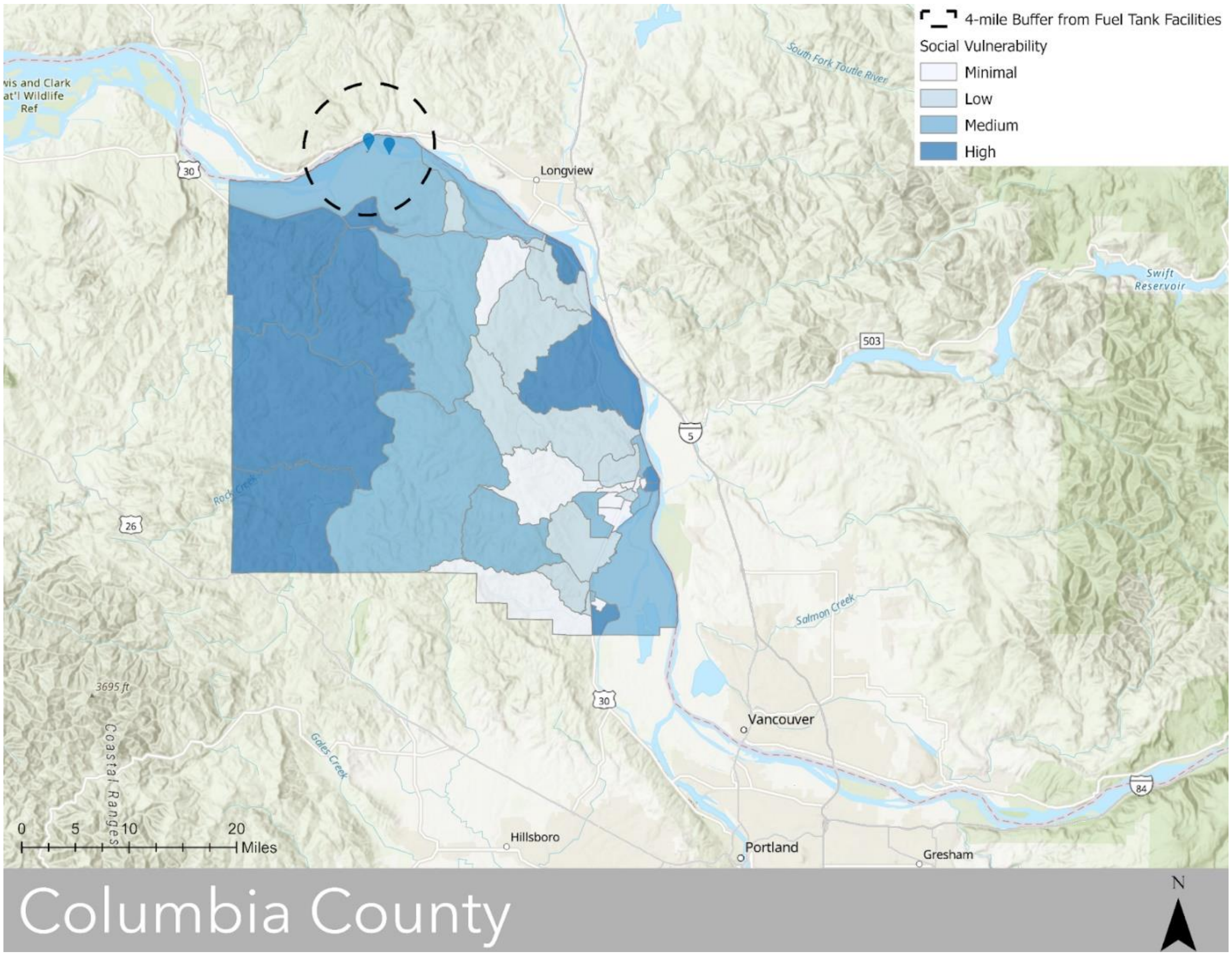


**Figure 2. Social Vulnerability (Census Block Group scale) of Columbia County**

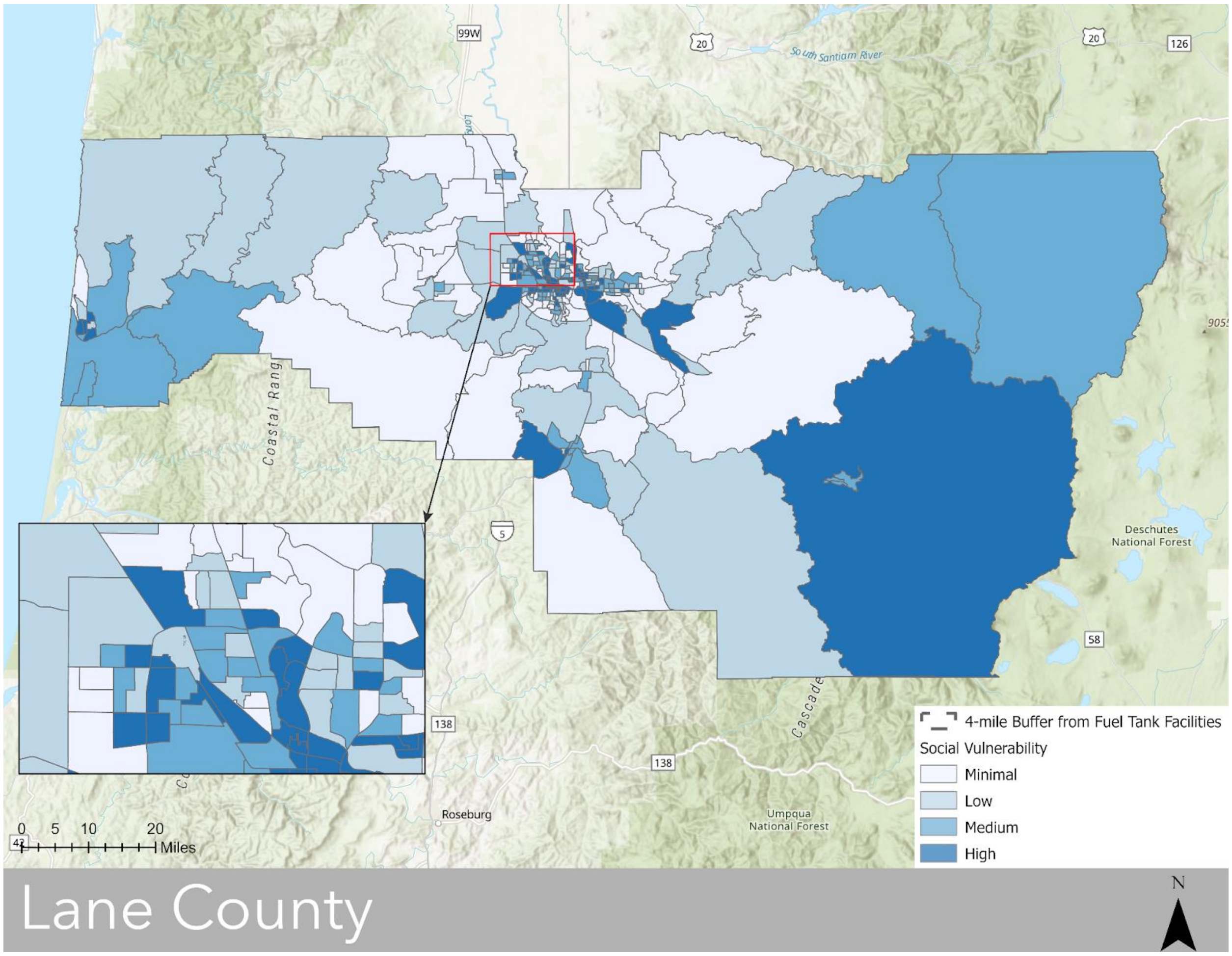


**Figure 3. Social Vulnerability (Census Block Group scale) of Lane County**

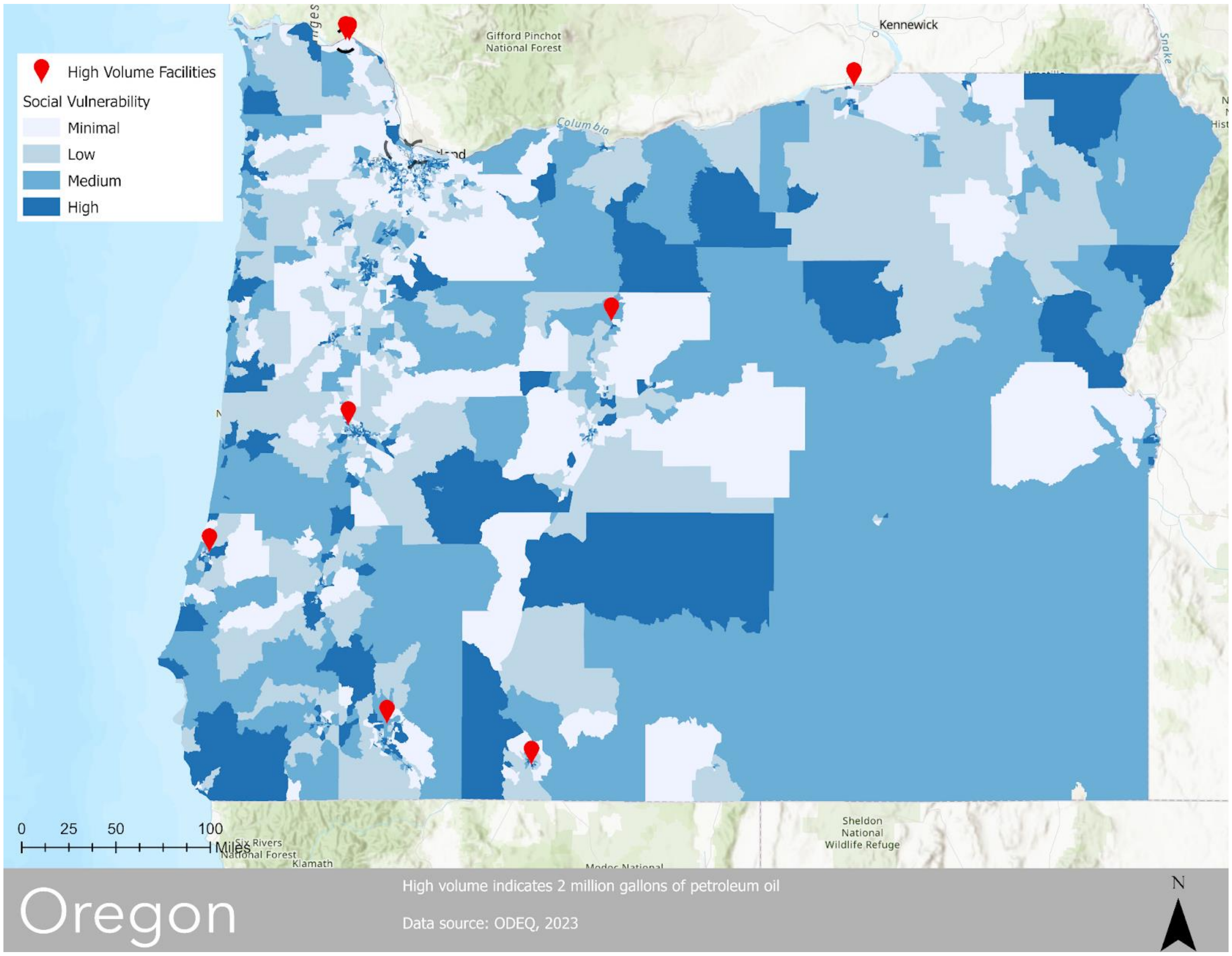


**Figure 4. Social Vulnerability (Census Block Group scale) of Oregon**