Service Area of Tsunami Shelter: A Case Study of Seaside City, Oregon

Chenqiang Liu

1. Introduction

From the beginning of twenty-first century, devastating tsunami events, caused by earthquake, volcanic activity, and landslides (NOAA, 2018), happen frequently and burden to individuals and society. The institution of ITIC (International Tsunami Information Center) documents almost of all tsunami events. Here this study just extracts and summarizes several devastating tsunami events from 2000 which is shown as Table 1.

Table 1: *Tsunami events summation*

Year	Location	Mw
Nov. 2000	New Ireland, Papua New Guinea	8.0
Jun. 2001	Peru	8.4
Sep. 2002	Papua New Guinea	7.3
Sep. 2003	Hokkaido, Japan	8.3
Dec. 2004	Northern Sumatra, Indonesia	9.0
Mar. 2005	Northern Sumatra, Indonesia	8.5
Nov. 2006	Kuril Islands	8.3
Sep. 2007	Southern Sumatra, Indonesia	8.4
Sep. 2009	Samoa Islands	8.0
Feb. 2010	Off Central Chile	8.8
Mar. 2011	Honshu, Japan	9.0
Apr. 2012	Northen Sumatra, Indonesia	8.6
Feb. 2013	Solomon Islands	8.0
Apr. 2014	Solomon Islands	7.6
Sep. 2015	Off Illapel, Chile	8.3
Mar. 2016	Southwest of Sumatra, Indonesia	7.8
Jun. 2017	Karrat Fjord, Greenland	(Landslide)
Sep. 2018	Palu, Indonesia	7.9

The Cascadia Subduction Zone (CSZ) is a convergent plate boundary that stretches from northern Vancouver Island in Canada to Northern California in the United States (Wikipedia). Existing researches indicate that the likelihood of an magnitude 9.0 earthquake occurring in the next 50 years at CSZ is 7-12% which poses one of the greatest natural threats on the Northwest United States (Goldfinger et al., 2012; Schulz, 2015a,b). This disaster will trigger a near-filed tsunami with waves of ten meters or more with large probability, which is likely to come onshore within 20-40 minutes (Wang et al., 2016; Mostafizi et al., 2019; Chen et al., 2022). CSZ tsunami causes severely damage of infrastructures and wealth and life of humans. Tsunami inundation zones in Oregon place approximately 22,201 residents and an average of 53,713 day-use visitors at-risk (Chen et al., 2022).

Even though the advanced technologies, such as intelligent sensors, wireless communication, and cloud computing etc., benefit human daily life, we still appear weakness and helplessness in front of natural disasters. We can't predict and prevent the CSZ earthquake and tsunami, but we can learn about this events, study the evacuation behaviors, assess the evacuation scenarios, and educate our community how to evacuation.Researchers and practitioners make tremendous efforts to predict and deal with natural hazards. This project aims to analysis the tsunami hazard zone and study on the service area of tsunami shelter.

2. Literature Review

Prior research relies primarily on two methods of tsunami evacuation modeling: GIS based method and agent-based method. Agent-based modeling refers to a model in which individual persons (agents), each with their own attributes, interact via a pre-defined set of rules such that emergent human behavior on a large scale can be observed (Wang et al., 2016; Mostafizi et al., 2019; Chen et al., 2022).

GIS method relies on GIS tools to perform Least Cost Distance (LCD) analyses of evacuations (Priest et al., 2016; Wood and Schmidtlein, 2013). According to Tang and Wannemacher (2005); Graehl and Dengler (2008); Dewi et al. (2012); Sambuaga and Lee (2021); Bonilauri et al. (2021), these models take characteristics of the evacuation landscape, such as elevation, slope, land use and coastal line distance, into account to analysis the hazard zone of tsunami, shortest routes for evacuation, and the location of shelters.

Generally, two types of evacuation can be considered: horizontal evacuation, where exposed populations are moved out of the danger zone, and vertical evacuation, where population seek safety by gaining a high point within the danger zone. which may include specially designed and constructed towers (Bonilauri et al., 2021)

For horizontal evacuation, Wang et al. (2016) proposed a multimodal evacuation simulation for a near-field tsunami (Seaside city, Oregon) through an agent-based modeling (ABM) framework in NetLogo. Two objectives of this study are: i) investigating the relationship between milling time and mortality rate, and ii) exploring the choice of different transportation modes (i.e., walking and automobile).

For vertical evacuation, Mostafizi et al. (2019) presented an ABM frame to evaluate vertical evacuation behavior and vertical shelter location impact. They found the location of vertical shelter significantly impacts the total mortality rates. With increasing population choosing vertical shelter, the total mortality rate reduce notably. in Chen et al. (2022)'s research, considering the "levee effect", they coupled FN-curves with ABM to assess the level of risk for different recurrence intervals of CSZ tsunamis, and determined the best vertical evacuation structure locations.

Since the class content, this project focuses on horizontal evacuation using GIS method.

3. Methodology

3.1. Study area

The study area is Cascadia Subduction Zone (CSZ) Seaside city, Oregon (shown as Figure 1).The city of Seaside is a small coastal community with 3.9 square miles and 7,084 residents in Oregon Seaside (2022). Among the 26 cities and 7 counties in tsunami inundation zones in Oregon, Seaside city has the most developed land, residents, employees, population-dependent facilities,public venues, overnight facilities, and total parcel value (Chen et al., 2022)

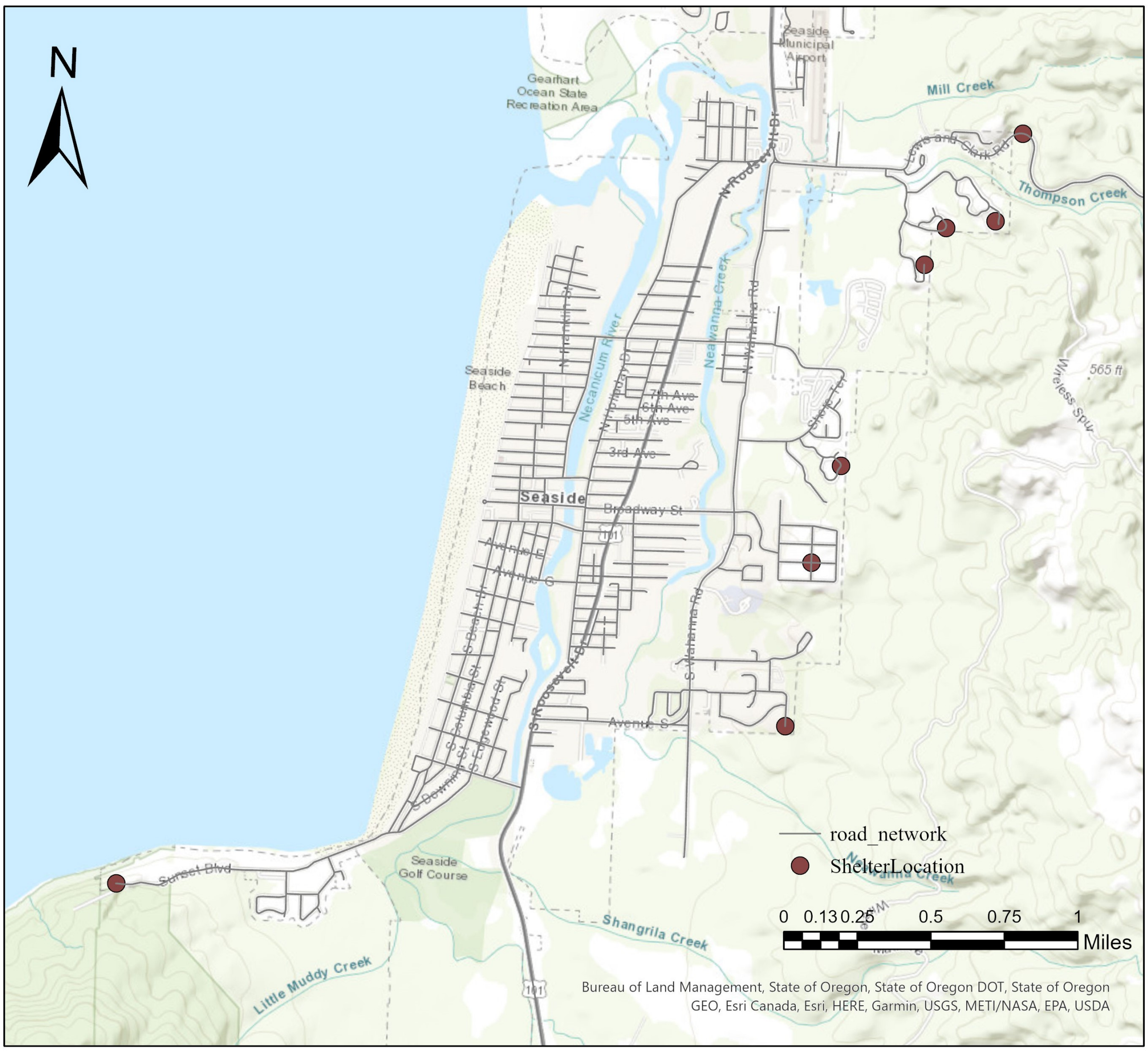

Figure 1: *Study area Seaside city, Oregon*

3.2. Data

The dataset comes from three sources:

- Road network data: derives from Oregon Spatial Data Library (https://spatialdata.oregonexplorer.info/geoportal/);

- Elevation data: comes from National Oceanic and Atmospheric Administration (NOAA, https://coast.noaa.gov/dataviewer/#/lidar/search/);

- Shelter location data: extracts from a GitHub in which contains shelter location and population distribution (https://github.com/armostafizi/Evacuation Model). It was collected by our group project in many years ago

3.3. Spatial analysis

Many factors involve in the analysis of tsunami impact areas. This project conducts tsunami hazard zone analysis based on the elevation and slop. We analyze the hazard zone based on each factor separately. Then, the tsunami vulnerability map is generated by combining each result using weight sum tool which can be combine multiply raster layers together.

A common sense is that where is lower elevation, there is higher risk of inundation. Therefore, elevation is an essential factor for tsunami hazard zone analysis. In addition, the slope with lower degree has higher risk to be inundated. According to Sambah and Miura (2014), the vulnerability is classed five levels - high risk, slightly high risk, medium risk, slightly low risk and low risk which is shown in Table 2

Table 2: *Vulnerability class based on slope and elevation*

Elevation (ft)	**Slope (%)**	**Vulnerability Class**
< 5	< 2	High
5 - 10	2 - 6	Slightly high
10 - 15	6 - 13	Medium
15 - 20	13 - 20	Slightly low
> 20	> 20	Low

The weighted of tsunami vulnerability map is carried out based on elevation and slope using *Weighted Sum* tool. The weight is also derives from Sambah and Miura (2014) (shown as Table 3). Since this project doesn't analyze the impacts of coastline distance and land cover, it is necessary to adjust the weights. Proportion method is used for the adjusted weights.

Table 3: *Weights for summation*

Parameters	**Weights (%)**	**Weights in project (%)**
Elevation	45.96	**64.29**
Slope	25.53	**35.71**
Coastline Distance	16.71	-
Land Cover	11.81	-

3.4. Walking speed

As for walking speed, the Manual Uniform of Traffic Control Devices (MUTCD, 2009) suggests speeds of 3.5 or 3 ft/s may be more appropriate. Also, the traffic design book *A policy on geometric design of highways and streets*, published by ASSHTO, suggests the range of walking speed is from 2.5 ft/s to 6.0 ft/s. Many researchers state that the speed should be higher than the suggestion speed. However, the physical characteristic of human can be ignored. We could not keep high level energy constantly, especially when the evacuation distance is so far. Therefore, we prefer to a higher speed but not exceed the suggests speed, that is 4.5 ft/s for walking on level. When it comes to slope impact, this speed will decline with increasing slope. Walking speed is calculated by EQ (1). Where V denotes to walking speed and s refers to the degree of slope.

$$V = 4.5 - 0.0367s \tag{1}$$

3.5. Service area

To analysis service area of shelters, we need to create a network database first using *Create Network Database* tool and the configure the *Cost, Restrictions, and Travel Modes* in the *Travel Attributes* page.

After warning, tsunami wave is likely to come onshore within 20-40 minutes (Wang et al., 2016; Mostafizi et al., 2019; Chen et al., 2022). Therefore, this study analyze the service area within 30 minutes using *Network Analysis* in *Analysis* tab.

4. Result

4.1. Spatial analysis

The tsunami hazard zone analysis was conducted by elevation based method and slope based method. Then we considered the two results to make the vulnerability map using *Weighted Sum* method. Figure 2 shows the tsunami hazard zones ranked by five classes. The lager number the higher risk. Figure 3 and Figure 4 are the results of slope based method and final vulnerability map respectively.

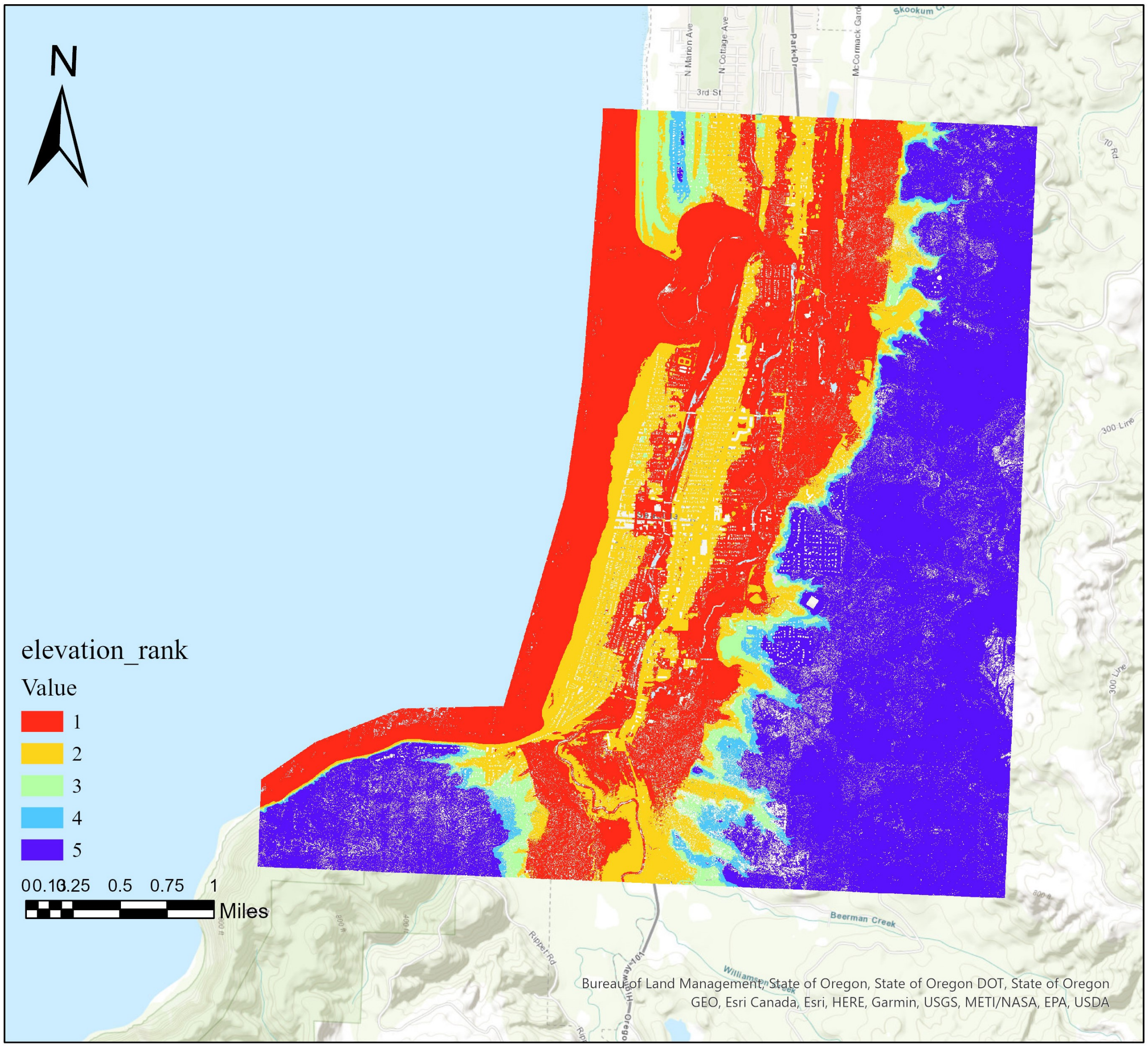

Figure 2: *Tsunami hazard zone based on elevation*

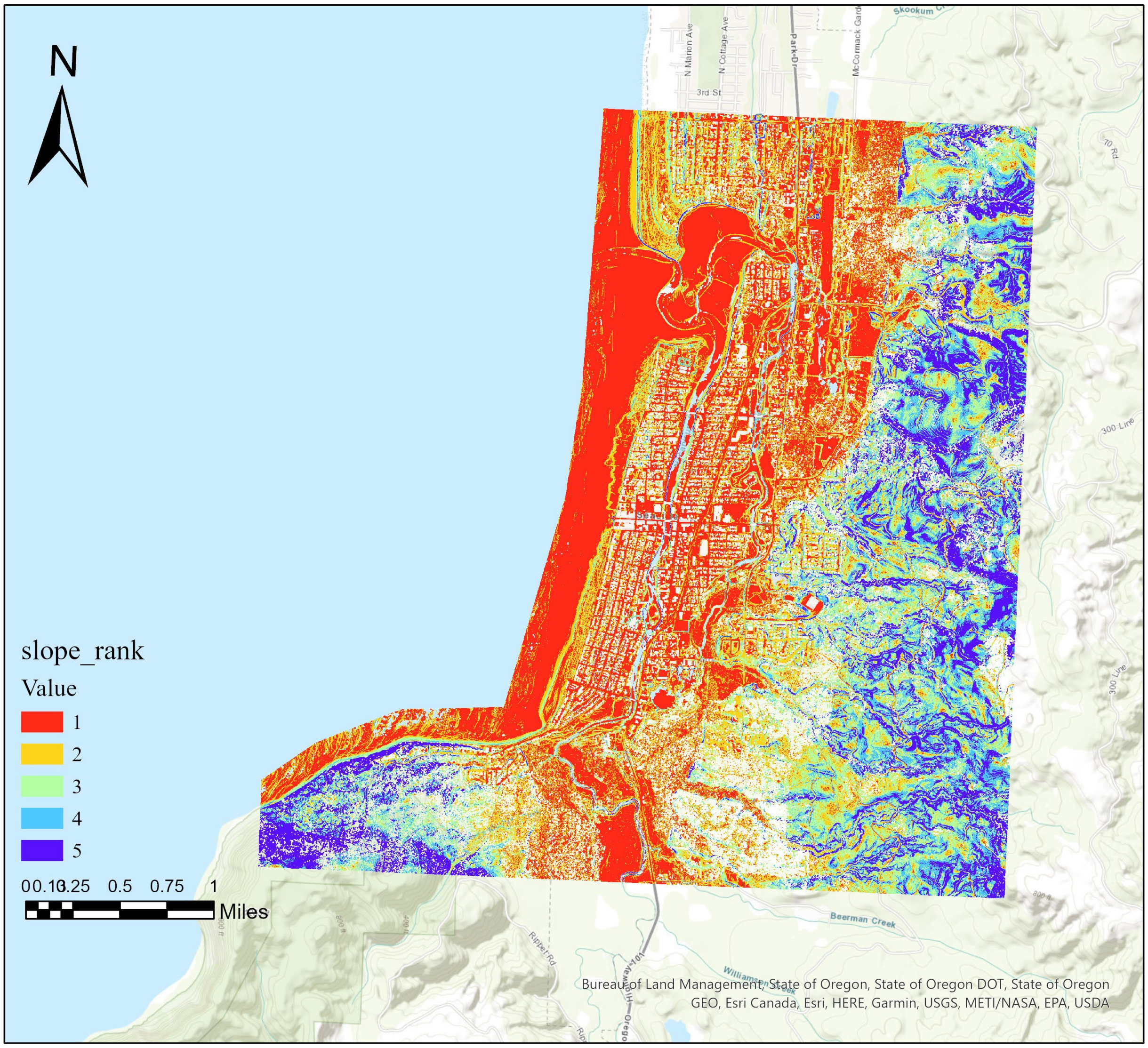

Figure 3: *Tsunami hazard zone based on slope*

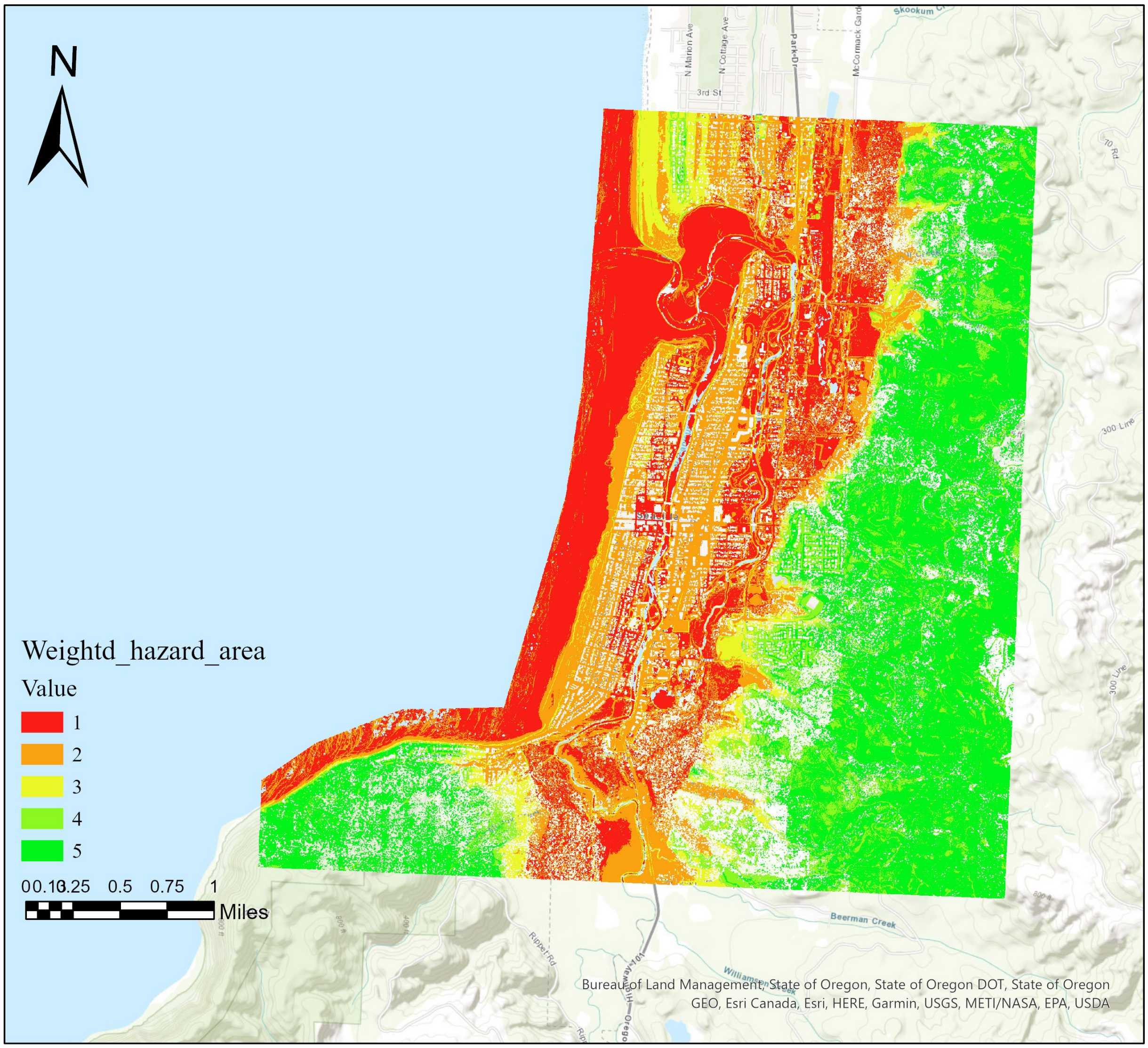

Figure 4: *Vulnerability class map*

4.2. Service area

We create a walking mode considering the impact of slope on walking speed. Then the shelters service areas were analyzed. As shown in Figure 5, The service areas can cover most of sites of residents. However, there still some residential places and partial beach are not covered. That mean a proportion of residents and tourists couldn't arrive at shelters before tsunami wave arrives.

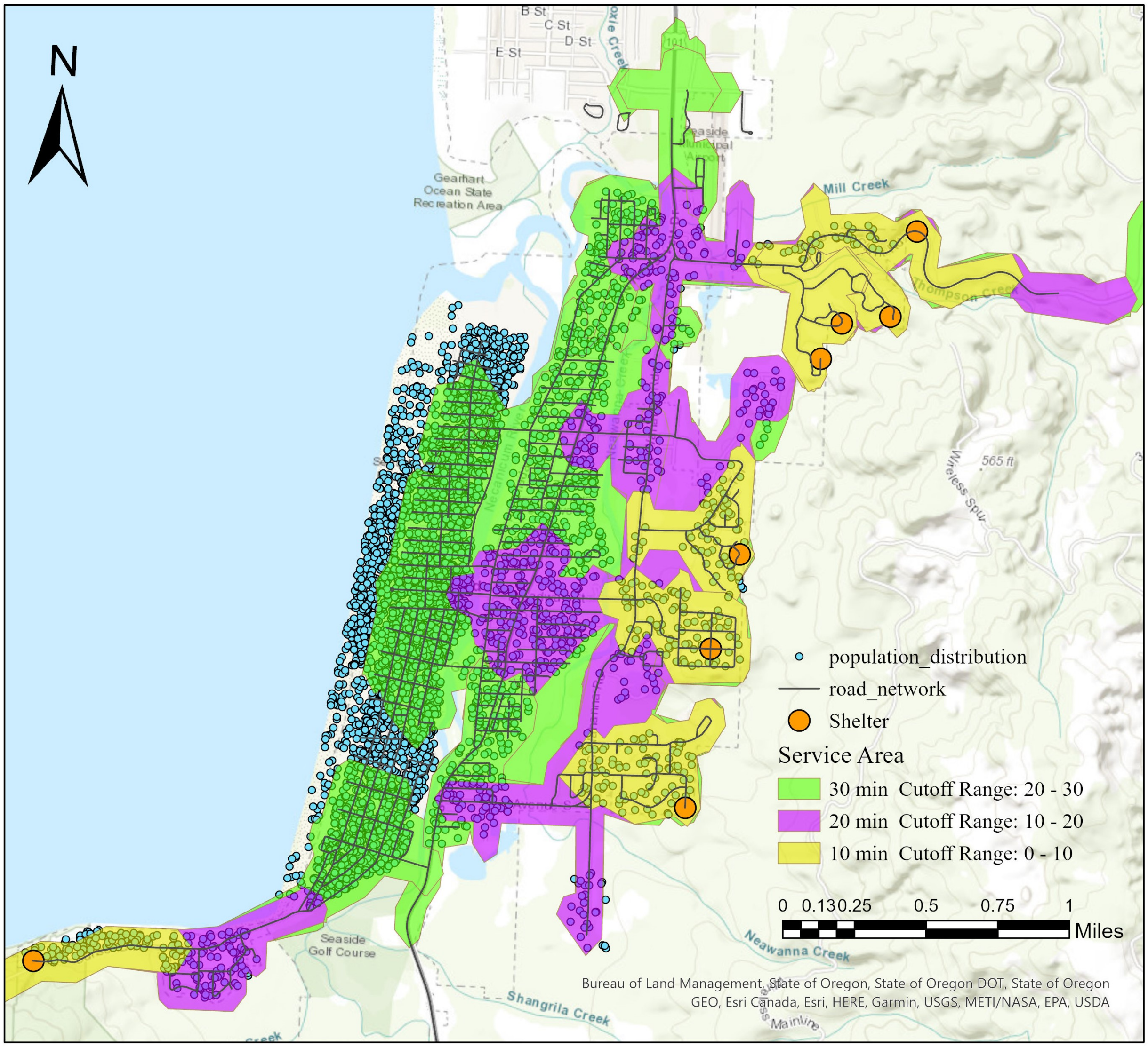

Figure 5: *Shelters service areas within 30 minutes*

5. Conclusion

This project implemented tsunami hazard zone analysis and shelters' service area analysis in ArcGIS Pro. Regarding the spatial analysis, we used elevation based method and slope based method. The final vulnerability map was generated by weighted the two results. For the service area of shelters, this research took slope impact on walking speed into account. Most of areas of Seaside city are in the service areas. However, some population still couldn't reach the shelters before tsunami waves arrive.

According to the previous research, Constructing vertical shelter is an effective alternative option. We highly recommend to:

- build vertical shelter in the 30 minutes service area, because those people take too much time to reach the shelters. We could not guarantee the tsunami wave arrive the shore always less than 30 minutes.

- build vertical shelter at the rivers' west area, because part of tourists and residents are not in the service area. Also, the density of population on west of the river is greater than east of the river.

For the future work, Taking coastline distance and land cover into account to analyze tsunami hazard zone are good points. Shelter capacity is another aspect worth to exploration. Most urgent (to my best knowledge) effort is to education local residents and tourist how to evacuate, and to build infrastructures guide them and make it convenient to evacuate a safe place.

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