ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

GIS BASED ANALYSIS AND ASSESSMENT OF TSUNAMY RISK

CASE STUDY OF GOCEK BAY – TURKEY

M.Sc. THESIS

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To my beloved Parents,

FORWORDS

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June 2017 Hafidhou **ALI MVOUNA**

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ABREVIATIONS

DEM **:** Digital Elevation Model
EV **:** Economical Vulnerability
GIS **:** Geographical Information System
PV **:** Physical Vulnerability
SV **:** Social Vulnerability
TV **:** Total Vulnerability

SYMBOLS

$\mathbf{P_0}$	**:** Probability of Occurrence
$\boldsymbol{d}$	**:** Distance from source to shoreline
$\boldsymbol{L_i}$, $\boldsymbol{l_i}$	**:** Point longitude and latitude
X	**:** Percentage of area female number
NFsa	**:** Number of female in a selected area
NFs	**:** Number of female in subarea
$\mathbf{I_i}$	**:** Tsunami Intensity

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GIS BASED ANALYSIS AND ASSESSMENT OF TSUNAMY RISK CASE STUDY OF GOCEK BAY – TURKEY

SUMMARY

The event of tsunami has a high considerable impact in local and global level. The risk of tsunami cannot be eliminated but it can be efficiently assessed and analyzed for setting a possible solution to reduce its impact. During the hazard prevention, human lives and properties can be saved and environmental damage can be reduced. Determine the spatial location of the tsunami and its impacts has a vital importance for disaster management. At that stage, geographical information system becomes a major concern with its ability to provide accurately and spatially information about such a risk.

Geographical Information System (GIS) as "*a set of tools used for capturing, storing, manipulate, analyzing and displaying spatial data related to a spatial location for a specific problem*" is used effectively to assess and analyze the risk of tsunami and help to response strategy plan. Tsunami event numerical data from historical document have been manipulated to determine the probability of tsunami event which might occurred.

The aim of this study is to combine and examine different spatial data used to determine the risk relied on tsunami hazard. The obtained results are successfully used for the area where under the risk such as Göcek Bay in Turkey. Göcek is situated in north west of Fethiye District of Mugla province and it is one of the most popular Turkish premier yachting locations. Its potential tourism activity contributes on the national economic development.

Furthermore, the use of GIS technology necessitates of different types of spatial data such as digital elevation Model (DEM), satellite imagery, and land use/land cover. The compilation of these data generates the elevation map, land use land cover map, inundation map and the risk map depending of different tsunami intensity values. This study combined both risk vulnerability components and data analysis for developing a tsunami mitigation planning.

This approach is used to achieve this analysis and assessment that includes physical, social and economic factors, developing methodology integrating hazard measure and its risk vulnerability and apply different risk frameworks for the Göcek area. The study presents the hazard information, the vulnerabilities and different map outputs. The risk map combined the vulnrability score and hazard information while the inundation map is based on physical and historical data. The result obtained in this study can be used for different relocation process in the coastal area required by local and central government.

CBS TABANLI TSUNAMİ RİSKİ HAZIRLIĞIN ANALİZİ VE DEĞERLENDİRMESI ÖRNEK: GÖCEK KÖRFEZİ– TÜRKİYE

ÖZET

Tsunami olayı, yerel ve küresel düzeyde önemli derecede etkiye sahiptir. Tsunami riski ortadan kaldırılamaz, ancak etkisini azaltmak için olası bir çözümü belirlemek için verimli bir şekilde değerlendirilebilir ve analiz edilebilir. Afet önleme çalışmaları ile insanların yaşamları ve mülkleri kurtarılabilir ve çevresel zararlar azaltılabilir. Tsunami gibi afetlerin konum bilgisini ve olası etkilerini belirlemek afet yöneticisi için hayati bir önem taşır.

Tsunami riskini değerlendirmek ve analiz etmek ve müdahele strateji planının modellenmesine yardımcı olmak için etkili bir yöntem olan, "konum bilgisine ilişkin konumsal verileri elde etmek, depolamak, manipüle etmek, analiz etmek ve görüntülemek için kullanılan araçlar kümesi" olan CBS (Coğrafi Bilgi Sistemi) kullanılır. Tsunami olayına ait tarihsel belgelerden elde edilen sayısal veriler, meydana gelebilecek tsunami olayının olasılığını belirlemek için manipüle edilmiştir.

Bu tezin amacı, Tsunami tehlikesine dayalı riski belirlemek için kullanılan farklı konumsal verileri incelemek ve birleştirmektir. Elde edilen sonuçlar, Türkiye'de Göcek Körfezi gibi risk altında olan alanlar için başarıyla kullanılmaktadır. Göcek, Muğla'nın Fethiye İlçesi'nin kuzey batısında yer alan ve en popüler Türk yatçılık merkezlerinden biridir. Potansiyel turizm faaliyeti, ulusal ekonomik kalkınmaya katkıda bulunur.

Ayrıca, CBS teknolojisinin kullanımı, sayısal yükseklik Modeli (DEM), uydu görüntüleri, arazi kullanımı / arazi örtüsü gibi farklı konum verileri gerektirir. Bu verilerin derlenmesi ile yükseklik haritası, arazi kullanım / arazi örtüsü haritası, sel baskını haritası ve farklı tsunami yoğunluk değerlerine bağlı risk haritası üretilir. Bu çalışma, tsunami etkisini azaltma planı geliştirmek için hem risk güvenlik açığı bileşenlerini hem de veri analizini birleştirdi.

Bu yaklaşım, fiziksel, sosyal ve ekonomik faktörleri içeren bu analiz ve değerlendirmeyi gerçekleştirmek, tehlike ölçütünü ve risk açığını bütünleştiren bir metodoloji geliştirmek ve Göcek bölgesi için farklı risk çerçeveleri uygulamak için kullanılmaktadır. Çalışma, tehlike bilgisini, tehlikeye maruz açıkları ve farklı harita ürünleri sunar. Risk haritası, güvenlik açığı skorunu ve tehlike bilgilerini birleştirirken, sular altında kalma haritası, çalışma alanındaki muhtemel tsunami oluşumunu belirleyen fiziksel ve tarihsel verilere dayanmaktadır. Bu çalışmada elde edilen sonuç, yerel ve merkezi hükümet tarafından gerekli kıyı bölgelerinde yerleşim değiştirme işlemleri için kullanılabilir.

Anadolu yarımadası, tsunami ve deprem riski altındaki bölgeler arasında tanınmış alanlardan biridir. Türkiye'de tsunami gibi doğal tehlike geçmişi sırasında pek çok çarpıcı örnek hasar gördü. Daha batıda, Marmara Denizi'ndeki bu depremler kıyı şeridini vuran ve ikincil hasar yaratan Tsunamileri de başlattı. CBS ortamında uzaktan algılanmış verilerle birlikte modern teknolojiler,

Kriz Yönetimine yardımcı olmak için geniş bir alan açmaktadır. Herhangi bir Kriz Yönetim Sisteminin en önemli bileşeni, özellikle CBS kullanılmasının birçok yönden katkıda bulunabileceği bir Kriz hazırlık planıdır. Kriz hazırlığı, böyle bir felaket durumunda nüfusun önlenmesinde önemli bir role sahiptir. Kriz yönetimi, tüm vatandaşlar için sürdürülebilir bir yardım sağlamak için paydaşlar arasında işbirliğine ihtiyaç duyuyor.

Çalışmamızda, Göcek bölgesi için deprem ve tsunami riskinin analizi ve değerlendirilmesinin muhtemel katkılarını vurgulamayı amaçlıyoruz. Tartışılan unsurlardan bazıları, halihazırda kurulmuş olan veya dünyada araştırılmış mevcut uygulamalardan, bazıları da Türkiye'nin farklı bölgelerindeki farklı araştırmalardan alınmıştır. Günümüzde kriz yönetimi sistemi üç farklı aşamada sunulmaktadır: Krize Karşı Hazırlık Planı, Erken Uyarı Sistemi ve Kurtarma ve Yönetim Eylemi.

Depremler ve tsunamiler gibi doğal tehlikeler mutlaka potansiyel bir ciddiyet oluşturmaz. Risk, doğanın oldukça faal olduğu ve insanların bulunduğu yerlerde insan etkinliği yerlerinde görülür. Kentsel alanlar inşa etmek. Bu insan canlılığı riskinin, nüfusun ve toplumun faaliyetleri ile birlikte doğal koşullara bağlı olduğu anlamına gelir.

Doğal felaketler genellikle nüfusun konumuna bakılmaksızın ortaya çıkar. Bununla birlikte, bazı yerler insanların yaşamı için yüksek risk taşırlar, ancak diğerleri gibi yoğun olarak kullanılmazlar. Nüfus artışı ve tarımsal veya kentsel yerleşim gücü için kullanılabilecek araziye ihtiyaç duyulması, bu gibi riskli alanları kullanmak için.

Tarihten dolayı, insanlar bu risklerin farkındaydılar; bununla birlikte, tarımdaki rekabet ve sosyal faktörlere bağlı olarak, bu gibi tehlikeli alanlara eriştiler. Volkanların yakınında bulunan bazı alanlar bile verimli topraklar üretti ve çiftçilik için cazipti. Sahil şeridi, balıkçının çalıştığı ve yaşadığı, hatta Tsunamiler için yüksek bir risk mevcut olabileceği yerlerdir. Günümüzde esas olarak kentsel yayılım risk seviyesini yükseltti, aynı zamanda yüksek riskli bölgelerde yaşamak ve çalışmak da bir olgu haline geldi.

Muhteşem tarihi yerleri ve doğal cazibe merkezlerinin yanı sıra Türkiye, ekonomik bakımdan önemli yerler ile önemli bir jeopolitik konuma sahiptir. Türkiye, denizlerle çevrilidir ve aktif faylarla şekillenmiştir ve kaçınılmaz etkileşimlerle sonuçlanarak tsunami tehlike potansiyeline sahiptir. Bu aktif faylardan bazıları Marmara Denizi'ndedir. Altınok ve ark. 2011 yılı boyunca Türkiye ve çevresindeki kıyıları M.Ö. 17. yüzyıldan MS 1999'a kadar etkileyen 134'den fazla tsunami vardı. Bu tsunamiler, depremler ve / veya denizaltı heyelanlarıyla tetiklendi.

Tsunami etkisinin azaltılması, insanlar için daha hızlı boşaltma sağlanması ve yapıların tsunamilere karşı dirençliliğini ve performansını arttırarak sağlanabilir. Tsunami modellemesi, tsunami tehlike değerlendirmesinin önemli evrelerinden biridir. Tsunami sayısal modellemesinde, yeterli özünürlükteki kaynak mekanizmaları, batimetrik ve topografik veriler ile olası tsunami senaryolarının seçimi kullanılır.

Bu yeni yönlere dayanarak ve son deniz jeofizik verilerine dayanılarak, tsunami geni depremleri, tsunami yoğunlukları ve güvenilirlikleri revize edilmiştir. Veritabanının güncel hali, çoğu 3500 yıldır Türk sahillerini ciddiye alan 134 olayı içeriyor. 76 olayın güvenilirlik endeksi, "kıyaslanabilir" ve "kesin" idi, böylece Türk kıyı bölgesi boyunca risk değerlendirilmesi ve önleme politikalarının uygulanması için kullanılabilirler.

Güvenilir tsunami veri tabanları, risk analizi ve değerlendirme, tehlike değerlendirmesi, dalga sayısal modelleme ve halkın farkındalığı gibi çok çeşitli tsunami yönetimi için büyük önem taşır. Bu tür olayların sonuçları, kıyı kentleşmesinin artması bakımından son derece ciddi olabilir. Türkiye kıyılarında yaklaşık 8300 km uzunluğunda ve nüfusun yaklaşık üçte birinin yaşadığı, düşük kıyı şeridi boyunca birçok toprak bölünmesi var.

Ayrıntılı, gerçek bir tsunami yoğunluğu ölçeğinin olmaması, tsunami etkileri tanımlarının standardize edilmesinde ciddi sorunlar ortaya çıkarmakta ve bu durum siteyle siteye ve durumdan karşılaştırılmaktadır. Uzun sismolojik geleneği takiben, aşağıdaki ilkelere dayanan yeni bir 12-dereceli tsunami yoğunluk ölçeği kurulmasını önermekteyiz: (a) kaynaktan kıyı şeridine kadar dalga genliği (veya yükseklik) gibi fiziksel parametrelerin bağımsızlığı; (B) hassasiyet, tsunami etkileri ile ilgili farklılıkları bile tanımlamak için yeterli sayıda yoğunluk sınıfının dahil edilmesi; Ve (c) yapıların insan ve doğal çevre ve zayıflıkları üzerindeki olası tüm etkileri göz önüne alarak her yoğunluk derecesinin ayrıntılı tanımı.

Bu parametrenin tümü, riskin ölçülmesine ve risk çalışması paydaşının karar verme için gerekli olan etkili bir hafifletmenin yapılmasına izin verir.

1. INTRODUCTION

1.1 Background

According to the geographical location of the study area (Göcek Bay Area), historical study and analysis show a possible tsunami occurrence for several reasons. This tsunami prone area is representing one of the touristic and social strategy contributing the national economic development. The economic and social representation study area is further explained in chapter two. By that, proposing and developing a GIS based analysis and solution of the tsunami risk analysis and assessment capable to achieve a maximum suitable and possible mitigation is our actual deal. The methods and problem solving strategy is explained in chapter four.

Determine the event location and its possible impact is important stage for response and recovery planning. During the hazard prevention (or mitigation), it is possible to save environment and human lives.
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, but if the tsunami comes to the shoreline, it rises to the inundation distance and can cause loss of lives and property damage (Yalciner et al. 2005).

To deal with this issue, both physical facilities and technological settings are needed. In this sense, information about demography, social and economic development, infrastructure and other spatially data was used by using GIS. For example, the capability to answer spatial queries, such as where are the affected can be and how shelters can access to that area, in case of emergency situation, can be solved using GIS technology (Goodchild, 2006).

Therefore, since the damage from tsunami event is important, the vulnerability of any respective area and all over the world should not be neglected. Göcek plays an important and potential role for marinas and stops the Mediterranean voyage along the coast of Turkey.
Tsunami risk cannot be avoided but it can be analyzed and probably reduced by using tools and models to combine information, in order to produce effective and meaningful estimation of the tsunami risk facing the coastal area like Göcek Bay (Seda Salap et al. 2012). A tsunami risk plan is developed to guide urban planners, emergency managers, and decision makers to discover the impact, list the and settle the results into preparedness and urban development planning.

A method for analyzing and assessing the tsunami risk is to model the event parameters using Geographical Information System (GIS) technologies. GIS creates new opportunities for managing the large amount of data (spatial, social and economic information), interact with the interface with the external analysis programs and presenting the results in such a way that can be useful for disaster planning strategies and risk mitigation as well.

Tsunami have an important and considerable impact on human lives. Figure 1.1 shows the record of tsunami events in turkey from 1945. During this time there were sept tsunami events in turkey from 1945 to 1999, then many causalities could be encountered.

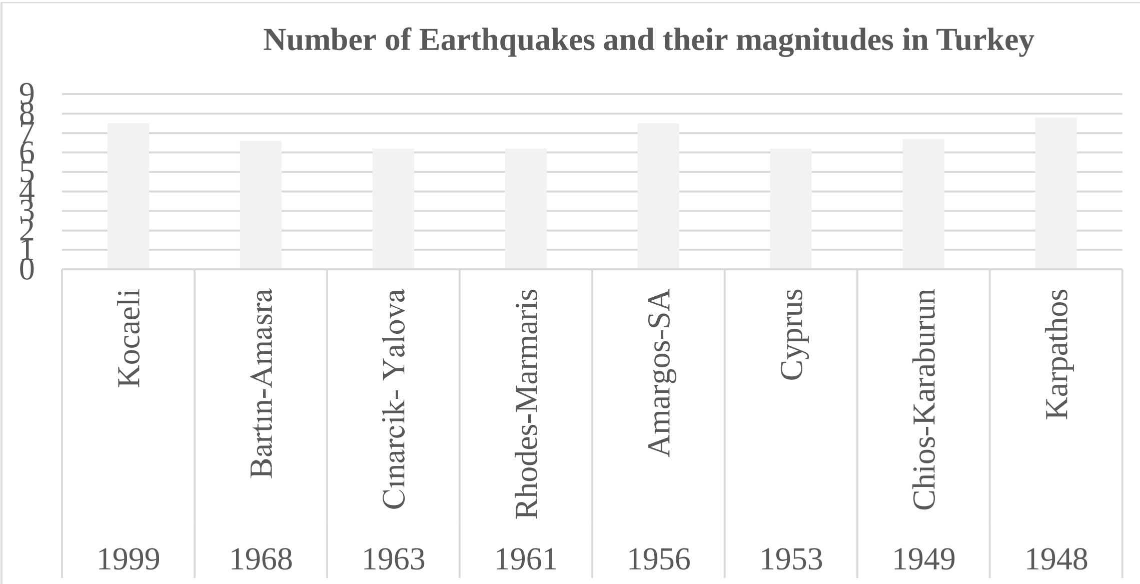

Figure 1.1: Number of Earthquake’s Tsunami and their Magnitudes

In general, tsunami is caused by earthquake events. Therefore, geographical and seismological data are crucial for tsunami risk analysis and assessment.
Economic level and rapid population growth in turkey result the increase of infrastructure developments, industrial activities, and settlements in coastal areas vulnerable to natural hazards, especially tsunamis.

1.2 Problem Statement

Turkey has a considerable number of coastal regions (villages) that plays a considerable role in terms of economy, administration and touristic and economic center, and also provide a large amount of incomes impacting the annual gross domestic product specially from its tourism sector.
Consider that Göcek Bay Area is at risk from tsunami impact, efforts have been done to assess the tsunami risk related to this region. There is lack of data about the distribution of both national and region based tsunami hazards. Therefore, it is important to evaluate the tsunami potential, bring out an assessment from the physical, social and economic vulnerability components. The research problem is illustrated in the simple line framework (figure 1.2) presented below.

There is potential to use GIS as a tool to process data in natural hazard assessment. GIS can make task more efficient and rational for pre-impact planning, post-event response, and mitigation process. Moreover, GIS technology support spatial decision making which is common to natural hazard risk assessment by using “what if” analysis - by varying parameters and creating alternative scenario in a spatial context.

However, there are some limitations and constraints of using GIS tools for risk analysis and assessment. GIS capability depends on the quality and range of available input data which determines the objective of data utilization. GIS faces problems obtaining reliable and valid geo-reference data for the required detailed risk analysis, and how to store and maintain the data in high quality format (Gaspar et al 2004). GIS also requires the right decision to be made in overlaying and manipulation the data, because it cannot do all of those things automatically. In other words, GIS use still requires a strong understanding of how the hazards relate to each other in space and over time (Cutter et al., 2013).

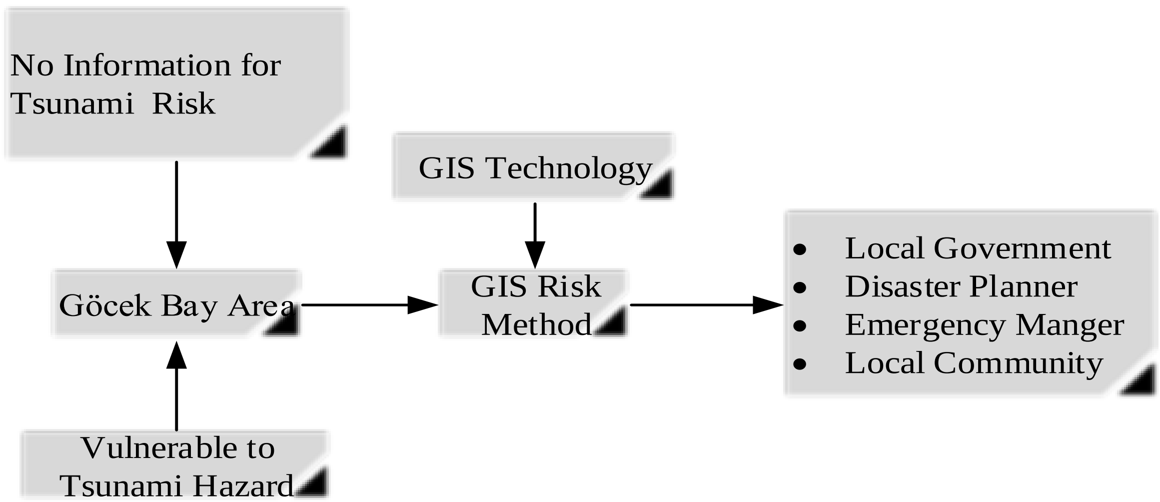

Figure 1.2: The problem Statement Framework

The model explained here uses data available at small scale community level of study, so that local managers and public servants can prepare risk assessments for their respective region. In case of disaster, information needed at this level of scientific analysis may provide more information useful for tsunami run-up probability.

1.3 Research Aim and Objective

Because Göcek Bay Area is vulnerable to tsunami hazard, a tsunami risk analysis and assessment has been used and is ready to be applied in other national coastal region. The result guides local people who live in coastal area, and local authority for a tsunami mitigation planning development including city development plan, land use zoning and regulation, economic improvement activities, education and awareness campaigns.

The objectives of the study are dedicated on:

- Developing a solution of tsunami risk analysis and assessment that includes physical, social, economic and infrastructure factor development that can be adapted for other coastal location.

- Proposing a spatial methodology to integrate multiple factor and measure the hazard, vulnerability and the risk of tsunami hazard.
- As case study, use the tsunami risk assessment study for coastal regions.

1.4 Thesis Outline

The thesis comprises six chapters.

- Chapter one provides the background information and the problem statement by explaining the vulnerability of the study area. However, this chapter gives the aims and objectives of the study. With respect of the framework, the objective of the thesis is shown in chapter two.

- Chapter two gives a review of the tsunami risk assessment modelling that is done in the context of disaster management. This chapter provides information about GIS technology that is used as a tool in this hazard risk analysis and assessment. The different risk vulnerability and assessment map is explicitly presented in chapter five.

- Chapter three provides background, which explains the geographical, social, and explains how the economic factor as vulnerability components is important in the study area. Here, we present the impact of the socio-economical factor in the study area.

- Chapter four presents the simple research framework for tsunami risk assessment used in this study. Moreover, this chapter gives the details of the materials and methodologies that are needed for conducting the study.

- Chapter five presents the details of the results found in this study. This chapter also provides the hazard, vulnerability, the inundation and risk maps of the study. The result is obtained and discussion from analysis and assessment of different vulnerability cases using historical data are explained in chapter four.

- Chapter six presents a model of analysis and assessment in function of the available results, conclusion and recommendation, which presents all assessment and provides a discussion of their results for future use.

2. TSUNAMI RISK ASSESSMENT AND GIS

The proposed model of the tsunami risk vulnerability analysis and assessment of the presented tsunami prone area follows national and international facts and standards. Several studies and conferences based on mitigation of tsunami risk analysis and assessment are conducted and provide frameworks for both post tsunami pre-tsunami hazard solution. The result of this problem using GIS as a tools for different potential analysis methods are explained in chapter four as well.

In recent years, many natural disasters such as floods, tsunami, earthquakes and storms have costed lives material losses and caused a drawback on developing countries in general. Many studies have been considered to deal with such disasters by understanding the risk and analyzing the possible vulnerability impact and set a solution for reducing the severity of disaster (ISDR, 2002). In Yokohama (May 2004), the World Conference on Natural Disaster Reduction established the Yokohama framework that consists of prevention, preparedness, reduction of vulnerability, on time warning system and disaster reduction policies (ISDR 2002, Briceno, 2004). Furthermore, the same conference has been done in Hyogo on 18 – 22 January 2005 establishing the Hyogo Framework to identify the specific gaps and update the Yokohama strategy. It consists of five areas: (i) governance framework, (ii) risk identification, assessment, monitoring and early warning, (iii) knowledge and education, (iv) risk factors reduction and (v) preparedness and recovery (ISDR, 2005).

A tsunami risk assessment requires the use of synthetic data and the mapping of the special relationships between the tsunami hazard data and the elements at the risk such as casualties and damaged properties. A GIS is a mapping software able to facilitate for the objectives of a tsunami risk analysis and assessment study because of its ability to store, manipulate, analyze and display the large amount of spatial and non-spatial data. This chapter describes the major of tsunami risk assessment components, followed by a broad overview of GIS and concludes with tsunami risk assessment. The data type, the processing output and assessment to mitigation are presented in chapter four.

2. 1 Impact of Tsunami

The occurrence of natural hazards in coastal region such as Göcek Bay Area is not a recent phenomenon, but the desire for better understanding about the potential, its risk vulnerability, and impact is relatively new trend.

Moreover, in poor or developing countries, the impact is usually greater due to the historical development of country wise social, economic, political and cultural setting. These factors push up the vulnerability to natural disasters.

Tsunami risk vulnerability is much high in coastal communities and have impacted on human settlement and ecosystem. Physically, a tsunami’s run-up, oscillation on the bay, and floating debris facilitates and causes the event impact.

The impact and severity can vary from short term, such as injuries, death, and material loss to long term, such as health, social and economic problem. In coastal area with ports and industries, a tsunami can generate secondary impacts, such as fire, disease contamination.

The possibility of tsunami events occurrence in many regions of the world is important and has serious drawbacks for human life, different infrastructure, property, economy, business and the environment level. Highly destructive tsunamis have been recorded at a number of location in turkey, such as in Kocaeli (1999), in Bartın-Amasra (1968), Cınarcik-Yalova (1963), Rhodes-Marmaris (1961), Karpathos (1948), etc. effecting almost every sector of the economy, including fishery, tourism, transportation, housing and health.

2. 2 Assessment of Tsunami Risk

Several studies have analyzed and assessed the tsunami risk for coastal communities like the case of Göcek Bay Area. For example, we can analyze the tsunami hazard based on historical data or assess tsunami risk based on numerical modeling while we can estimate tsunami risk based on historical data of submarine earthquake event.

However, tsunami study area and objectives differ with respect of the researcher perspectives.

- Scientists focus on distribution, the mechanism generation and the possible frequency of events occurrence.
- Disaster planners and emergency managers will be interested in the tsunami characteristics such as run up, its impact, the response strategy plan, recovery and rehabilitation strategy.
- Urban planners are mostly interested in the tsunami flood area and the vulnerability of buildings and human land uses.
- Insurance companies will be interested in tsunami frequency magnitude relationships, so they determine the risk and exposure, and establish suitable insurance premium levels.

All of these concerns and interests are beneficial because the determination of hazard risk has a practical benefit for the protection ability of the population and economic development, and for defense (Tinti, 1991). In order to make comprehensive assessment of event risk for any region, procedures identified in natural hazard studies can be used to create a framework (table 2.1).

Table 2.1:Hazard assessment Step (Source: Disaster management – James Cook University).

Step	Source
1. Assessment of:	
- Hazard identification and Frequency	- Cutter et al. (1997)
- Hazard Frequency and Magnitude	- Zbinden et al. (2003)
- Hazard Potential	- Dwyer et al. (2004)
- Hazard exposure	- Greiving et al. (2006)
2. Assessment of:	
- Tsunami Vulnerability	- Cutter et al. (1997),
- Vulnerability and Risk Estimation	- Ferrier and Haque(2003)
3. Production of:	
- Data integration	- Cuter et al. (1997)
- Hazard mapping of affected area	- Zbinden et al. (2003)
- Social consequences	- Ferrier and Haque (2003)
- Risk and risk map	- Dwyer (2004), Greiving (2006)
- Special needs and infrastructure	- Cuter et al. (1997)
- Financial calculation	- Zbinden et al. (2003)

From table 2.1, it is possible to create the overall framework (figure 2.2) for tsunami hazard assessment consisting of three important stages (hazard identification, vulnerability and risk assessments): (i) mitigation measure to reduce the risk, (ii) analysis of existing and needed capacity to develop and implement mitigation measures, and (iii) strategic plan developed as action plans to reduce the risk from tsunami hazard.

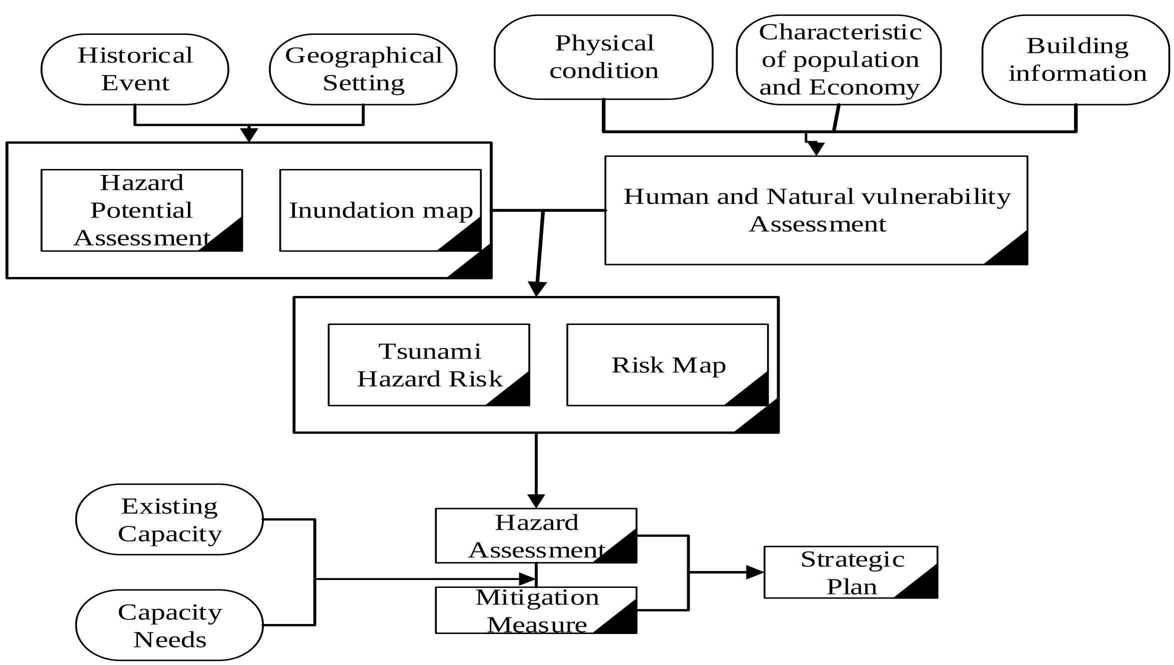

Figure 2.1: Tsunami Framework for Analyze and Mitigation

From table 2.1, it is possible to create the overall framework (figure 3) for tsunami hazard assessment consisting of three important stages (hazard identification, vulnerability and risk assessments): (i) mitigation measure to reduce the risk, (ii) analysis of existing and needed capacity to develop and implement mitigation measures, and (iii) strategic plan developed as action plans to reduce the risk from tsunami hazard.

2. 2.1 Hazard assessment

To achieve the goal of the current study, a list of steps is to be considered with respect of developed countries available studies.

Hazard identification is an important key in hazard risk assessment. For example, in the United States of America (USA), identification of the hazard is a basic key element in hazard mitigation program that goes in parallel with the risk assessment (Cutter et al. 2000). The understanding of hazard process, patterns, probability and potential are important for preventing and reducing hazard impact (Alcantara-Ayala, 2002). In tsunami hazard management, both tsunami and historical data of submarine earthquake are important to determine the probability of tsunami. Moreover, historical events are used to assess hazard frequency and geographical conditions to assess possible hazard magnitude (Clague et al., 2003).

As tsunami can occur at any time and any place, we need to reduce the impact if a tsunami occurs in the study area. For this region with high probability of tsunami occurrences, the government can give funds to build seawalls to protect against future tsunami in that area.

The important questions of "when", "where" and "why" need to be answered in hazard identification. For example: when did the event occur? Was there any mitigation effort at that time? what are the localized likely causes? Are there any local characteristics that prevent the event? is any period pattern for the event? is there any building standard in the area? where is the most vulnerable area for this event?

2. 2.2.1 Historical data

In this section, we discussed the impact of the historical data on analyzing and assessing the tsunami and its severity by using GIS technology. It is served to use tsunami historical data in order to calculate the possible probability of tsunami occurrence. The historical data used for the case study is explained chapter four (section 4.2).

Historical data analysis is the first step in the hazard assessment process. Various resources can be used to achieve this, such as local library materials, newspaper archives, similar studies and discussions with local people impacted in a past event.

Historical data can be compiled to determine the frequency of the hazard occurrence. However, data collected within long time, is usually accurately less because of the lack of sophisticated instruments used during measurement. The probability of tsunami occurrence can be calculated by several methods. The probability of tsunami occurrence is calculated by dividing the number of occurred hazard by the number of period for the same events. For example, if a tsunami occurs 4 time in the same area over 80 years, then the probability of tsunami occurrence in that area is 4/80 or simply 20 per year. Some researchers calculate the tsunami occurrence return period by inverting the calculation i.e. 80/4 = 20, meaning of, a tsunami my probably reoccur in the same area after 20 years (Kulikov, 2005).

2. 2.2.2 Tsunami wave characteristics

It is a large wave on the ocean, usually caused by an undersea earthquake, a volcanic eruption, or coastal landslide. A tsunami can travel hundreds of miles over the open sea and cause extensive damage when it encounters land.

It is because of their long wavelengths that tsunamis behave as shallow-water waves. A wave is characterized as a shallow-water wave when the ratio between the water depth and its wavelength gets very small. The characteristics are explained in figure 2.2.

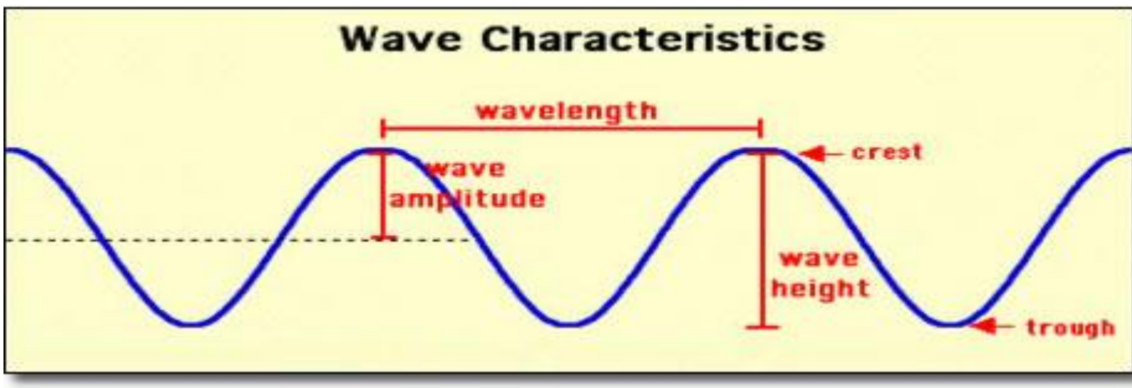

Figure 2. 2: Tsunami Wave (Source: http://www.sms-tsunami-warning.com).

Their characteristics are:

- When the wave enters the shallow water, it shows down and its amplitude increase.
- As the tsunami approaches the coast and the water becomes shallow, the wave itself compresses the velocity below 50 m/h.
- Because of its possible and large water displacement, individual cannot surf them.
- Since the wave has a long wavelength, the tsunami takes a couple of minutes,

When a tsunami finally reaches the shore, it may appear as a rapidly rising or falling tide, a series of breaking waves, or even a bore. Sometimes the tsunami may break far offshore. Or it may form into a bore: a step-like wave with a steep breaking front.

The water level on shoreline can rise many feet. In extreme cases, water level can rise to more than 50 ft. (15 m) for tsunamis of distant origin and over 100 ft. (30 m) for tsunamis generated near the earthquake's epicenter.

One coastal area may see no damaging wave activity while in another area destructive waves can be large and violent. The flooding of an area can extend inland by 1000 ft. (305 m) or more, covering large expanses of land with water and debris. Tsunamis may reach a maximum vertical height onshore above sea level, called a run-up height, of 98 ft. (30 meters).

2. 2.2.3 Characteristics of Land Use

The land use management has important role in the degree of risk severity. The allocation of buildings and infrastructures is a function of the inundation distance. The total area covered by water depends not only on the other characteristics of the event from its epicenter but also the building construction. Moreover, the more the distance or space in between buildings the more penetration of water and then high inundation distance. In the other hand, the low the space between buildings to others the less is the inundation distance as the water cannot penetrate and occupy much area.

Moreover, the land use or construction management of the area is important for the stabilization and protection the land. Setting a policy and regulation governing the coastal land is an important challenge.

Since evacuation is one of the most important stages in the disaster planning, developing functional networks of evacuation routes, vertical evacuation shelters and identification of existing safe escape places are highly necessitated. On the other hand, development of evacuation routes will lead proper access to the areas while construction of vertical evacuation shelters leads to public facilities development with strategic building proposals such as shopping complex, community centers, cultural centers, observation towers.

2. 2.2.4 Geomorphological Condition

Geomorphology is the study of the nature, history and evolution of landforms and the processes which create them. It has a considerable impact on tsunami effect.

Even though the tsunami waves approach the study area in different patterns, the consequences are found to be mainly dependent upon the coastal physical structure and local geographic setting. The inundation and run-up level vary from point location to another regardless of the tsunami intensity. The percentage of inundated area in the total coastal area varies with respect of the geomorphology of the coast (URL2).

The Mountains immediately behind Göcek are not particularly high. The land around Gökçeovacıkis generally around 400 – 600 m above sea level while the median altitude Turkey is 1,128 m. What is more striking being the gradients and the depth of the sea close to land? Final emplacement of the Lycean Nappes was around 10ma. The last mountain building event in Britain was around 300ma.

The products of weathering and erosion will become stable at a slope of around 30 degrees. Where there is sufficient fine material (less than 0.6 mm) to fill the spaces between the coarse materials and there is good drainage with suction pressures will be generated and near vertical slopes will remain stable for periods of a few months to many years. Surface water will erode these steep slopes, water in the soil will reduce the suction and vibration may trigger a sudden collapse.

2. 2.2.5 Vulnerability assessment

Göcek Bay Area is vulnerable to the tsunami hazard, a tsunami risk analysis and assessment is used as a study to create a model of the tsunami risk that can be applied not only in the study area but in other part of Turkish coastal region. This assessment calculation is represented in chapter four (section 4.3.3).

After hazard and its characteristic identification, vulnerability assessment is the next step to undertake. It is critical and necessary because the impact of hazard differs from a place to another depending on its characteristics. Vulnerability assessment depends on how close the surface area is to the tsunami source, and their social and economic condition.

The vulnerability assessment is also important in order to make disaster planning and mitigation activities both sensible and effectives. Mitigation is carried out effectively by analyzing the vulnerability parameters. However, in real life, the risk manager pays less attention to vulnerability assessments than the mitigation and preparedness.

Vulnerability is a function of three functions:

- The hazard potential
- Action to be taken during event (Risk resiliency).
- Reconstruction process (after the event severity).

There are major factors influencing social vulnerability including:

- Access to resources limitation (information, knowledge and technology)
- Political power, social capital (including social network)
- Beliefs and customs, building, age range, type and density of infrastructure.

Natural hazards vulnerability is related to the level of development and poverty of the society. Development can raise the risk vulnerability while poverty reduction pays less attention to risk reduction. Often a natural hazard study is highly considered when it occurs in the populated and developed countries with high level of economic activities (Greiving, 2006). However, for a coastal city, the development in the water-front area is unavoidable because of the function of harbors, hotel and recreational facilities (Wood and Good, 2004). The consequence is that coastal area have high vulnerability to disaster, they are in an economic center, it may contain much infrastructures and high population density (Boulle et al, 1997). Therefore, a planning of coastal zone necessitates an understandable assessment of the hazard prone area coastal in developing zoning and land suitability analysis.

2. 2.2.6 Vulnerability components

The study area disposes a socio-economic and environmental characteristic that without a suitable solution can be exposed to disastrous event like tsunami. The detail and choice of each component is presented in chapter four (section 4.3.3.1).
Four are the components of vulnerability use along with the study: physical, social, economic and environmental.

- The physical component refers to the location of the built environment, such as a density levels, remoteness of an area, its setting and the quality of building construction.

  Density is one of the variables that determines the severity of the disaster. Where the demography is concentrated in a limited area, any hazard event can cause more injury and death would occur more than if these people were more dispersed (Boulle et al, 1997). But people who live in a remote area will experience difficulties for evacuation if any hazard occurs in that area (ISDR, 2002). The setting of the environment also determines the severity of a disaster. For example, people who live in a hazard prone area will be more vulnerable than live in less hazardous area (ISDR, 2002).

- The social component is related to the choice of wellbeing individuals, such as age and gender issues. Gender characteristic, particularly the role of women is also important since women have a well-known responsibility of assuring domestic life management. Therefor women are more likely vulnerable in time of crisis (ISDR, 2002).
- The economic component is related to the economic level of individuals, or societies. The poorest people having a lowest quality of house in a specific hazard location will have the less opportunities to deal with potential disaster impact. Wealth enable communities to absorb and recover from losses more quickly due to insurance, social safety nets and entitlement program (Cuter et al., 2003).
- The environment component covers ecological actions of sustainable development and is related to the reduction of disaster risk (ISDR, 2002). Furthermore, environment has an important contribution in reducing. For example, the relation between individual and the environment is important aspect to understand flooding hazard, this reasons encountered when flooding has caused a risk in Manila (Philippines) when there was a lack of environment impacts with human activities over the time.

Vulnerability is not only functional of human activity, but the interaction with natural, cultural and political settings is considerable. Therefore, vulnerability is divided into two groups: human and natural vulnerability – where vulnerability is related to the social, economic, political and cultural systems, and natural vulnerability depends on the nature of the hazard related to the geographical location of an area, such as volcanic, flooding, tsunami and cyclone vulnerability (Alcantara-Ayala, 2002).
The hazard vulnerability in this case is a function of location based parameters such as distance from the shoreline, depth of inundation, building construction, preparedness, knowledge of the hazard, ability to avoid the hazard, social and economic factor. Furthermore, each coastal location has different conditions and these conditions make the location more or less vulnerable to the hazards.

We can use variable as indicator quantifying the social for such natural hazard vulnerability, it can be age, income, gender, employment, resident type, household type, health insurance, house insurance, car ownership, disability, language skill, and debt or saving (Dwyer et al., 2004).

For tsunami hazard assessment paradigm, building condition is another function to determine risk vulnerability. For example, a building in a road perpendicular or parallel to a beach has a high negative impacts from tsunamis (Bush et al., 1999). If the building is parallel to shoreline, it is more vulnerable to the tsunami force (Papadopoulos and Dermentzopoulos, 1998).

2. 2.2.7 Data and information

Disaster planners and emergency managers need a set of spatial data for spatial analysis. This will help decision maker after analyzing and assessment stage to cope with the mitigation procedure. GIS specialist uses several resources for data selection as input for better and efficient analysis.

To create a vulnerability assessment for physical, social, economic and environmental factors, a range of spatial and non-spatial data are needed; for example:

- Land elevation and terrain slop – relate to the wave run-up height and inundation area
- Satellite image – related to the land use and affected area
- Age and population - relate to the social factors
- Income is the economic status (income and political power)
- Market and land use relate to economic factor used to calculate the potential for damaged areas.

The data should represent the corresponding information needed to create the vulnerability assessment. For this assessment, synthetic data is important even it does not complete and sufficient detailed. However, there are some parameters to consider, such as data availability, spatial resolution (McLaugglin, 2002). Moreover, the use of geo-indicators, such as elevation, vegetation, land sat image, slope, and soil structure type are very useful to provide sufficient information about natural vulnerability to coastal hazards (Bush et al., 1999).

2. 2.2.8 Risk vulnerability methodology

Risk vulnerability is the actual problematic of Göcek Bay Area specially the case of tsunami risk. The assessment method is based on the objective to reveal the physical, social, economic, and environmental conditions that will increase or decrease vulnerability to tsunami hazards. And this method is explained in chapter four (section 4.3). We can define eight step assessment methods which includes:

- Definition of the study area: Stakeholders are responsible in the process of area selection using information from the assessment, they should take part.
- Time based situation analysis: After selecting the study area, the development of the knowledge through literature review takes place and discuss with stakeholders to gather information about the study area.
- Causal model development: This problem describes and assesses different factors, including interactions between factors exposed to vulnerability.

- Indicator of exposure development: It is necessary to develop indicators that are, meaningful, understandable by stakeholders and they can be presented by map.
- Operational model of vulnerability creation: It is produced by combination of weighting and indicators.
- Feature projections development: Projections of variables should be on the scenarios of values.
- Communicating the result: It should be in a two-way direction between problems researchers and stakeholders.

There are five criteria to evaluate the vulnerability assessment: (i) the analysis knowledge, (ii) vulnerability should focus in the study area and the analysis should be in the same spatial scales, (iii) the results should be multiple and interactive, (iv) the assessment allows the differential adaptive capacity and (v) the information generated should be prospective.

2. 2.2 Risk assessment

The risk for each natural hazard, including a tsunami, is different from one area to another, depending on its vulnerability. The result of risk allows the major concerns (disaster planners and emergency manager) to focus on limited resources on the areas and prioritize the area for evacuation, recovery or rehabilitation procedure (Wood and Good, 2004). The goal of risk assessment is to set different locations within different sort of risks from the hazard through map processing. The methodology and the risk assessment with respect of the vulnerability component is discussed in detail in chapter four (section 4.4).
Hazard risk assessment should consider three dimensions of exposure: economic, social, and ecological dimensions.

- The economic function refers to the factor that affecting the region on economic system.
- Social refers to highly vulnerable people such as the disabled or poor people.
- The ecological dimension presents to the ecosystems and environmental vulnerability setting of a region.

There are some different approaches in defining the risk. However, in principle, they are the same in their application and depend on the usability. The different risk approaches calculations, including their explanation are presented in Table 2.2. From these methods, an increase or decrease of each factor influences the degree of the risk. By that, the risk assessment result should be interpreted on a specific temporal and corresponding spatial scale.

Table 2.2: The Risk Calculation

Risk Calculation	Explanation
1. Hazard x Vulnerability x Manageability (Shook, 1997)	In this analysis, questionnaire is used to get result. Participant are selected in function of their understanding of society, the government initiative regarding disaster.
2. Hazard x vulnerability x Value (Papadopoulos and Dermentzopoilos, 1998)	In this case, real tsunami data and tsunami wave numerical simulation and probability approach to provide a good tsunami assessment. The quantitative and semi-quantitative assess the "vulnerability" and "Value".
3. Hazard probability x Vulnerability (Ferrier and Haque, 2003, Cutter 2000).	In this analysis, they determine risk occurrence probability and result in a vulnerability to loss.
Hazard x Exposed Element x vulnerability (Dwer, 2004, Tram 2009)	In this case, hazard refers to hazard occurrence, and its impact. Exposed element refers to the people, object exposed to the hazard. Vulnerability refers to the capacity of exposed element during the event.
4. Hazard x Vulnerability x Time (Hennecke et a., 2004).	Here, hazard was considered to be the hazard probability in one area. Vulnerability comprises the exposure of human, land and property values. Time as variable within risk can change a consequence of hazard vulnerability.
5. Hazard probability x Extent of impact (Plattner, 2005).	Here, we define hazard as a product of frequency of event occurrence and the extent of its consequences.

To create a complete analysis for the tsunami risk assessment, some process or steps are to be considered.

- Collecting and analyzing data related to various parameters influenced by tsunami waves. Here, we use geomorphological, geological and environmental parameters to create an environment map, road network to create a road network map.
- Analyzing the impact of the tsunami waves. We create tsunami impact map presenting land use property damage, road damage, lifeline damage, population and socio-economic impact.
- Develop a set of mitigation and prevention plans. Here, tsunami risk management map is created, included the prevention and mitigation measures based on the potential impact map.

The tsunami risk scenario is therefore developed based on existing historical data, numerical modeling and the worst-case scenario. For example, maximum wave run-up is expressed as vertical or horizontal and more than 2 m of run-up is considered dangerous.

2. 2.3 Tsunami mitigation

Create a model of the tsunami risk analysis and assessment that can be applied Göcek Bay Area means to provide not only one way but a series of effective mitigation.
Hazard mitigation is a final process when the vulnerability, and risk assessment have been achieved. It is necessary that all results in the hazard assessment are integrated to the decision-making process.

Strategy for natural mitigation is worldwide, but the implementation stage one must consider the location based characteristics. The Hyogo framework identified the specific problems and challenges from the previous strategy on five areas which is represented by figure 2.2:

- Government based framework (including organizational, legal policy framework),
- Risk identification, assessment, monitoring and early warning system,
- Knowledge based management and education
- Risk factor reduction proposition
- Preparedness for efficient response and recovery.

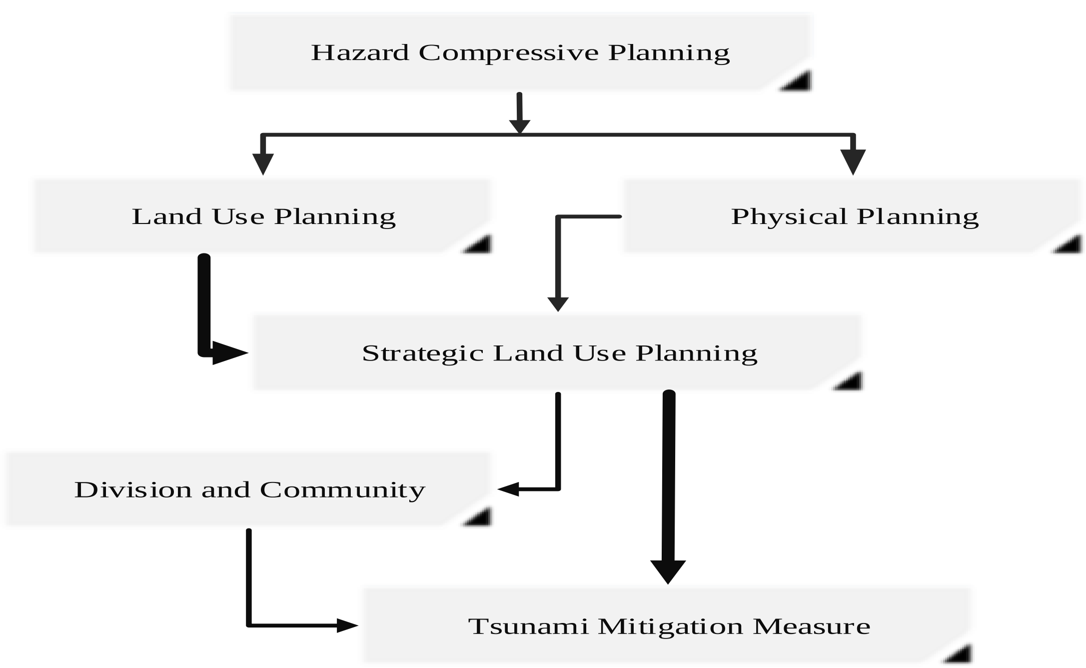

Figure 2.3: Mitigation Stages

In the hazard assessment process, the risk is not only influenced by manmade or natural vulnerability, but is also a function of mitigation and prevention actions implemented before the phenomena. The tsunami hazard can be controlled and reduced by a mitigation policy and in the other hand the risk can have high impact because of non-existent mitigation plans.

According to this definition, many activities can be included in the mitigation. They can be structural – by developing structures such as seawalls; or non-structural – by developing land use planning, preparedness and public education, hazard and risk map (Clague et al., 2003).

2. 2.4.1 Risk education

To facilitate an effective mitigation after an efficient analysis and assessment, risk type knowledge based is necessary for all stakeholders.
Public education must be conducted regularly, especially in the area with high probability of tsunami occurrence. Learn the characteristics of tsunami, probability and variation of tsunami magnitude, proper response and community readiness are to be taught in the public education especially for coastal communities (Clague et al., 2003). We can use learning materials like pictures, maps, questionnaires, and event available scenarios are very useful in the education programs. A tsunami prone community should comprehend the characteristics of tsunami, to be able to manage its impact, and have mitigation plan. These actions are used as a basis for action plans, such as:

- Providing tsunami information for all concern stakeholders,
- Evacuation alarm and network route,
- Training facility,
- Inundation maps, guidelines and zoning,
- Open meetings and workshops.

An effectiveness of public mitigation is possible if there is education and an understanding of risks for the susceptible area and human vulnerability (Ferrier and Haque, 2003). Early warning system is also important because if people are warned before the tsunami occurs, the possibility to overcome the situation is high enough. However, they are only effective for tsunamis with long distance waves; for distance less than 100 km, the signal is not effective because there is a limit time to warn and evacuate people. Therefore, in coastal communities, people should think of constructing high building for vertical evacuation.

2. 2.4.2 Strategic plan

To evaluate the tsunami potential, to assess and to map the physical vulnerability aspects, disaster manager or risk planner should develop a strategic plan for mitigation.
For tsunami mitigation, the change in the natural hazard paradigm is depends on community planning, including land use and land cover planning, inundation area management plans, reduction of vulnerability strategy (Clague, 2003). Hazard identification is done through scientific studies, workshops, tsunami modeling and the development of tsunami inundation maps.

The maps can be used as a guide for directing local investment development and specific land uses and cover for sustainable places. In function of these information, the community will evaluate the area vulnerability and be prepared for worst case situation. Therefore, inundation map generation has high priority in tsunami mitigation planning.

The mitigation plan provides guidance for stakeholders for reducing risk vulnerability to coastal hazard. Procedure is by the following steps:

- Hazard mitigation or management plan should be static for different forms of vulnerability reduction.
- Those forms should cover activities to reduce human vulnerability, gives more facilities to access to resources, institution based coordination, public awareness.
- As the hazard is not limited by the administrative boundary, the plan must be communicated with the rest of jurisdictional area.

Focus open group discussion, and community surveys can facilitate the level of understanding of coastal communities for future tsunami hazard. These surveys can be used as feedback for the local governments for evaluating the mitigation programs. Local people will prepare medical or emergency facilities at once. In other hand, they do not prepare because they knew that it implies a financial budget. These condition are caused by the irregular propagation of hazard information, the complex nature of impacts, and a low risk perception because a tsunami is a rare event (Johnston et al., 2005).

2. 2.4 Geographical Information System

In this study, GIS technology is used. GIS is a computer based application software tools that can store, manipulate, transform, analyze, and display the spatial and referenced data for specific purpose (Heywood et al., 2006).

GIS data formats and their functions, including analysis tools, map productions, and modeling data present a real life cases illustrated in chapter five.

2. 2.5.1 Data structure

Geographic data present three forms, (i) map data, (ii) attribute data, and (iii) image data.

- Map data are spatial data and contains the location data and shape of the spatial features. GIS uses three type shapes to present features: points (building), lines (road or river), and polygon (forest and urban area).
- Attribute (tabular data) data is the data description of what GIS relies to a map features.
- Image data can be in from of satellite images, aerial photographs or scanned maps.

In GIS, there are two main ways to display spatial data model, known as raster and vector spatial data (figure 2.4). A group of cell creates and presents individual grid cell, and the shape and character of an entity. The size of grid cell influences how spatial entity can be presented. A vector data model uses two-dimensional Cartesian (X, Y) coordinates to store the shape of spatial data. In the vector presentation, point is the basic building block within all spatial data are made. Therefore, the more complex the representation of a feature, the greater the number of points required to simulate it (Heywood, 2006).

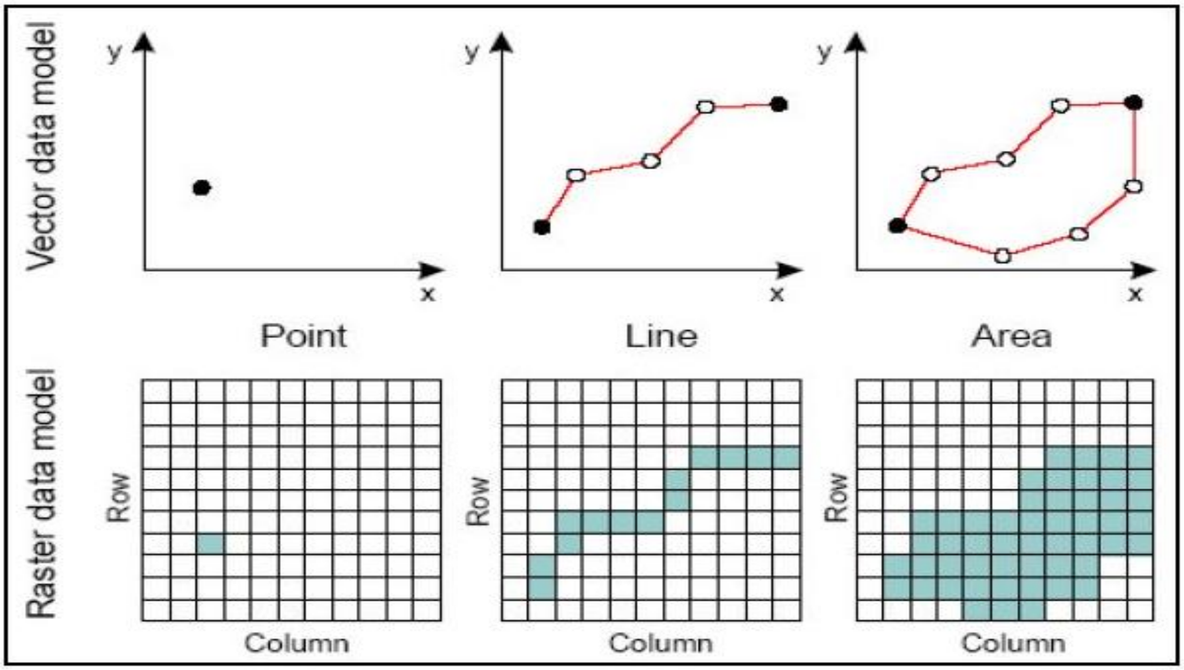

Figure 2.4:The Raster and Vector Data Model (Source: Davis (2001))

Spatial data used here, including land use, elevation data, building stock can be represented in GIS as features data along with their attributes. The features are represented as points, lines, and polygon and the corresponding attributes stored in database tables.

2. 2.5.2 Analyzing and modelling capability

One of the most import function of GIS is analysis feature of both spatial and non-spatial data. Both database management system and GIS support database analysis, but GIS also support map analysis. It is useful to think of GIS map analysis in a layered-model context (figure 2.5).

The layered GIS model is analogous to transparent map that can be accurately stacked upon one another. Each layer contains one map. GIS provides a set of tools computer programs in the form of operating commands, permit spatial inquiry, manipulation and analysis; which allow the user to perform a specific set of operations on map and attribute data (Heywood et al., 2006).

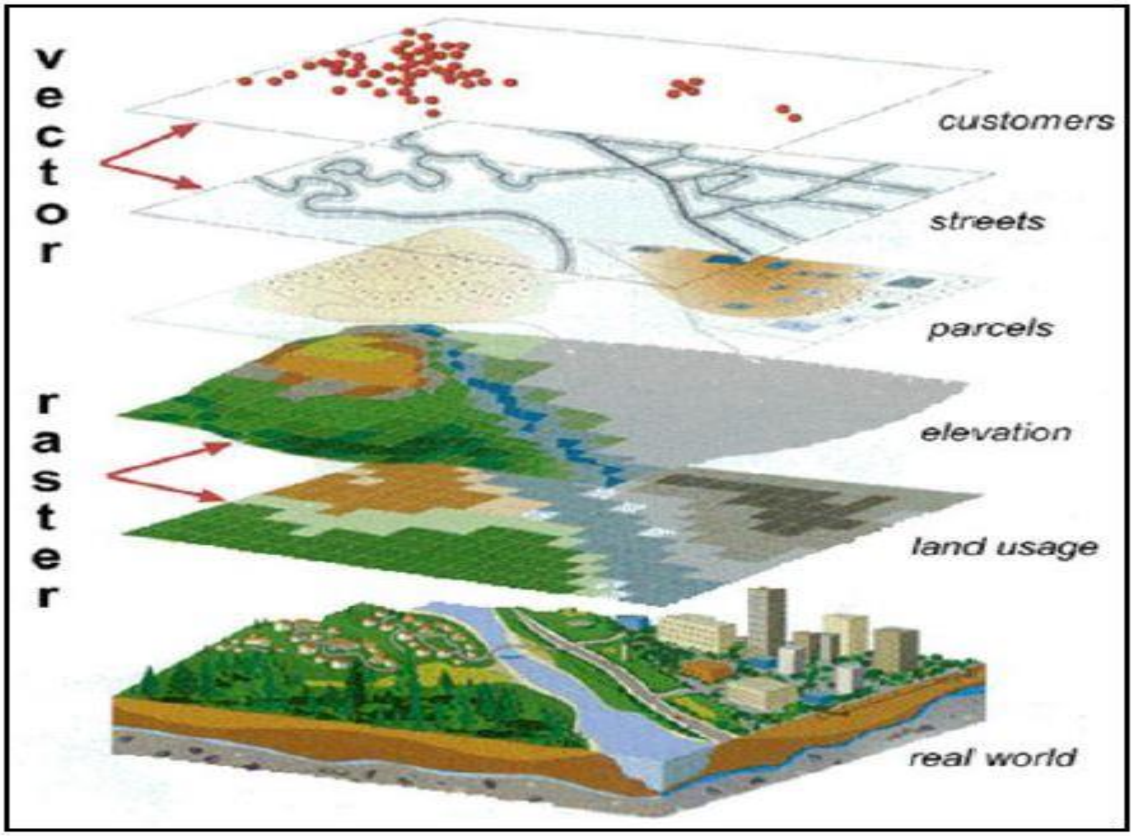

Figure 2.5: GIS layered Model (Source: Hill 2006)

2. 2.5.3 GIS in tsunami risk assessment

Many studies have used GIS to assess tsunami hazard risk by creating hazard, vulnerability and risk map. Moreover, many existing natural hazard assessment methods such as flood, landslide and earthquake have been used for tsunami risk assessment.

In Sri Lanka, GIS has been used with numerical data and risk model for hazard assessment that justifies the useful for post-tsunami action and plan for development. The GIS processing includes physical data (bathymetry, topography and hydrology) and human environments data (building, harbor facility, road and rail network and land use). The result is a maps presenting the suitable area for reconstruction project (Garcin, 2008).

In Greece, GIS has been used to develop a tsunami risk management project pilot. Three stages of methodology are used:

- Data collect and analysis related to the physical planning, such as land use or land cover, road networks, and geological data.
- Quantitative details of the impact of a tsunami and
- Developing a set of approaches for preventions and measures mitigation.

GIS has been used for vulnerability assessment approach for tsunami hazard. It integrates factors that contributes tsunami vulnerability such as built sectors, sociological data (density and number of people per house and per building), and physical data.

In USA, GIS has been used to assess the vulnerability of Oregon port to earthquake and tsunami hazard by integrating the hazard characteristics, physical data, social and economic details. Here, four groups of GIS layers have been used: (i) study portrayal layer (ii) hazard potential, (iii) community assets (subsidence landslides, population and essential facilities), and (iv) community vulnerability (representing the vulnerability of the study area in order to identify the area of multiple hazards or community assets).

All data that used hazard and vulnerability components must be easy collected and scaled, such as elevation data, land use and cover, satellite imagery, social and economic data.

3. STUDY AREA

3.1 Geography

This study focuses on the Göcek Bay Area which conceived as tsunami vulnerable area for several vulnerability factors. Göcek is one of the most beautiful towns in Turkey, situated at the edge of the Taurus Mountains at the lyrical coast of the Mediterranean, with 18km from the Dalaman airport. Moreover, in order to set out analysis and assessment study, the geographical setting of the study area and its information are important.
Göcek is located in Muğla Province, and covers approximately 816 km² of which 345 km² is the marine zone and has a coastline of 235 km (URL1).
Göcek has grown from a small agricultural town 15 miles North West of Fethiye into one of Turkey’s premier yachting locations, rivaling Marmaris and the Bodrum Peninsula. This is largely as a result of its natural advantages, being at the top of a deep gulf sheltered by the island of the same name. The town hosts a total of no less than six marinas, Port Göcek, Club Marina, Göcek Village Port, Göcek Exclusive, Skopea Marina, and Göcek Municipal Marina. This area covers the Fethiye cost, spatially located in 36°45'11.00" N - 28°56'8.00" E.
The region has a typical Mediterranean climate with hot summers and mild and rainy winters. Annual average precipitation in the region is between 1,250 and 1,500 mm. Due to the geographical position of the area (mountains extending vertically from the sea), the interiors receive more rainfall than the coasts and humidity is lower than other coastal zones. The figure 3. 1 shows the study area boundary in form of satellite image.

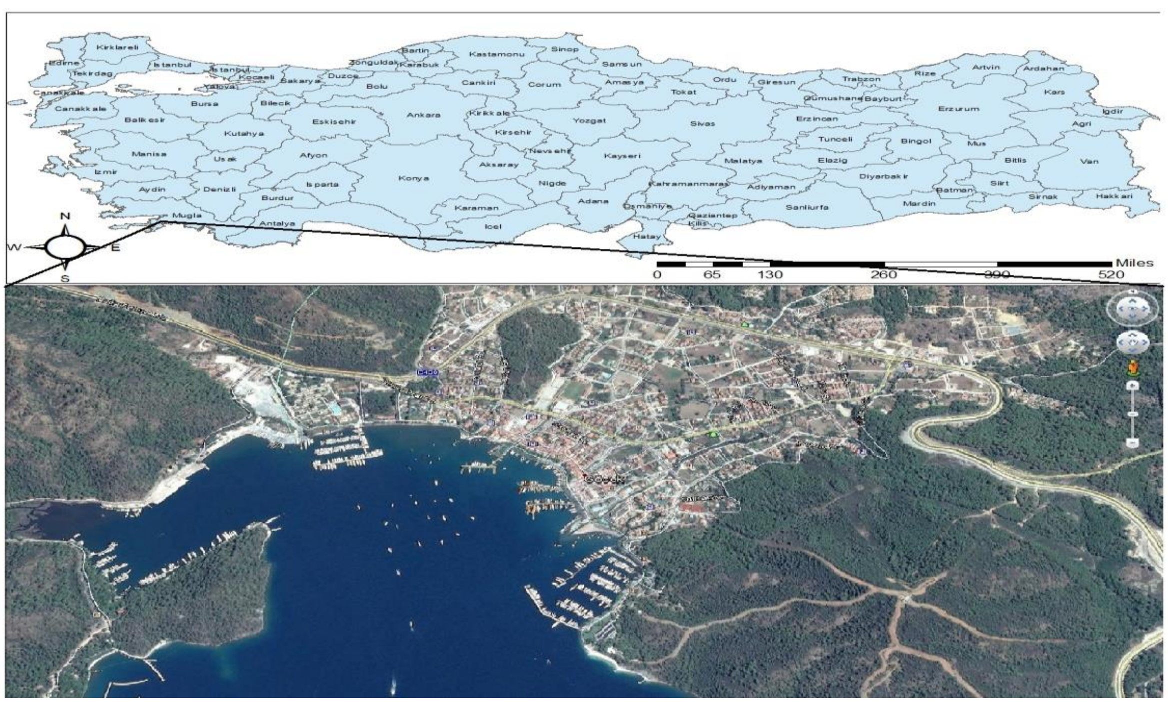

Figure 3.1:Study Area

3.2 Social and Economic Description

Göcek Bay activities represent a considerable impact in the national economy. By that, using GIS to setup a study on tsunami analysis and assessment of the study area means having a global view of the social behavior and the economic level of this respective study area. The impact of tsunami risk on the society and economic level of the region will be clearly demonstrated in chapter four and chapter five.

Fethiye-Göcek consists of a district center having five different towns (Ölüdeniz, Karaçulha, Çamköy, Çiftlik and Göcek Bay). Based on 2016 census, districts within Fethiye-Göcek have a total population of 28,492 people of which 51% are men. The reparation of the population is given the table 3.1.

Table 3.1: Fethiye-Göcek Regional Population in 2016

Town	Total	Male	Female
Çamköy	3,940	2,027	1,913
Çiftlik	2,620	1,358	1,262
Göcek	**4606**	**2320**	**2286**
Karaçulha	12,794	6,452	6,342
Ölüdeniz	4,532	2,383	2,149
TOTAL	**28,492**	**14,540**	**13,952**

The population of Göcek is 4606, increasing to 5,000-6,000 in the summer. Figure 3.2 shows the repartition of the regional population and much the study area might be vulnerable based on its demographic factors.

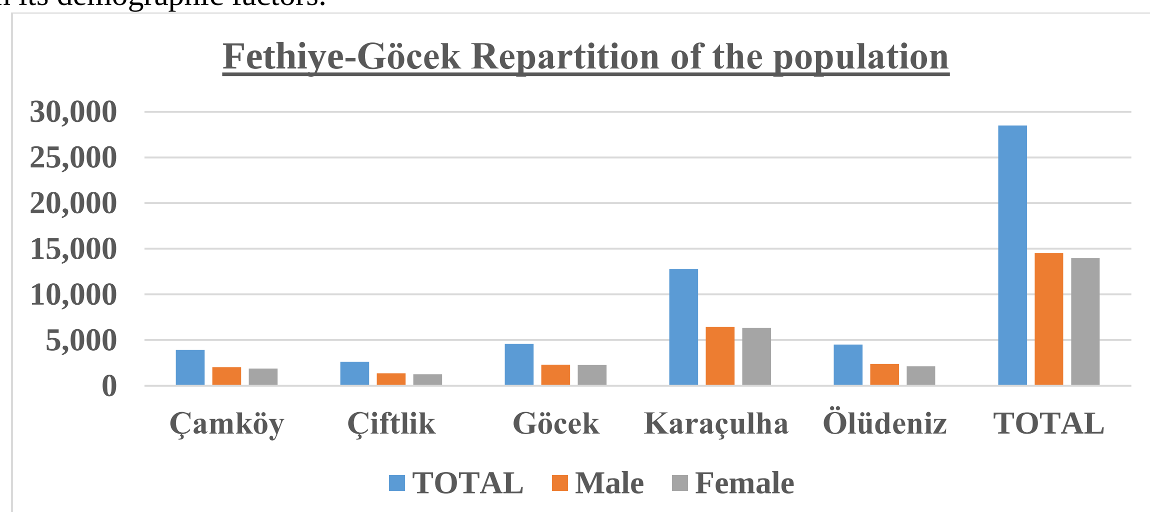

Figure 3.2: Regional Repartition of the Population

The bay literacy rate is 96% for the district (compared with 94% in Turkey overall) with 7% of the residents have graduated from university.

The socio-economic profile of Göcek Bay town is compiled to be higher than its neighboring settlements (town) with a growing shift from agriculture and animal husbandry practices towards the service sector. In line with a considerable increase in demand for yachting and tourism accommodation, the exponential increase number of restaurants and shops have developed to support the (yacht) tourism sector. An upscale real estate market has also gained importance in the town.

3.1 Provisioning Services

Göcek Bay area activities are based not only on production but is also able to produce services contributing in the growth the economy. Among those services, there are:

- Food: the main food of the region is fish and other related sea products.
- Raw Materials: these products relate to the extraction of marine organisms for all purposes other than human consumption. Marine raw materials include seaweed for industry and fertilizer, fishmeal for aquaculture and farming, pharmaceuticals and ornamental goods such as shells.

4. MATERIALS AND METHODS

4.1 Research Framework

The proposed framework for the tsunami hazard assessment developed and used in this study is based on the literature and previous studies in tsunami hazard assessment. This framework is based on fact that there is no existing tsunami risk assessment framework that can be used as guidance for coastal manager in Turkey, particularly in Göcek Bay to evaluate, assess and implement tsunami risk assessments.

Three important stages represent this framework (figure 4.1): (i) hazard assessment including tsunami potential assessment, (ii) vulnerability assessment including physical, social and economic vulnerability and (iii) risk assessment including risk analysis. As the framework will be simple, the assessment and its corresponding information is completed by the produced GIS map. The general framework for these stages is presented in chapter five (section 5.1)

The concern authority has interest to know which public or private building (houses, hotels, villas, restaurants or schools) as they may be vulnerable and at a risk to tsunami impact. People prefers to live a safe area in case of evacuation if a tsunami occurs. The information provided in this study permits the availability of different maps to achieve the needs.

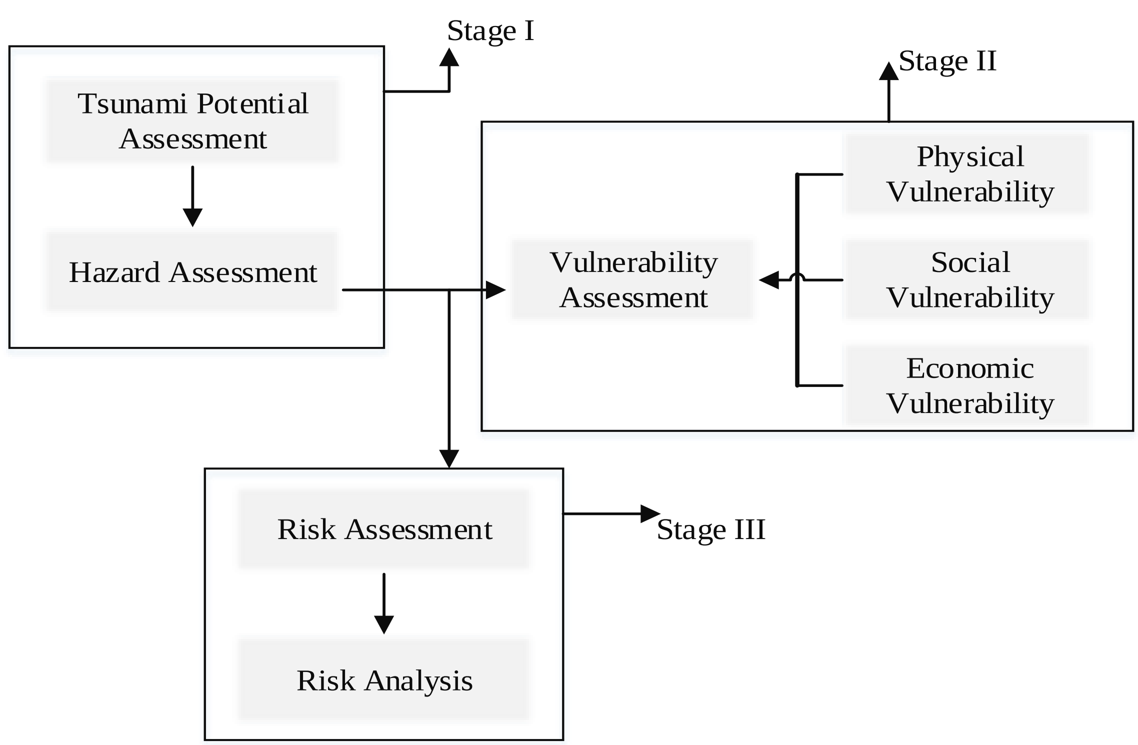

Figure 4.1: Simple Framework for Tsunami Risk Assessment

4.2 Data Source

The principal data for this tsunami risk analysis and vulnerability assessment included: tsunami and submarine earthquake records; geographical information including, elevation and land use, satellite imagery and demographic, social and economic conditions as explained in chapter two.

The detailed explanation of data used for this study includes:

- The historical data of submarine earthquakes and tsunami events.
  The first of the Fethiye earthquakes was on April 24, 1957, and on the following day the second and larger event about seven hours later having magnitude of 7.2 within aftershocks having 5.1 of magnitude. The last 25 seconds had a magnitude of 7.1; while another second event occurred at 04:26 hours on April 25; having a duration of 60 seconds within a magnitude of 7.3.
  The data is used for computing the possible probability of occurrence of another earthquake and tsunami event in the same area and then for deciding the corresponding worst-case tsunami run-up scenario.
- Elevation Data
  The elevation data are derived from survey in Fethye Göcek Bay coastal areas. They present elevation points between two different point locations. These data are used to classify the ground elevation and the percentage of the slope in the physical vulnerability assessment. Data is obtained in vector format and analyzed in raster format.
- Land use data
  The land use data are acquired in Fethye Göcek Bay municipality on November 2006 and August 2009 for the purpose of controlling and monitoring land use and land cover change. The data are obtained in vector format and used for analyzing tsunami risk factors.
- Social and Economic Data
  The data were collected in 2016. It is used for this study to analyze the number of people, the percentage of females and males presented, children and elder, poor family, fisherman and yachts in activity.

  In this study, the used this data needs a considerable processing and further transformation in order to generate the variable used for spatial analysis. All of type of data are collected differently for the aim of providing efficient analysis and assessment.

4.2.1 Software

During the study, Microsoft Vision 2016 and Microsoft Project 2016 are used respectively for diagram creation and thesis planning and management. For GIS spatial analysis and network analysis, ArcGIS 10.1 from ESRI is used. Microsoft Excel was used as well for generating and displaying different charts. SASPLANET160707 is used for downloading satellite images.

4.3 Methodology

After the end of the listed events, a number of measures have been taken to collect information and set sufficient tools for analyzing and assessment. Disaster planner consider GIS as a powerful tool to analysis of such a fact. In this study, synthetic data within the available historical data are used to perform different results analysis and assessment.

A set of scenario has been created to illustrate the risk and inundation area depending on the area structure by using GIS. To achieve this stage, several and different data types are used as well such as terrain elevation, land use, satellite image and social and economic attributes. The analysis method used in this study is explained in chapter five.

4.3.1 Tsunami potential assessment

The historical data presented in section 4.2 and tsunami events are analyzed to output the recurrence time of possible and next earthquakes and tsunami. The probability of occurrence for earthquake and tsunami events was defined using Cutter's formula (1997):

$$Po = \frac{NE}{NY} \tag{4.1}$$

Where Po, the probability of occurrence, *NE* the number of events and *NY* the Number of years. The historical data is used in this way to decide worst-case tsunami run-up height to set a hazard assessment. The worst in this case is based on the maximum run-up height value encountered in Göcek Bay area.

4.3.2 Hazard assessment

The hazard is represented by the inundated zone produced by overlaying the elevation data, the worst-case run-up scenario and the location features like building, road. etc. The inundation zone is defined as the area perimeter between the shoreline and the contour of the highest recorded tsunami run-up defining the inundation distance.

In Göcek Bay, the highest recorded tsunami run-up was 4m within 15 Minuit, then the inundation zone was the area between the shoreline and the 4m contour. Table 4.1 presents the classification of the inundation zone based on the 4m run-up scenario, including the scoring of the neighboring zone.

Table 4.1: The classification, scoring and weighting for inundation zones

Inundation zone	Class	Score	Weight	Total
a. < 2 m	High Inundation	4	100	400
b. 2 – 3 m	Medium Inundation	3	100	300
c. 3 – 4 m	Low Inundation	2	100	200
d. > 4m	Very lower inundation	1	100	100

The tsunami run-up height is function of the area structure, the shape or the water depth of the cost line and characteristics of the tsunami wave. It means, a positive value of the run-up height carries out the possibility to map the risk while a positive value of inundation distance means the tsunami risk manager should take new measure of mitigation.

4.3.3 Vulnerability assessment

All vulnerabilities from tsunami event depends on the location composition and wave length of the tsunami which determines the inundation level. The social and economic vulnerability are combined with the physical vulnerability to produce the total vulnerability. The total vulnerability is calculated by:

$$TV = PV + SV + EV \tag{4.2}$$

Where TV = the total vulnerability, PV = social vulnerability and EV = economical vulnerability.

As it has been introduced in chapter two, the total vulnerability in Göcek Bay area is a combination of those factors:

- Physical vulnerability: distance from the shoreline, ground elevation.
- Social vulnerability: total population, number of females, elders and children and disable people.
- Economic vulnerability: number of poor families.

4.3.3.1 Choice of vulnerability factors

As the vulnerability to tsunami devastation is not consistent with the study area, many factors were identified and information about each factor was collected to generate the solution. The physical, social and economic vulnerability are:

- Distance from the shoreline: It is an important parameter for tsunami event characteristic and the level of damage and casualty range depend on the distance from the source of tsunami to the main land. The further the distance from shoreline, the less will be the run-up height and inundation area of tsunami wave. The classification for distance from shoreline is made from the formula:

$$d = \sqrt{L + l} \tag{4.3}$$

Where; d is the distance from source to the shoreline. $L=(L_1-L_2)^2$, respective longitude of the point source and any point of the shoreline, $l=(l_1-l_2)^2$ respective latitudes of the source and the same point from shoreline.

- The ground elevation: It controls the run-up height of the event. The high the height of the tsunami wave in the coastal area, the further the distance of inundation inland.
- Total population: Here, a large number of area population implies a difficult evacuation process and high number of victims can be encountered. This factor was used as social impact indicator within the study area.
- Number of elderly and children (based on age): The third of the total population are children. Both children and elder are more vulnerable to the power of tsunami wave and less likely saved. In this study, the definition of age group in the total number of children (0-14 years old) and elder (≥ 60 years old).
- Number of poor families: This group has lower ability to have substantial house that can be used as shelter, they have less access to health services and few resources to aid in recovery from a tsunami event. In the other hand, high class family can quickly recover from tsunami event loss because of their insurances.

4.3.3.2 Weighting and scoring method

The weighting and scoring method of each factor of vulnerability varied with respect of the study area and the risk severity due to:

- Factor matching a much or low contribution in determining the tsunami vulnerability area.
- The difference in contribution of each level in the relevant factor.

Table 4.2 presents the distance from the shoreline and ground elevation equally weighted (40%). All those factors would have a considerable effect within the coastal area if tsunami occurred there. The table 4.3 represents the weighting and scoring values for social vulnerability components.

Table 4.2: Classification, Weighting and Scoring for physical factor

Factors	Class	Score	Weight	Total
1. Distance from Shoreline				
a. <400 m	High Vulnerability	3	40	120
b. 400 – 600 m	Medium Vulnerability	2	40	80
c. > 600 m	Low Vulnerability	1	40	40
2. Ground Elevation				
a. < 2m	High vulnerability	4	40	160
b. 2 – 3m	Medium vulnerability	3	40	120
c. 3 – 4 m	Low vulnerability	2	40	80
d. > 4 m	Very low vulnerability	1	40	40

Table 4.3: Score and Weight for socio-economic factor. **Source**: Cutter and al.(1997)

Factors (a)	Number (b)	Proportion (c) *	Score (d) **	Weight
1. Social				
a. Total Population	P	b/Total Population	c/max. of proportion	25
b. Children	Cd	b / Total Children	c/max. of proportion	25
c. Aged**	A	b / Total Aged	c/max. of proportion	25
d. Disable people	DP	b / Total disable	c/max. of proportion	25
2. Economic				
a. Poor family	PF	b/Total poor family	c/max. of proportion	50
b. Fisherman	FM	b/ Total fisherman	c/max. of proportion	50

* Determine the percentage of the factor in the area to total number in one sub-area

** Value of scale for all social and economic variable

*** Number of elders and children.

The method shown in this table presents one way to represents vulnerability values to a cumulative and spatial score. For the classification of social and economic vulnerability factors, the higher score will be more vulnerable than the lower scored value. The weight and scored value for this corresponding area is calculated and presented in chapter five.

4.3.4 Risk assessment

The risk is a function of the hazard and its vulnerability. It does mean that a high inundation is not automatically at high risk. On the other hand, a high vulnerability area is not necessary or automatically at high risk. According to the International Strategy for Disaster Reduction (ISDR,2002), the risk assessment is calculated from:

$$Risk(R) = Hazard(H)xVu\ln erability(V) \tag{4.4}$$

H = Hazard Inundation Zone Score and V = Total Vulnerability Score.

Hazard represents the location intensity and probability of the hazard, while the probability represents the physical, social and economic component that affects the hazards.

4.4 Data Processing

4.4.1 Map preparation

Processing data for the analysis and assessment, three types of data have been used. The details of each of them is given in the next two sections.

4.4.2.1 Digital elevation model

A digital raster data format, Digital Elevation Model (DEM) has information about coordinate positions (x, y) and elevation values (z) in each grid pixel. It is used to describe the topographic condition of Göcek Bay area. In this case, as started in figure 4.2, DEM is used for analyzing the hazard and physical vulnerability assessment.

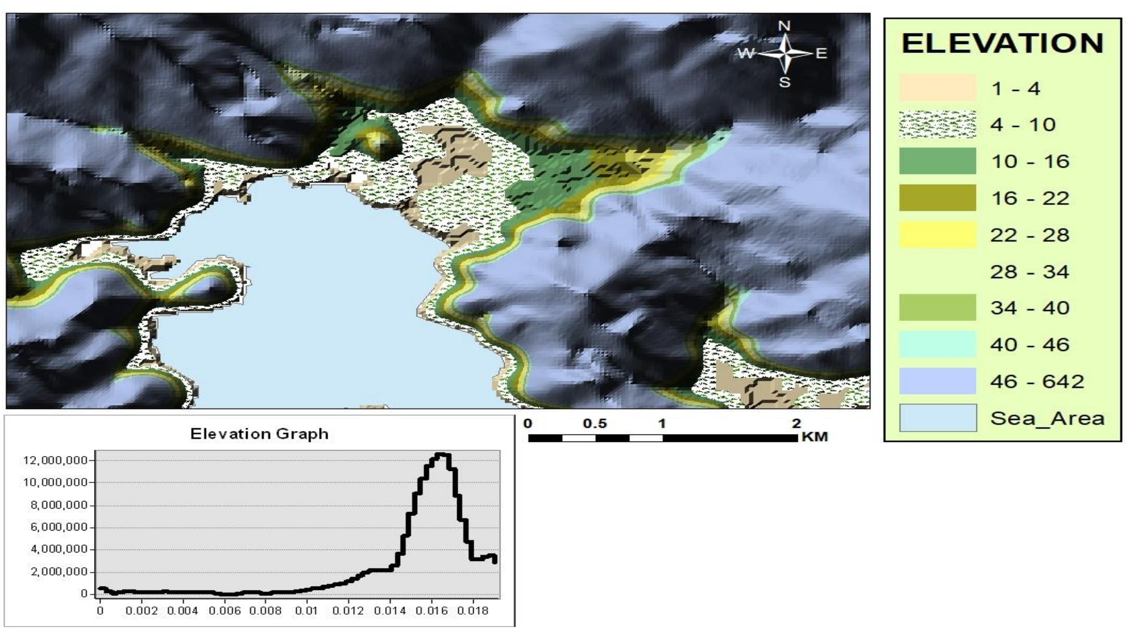

Figure 4.2: Digital Elevation Map

The digital elevation model is generated by analyzing elevation data. In this study, from the topographic map, the data is derived from the spot height, and elevation points. When the data are combined, the elevation point is computed using triangulated irregular network (TIN) 3D analysis method because it is an appropriate way for creating elevation surface as it generates surface through gaps between known points.

4.4.2.2 Land use and cover

The land use maps are created by serving of the urban planning maps. In this study, major land uses, such as building (industries, residence area, etc.), public place, vegetation, grass fields, road, etc. are the most representatives.

The land use maps were use in this case to output the area of each land use that is located within each zone at risk from tsunami in Göcek Bay area.

4.4.2.3 Satellite image data processing

In this study, GIS used another input data which is satellite imagery. Those data are downloaded and processed with ASAPLANET-160707. Moreover, the image data has been rectified to get the explicit geometric and radiometric distribution features on the earth surface (World Geodetic System: WGS84) projection. Finally, the image was edited to increase its quality for efficient analysis processing.

4.5 Output

In order to perform effective analysis, data have been aggregated and operated and then visualized the analyzed results. For each output map, the analysis is shown in separate map: hazard map, risk map and the social and economic vulnerability map.

In this study, the spatial resolution that considered for data processing was grid cell within 5m x 5m. The scale of mapping outputs used was 1:30.000. This resolution is used is for synchronize all input data having different spatial resolution, and to create detailed maps for the actual problem. The output map data is presented in chapter 5.

5. RESULT AND DISCUSSION

5.1 Research Framework

The framework reflects activities needed to present assessment process. It consists of three different stages: (i) hazard assessment, (ii) vulnerability assessment and (iii) Risk assessment. To determine the assessment, the tsunami run-up occurred in the respective area is also to be known as well. The vulnerability factor determines the vulnerability assessment of that study area. This assessment includes three factors influencing vulnerability such as physical, social and economic vulnerability. Furthermore, hazard assessment and vulnerability assessment are combined together to determine the risk assessment.

The research framework can also be used to as a model for coastal area management for Turkey risk assessment. The detail explanation has been shown in figure 5.1.

By that, the output map for this study has important impact and shows tsunami inundation zone, the risk map, physical, social and economic vulnerability distribution.

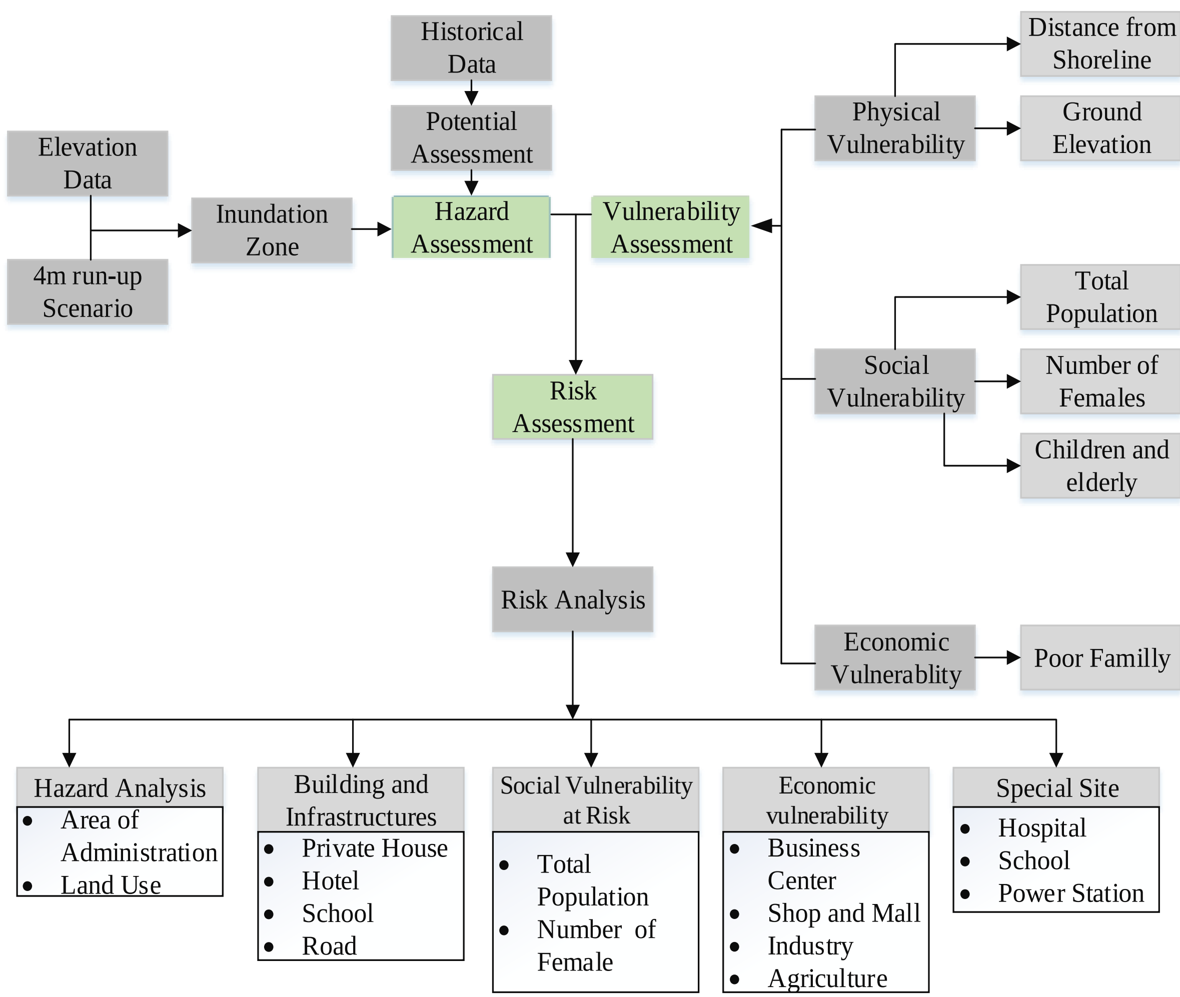

Figure 5.1: General Research Framework

Hazard assessment framework has considered individual or institutional perception about the risk. Therefore, for practical vision, the assessment is flexible to be used and understandable by different local institutional managers.

5.2 Hazard Assessment and Analysis

5.2.1 Risk potential assessment

5.2.1.1 Historical records

As it has been explained in chapter four (Section 4.2), data serves to determine the probability of next tsunami event of occurrence. The historical data of tsunami and according to submarine earthquakes are listed in table 5.1.

Table 5.1: Historical Submarine Earthquakes data

Date	Location	Tsunami Source		Tsunami Parameters	
		Event Dept.(km)	Magnitude	Tsunami Intensity I_i	Run-up Height (m)
April 24, 1957	Gocek Bay	35.00	7.20	I_1	3.00
1900	Fethiye regions	10.00	6.00	I_2	4.00

From this historical data, it is possible to calculate the tsunami probability of different intensity scale K_0. This intensity and the method calculation is outlined in section 5.2.2. Table 5.2 shows tsunami result from 1900 to 1957 (57 years) that Fethiye Gocek Bay region had and shows that during this period only one tsunami event occurred. This result and according to Cutter formula shows that after a period of 57 years there should be a tsunami event in this study area.

Table 5.2: Tsunami Occurrence Probability Calculation

Tsunami Intensity K_0	Wave Height for Intensity scale	Number of Event	Probability / Retur Period (Year).
I_1	+1.8	1	**57**
I_2	+1.3	No data	**No data**

Hence, the historical data are much important in analysis and assessing the tsunami risk by determining the possible risk occurrence probability. This probability helps decision maker to move procedure to the final stage of hazard management (chapter 4).

5.2.2 Hazard assessment

5.2.2.1 Tsunami intensity calculation

Tsunami effect regardless of its causes is directly proportional to the intensity and its wave. The idea is to relate the intensity of the tsunami wave with the possible magnitude and the run-up value. The run-up height is functional of the structure, shape, water depth, or the structure and wave characteristics. These tsunami variables are important and useful for risk mitigation and planning. Whenever the tsunami intensity and run-up value are known in advance, it is easy for the risk planners to identify the risk area, and then the mitigation can be effectively defined and developed.

Iida et al. (1967) developed the concept of tsunami intensity in function of tsunami height defined as:

$$I = \log 2(H) \tag{5.2}$$

Where, I as the tsunami intensity and H is the location run-up height.

The data from historical archive permits us to calculate the corresponding tsunami intensity I by using the formula number 5.2 as it is started from table 5.3.

Table 5.3: Tsunami Intensity from Historical Data

Use Case	Magnitude	Run-Up	**Intensity**
April 24, 1957	7.20	3.00	**1.585**
1900	6.00	4.00	**2.000**

From the available case of tsunami risk in the study area, the run-up value did not exceed 4m level because the low wave intensity from the tsunami source.

The study provides a possible next tsunami occurrence and the table 5.4 presents as started in the risk map (figure 5.5) the intensity and magnitudes of the proposed cases. In order to present the different cases scenario, the run-up value is assumed from 5m and above and the magnitude varies from 5m up to 10m according to the historical data.

Table 5.4: Assumption of Possible Tsunami Intensity

Use Case	Run-Up	**Intensity**
1	5	**2.322**
2	6	**2.585**
3	7	**2.807**
4	8	**3.000**

The supposed list of scenario shows that the more the intensity I, the high the run-up of the tsunami is considerable and the inundation distance increases. The relation between the run-up and the inundation distance is shown figure 5.2.

5.2.2.2 Tsunami inundation zone

Inundation area is the surface whereby from the sea level water tsunami wave penetrates and floods it with water. This permits tsunami risk manager to determine both the run-up height, the inundation distance and the flow depth (tsunami height). Figure 5.2 shows what can be tsunami inundation zone, and how it impacts on determining other risk factors.

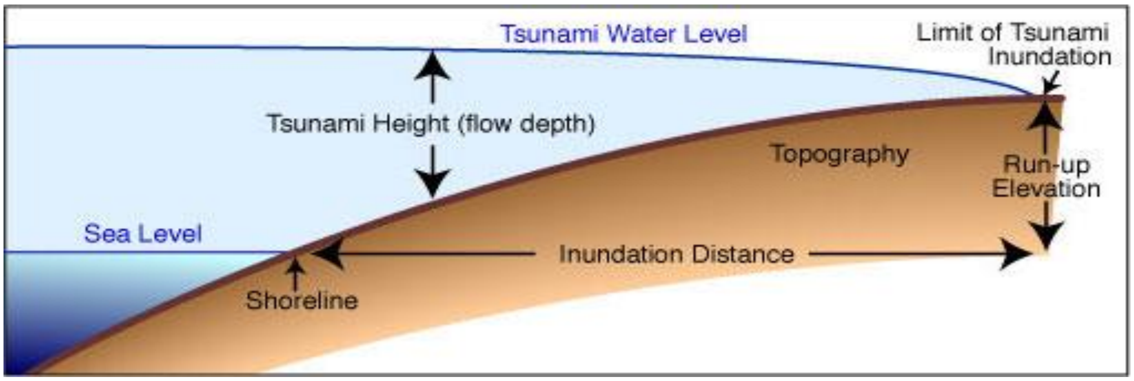

Figure 5.2: Inundation Distance(Source: https://walrus.wr.usgs.gov/)

Fethiye Gocek Bay April 24, 1957 tsunami event had a 35.00km of flow depth where the run-up height was 3.00 m (table 5.1). This shows that in some cases, the higher the flow depth the greater the value of the run-up height. In this regard, the impact of the risk event is much considerable in such a way the mitigation and recovery become the real deal in the municipality management processes.

Furthermore, the main problem of this research is to assess the risk effected after its occurrence. And due to lack of reliable geo-spatial and historical data in the coastal area, the prediction and efficiency of the result was not to notify.

Fethiye Göcek village has prepared a report of historical data in order to create database. Data include population living in building, number of elder and children, the elevation data, etc. Digital elevation map was prepared from 1:30 000 scaled topographic map (figure 2.2). It has been used to determine the elevation of road and building, the number of affected building and the building vulnerable to be affected. The figure 5.3 shows the inundation map presenting the areas ender the risk.

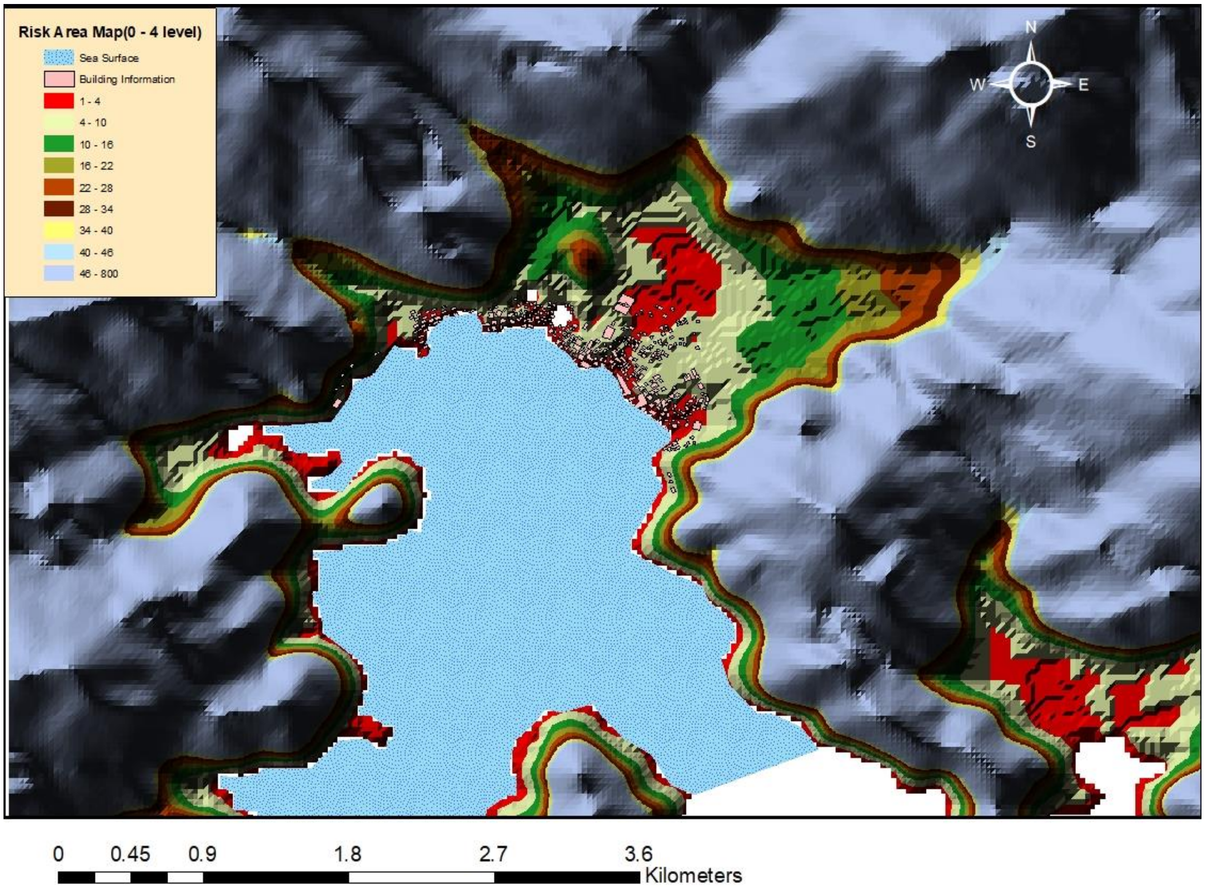

Figure 5.3 : Tsunami Risk Map from 0 up to 4 level of elevation

The area with light color has the lowest distance (height) from shoreline. The building in red color area are affected while those in gold color are not. The result shows that the less the distance from shoreline, the more the corresponding area is affected by the severity of the risk.

5.3 Vulnerability assessment and analysis

5.3.1 Physical vulnerability

Physical vulnerability presents the lack of facility of individual group of the corresponding study area to anticipate, cope with, resist and recover from the impact of tsunami risk. Two factors affect this vulnerability: (1) distance from shore line, and (2) ground elevation (chapter four). The scores of the different physical vulnerability parameter are presented in table 3.1 below.

- The distance from shoreline impacts the damage level and the event causalities. The further the distance from shoreline, the high will be the run-up height and inundation area of tsunami wave.
- The ground elevation in the other hand, affects the level of tsunami run-up height. The high the tsunami wave height, the high the distance of inundation area depending on the elevation rise.

The result of this study shows the vulnerability rank for each and every vulnerability component and its impact.

5.3.2 Social vulnerability

The social vulnerability explained how Fethiye Göcek Bay region is vulnerable on tsunami in function of its demography, number of age group (Children and Elders). The distribution of the social category is respectively represented in chapter three (section 3.2) and chapter four (section 4.3.3.2). This vulnerability data determines social category having the highest level of vulnerability. The selected category is mostly vulnerable because of its lack of capacity to cope with the hazard risk phenomena. Table 5.5 represents the social category repartition.

Table 5.5: Social Category Repartition (2016)

Factors (a)	Number (b)	Proportion (c=b/t)	Score (d=c/Max(c))	Weight	Total
c. Aged	433	0.094	0.691	25	17.30
d. Children	626	0.136	1.000	25	25.00
Total Population: 4606					

With the total number of population in the area, the number of old people has less meaning while the number of children is considerable. By that, the vulnerability effect is much high in children population group. The vulnerability ranks of each and every social category is shown in the graph below (figure 5.4).

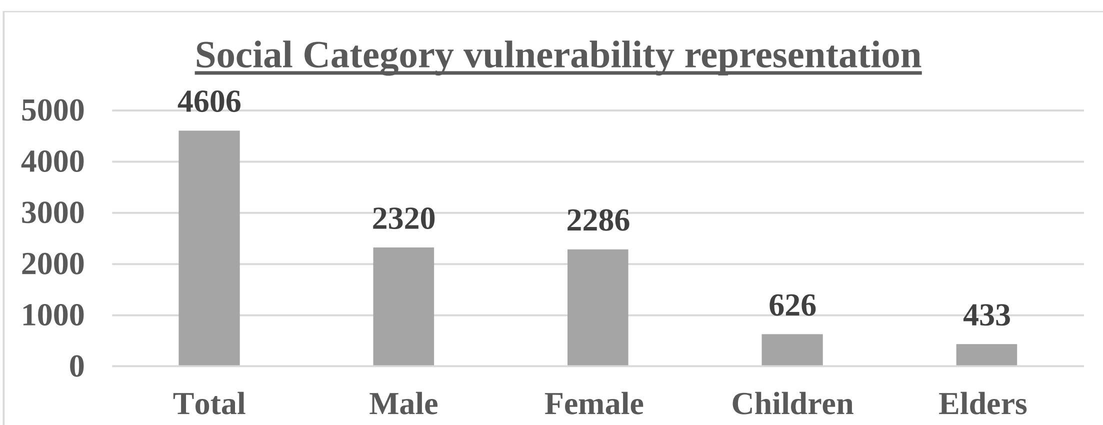

Figure 5.4: Social Category Vulnerability Representation

5.3.1 Economical vulnerability

Like social vulnerability, economic vulnerability reflects how the level of life is different from one social category to another in terms of economy. People having different income level are affected accordingly by the same event and in the same location. In this regard, poorest people will have much to deal with the potential disaster impact.

Agriculture, fishery and tourism are three economic activities which positively impact the gross domestic income of all area (Fethiye). Actually the town has omitted those activities for its attribution of celebrity and everyone is depending on tourism. Göcek has the highest economy level of the region (Fethiye) because of its agriculture and animal husbandry activities. In line of this, the increase of demand for yatch and tourism accommodation, the number of shop and restaurant has been increased. The table 5.6 shows the economic contribution of the surrounding region in comparison of the study area.

Table 5.6: Economic Factor of the Study Area with its Surrounding Area

Area	Economic Vul. Score (EV Score) TL	(EV Score)%	Class
Ciftlik	80 000	0.4	**High Vulnerability**
Karaculha	1 105 000	5.6	
Oludeniz	2 800 000	14	
Camkoy	5 200 000	26	
Gocek	**10 500 000**	**53**	**Low Vulnerability**

5.1 Discussion

The tsunami assessment is the first objective of this study for providing an assessment of Gocek tsunami event. In this study area, historical data shows that the tsunami hazard has a considerable threat specially in coastal area. Two types of measure can be applied to reduce the damage from the hazard. There is structural measure conceived as expensive like sea walls, break water, etc. And non-structural measure including land use management and building zoning and infrastructure relocation, preparedness for emergency to coastal community, and public education facility so that local people can be able to understand the hazard and its nature.

Tsunami characteristic data are important to determine the probability of occurrence, including the date, the magnitude of the event, the impacted area, the run-up, the maximum inundation (chapter 4). This probability helps local government, disaster planers and emergency manager for decision making. To make people prepared for tsunami risk, they have to be concerned on it, and agree with the risk severity in function of the magnitude.

In this case, the goal was to provide a tsunami hazard assessment by multitude spatial data and produce sufficient for the assessment. Some scenarios are used by using the location based tsunami run-up value from historical data and then determine the inundation and the risk area.

According to the result, the risk severity of next possible tsunami   will be high because of the increase number of building, industrial activity and coastal infrastructure in the coastal area.

The inundation map used to identify and evaluate the location of public infrastructure in coastal area (figure 5.3). This can be used to identify which side of the area the relocation procedure should be used. The map can be used to communicate the local agency, local resident, tourists about preparedness and response in case of tsunami event.

The study used set of assessments, locates and determines the physical, social and economic vulnerability to any tsunami hazard in Göcek region. In this study, physical aspect determines the vulnerability area in function its physical settlement, such as distance from the shoreline and the ground elevation. But the social vulnerability explains the vulnerability based on the social conditions such as number of people, number of female, age group. By analyzing those vulnerability types, local government has clear idea regarding where a new development has to take place.

Physical, social and economic factor used here are from available parameter from municipality and several research study in the same area of study. Furthermore, the clearer are the vulnerability parameter, the more detailed the assessment can be developed.

The risk assessment represents the inundation map showing the possible vulnerable area having impact on the physical, social and economic level, and the coastal infrastructure as well. Risk assessment is important and guides the risk management stakeholders in order to know which area, coastal infrastructure, or social group is mostly in risk of the tsunami severity. When the assessment result is found, all parties are allowed to focus on the available and limited resources for the evacuation, recovery or rehabilitation. Moreover, they should locate the risk and determine the significance of the risk both quantitative and qualitative.

The risk is the expected loss from actions between the tsunami hazard and the area vulnerability condition. The tsunami inundation map (figure 5.3) is the final result from its assessment. It is clear from the risk distribution that the region represents some area with high risk of tsunami because of the its increase number of female, industrial activity growth, or the lower economic level of any social category.

For future mitigation development, risk manager should set measures of people preventing from tsunami wave prone area. By that, GIS specialist has the responsibility of mapping the potential exposed area at the same time with the mitigation process. Figure 5.5 show from level of 5m of elevation the different risk area.

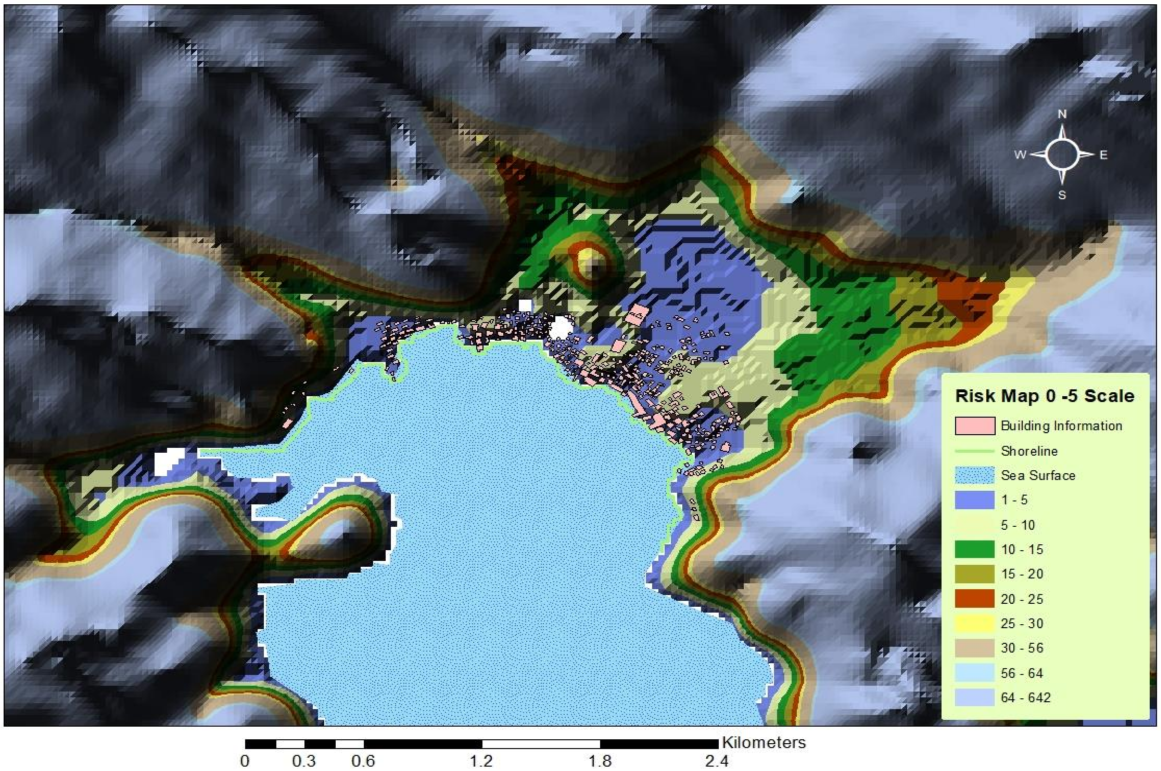

Figure 5.5: Risk Map 0 - 5 Scale

This result used elevation data and physical components GIS overlay with administrative boundary and spatial components, land use and land cover, in order to identify the risk area. The risk analysis framework is represented in figure 4.1.

6. CONCLUSION AND RECOMMENDATION

The historical data of different earthquake and tsunami events are used to identify the highest tsunami run-up for the hazard analysis and assessment. According to the historical data the worst case tsunami run-up value in Göcek Bay area was up to 4 m in April 24,1957. For better assessment, this 4m of run-up led to 5m.

The compilation of hazard and assessment is the tsunami event risk map which results the risk assessment. The total vulnerability combines both physical, social and economic factors. To analysis the actual problem, the risk map is the overlaid of the elevation data with the land use and cover satellite image to identify the impact of the event on both vulnerability factors.

Three stage are explained in the general research framework which are the hazard, vulnerability, and its risk assessment. It serves to local government, disaster planners, and emergency manager depending on the resource availability for decision making and strategy plan. This framework can also be used for modeling other coastal areas. The map data played an important role for to determine tsunami inundation zone, the event distribution analysis and completes the assessment by improving the information.

GIS as a set of tools is used to facilitate risk assessment process, and map the tsunami hazard in management by efficient analysis, and upgrade spatial data from existing data of this specific study area. The map results can be used for tsunami preparedness mitigation program.

According to the present study, it is important for the Göcek area to have an effective tsunami preparedness and its corresponding mitigation program. The local and central authorities are recommended to:

- Consider the risk management in all type of coastal area development, social life, economic and education activities.
- Conduct ın both sides all type of educations about coastal prone area presenting a considerable impact of society.
- Propose accordingly a special mitigation program framework to the exposed area and its corresponding population.
- Analyzing risk area by proposing different cases to determine the possible event occurrence.
- Obtain better result by using numerical and GIS technology.

This type of analysis can be used for other coastal communities and local government jurisdiction in Göcek area, and the central authority and all tsunami vulnerable countries as well.

An important stage of risk management is the communication in cases of disasters. Beside the communication between any type sensor technologies and the risk management control Center with its geo-spatial servers, communication is needed to develop a type of alarm to vulnerable society and to keep frequently contact with the shelter teams.

Today there is still a weak point in all over national coastal risk management. Several and good ideas and concepts could not provide efficient solution due to lack of coastal tsunami risk data or lack of good financial condition to handle the problem. However, it is much easier for decision makers to start new activities, if the problem is well defined with all respective detail in a well-balanced way. Scientists usually have a lack of knowledge how to present the results even they have nice tools to build scenarios and simulations.

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APPENDIX A.1

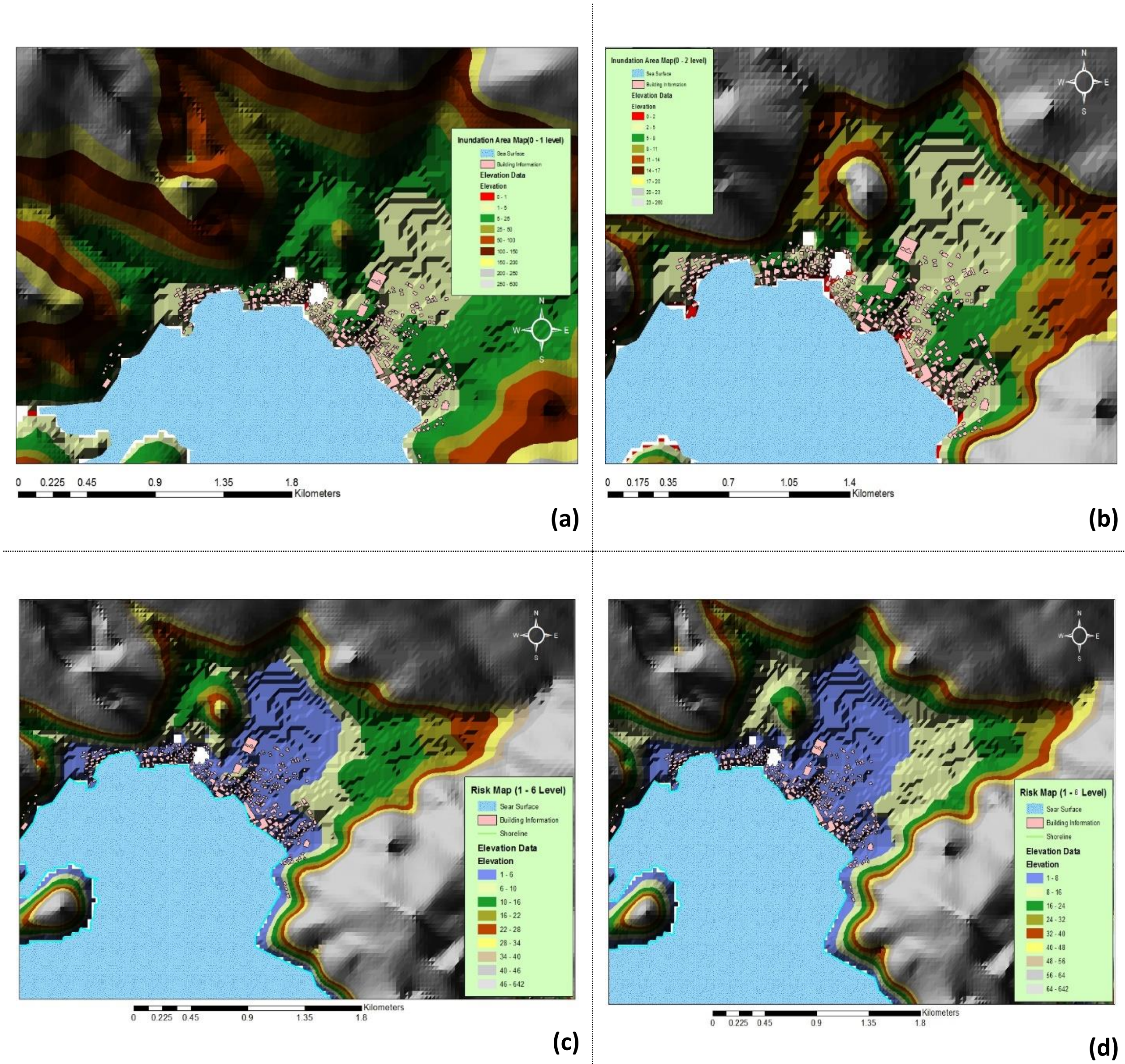

Figure A.1: Other Map scale: (a) Inundation Map (0 -1, 0 - 2 , 1 -6 and 1 – 8) scale

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