Tsunami Risk Analysis and Disaster Management by Using GIS: A Case Study in Southwest Turkey, Göcek Bay Area

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ABSTRACT

Sea disasters, especially tsunamis, can cause loss of lives and property damage when it comes to shores. Locating the spatial distribution of a catastrophic event like tsunami and knowing its impact has vital importance in response and recovery stages in case of emergency. Through hazard mitigation, lives and property can be saved and environmental damage can be reduced. In this study, for Göcek Bay, a tsunami simulation has been produced using NamiDANCE software. The simulation results are used as input to produce inundation maps to detect the buildings which are possibly prone to inundate in case of a tsunami. Based on the applied network modeling, the uses of obtained outputs in the preparation of emergency action plans are discussed.

Keywords: Tsunami, GIS, Network Analysis, Inundation Maps

1 INTRODUCTION

Tsunamis, which mean "Harbor Wave" in Japanese are large, long water waves caused by underwater earthquakes, submarine volcanic eruptions, or the impact of extraterrestrial bodies or landslides. Although wave height is relatively small in open seas, when the tsunami hits the coastline, it may rise to several meters and can cause loss of lives and property damage when it comes to shores (Yalciner et al. 2005).

Locating the spatial distribution of a catastrophic event like tsunami and knowing its impact has vital importance in response and recovery stages in case of emergency. To deal with this issue, not only basic activities but also technological solutions should be used. In this sense, information about human populations, infrastructure and other spatially distributed data can be managed by the use of geographic information technologies. For example, the ability to provide answers to vital questions, such as where the most affected areas are and how they can be reached, to save time in an emergency situation, can be addressed by means of GIS technology (Goodchild, 2006).

In hazard management, GI Science is used to guide and monitor land use, delineate transportation routes for potential evacuations, and re-delineate hazard zones based on new knowledge or changes in the natural or human use systems (Greene, 2002).

According to historical documents, related publications, tsunamis have been generated in Eastern Mediterranean sea in history. Therefore, the vulnerability of the area cannot be disregarded when the extent of the damage caused by tsunami is considered. Göcek has an important role and potential for marinas as a stop of the blue voyage along Mediterranean coast of Turkey. High income people also choose to keep their yachts in those marinas for shelter. These specialties of Göcek make this bay a very significant district in terms of tourism and economy.

The town has been ministered under Muğla municipality and located in the South-West coastal of Turkey (Figure 1). Its aerial extent is around 10km^2. Population of the Göcek town is 3625 according to 2007 census survey (URL 1). Moreover, most of the population accumulated in the coastal zone of the town. Therefore, a possible tsunami can cause severe affects that cannot be disregarded.

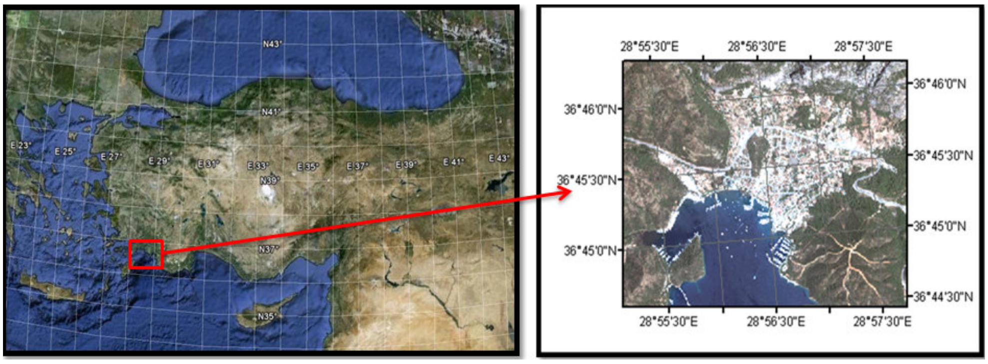


Figure 1: Study Area: Göcek Peninsula, Turkey

This project introduces damage maps prepared for Göcek by using NamiDANCE in line with GIS software to make a risk assessment based on evaluation of these maps. After assessing the hot spots for evacuation, geospatial analyses are conducted by means of disaster response and recovery.

2 GEODATA INTEGRATION

Different sources of data have been used for the study to form the disaster management database. Most of the data is gathered from Ocean Engineering Research Center (OERC) in Middle East Technical University (METU), which conducts projects about south-west coastal of Turkey, and some other data has been derived from the processing of the existing data like site investigations.

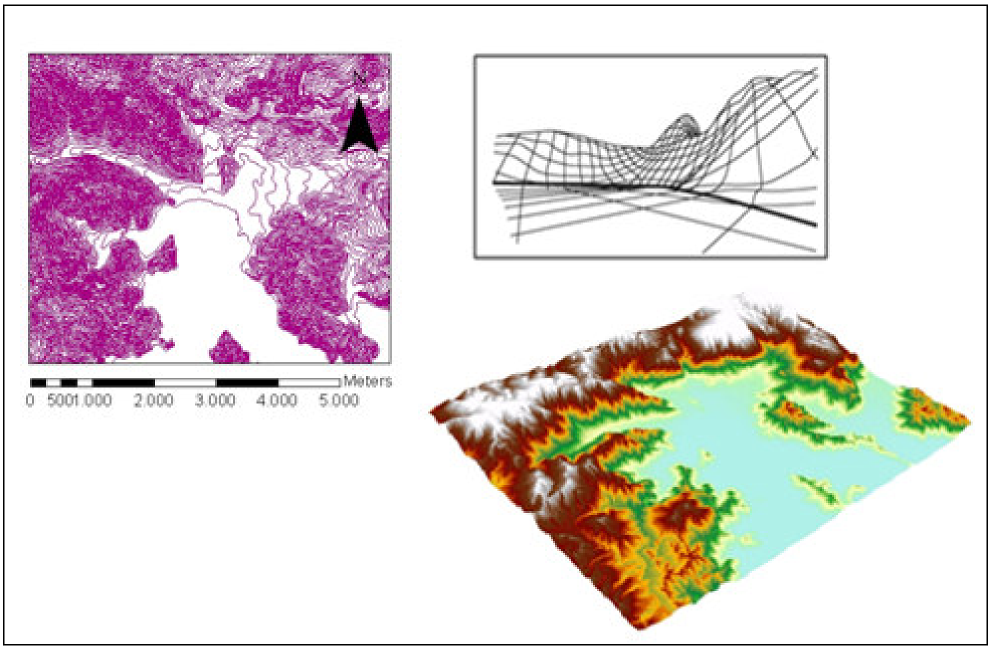


Figure 2: Triangular Irregular Network of the area generated from contour maps

The satellite image used in the study was acquired on 9th of August, 2009. Digital Elevation Map (DEM) was prepared from 1/25000 scaled topographic maps obtained from Turkish General Command of Mapping (Figure 2). The created DEM has been used to determine the elevations of roads and buildings. By using the information on topographic maps, satellite image is registered and building and road layers are digitized from the satellite image. To detect the inundated areas, a tsunami simulation has been performed by NamiDANCE software.

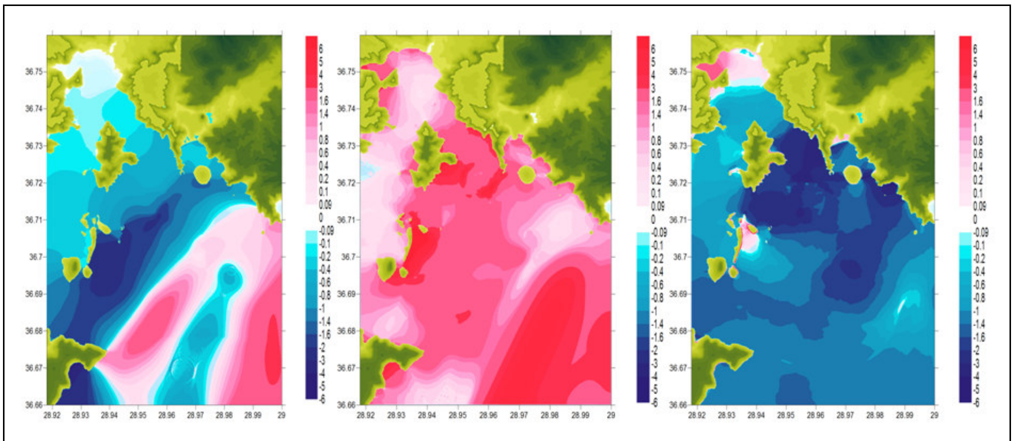
Attribute information about the created database are assigned by using former reports which were prepared for Göcek village or Muğla municipality sources taken from web resources. For example, population of people living in buildings is defined by proportioning the total population with the building area. Besides road specifications like width, type or lane information are assigned based on the experts' knowledge from region.

3. TSUNAMI SIMULATION WITH NAMIDANCE

In order to understand the possible effects of tsunamis in the region affecting Göcek Bay, the tsunami source parameters, that can create a tsunami possible to hit the Fethiye Peninsula, are computed using Eastern Mediterranean fault mechanisms, prepared in the EU funded TRANSFER project. The tsunami simulations are performed using NamiDANCE in one domain covering Göcek Bay for selected tsunami case. NamiDANCE is software developed by the corporation of METU OERC and Nizhny Novgorod State Technical University Department of Computer Engineering (URL 2). Tsunami numerical modeling by NAMI DANCE is based on the solution of nonlinear form of the long wave equations with respect to related initial and boundary conditions. There were several numerical solutions of long wave equations for tsunamis. Among those, the explicit numerical solution of Nonlinear Shallow Water (NSW) is preferable since it uses reasonable computer time and memory, and also provides the results in acceptable error limit (Shuto *et al*, 1990)

The bathymetry, generated in METU OERC within the scope of the TRANSFER Project, and tsunami source are given as input to the software, with the same grid size covering the study domain which is defined as 10 m in this study. The file formats for bathymetry and tsunami source files are .grd. The simulation duration is taken as 30 min of real-time computation with the time step of 0.1 sec. The software computes the propagation of the tsunami wave at every 0.1 sec and gives the outputs in every 60 sec. In order to be able to compare the maximum positive and maximum negative wave amplitudes near Göcek, artificial gauges are placed to specific locations in the study domain. In the simulation all tsunami parameters in the near shore area of the Göcek town are computed. Initial wave is selected as a site specific tsunami, and its' characteristics represent a tsunami characteristics based on the tsunami generated in the offshore area.

After a 30 minutes long simulation, the software gives the propagation of the tsunami, run-up in addition to sea states at specified time steps and maximum amplitude during the simulation duration. The initial wave conditions, maximum positive and minimum negative wave amplitudes obtained from the simulation results are given in Figure 3.



(a) (b) (c)

Figure 3: Wave Amplitudes at the first Case (a) Maximum wave height (b) Sea Surface Condition at 10^{th} minute (c)

According to the simulation results, the arrival time of tsunami to Göcek from simulation source is with the wave height of 1.3 m. As can be seen from the Figure 3, the western part of Göcek is affected the most compared to the other coasts in the bay. The reason is the water depth is shallow there and that part is an enclosed area which traps and amplifies the tsunami energy. By using these simulation results and topographical data, inundation maps for Göcek have been prepared in GIS environment.

4 ANALYSIS

4.1 Simulation Results and Inundation Map

Inundation maps show the places which can be flooded after the tsunami. These maps are valuable sources to show the zones threatened. NamiDANCE gives the sea surface profiles as output files in .grd format along the bathymetry. These output files are then converted into ASCII XYZ.dat files containing longitude, latitude and wave height attributes along the bathymetry at each grid as point data. Those points are used as an input file for GIS software. . Therefore, beside spatial attributes of the points, inundation values are also added to the database.

In Figure 4, an inundation map which is formed by using NamiDANCE output is shown. The points which carry the inundation information as an attribute are used to create an interpolation surface.

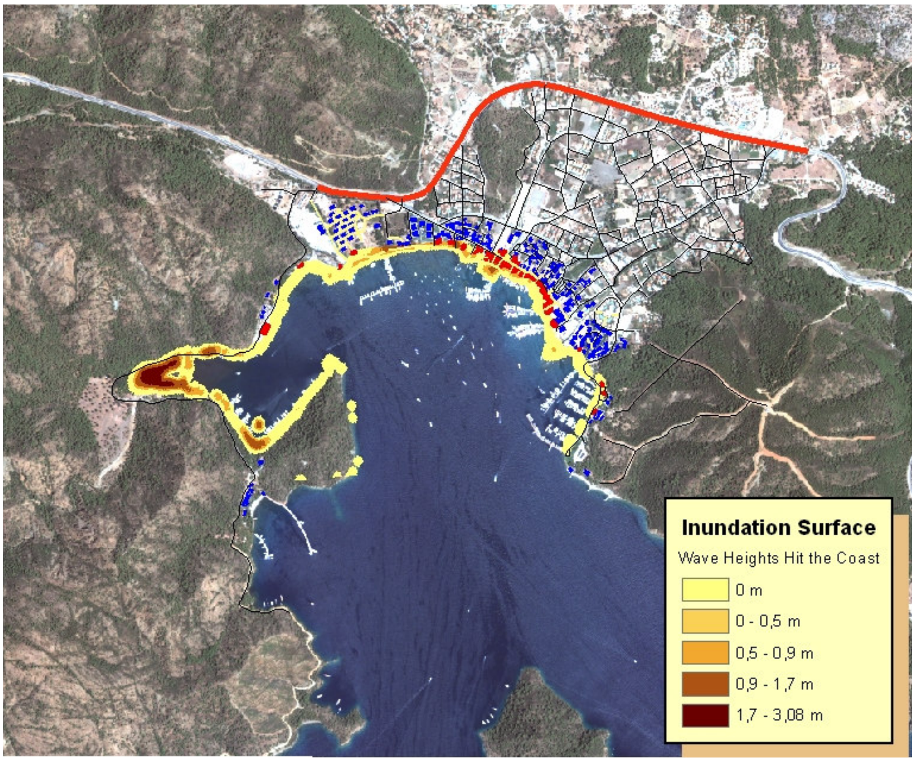


Figure 4: Inundation Surface in meter

To create a continuous surface or map of the phenomenon, predictions are made for locations in the study area based on the semivariogram and the spatial arrangement of measured values that are nearby. There are various kinds of interpolation techniques used in geostatistics. Those are divided into two as stochastic and deterministic according to their model interpretation. Stochastic interpolation techniques create surfaces incorporating the statistical properties of the measured data. Because they are based on statistics, these techniques produce not only prediction surfaces but also error or uncertainty surfaces, giving an indication of how good the predictions are. In this study, Kriging has been chosen as the stochastic interpolation method for the inundation mapping. Kriging is similar to Inverse Distance Weighting which is an exact interpolation method, in that it weights the surrounding measured values to derive a prediction for each location. However, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement among the measured points (Zimmerman *et al.*, 1999). Kriging also forms weights from surrounding measured values to predict values at unmeasured locations and the closest measured values usually have the most influence.

Thus, in the places where information related to inundation does not exist is estimated by using Ordinary Kriging method. This operation has been performed by using Spatial Analyst tool in ArcMap.

4.2 Mitigation and Response Strategies

In the literature, risk has been defined as a condition in which there is a possibility of an adverse deviation from a desired outcome that is expected or hoped for (Vaughan, 1997). A more algebraic definition that is frequently used is given by the formula risk= hazard*vulnerability, where ''hazard'' is defined as a process or phenomenon that may, with a certain probability, constitute a damaging event, and ''vulnerability'' is a condition or process resulting from physical, social, economic and environmental factors that determine the likelihood and scale of damage from the impact of a given hazard (Cochard *et al*, 2008). A priori risk management should definitely focus on preventing people from being caught by tsunami waves by careful mapping of potential exposed areas and possible protection features and taking appropriate risk mitigation actions.

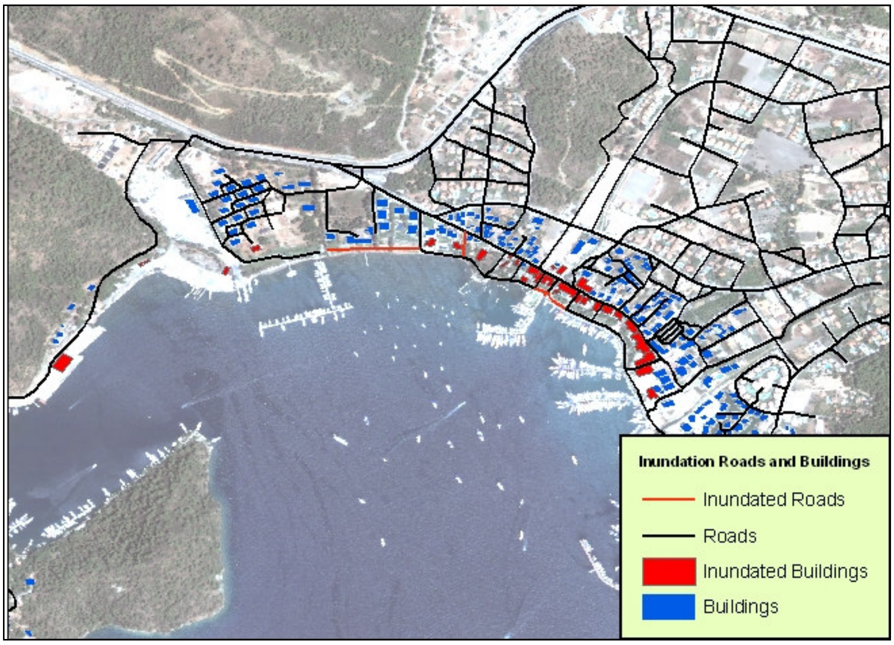


Figure 5: Risk Map for Göcek

Therefore, before defining the risk, first hazard and vulnerability of the case should be specified clearly. Mitigation plan for a disaster management includes reconstruction and preparedness stages for the disaster event. Since we know the extent of the hazard in terms of source of the waves caused by earthquake, affected zones can be determined by using GIS. The inundation map formed in GIS environment is used for this purpose. The intersections of the building and road layers and inundation map layer have been used to detect the buildings affected by tsunami waves. Besides this, zonal statistics tool has been used to extract the elevation information from DEM. Finally, by considering the inundation possibility and elevation parameter, a risk map has been prepared for Göcek after the tsunami (Figure 5).

The network has been established by using the ArcMap's Network Analyst tool. This network was based on road layer. In the network, highways, streets and walkways are connected to each other at the end points.

Next step for response strategies is to form the network. By considering the connection of coastal areas which are prone to inundation and predefined safe facility zones, the road network model which comprises of connected highways, streets and walkways have been established with a coherence based on real-world scale.

In the network dataset generation, attributes are defined to determine the cost that the network will be based on. In our study three attributes of road layer are assigned as cost dependencies. These are minutes that the duration to take the road, road length and road elevation. Each subtype has been assigned to a specific average velocity. Based on these average velocities, the durations are calculated for each road segment. Finally, network is built depending on these parameters.

In the closest facility tool of network analyst, first incident locations and facilities are specified and added as a layer to the map. In this study, inundated buildings are loaded as incident locations to the analysis and safe facilities are selected as the places at which in the case of an emergency people can be transported and settled safely. As an example of the facility location, open bazaar place in Göcek village has been chosen. It is selected because it is far enough from risky zones and a large open area where many people can accommodate. Finding the closest facility to an incident follows the same work flow as other network analyses. After assigning facilities and incidents; network analyst has been run to solve the route. The resulted route solutions for network can be seen in Figure 6.

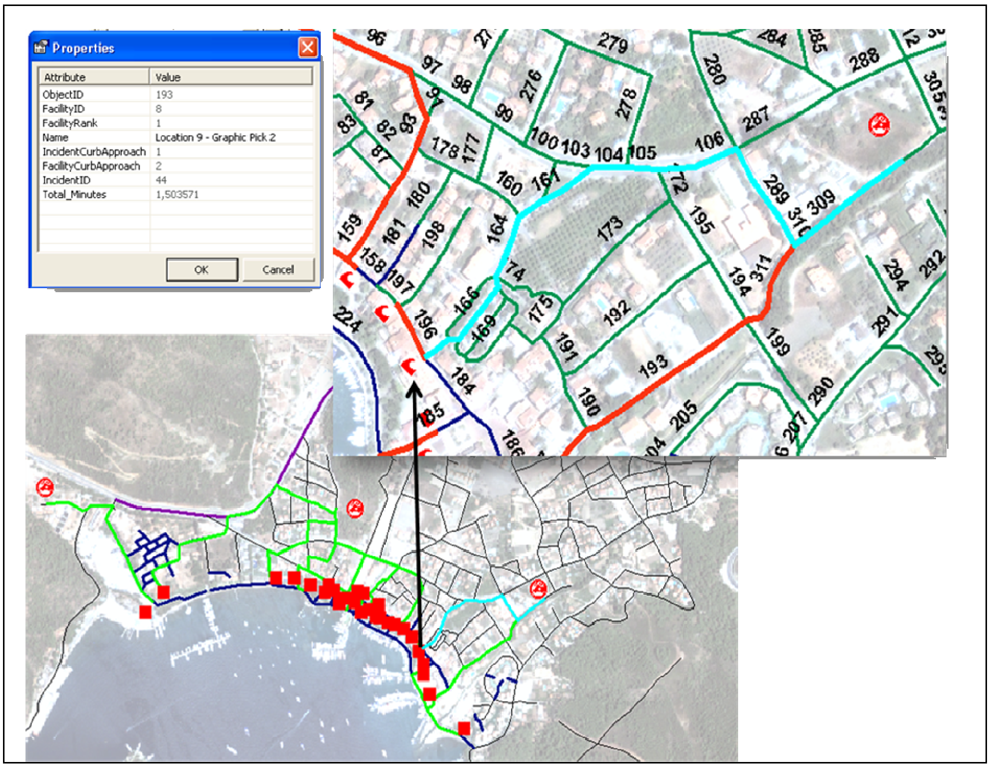


Figure 6: Closest Facility Solution for Roads Network for Göcek Village after Tsunami (selected road is in cyan)

5. RESULTS AND DISCUSSION

The main outcomes of the study are determining the inundated buildings and roads and calculating the optimum routes to the closest facilities in case of emergency. The analyses conducted in this study are based on the source data gathered. These data are integrated with spatial data in order to determine the optimum routes from inundation zones to safe places, thus an evacuation plan was assessed.

34 buildings out of the 183 digitized buildings are inundated in our case scenario. Height attribute for building objects are input to the database by using the site investigations. Fastest optimum routes are defined from four possible safety facilities to those affected buildings to evacuate people who are living on. These important findings and results should be considered in case of an emergency situation for disaster mitigation and preparedness.

After the tsunami waves reach to the coastal, time to rescue people becomes a very critical parameter to consider. Even though the locations, scales, and intensities of events are almost impossible to anticipate, it is still feasible to build many elements of a GIS response in advance. It will be clear to anyone familiar with GIS and disaster management that applications for virtually every GIS function can be found somewhere in this application domain. But one aspect distinguishes the domain from any other the need for speed. The phrase golden hour is often used to describe the opportunities for saving lives that exist primarily in the first hour following an event, and decline rapidly thereafter. In this context every aspect of a GIS project needs careful examination, from training and preparation to data gathering and product dissemination, to see whether critical bottlenecks can be removed.

It is also vital that has been learnt from the experience of previous disasters, by capturing and archiving the GIS methods that worked, by documenting lessons learned, and by iterating designs and plans. Catastrophic events like tsunamis, earthquakes, and floods cannot be eliminated however precautions can always be developed. Especially by the help of developing technologies, the preparedness to those kinds of events can be possible. This study will help to improve preparation of the evacuation plan which can be organized by the government for Gocek in case of a tsunami. Inundation map generated for the study by the result of a tsunami simulation is a guide for areas to be protected and evacuation map and network analysis conducted for the case of emergency is a guide map for the hot points which should be evaluated for the rescue operation at the first place. By using GIS in this sense, the risk maps and evacuation plans can be arranged for disaster management and those outputs can be used in the emergency action plans (EAP). Applications of the emergency action planning are the responsibilities of local authorities who have the statutory obligation. Warning and evacuation should be organized by the EAP coordinator. People involved in the implementation of the EAP should be familiar with the elements of the EAP. Therefore an exercise schedule and the plans for the EAP program should be included in the appendix of the plan. The exercises should involve an annual drill as well as periodic desktop and functional exercises.

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