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Hypothetical Tsunami Scenarios and Evacuation Intention: A Case Study of Orange County, California

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Abstract

Historically, California has had 14 tsunamis since 1812 where the heights of the waves were higher than three feet. One of California's major tsunamis followed the 1964 Alaskan earthquake and caused 12 deaths, with damages totaling to at least 17 million dollars. According to Jose Borrero and Costas Synolakis in their report, "Tsunami Inundation Mapping, Field Survey Report and Final Recommendations for Orange County", the worst case Tsunami scenario in Orange County, California, is a wave of approximately 10 meters or 32.81 feet (Tsunami Annex, 2009). Having evidence of historical tsunami events, even if not major ones, in addition to the probabilities of tsunami occurrences in the future requires the attention of both responsible administrative officials and the foundation of sound research directed toward planning for such events. The goal of this study is to measure how the surveyed population would respond in different, hypothetical tsunami scenarios should Orange County Officials advise the population to evacuate. The methodology consists of a survey of 235 people who live along the coastal area of Orange County, California. Method of Splitting Tsunami (MOST) model maps and GIS were used to delineate the evacuation and shadow evacuation zones in order to locate the spatial distribution of the population within these two zones. The results of this research indicated that the evacuation participation rate increases as the heights of the tsunami waves increase. The average socioeconomic characteristics of the sampled population vary from the sampled population when compared with the 2010 US Census data. This research may be useful for emergency managers, policy and decision makers.

Keywords: Evacuation; GIS; Tsunami; Socioeconomic; Demographic

Background

Tsunami is one of the natural disasters that is characterized by its sudden occurrence and have the potential to result in devastating consequences. Such disaster requires communities to be prepared by identifying the possible affected areas of tsunami event. The variations in socioeconomic and demographic characteristics of a society in addition to the variety of physical settings that can affect the character of a disaster necessitate measuring the response of the affected population using various tsunami scenarios for evacuation planning. Research shows that behavioral responses of evacuees during an evacuation are generally affected by a number of socioeconomic factors such as age, race/ethnicity, education, family size, and social/physical cues [1]. Therefore, variation in the demographic and socioeconomic characteristics from one coastal population to another will result in different evacuation responses of the evacuees, affecting in turn the evacuation process. There has been considerable evacuation behavioral research developed side-by-side with evacuation transportation modeling to understand the evacuation process and to plan for it according Lewis, ORNL, PBS&J; Franzese and Han; Urbina; Lindell and Prater; Yazici and Ozbay, Trainor et al. [1-8].

Hazard map represents critical part of any evacuation plan since it examines the population and area at risk based on specific conditions of the hazard. The hazard analysis based on the hazard map aims to highlight the possible affected area of a specific hazard event, such as a hurricane [9]. Identifying the spatial extent of the potential risk area is not the only objective of the hazard analysis; it also helps in directing attention toward other hazards associated with the specific hazard event itself. In case of a hurricane event for instance, a hazard analysis helps to identify the areas at risk of damage that results from a storm surge, hurricane-force winds, tornadoes, or fresh water flooding. This could be done through utilizing the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) model, considered to be the basis for the hazard analysis component of the hurricane evacuation plan and is typically used to identify different evacuation zones based on various hurricane conditions [9,10]. There are a number of studies that have used hazard analysis as part of evacuation planning. A hazard analysis takes various forms to identify the area that would need to be evacuated. These forms might include a hazard profile of the area in which general information about each hazard is specified. Another form of the hazard analysis is the history of hazard activity in the region. Additionally, a geo-spatial analysis of a hazard, e.g., inundation areas, wind fields, dam location, etc., is considered to be effective within the overall hazard analysis.

One of the critical components of the evacuation plan is the behavioral analysis, which predicts the way a threatened population will respond to a disaster [9]. Variations in the demographic characteristics will be reflected in different behavioral responses in different disaster events. Usually the population evacuation behaviors vary from one place to another for the same hazard, i.e., a hurricane, and, from one specific hurricane to another in the same place [11,12]. This understanding indicates that there will be variations in behavioral evacuation responses to different disasters, e.g., hurricanes and tsunamis. There are several factors that need to be considered in the behavioral analysis: the evacuation participation rate, evacuation time, public shelter use, evacuation destination, and vehicle use [9,13]. Identifying and understanding the specific variable characteristics of each of these factors would enhance evacuation planning. Baker [11] stated that usually few people evacuate before evacuation orders

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are issued, and they evacuate as quickly as the situation requires. Furthermore, mobile home residents are more likely to evacuate when compared with built-site-home residents due to the perceived vulnerability of the hurricane risk, the strength of the house itself and the storm severity. The behavioral analysis component of the U.S. Army Corps of Engineers' hurricane evacuation study [14] measured the evacuation participation rate, the timing of response, the number of vehicles to be used for evacuation, and the percentage of population that would seek shelters. The study showed that not all of the population within evacuation zones would participate in the evacuation process. Estimates of evacuation participation rates produced from a behavioral analysis are used to establish assumptions for transportation and shelter analyses. Luathep et al. [15] conducted a flood evacuation behavior analysis in urban areas before, during, and after a flood event. They used a questionnaire survey to interview the affected population and then applied logistic regression to develop two flood evacuation models: the evacuation decision model and the evacuation mode choice model. The results showed that gender, number of adults, and levels of ability or disability of persons are the significant factors that affect decision-making. Ricchetti-Masterson and Horney [16] studied whether such factors as social control, social cohesion, and social capital could have modified the relationship between demographic groups and the failure to evacuate during Hurricane Irene. This was done through conducting a cross-sectional stratified two-stage cluster sample among residents of Beaufort County, NC. The results showed no significant association between demographic or social factors and evacuation in bivariate analysis. A behavioral analysis provides the analyst with significant findings relative to the behavioral characteristics of the targeted population in case of evacuation. The evacuation process can be modeled based on the output of the behavioral analysis, which gives an overview of the possible evacuation obstacles before the occurrence of an actual evacuation.

Lammel et al. [17] conducted a tsunami evacuation study in the urban coastal areas for the city of Padang, in western Sumatra, Indonesia. Their research aimed to estimate the evacuation time, identify bottlenecks, and detect highly endangered areas of the study area. They used GIS to extract information from remotely sensed data, such as street data and building shape in order to classify them, based to their vulnerability. The researchers then combined the Digital Elevation Model (DEM) with their data to form a hazard analysis for the study area. From the hazard analysis, they produced tsunami inundation zone maps and found that the flow velocity of water from a tsunami is higher between buildings. They performed a vulnerability analysis using census data, specifically for population density, sex and age at the residential district level to measure the population distribution and the inhabitants' physical capability to evacuate. Further to their study, they conducted a behavioral analysis by using a questionnaire survey of 1000 household; they asked the residents about their daily activities in order to estimate their distribution as a function of time in case of a tsunami. The Multi-agent Traffic Simulation (MATSim) model was used to model the evacuation by each agent's decision separately within the below-10 m zone. The results were invalid due to limited inundation scenario characteristics and the distribution of population.

Taubenbock et al. [18] studied tsunami evacuation and the early warning system for the city of Padang by integrating data and methodologies from multiple disciplines such as engineering, remote sensing, and the social sciences. Their focus was on high geometric and thematic analysis to meet the needs of small-scale, heterogeneous and complex urban systems. Hazard analysis was conducted through combining the Tsunami model with the Australian National University and Geoscience Australia (ANUGA) tool to measure run-up on land. Four hazard zones were identified from different scenarios that measure the time between the warning of an earthquake and the arrival of a tsunami wave front. In their vulnerability analysis, Taubenbock et al. [18] assessed the height of individual structures, measured building size, specified roof types, and determined built-up density by using a digital surface model in combination with two different house masks derived from remotely sensed data. Resulting data were then used with fieldwork experience to identify residential, mixed, commercial and industrial usages on a basic level. Additionally, the fieldwork experience was used to localize the critical infrastructures such as hospitals and schools. The integration of hazard maps with the 3-D city model and time-dependent population distribution led to produce a probabilistic and quantitative assessment of the affected buildings and people depending on different scenarios. In addition, they calculated the average number of people per square meter using a sample of 500 geocoded buildings, distributed around Padang. Further, they conducted a behavioral analysis by using the results of a questionnaire survey of a sample population of 1000 inhabitants to provide them with the necessary socioeconomic data that described the daily activities and mobility data of their research population. A regression model was applied to identify the socioeconomic variables that would most likely affect evacuation intentions. The researchers applied a transportation analysis of tsunami evacuation by using the multi-agent traffic simulation model (MATSim) to estimate bottleneck occurrence and evacuation time.

Dall'Osso and Dominey-Howes [19] conducted a survey analysis to evaluate the importance of tsunami evacuation maps for Sydney, Australia. They produced these maps using the Papathoma Tsunami Vulnerability Assessment (PTVA) model, which is a GIS-based model, developed using information about tsunami impact and results from post-tsunami surveys and building damage assessments. The attribute of the model allows for assessing building vulnerability. The outputs of the model were used to classify the study area into tsunami evacuation maps that consist of safe evacuation areas and safe evacuation buildings for the purpose of vertical evacuation. These maps then were introduced to the public of the study area (Sample size 894) along with a short questionnaire. The results show that these maps represent a significant resource for tsunami evacuation and may be used for planning and emergency response purposes.

Orange County as Study Area

Orange County, California serves as the study area for this research. It was chosen due to its location in the southern part of California where most of the area's active seismic faults exist. Barberopoulou et al. [20] stated that the Catalina fault, west of Santa Catalina Island, in addition to the Lasuen Knoll, that lies submerged to the southeast of San Pedro Bay, may produce future tsunamis affecting the coastal areas of Orange County and northern coastal areas of San Diego County. Contributing to tsunami risk factors in this area are the topographical characteristics of Orange County, specifically its low elevated areas along the coast. The flat coastline of Orange County can expose it to critical damage and flooding from at a minimum a 4 meter tsunami [21]. Also, Lin et al. [22] have estimated that almost 750,000 people of Long Beach and Orange County will need to be evacuated from the coastal areas if a large tsunami hits California. There are several local and distant tsunami sources such as Chile, Alaska, Japan, and the Cascadian sub-duction zone; the Newport-Inglewood Fault might as well affect the coastal areas of Orange County [23]. This county, with a total population of 3,010,232, represents the third largest populated county (12.4%) in California according to the 2010 U.S. Census.

Furthermore, the population of the Orange County is considered to be diverse demographically: 74.5% of its population is white, 2% black or African American, 1.1% Asian, and 34.1% is Hispanic or Latino [24]. This demographic diversity represents a somewhat ideal situation for studying the role of social vulnerability in tsunami evacuation. The county is divided into seven sub-divisions: North Coast, Central Coast, South Coast, Mission Viejo, Silverado, Irvine-Lake Forest, and Anaheim-Santa Ana-Garden Grove. All of the three coastal sub-divisions of Orange County are at risk of tsunami inundation from both local and distant tsunami sources. For Orange County specifically, four-to-five-foot tidal surges hit the Huntington Beach area from the 1964 Alaskan earthquake causing moderate damage. The entire coastline of Orange County is at risk of tsunami run-ups since large destructive waves of unknown source have been reported to have hit the area from Malibu to Laguna Beach. During that event, a run-up of 260 meters occurred inland of Newport Beach, with waves three meters above mean high tide level [25,26]. Dr. Jose Borrero, University of Southern California, validated the probabilistic assessment of predicting wave highest done by Gracia and Houston where the highest tsunami wave could occur from a100-year tsunami event and reach a 9.2-foot maximum, while for a 500-year event, the maximum wave height may reach the maximum of 16 feet.

Evacuation and Shadow Evacuation Zones Preparation

One of the major challenges of tsunami hazard analysis research in addition to both the limited accuracy of Digital Elevation Models (DEM) and the bathymetric data used to model tsunami inundation is the reality that tsunami events are rare. These challenges have prompted studies that have employed the use of simulation models in which different data inputs and modeling approaches, such as [17,18-31], were used to study various tsunami inundation scenarios. While this research doesn't focus on producing a new tsunami modeling approach, it mainly utilizes the product of an existing tsunami model, one created for the purpose of simulating tsunami inundation from different tsunami events: the Method of Splitting Tsunami (MOST) Model.

The MOST (Method of Splitting Tsunami) model is a collection of numerical simulation codes that are able to simulate three processes of tsunami development: earthquake generation, propagation, and inundation [32,33]. The MOST Model results (maps) produced by the cooperative work of the Tsunami Research Center of the University of Southern California and the California Emergency Management Agency used in this research to identify tsunami evacuation and shadow evacuation zones in Orange County, CA. For the purposes of this researcher, the inundation area specified on these maps serves as the basis for further delineating evacuation zone and shadow evacuation, areas based on the distance of the farthest inundation point, as determined by the MOST Model, to the coast of the Orange County region. Defining these zones provides the necessary context for identifying the number of households and vehicles per household in each.

The MOST model maps represent the extent of the tsunami inundation results from multiple scenarios. This means that the full extent of the MOST model result covers the maximum inundation area that a tsunami might cause. Therefore, the extent of the inundation area in the maps produced from the MOST model for Orange Country will be used as the evacuation zone. The MOST model maps are available in (PDF) format on the website of the Department of Conservation (http://www.conservation.ca.gov/). There are several steps in the conversion of the MOST model inundation area from (PDF) to a single shapfile in order to perform further analysis. First, a total of six (PDF) files, representing the extent of the tsunami inundation along the coastal area of Orange County, were downloaded. These (PDF) files were converted into (JPEG) format using Paint Software from Windows Accessories in order to be displayed in ArcMap. These six (JPEG) files were then added into ArcMap to digitize the inundation zone (evacuation zone). However, since these (JPEG) files do not have spatial reference, they were geo-referenced using Orange County shapefiles. The Mosaic tool was used to merge all six geo-referenced (JPEG) files into one in preparation for the digitizing process. The Orange County boundaries shapefile was used as a reference to select random control points over the entire county. The digitizing tool was used to digitize the inundation area, the pink area of the MOST model maps. The digitized inundation area represents the evacuation zone for Orange County from various local and distance tsunami sources. This digitized area, i.e., evacuation zone will be used later to identify various socioeconomic variables for further analysis in future research.

For the shadow evacuation zone, there is no existing data or product that represents the shadow evacuation zone in the event of a tsunami run-up in Orange County, California. Since the evacuation zone covers almost the entire Orange County coast, the shadow evacuation will cover the same area to a different extent. Defining how far the shadow evacuation zone extends inland was determined based on the distance of the farthest inundation point of the MOST model output (Evacuation Zone) to the coast: a distance of 7,254 m. The buffer tool was used to create a buffer of 7,254 m around the digitized inundation zone (Evacuation Zone); it (the buffer) was created to insure that the area of the shadow evacuation zone would equal double that of the evacuation zone (Figure 1). The use of the buffer tool around the evacuation zone also insured the greatest similarity possible between the shape of the shadow evacuation zone and that of the evacuation zone. The delineated evacuation and shadow evacuation zones will be used to locate the population at risk of different tsunami scenarios. Identifying the population at risk of various tsunami events in different tsunami zones will assists in measuring how the population in both of these zones may behave in case of tsunami evacuation order.

Objective of the Study

The main objectives of this study are:

- To identify the number of households for each block group within the evacuation and shadow evacuation zones.
- To measure the evacuation intentions of the sampled population in evacuation and shadow evacuation zones for 10-, 20-, 30-foot hypothetical tsunami scenarios.
- To define the demographic characteristics of the sampled population.

Methodology

Number of households and number of vehicles per households in evacuation and shadow evacuation zones

Identifying the evacuation and shadow evacuation zones is a necessary component of the hazard analysis for calculating a tsunami hazard in Orange County. As mentioned above, the original set up of the hazard analysis was done using the MOST model through the collaborative efforts of the Tsunami Research Center of the University

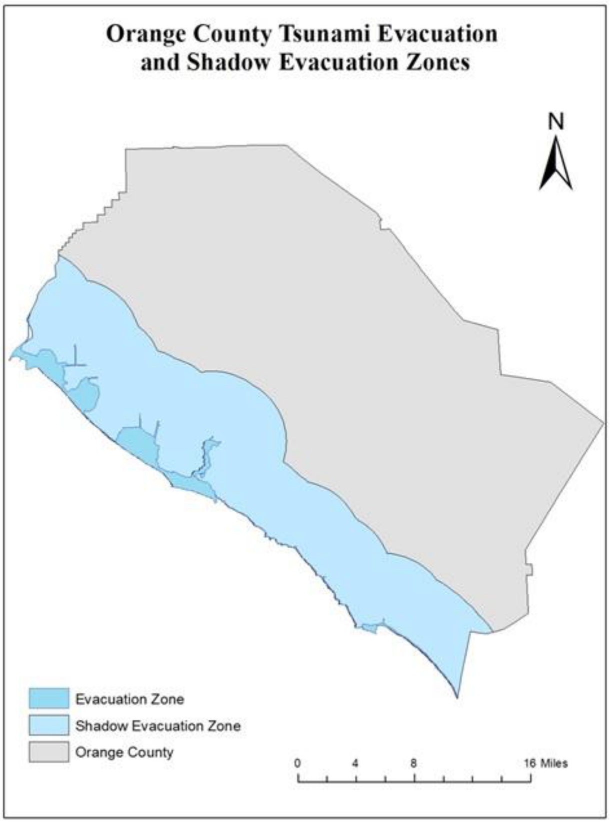

Figure 1: Tsunami evacuation and shadow evacuation zone for Orange County, CA.

of Southern California and the California Emergency Management Agency. Extending the results of the MOST model through further analysis by integrating the hazard analysis results with the number of households and number of vehicles per household will assist in specifying the vulnerable population and its distribution. Such specification will lead to creating a general overview of the evacuation needs in the county; locating the vulnerable population is necessary in order to conduct the behavioral and transportation analyses as part of the evacuation planning – a process to be done through selecting the sample population, evaluating responses in different tsunami scenarios, and then generalizing their responses to the whole population at risk of tsunami inundation.

The 2010 US Census number-of-household data, at the block group level, was used to define the number of households in each block group. This Census data consists of three main attributes: total number of households, total occupied households, and total number of vacant households for each block group. The household census data table was joined to the Orange County, CA block group shapefile through GEOID field to define the spatial distribution of the households within the county. Joining the US census household-data table to the Orange County block group shapefile led to the ability to identify spatially the number of household for both the evacuation and shadow evacuation zones, by using the total number of household field from the joined household block group shapefile. This was done by using the joined shapefile to select those polygons with centroids located in either the evacuation or shadow evacuation zone. Horner and Murray [34] estimated the size of the population within the service coverage for bus transit using centroid of census block, block group, census tract and areal interpolation. Using these approaches revealed there is a tradeoff when deciding on the method to be used for analysis. The areal interpolation method is not stable across aggregation levels, and the polygon centroid method is sensitive to the scale changes in terms of the census geography used to represent the demand. However, since the scale of analysis in this research is stable (block group level) among various evacuation analyses, the polygon centroid method was selected to identify the block group polygons regardless of their zone of location, whether evacuation or shadow evacuation.

Maps for number of household per block group were produced from the combined data to locate the concentrations of the number of households within each zone (Figures 2 and 3). The maps show that the block group polygons in the middle area of Orange County consist of the highest number of households in both the evacuation and shadow evacuation zones. However, when comparing the number of households in the evacuation zone to the number of households in the shadow evacuation zone, as mentioned in Table 1, it is clear that the shadow evacuation zone has a larger quantity of total number of households in each block group due to its spatial extent.

Survey

There are several factors that should be included in a behavioral analysis; these include: the evacuation participation rate, evacuation times, public shelter use rates, evacuation destinations, and vehicle use [9,13]. Surveys are considered the main data source for a behavioral analysis; they measure the population's responses based on a hypothetical hazard event or their experience with a hazard. A telephone survey was created to measure the behavioral responses

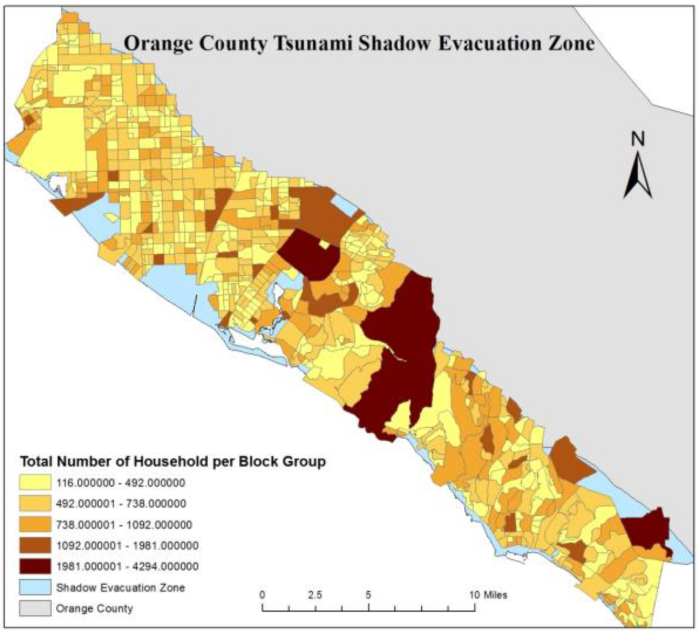

Figure 2: The concentration of the number of households within the evacuation zone.

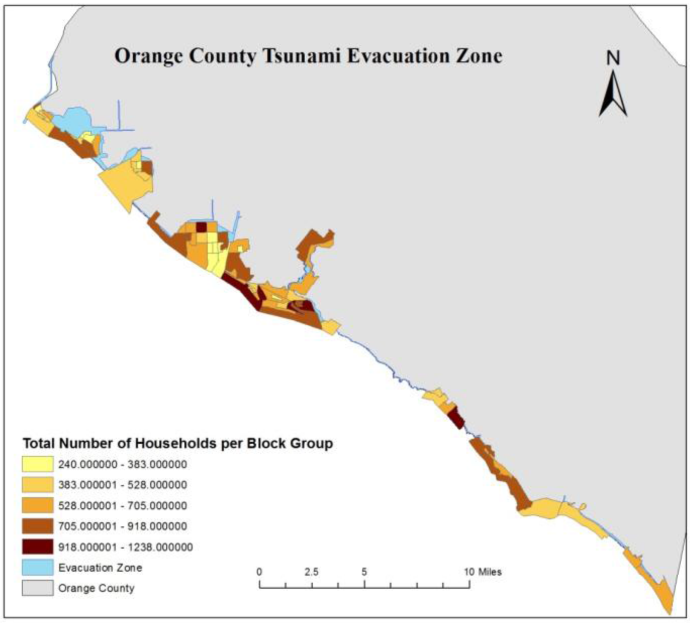

Figure 3: The concentration of the number of households within the shadow evacuation zone.

of the Orange County population to different hypothetical tsunami scenarios as part of a larger project that aims to measure the evacuation clearance time from various tsunami events. The survey was divided into three sections: 1. Information Sources and Resident Awareness in Orange County, California, which focuses on the subject's knowledge of the tsunami phenomenon in his/her geographic area and their preparedness, 2. Evacuation scenarios, which focus on how the population will behave in 10-, 20-, and 30-foot tsunami inundation scenarios, and, 3. Demographic information, which focuses on specifying the demographic characteristics of the sampled population. However, for this study, the evacuation intention and the demographics of the sampled population will be discussed.

The selection of the survey questions was based on a combination of an existing hurricane and tsunami research that studied the behaviors of the population at risk of tsunami and hurricane [35,36]. The reason for combining the hurricane research with the tsunami survey design was based on the larger number of hurricane studies done to capture the behaviors of the evacuees, compared to the tsunami studies, which focused mainly on the intention of evacuation [17,18,37]. For the tsunami scenario section of the survey, specifically, the researcher is concerned with knowing if the sampled population would evacuate in case of an evacuation order by government officials of Orange County in the events of tsunamis of 10, 20, and 30 feet. According to Osborn

Zones	Number of Polygons	Total Number of Household Per Block Group	Total Number of Occupied Households	Total Number of Vacant Households
Evacuation Zone	71	42,490	36,192	6,298
Shadow Evacuation Zone	651	3,94,159	3,72,019	22,140

Table 1: Total number of household per block group for evacuation and shadow evacuation zones.

	Evacuation Zone% (n=185)			Shadow Evacuation Zone% (n=50)		
	10 ft	20 ft	30 ft	10 ft	20 ft	30 ft
Yes	72%	86%	90%	46%	52%	56%
No	20%	12%	7%	50%	44%	38%
Depends	5%	2%	2%	4%	4%	6%
Don't know	3%	1%	1%	0%	0%	0%

Table 2: Evacuation intention rate in both evacuation and shadow evacuation zones.

[38] and Tsunami Annex [26] the worst-case scenario for such an event in Orange County would be one involving a 32-foot inundation; therefore, the researcher chose to measure the resident behaviors based on 10-, 20-, and 30-foot scenarios. Survey questions in this regard are important to get a sense of the extent to which people are willing to participate in different tsunami evacuation events.

The survey also focuses on the demographic information of the sampled population, which will help in identifying personal characteristics of the sampled population who have responded by saying they would or would not evacuate in case of a tsunami event. It may, in addition lead to identifying specific trends in the evacuation decision. This information includes age, gender, race, marital status, education, income, number of people within the household, and type of household. The survey was conducted by the Kerr and Down research staff, to whom the researcher provided the GIS layers that represent both the evacuation and shadow evacuation zones for sampling purposes produced from data contained in the hazard analysis chapter. The population sample size was 235 with a 90% confidence level and a ±5.36 error rate. The selection of the sample size of 235 was due to the limited funding for this research, i.e., collecting more samples would require more financial resources. A total of 185 samples were collected within the evacuation zone and 50 samples were collected within the shadow evacuation zone. The reason for selecting the sample quantities of 185 in the evacuation zone and 50 in the shadow evacuation zone was based on the understanding that the majority of the sample should be in the evacuation zone and that a portion of the sample must include respondents from the shadow evacuation zone. A simple random sampling was used, taken from published landline telephone listings. The Kerr and Down research staff recorded the answers of the sampled population along with the (x,y) coordinates of every respondent. The final output of the telephone survey was received in an Excel sheet that included all the answers along with the coordinates of each respondent. Statistical analysis will be performed to measure the variations within each variable. Generally, the output of the survey will be used to identify the demographic variables that may contribute to the evacuation decision-making process. Identifying these variables will contribute to understanding the factors that affect the participation rate, which in turn controls the evacuation clearance time.

Results and Discussion

The results discuss the intention for evacuation and the demographics of the surveyed population in two different sections.

Intention for evacuation

The survey questionnaire focused on the respondents' behaviors regarding three different tsunami scenarios -- wave heights of 10, 20, 30 feet. Respondents were asked about their intention to evacuate in each of the three different scenarios. Table 2 indicates that more than half of the population would plan to evacuate for each of the three tsunami scenarios, and that the evacuation participation rate would increase as the tsunami wave increased, from 10 to 20, then 30 feet in both of the evacuation and shadow evacuation zone. Most of the population would evacuate their homes immediately if an official announcement were made that suggested an immediate evacuation for a tsunami affecting the Orange County coast regardless of the tsunami scenario. There is a small portion of the sampled population that is uncertain as to their evacuation intentions since they believe finalizing their decision would be based on the following variables: the proximity of the tsunami at the time they receive information of its approach, whether other people need their help, the availability of transportation, the traffic conditions, their experience and their health or medical conditions. All of these factors would affect the timeliness of the evacuation decision of the portion of the sampled population that determined, in all three scenarios, that their decision would be based on an official announcement of a tsunami threat along with a recommendation to evacuate. This indicates effectiveness of the government officials' evacuation announcement in Orange County, California.

Demographic characteristics

Orange County, CA represents the third largest populated county (12.4%) in California, according to the 2010 U.S. Census, with a total population of 3,010,232. The goal of including the demographic section in the survey questionnaire in this research is to provide an overview of the demographic characteristics of the sample population. Furthermore, these demographic variables will also be tested, in future research, against evacuation decisions that were made by the respondents for each of the tsunami scenarios (10-, 20-, and 30-foot) to identify the variable most contributing to the evacuation decision. However, in order to allow for an assessment of the survey sample used in this study, it was critical to provide a general overview of the demographic characteristics of the county to evaluate the demographic variations of the population within the entire county. The same demographic variables (age, race, gender, education, income, and presence of a disabled person) that were used in the survey questionnaire for this research were downloaded from the U.S. Census website for year 2010 at the block group level. These variables represent the general demographic characteristics for the population of Orange County.

Demographic information identifies characteristics of the surveyed population that are critical in designing an effective evacuation model. Age represents a descriptor that provides an overview of how a population may behave towards an evacuation order. The importance of age stems from the association between the age of the respondents and specific illness and mobility problems, e.g., the elderly. Also, the age of the respondents might be linked to previous experience of the same disaster, a factor that may affect their evacuation decision [39]. The age of more than half of the sampled population in this study ranged from 45 to 79, as stated in Table 3. This conflicts with the majority age group for the overall Orange County residence (38%) range between 18-44 years of age. Race and ethnic backgrounds also provide significant information about the sampled population and how they might react to a specific hazard [40,41]. While designing the survey questionnaire, the race variable was divided into six categories: White, Black or African American, Asian, Native Hawaiian and other Pacific Islander, American Indian and Alaskan Native, and Others. This division was based on the categories that were defined for "race" in the Census data. According to this data, most of the population of Orange County assigned themselves within the category "White" in terms of their racial makeup, and the same trend was noticeable for the survey respondents who chose "White" as their race. Most of the sampled population is classified as white and non-Hispanic and the majority of respondents are married in both zones. Gender and education level are other important demographic variables that can lend insight as to how a population may behave in the event of an evacuation order [12,42,43]. The majority of the sampled population is female in both of the evacuation and shadow evacuation zone. The female population is also in the majority when Orange County is viewed as a whole. Regarding educational level, according to the U.S. Census data, most of the residents of Orange County have "some" college. This can be compared with the information obtained from the survey, in which the research sample indicated that the majority of the respondents within the evacuation zone held a bachelor degree and that a majority of respondents within the designated shadow evacuation zone had "some" college.

Income has also proved a significant demographic factor in predicting behavior towards a hazard event; it is known that higher income groups, when compared to those of lower incomes, tend to evacuate areas under disaster warnings [44]. The income data from the U.S. Census data indicates that most of the population of Orange County has an annual income that ranges between $100,000 and $199,999. However, the majority of the survey respondents have their incomes ranging between $50,000 and $99,999 for the year 2013 in both evacuation and shadow evacuation zones. Identifying respondent's income might indicate the location of the household, i.e., it may be in a poorer neighborhood, or the number of vehicles per household may be limited; income can also indicate type of household structure inhabited by the respondents. In response to the questionnaire item relating to the presence of a disabled person within the household, most of the respondents who answered in the positive, characterized the nature of the disability as one that posed physical disability. The U. S. Census data indicated that the majority of the disable population in Orange County belongs to the category of having difficulty in performing job duties.

Providing an overview of the demographic characteristics of the overall population of Orange County led to identifying the similarities and differences between demographic characteristics of the survey respondents and those of the population at-large of Orange County. It is clear there are demographic consistencies as these variables are defined within the survey responses and then compared with those calculated for the overall Orange County population, e.g., gender and race. However, there are notable variations in others of the demographic variables, such as age, education, income and, presence of disability, indicated in the answers of the survey respondents and those of the overall population of Orange County. These variations might be related to the sample size that was used in this research, which was limited to 235 samples, due to the available financial resources used in data collection. Another reason that might have led to the inconsistency in the demographic variables between the survey results and overall-county demographic characteristics is related to the fact that the survey samples were collected within specific geographic areas (evacuation and shadow evacuation zones that were delineated). Limiting the sample to a specific geographic location might not capture the variations of demographic characteristics in the same degree of detail that was reported for the overall population of Orange County. Providing the general demographic characteristics of the overall population of Orange County allows for an assessment of the survey sample.

	Evacuation Zone% (n=185)	Shadow Evacuation Zone% (n=50)
18-44	16%	12%
45-64	30%	32%
65-79	34%	30%
80 or more	15%	16%
Didn't Answer	5%	10%

Table 3: Age of the sampled population in both evacuation and shadow evacuation zones.

Conclusion

This research adds to ongoing research efforts that seek a better understanding of the complex relationships between human beings and their environment. Specifically, the impact of socioeconomic factors in determining the evacuate intention from various tsunami scenarios in both the evacuation and shadow evacuation zones.

This research explored the tsunami risk area of Orange County, California by integrating the output of the MOST (Method of Splitting Tsunami) model with the population distribution using Geographic Information System (GIS). It contributed to the tsunami evacuation research in two ways. First, delineating the tsunami evacuation and shadow evacuation zones assists in specifying the spatial extent of the tsunami risk area. The work performed in this paper was the first to explore the spatial extent of the shadow evacuation for a tsunami scenario event in Orange County, California. The results of this study should be beneficial to public officials and researchers who are interested in defining the spatial extent of the population at risk of tsunami in this region. The inclusion of the shadow evacuation zone in the tsunami risk zone is a necessity since evacuees who live outside the evacuation zone may decide to evacuate during an evacuation order; such decisions will affect the evacuation clearance time. Second, identifying the number of households in each of the tsunami evacuation and shadow evacuation zones became possible using GIS. The results of this research indicates that the concentration of the households within evacuation zone vary where the majority of the households are concentrated in the middle part of the evacuation zone. The same trend was noticeable in the shadow evacuation zone where most of the households are located in the middle part of the shadow evacuation zone. Such information provides an overview of the spatial distribution of the population at risk of tsunami. The spatial extents of evacuation and shadow evacuation zones that were delineated in this research were used as a reference to collect data about evacuation decisions and related behavioral characteristics of evacuees using a telephone survey. Furthermore, the risk tsunami area for Orange County that was produced from the combination of the evacuation and shadow evacuation zones will be used in the future research to define the evacuee points as well in the transportation analysis for the purpose of evacuation modeling.

Further responses indicate that for each of the three tsunami scenarios (10-, 20-, and 30-foot waves), more than half of the population would plan to evacuate, and, evacuation participation rates would increase as the heights of the tsunami waves increase. Most of the respondents would evacuate their homes immediately if an official announcement were made that suggested an immediate evacuation for a tsunami affecting the Orange County coast, regardless of the tsunami scenario, and the majority of those respondents selected the house of a friend or relative as a shelter.

Regarding the demographic characteristics of the survey respondents, the age of more than half of the sampled population in this study ranged from 45 to 79. Racially, most are classified as white, non-hispanic. The majority of the respondents are married and female. While the majority of the respondents held a bachelor degree, on the whole, educational levels ranged from less-than-high school to a doctorate degree. Annual incomes of residents who made up the population sample ranged from $50,000 to $99,999 for the year 2013, and a small portion of the sampled population had a disabled person in the home, with the majority of these classified as having a physical disability. All of these socioeconomic characteristics can be tested against the evacuation decision to identify the significant variables that contribute to specific evacuation decisions in each tsunami scenario. Overall, the behavioral analysis provided the general picture of the sampled population evacuation intention in Orange County, California regarding various tsunami evacuation scenarios.

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