ASSESSMENT OF SEA LEVEL RISE FOR COASTAL ZONE MANAGEMENT: VULNERABILITY OF FETHIYE BAY

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ABSTRACT

ASSESSMENT OF SEA LEVEL RISE FOR COASTAL ZONE MANAGEMENT: VULNERABILITY OF FETHIYE BAY

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Low-lying geographies are quite attractive and preferable for the populations in terms of settlement, agriculture and tourism. Based on the recent findings of archaeological research, it can obviously be seen that people has generally settled and developed civilizations on low-lying areas.

As one of the impacts of global climate change, accelerated sea level rise mainly due to thermal expansion of surface waters has become a growing threat especially for low-lying areas worldwide. Among the most profound impacts of sea level rise, coastal erosion, inundation of lands, flooding of coastal areas due to increased storm surges and salt water intrusion to fresh water resources (Ozyurt, 2010) come into prominence in the long term.

Fethiye as an attractive touristic destination in Turkey is exposed to many hazards like tsunamis and earthquakes throughout the history (Minoura et al. 2000). Topographical characteristics of this ancient town of Turkey, brings its importance into forefront in terms of the need for its coastal vulnerability assessment within the CVI (Coastal Vulnerability Index to Sea Level Rise) Model and FCVAM (Fuzzy Coastal Vulnerability Assessment Model) (Ozyurt, 2010).

The main objective of this thesis is to determine the vulnerability of Fethiye in order to be a guide for decision makers in taking measure and preparing adaptation plans for its sustainability in the long term scale. Within the scope of this thesis, the vulnerability assessment studies with both fuzzy logic and parameter based basic version are conducted and compared. The preliminary model result gives the coastal vulnerability level as high-moderate, but the fuzzy coastal vulnerability assessment model obtains vulnerability level within the moderate range. In light of the results of both model studies, inundation, coastal erosion and flooding due to storm surge rank in vulnerability priority as the most salient coastal impacts of sea level rise. This study aims to give an idea for authorities and decision makers on the optimal resource allocation and adaptation plans in the sense of coastal zone management practices.

Keywords: Coastal Vulnerability Assessment, Sea Level Rise, Geographic Information Systems, Fuzzy Logic, Fethiye, Coastal Zone Management

ÖZ

KIYI ALANLARI YÖNETİMİ AÇISINDAN DENİZ SEVİYESİ YÜKSELMESİNİN DEĞERLENDİRİLMESİ: FETHİYE KÖRFEZİ KIRILGANLIK DERECESİ

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Alçak rakımlı araziye sahip coğrafyalar, yerleşim, tarım ve turizm faaliyetleri açısından toplumlar için oldukça ilgi çekici ve tercih edilir olmuştur. Insanların genellikle bu alçak arazilere sahip bölgelerde yerleşik hayata geçtiklerini ve medeniyetlerin bu coğrafyalar üzerinde geliştiğini son yapılan arkeolojik araştırmalar açıkça göstermektedir.

Küresel iklim değişikliğinin etkilerinden biri olan ve genel olarak yüzey sularının ısısal olarak genleşmesi sebebiyle yükselen deniz seviyesi özellikle deniz seviyesindeki ya da deniz seviyesinin altındaki araziler için büyüyen bir tehdit oluşturmaktadır. Deniz seviyesi yükselmesinin en şiddetli etkileri arasında; uzun vadede, kıyı erozyonu, karaların su altında kalma tehlikesi, yükselen deniz kabarması ve tatlı su kaynaklarına deniz suyunun nüfuz etmesi dolayısıyla kıyı alanlarını su basması riski ön plana çıkmaktadır. (Ozyurt, 2010).

Ilgi çekici bir turistik merkez olan Fethiye bölgesi, tarih boyunca deprem ve tsunami gibi çeşitli felaketlere ev sahipliği yapmıştır. (Minoura et.al., 2000). Bu antik kentin topografik özellikleri, deniz seviyesine karşı hassasiyet modeli (CVI Modeli ve Bulanık Mantık Yöntemi ile Kırılganlık Modellenmesi (Ozyurt, 2010)) kapsamında yapılacak bir kıyı hassasiyet değerlendirmesi gerekliliği ile kenti ön plana çıkartmaktadır.

Bu tez çalışmasının esas amacı, uzun vadede bölgenin sürdürülebilirliği için alınacak önlemler ve hazırlanacak uyum planları çerçevesinde karar vericilere yol göstermesi amacıyla Fethiye Körfezinin kırılganlık önceliği derecesini belirlemektir. Bu amaç kapsamında, hem bulanık mantık yöntemi kullanılarak hazırlanan hem de parameter bazlı basit model ile yapılan kırılganlık değerlendirmesi çalışmaları gerçekleştirilmiş ve iki modelin sonuçları karşılaştırılmıştır.

Parametre bazlı basit model sonuçları, kıyı kırılganlık derecesini yüksek-orta aralıkta hesaplamakta olup bulanık mantık yöntemi kullanılarak hazırlanan kırılganlık değerlendirme modeli sonucunda ise bu derece orta aralık olarak belirlenmiştir. Gerçekleştirilen iki model çalışması sonuçlarının ışığında, deniz seviyesi yükselmesine karşı en çarpıcı etkiyi sırasıyla, karaların su altında kalma tehlikesi, kıyı erozyonu ve yükselen deniz kabarması dolayısıyla kıyı alanlarını su basması riski göstermektedir. Bu çalışma, karar verme yetkisine sahip resmi makam ve mercilere, kıyı alanları yönetimi uygulamaları açısından kaynakların en iyi dağıtımı ve uyum politikaları konularında fikir vermeyi amaçlamaktadır.

Anahtar Kelimeler: Kıyı Kırılganlık Değerlendirmesi, Deniz Seviyesi Yükselmesi, Coğrafi Bilgi Teknolojileri, Bulanık Mantık Yöntemi, Fethiye, Kıyı Alanları Yönetimi.

***To All Vulnerable Systems*,**

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“A good teacher is like a candle – it consumes itself to light the way for others.”

Mustafa Kemal Atatürk

In light of this quote, I would like to express my pleasure for having the opportunity to be one of the enlightened students of the lovely people in the Coastal and Ocean Engineering Laboratory.

Beyond all the academic work, this thesis is a product of all the smiles that I picked up from the family with whom I spent three years with. Unless those lovely people come together in the most peaceful area of natural diversity out of the building in the campus, I would probably have limited memories consisting of only lectures, laboratory sessions, projects, and thesis work.

I would like to express my sincere gratitude to my supervisor, Dr. Gülizar Ozyurt, for her inspiration and incentive attitude during my hard times. Working with her always motivated me to work hard, be diligent and do better.

I would like to thank warmly Prof. Dr. Ayşen Ergin for the joy of life and enthusiasm she gave whenever I saw her. Beyond her academic illumination during the lectures, I am proud of being one of the countless students whom she shaped their future.

I feel gratitude to Prof. Dr. Ahmet Cevdet Yalçıner for the vigor he provided by his smiles, his humanist attitude, and his vision of world. I have always been motivated by what he taught about life as well as the academy, and his memories about Subaqua Society. During my graduate years, I learned many things on letting a person free on her/his thoughts, not directing but guiding.

I am thankful to Dr. Işıkhan Güler for teaching me how to stand out against obstacles and negativities. I also learned many things from his informative talks on business life.

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Beyond my gratitude to all these people, I owe my family a debt of gratitude for providing me insight and tolerance (and all other things I need) in the course of my life.

Life is a combination of joy and sorrow that which one you will face with depends on your attitude to life and your internal peace. This thesis work helped improve my attitude towards life in various ways and I am thankful for this experience.

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LIST OF SYMBOLS AND ABBREVIATIONS

SLR	: Sea Level Rise
GHG	: Green House Gas
GIS	: Geographical Information Systems
FCVAM	: Fuzzy Coastal Vulnerability Assessment Model
CVI	: Coastal Vulnerability Index
CO2	: Carbondioxide
EAE	: European Environment Agency
CZM	: Coastal Zone Management
IPCC	: International Panel on Climate Change
WG1AR5	: The Fifth Assessment Report: Working Group 1
WG2AR5	: The Fifth Assessment Report: Working Group 2
RCP	: Representative Concentration Pathways
HES	: Hydroelectrical Power Plant (in Turkish)

CHAPTER 1

INTRODUCTION

Coastal areas are preferable for most people due to the aesthatetical, climatic and logistic reasons. The more people move to seaside regions, the higher population rates are observed. Especially low-lying areas owing to its topography are very attractive to build, to settle, to be engaged in agriculture, to obtain the food as one of the primary concern of people to survive.

On the other hand, coastal regions are the most vulnerable areas in terms of the allocation and utilization of resources and open to danger if no geographical protection surrounds them like a shell or mountain. These geographies can easily be exposed to sea water intrusion unless fjords or high mountains protect them from the hazards of open-sea.

Considering the rising of global sea level, utilization of freshwater resources become more of an issue especially in coastal areas which is the boundary between salt water and freshwater. It is necessary to determine the priorities before taking measures for the adaptation plans to be prepared to a probable upcoming hazards.

One method to determine the current situation of any area is to use a vulnerability model. There are many vulnerability models in the literature with different complexities such as parameter based, numeric, simulation (scenario) based dynamic models. Hayhoe et al. (2011) stated that any kind of vulnerability assessment is a representation of a systematic response model which could be as ordinary as a conceptional model based on box-arrow diagrams or as complicated as a geospatial model considering the changes in distribution and types of elements. (Dubois et al., 2011). The fundamental advantage of a parametric model is the simplicity whereas the representative parameters can often be insufficient to represent the changes in a natural process. On the other hand, numerical (process-response) models are more complicated to adapt the variables in a situation due to using linear or nonlinear modeling equations but a very convenient tool in terms of best representation of the hydrodynamic conditions. Due to the variety of parameters and sometimes insufficient data, it might be inadequate or impossible to apply each vulnerability model to all regions around the world. Hence, a variety of vulnerability assessment models is generated or modified in accordance with the needs of the vulnerable region.

Vulnerability assessment studies lead us to find out the main problem in an environmental mechanism. They also help to better understand where the communities are of the vulnerability range, what kind of preparations do the communities need and what the damage level will be in the case of any hazard. The vulnerability assessment studies play salient role in the sense of coastal zone management practices since the results of the studies guide the decision makers to make mitigation policies and adaptation plans for a vulnerable system.

1.1 Objective of the Study

The main purpose of this thesis is to assess the vulnerability priority of Fethiye Bay by considering physical and human based parameters and also to raise awareness on the upcoming threat of global sea level rise. The vulnerability assessment is conducted by two different methods. In the parameter based basic version (Ozyurt, 2007) which is called preliminary model, for the entire shoreline, a representative value is considered for each parameter. Nevertheless, it is understood that a single value can be misleading in the representation of the whole part. Thus; the fuzzy coastal vulnerability assessment model (Ozyurt, 2010) is utilized by examining the shoreline in detail by dividing it into many segmental pieces. Each coastal segment is represented by twenty different parameter values throughout the shoreline. Moreover, each segment within a certain parameter has to have different value than others within the same parameter class. The results of the fuzzy coastal vulnerability model study are then compared with the results of previous preliminary study of the author and her team (Ergin et al., 2012), which is based on basic mathematical operations. The comparison between the models is made in order to understand the reliability and practicability of the fuzzy model. In this way, the vulnerability priority of Fethiye Bay against various marine hazards in the short and long term can obviously be specified.

The model is sustainable and useful for further studies in order to determine the vulnerability of the coastal areas to sea level rise. Additional contribution of the study will be a mentor for decision makers and politicians in the preparation of mitigation strategies and adaptation plans against sea level rise from the point of coastal zone management especially before the situation takes a turn for the worse since global sea level rise is accelerating more than expected.

1.2 Outline of the Thesis

This thesis covers six main chapters including the introduction part. In this chapter, the study is introduced superficially. The next chapter will mention the previous studies on global climate change, global sea level rise, and vulnerability assessment. Then, third chapter will describe the coastal vulnerability assessment methodology and its implementation in the study area in detail. The fourth chapter will give the detailed information about the study site, the input parameters of the fuzzy model, a brief summary on processing the model. The fifth chapter will present the model results, the comparison of preliminary and fuzzy model results, different variations in the implementation of the model and the discussion part. The comparison of the two model will have the feature of being a control point for the reliability and practicality of fuzzy model. Finally, in the conclusion chapter, the study will be concluded and future recommendations will be specified.

CHAPTER 2

LITERATURE SURVEY

Considered the upcoming threat on sea level rise, an awareness on global change of climate and consequentially accelerated rise of sea level has been growing worldwide. A number of research studies and many approach models and scenarios to estimate the probable rise of seawater level in near future and to determine where we are currently of the climate cycle have been carried out for the last two decades although first recognition of the warming was in early beginnings of 1900. Authorities had regularly started to record the climate measurement and collected a great number of records at a wide range of stations worldwide in 19th century that it is realized and announced by 1930s that there had existed a salient rising trend in the measurements. Despite the insistence of some researchers on being in a cooling phase in near trend, it is noticed in a short span of time that this cooling period was temporary when the whole cycle is taken into consideration. (Edwards, 2010).

A worldwide institution, IPCC, deals with the global warming and its impacts for the future. IPCC organization arranges regular meetings and conducts projects that their assessment reports are published periodically after each year's meeting. Beside IPCC, many authors make research about the periodic circle of global warming and cooling process and the impacts the populations faced with in the past. Based on all these researches, they give salient efforts to make a prediction for the future in order to make mitigation and adaptation plans in adequate scale. All the graphs, the equations, the studies and efforts are done to remove the uncertainty.

Considering the worst case scenario among all research studies which require more than adequate amount of resource and time, the global economy probably may suffer from insufficient allocation for all mitigation activities. On the other hand, in the consideration of best scenario which underestimates the threat, some cities around the world may eternally submerge underwater in the next century. In this frame, the significance of removing uncertainity in expected rising level of seawater become a current issue that model studies and measurements are carrying out to lessen and even to remove this uncertainity.

The effort to remove this uncertainty necessitates a certain amount of investment from all countries. The cost of mitigation can be financed by conventional investment so long as borrowing from future generations as being the real beneficiaries of climatological investment. (Foley, 2007).

2.1 Global Climate Change

The earth history witnessed many fluctuating cycles based on thermal change that affects climate and all its related subjects.

Climate change refers to a change and the continuation of the climatic conditions which can be measured by using statistical methods in a time period due to the result of a natural process or human facilities. Global climate change will create surface temperature rise of oceans, sea-ice covers reduction, various changes in salinity rate, ocean circulation and wave climate. (IPCC, 2001).

Among the reasons of rapid global climatic change, emissions of CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 are effective in warming of the climate. The term of land use change can describe the concentrated emissions of CO_2, CH_4, N_2O due to deforestation, biomass and burning, deterioration of biomass due to lumbering and deforestation, peat fires. (IPCC, 2007).Global greenhouse gas (GHG) emissions have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. (IPCC, 2007).

Recent findings indicate that global warming is presumably due to increasing amount of carbondioxide released from fossil fuels as one of the main impact of human activities.(Crowley, T., 2000, McCarthy et al.,2001, Coughlin, S.S., 2006).

The concept of 'human dimensions of global resources change' lays a burden of being cause and effect on communities which have been seen as contributing causes of global resource change as well as exposing to the impact of global hazards. (Biermann et al., 2004)

Removing the risks of global warming is not possible since emissions of carbon dioxide as human contribution into atmosphere have been confined in the atmosphere for over a hundred years unlike classical air polluted elements confined only a few days at most. Similar to the necessity of reducing the inflow into a bathtub with a large faucet and a small drain in order to keep the water level constant in a bathtub, keeping global warming steady at the present rate needs a 60-80 percent cut of greenhouse gas emission. Even this stabilization of emission rate requires decades before starting to reduce the rate of global warming. (Victor et al., 2009)

Although it is known by the governments that emissions of CO_2 are caused due to fossil fuel burning of human, the worldwide countries do not serve the purpose on making strict laws to reduce the emissions since the carbon prices are too low for any alteration in practice. However, the arising economic crisis may cause to lower the rate of carbon emissions to a certain degree even but not completely stop. (Victor et al., 2009)

Even if the most successful numerical model approaches to reality with good estimates, the future will always be unpredictable for certainty. Due to this uncertainity, the single chance before taking decision for action plans is to observe and record today beside learning lesson from yesterday. Such a recurrent learning by doing treatment is necessary to follow a sustainable development line.(Campen and Lucht, 2004)

2.1.1 Impacts of Climate Change

It is expected in Europe that climate change will create local differences in natural resources such as an increase in flash flood risk, in frequency of coastal flooding, and coastal erosion due to storm surge and due to sea level rise. Moreover, there will be observed changes in mountainous regions that glacier retreat, reductions in snow cover and winter tourism, and widescale loss of species will be among visible impacts. Climate change projections in South Europe is expected to be worse that especially regions currently vulnerable to climate change will be exposed to high temperatures and drought seasons, reduction in water accessibility, crop yield, summer tourism. Health problems will also arise from heat waves in these areas as inevitable impacts of the climate change. (IPCC, 2007).

According to WG2AR5 (IPCC, 2014), climate change related problems on freshwater resources over the 21^{st} century is projected to increase with the increase in concentrations of GHG and in global population that will lead to freshwater scarcity in low latitudes. Climate change over the 21^{st} century is projected to create a reduction in freshwater quality and to pose threat to drinking water quality. Dry regions will very likely face with drought by the end of the 21^{st} century, whereas water resources is expected to be increased at high latitudes. There will be serious reduction in water accessibility from river and groundwater resources and reduction in water drainage and runoff due to increasing evaporation in Southern Europe. Extreme heat events will create health problems and adversely impact crop production, air quality, wildfire risk. Tropical and temperate regions are projected to face the adverse changes for major crops (wheat, rice, maize). Climate change is expected to negatively affect human health by exacerbatingly especially in developing countries with low income. (IPCC, 2014).

Coastal ecosystems such as mangroves, barrier islands, sand dunes, shingle ridges act as an absorber by storing water and soothing the excessive energy from tidal waves, coastal flooding and storms. Losing these ecosytems such as wetlands is the same as losing part of a structural flood control system. (Sayers et al., 2013). In WG2AR5 of IPCC (2014), it is stated that marine and coastal ecosystems as well as biodiversity are under the risk of being loss especially in the tropics and the Arctic. In the case of medium-to-high-emission scenarios, irreversible changes will very likely occur in the inland and freshwater ecosystems covering wetlands on local scale. (IPCC, 2014).

Although many impacts are expected to be observed on coastal areas, the main driving factor for these impacts will be global sea level rise due to climate change. Since these impacts are required to be understood in order to determine the vulnerability of coastal areas, for this purpose, additional literature is reviewed on global sea level rise.

2.2 Global Sea Level Rise

Sea Level Rise refers to an increase in seawater level mainly due to thermal expansion which can be observed as an impact of the global climate change. In the Fourth Assessment Report of IPCC, the authorities state that scientist insist on that global warming will cause to a negative contribution into the current sea level by the thermal expansion, consequentially inevitable loss of many coastal areas. (IPCC, 2007). It brings out the impacts gradually in the long term with domino effect.

Church and White (2006) and Bindoff et al.(2007) claimed that sea level rise in global scale rose at 1.7±0.5mm/yr for 20th century with an associated mean sea surface temperature of 0.6°C since 1950. The upward trend in temperature appears with 0.4°C/decade for Belgrade, Sofia, Ankara, Baghdad, and Riyadh. (Lelieveld J. et al., 2012)

According to the Assessment Report (AR4) published in IPCC Report (2007), the mean rate of projected sea level rise per century is also taken as 1.7±0.5mm/yr.(IPCC, 2007). Chambers et al. (2012) specified that sea level has been rising by 1.7mm/year for the last 110 years. (Chambers, 2012). Holgate (2007) states that the sea-level rates change year by year while large changes are observed in the early decades of the 20th century with 2.03±0.35mm/yr for 1904-1953, with 1.45±0.34mm/yr for 1954-2003. The highest level observed on 1980 was 5.31mm/yr whereas the lowest level seen on 1964 was -1.49mm/yr. The mean rate of global change of sea-level is taken as 1.74±0.16mm/yr. (Holgate et al., 2007; cited in Mahapatra M. et al., 2013)

Considering the studies conducted upon tide gauge measurement and satellite altimetry, a global sea level rise rate of 1.5 mm/yr to more than 2.0 mm/yr is reported for the 20th century. (Douglas, 2001; Cazenave and Nerem, 2004; Leuliette et al., 2004; Domingues et al., 2008; cited in Carillo et al., 2012). It is stated in the 4th year IPCC Report that a rate of global sea level rise as 1.8 ±0.5 mm/yr for 1961-2003 and 3.1 ±0.7 mm/yr for 1993-2003 is observed. (Solomon et al., 2007; cited in Carillo et al., 2012). Due to being a semi-closed basin connected to the ocean through the Strait of Gibraltar, rate of sea level changes in Mediterrenean basin is always different than the global rate. The study based on tide gauge data and conducted by Tsimplis and Baker (2000) gives an increasing trend in Mediterranean basin with a 1.2-1.5 mm/yr until 1960 and an decreasing trend in the period of 1960 and 1998. (Carillo et al., 2012).

According to the thirteenth chapter of WG1AR5 (5th Assessment Report Working Group-I) which is not an approved assessment report yet but published as one of the working group meetings' report, "it is most likely that global mean rate of sea level rise was determined as 1.7 [1.5 to 1.9] mm/yr between 1901 and 2010 for a total sea level rise of 0.19 [0.17-0.21] m, and the rate was higher at 3.2 [2.8 to 3.6] mm/yr between 1993 and 2010. (Church J.A. et al., 2013).

It is given in WG1AR5 of IPCC (2013), global mean sea level rises vary by different scenarios. Local sea level change is expected to be different than the global mean sea level change (GMSL) projections. (IPCC, 2013).

Table 2.1: Global Mean Sea Level Rises given in WGIAR5 (IPCC, 2013)

	Mean and Likely Range (in m)		
Scenario	2046-2065	2081-2100	2100
RCP2.6	0.24 [0.17 to 0.31]	0.40 [0.26-0.54]	0.43 [0.28-0.60]
RCP4.5	0.26 [0.19 to 0.33]	0.47 [0.32-0.62]	0.52 [0.35-0.70]
RCP6.0	0.25 [0.18 to 0.32]	0.47 [0.33-0.62]	0.54 [0.37-0.72]
RCP8.5	0.29 [0.22 to 0.37]	0.62 [0.45-0.81]	0.73 [0.53-0.97]

IPCC (2013) published the sea level rise projections based on different CO2 concentrations. The sea level projections beyond the year 2100 is categorized into three groups of GHG concentration. (Figure 2.1).

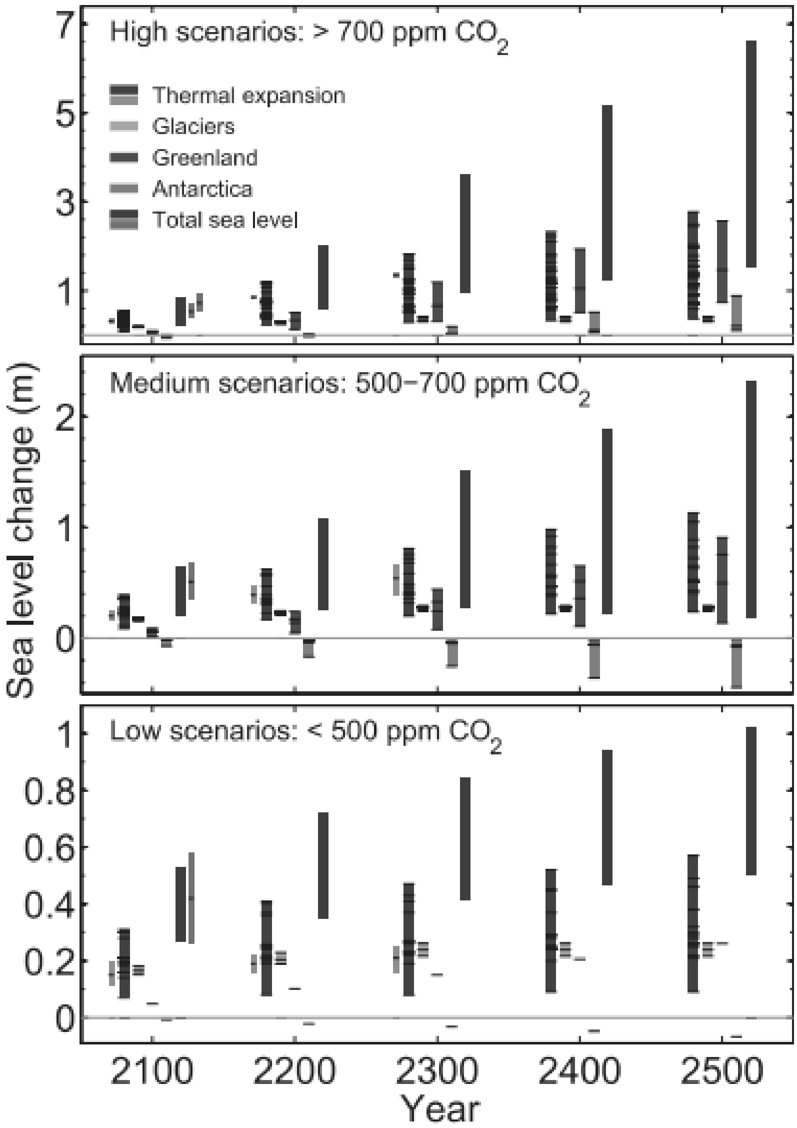


Figure 2.1: Global Sea Level Rise Scenarios based on different CO_2 concentrations (IPCC, 2013)

In WGIAR5, IPCC (2013) presented a graph describing central estimates and likely ranges for projections of global mean sea level rise for RCP2.6 (blue) and RCP8.5 (red) scenarios.

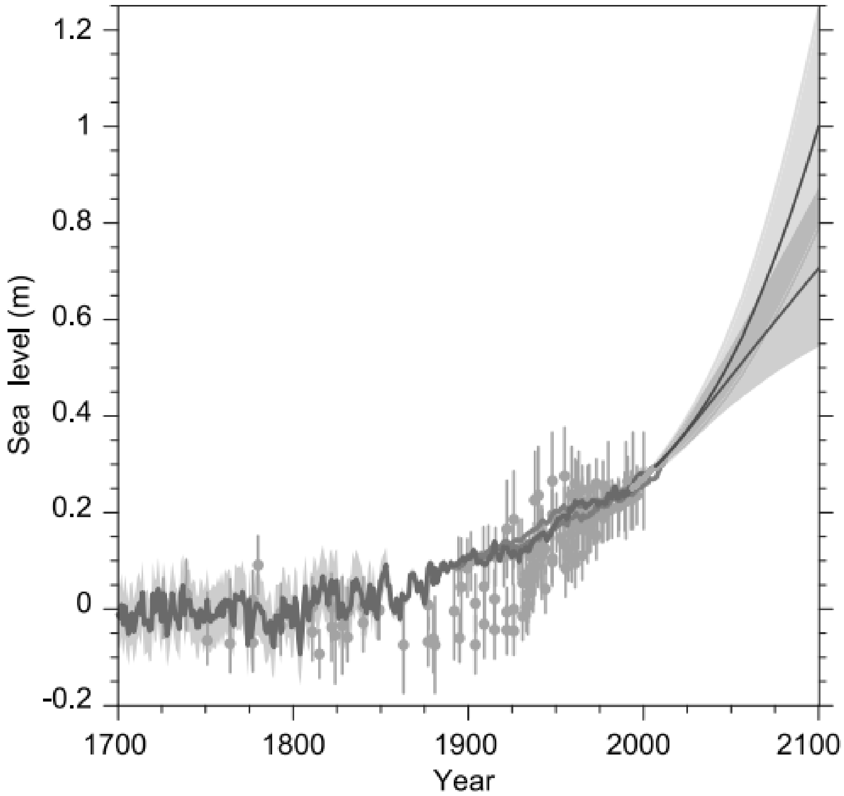


Figure 2.2: Likely Ranges for Projections of Global Mean Sea Level Rise for RCP2.6 (blue) and RCP8.5 (red) scenarios

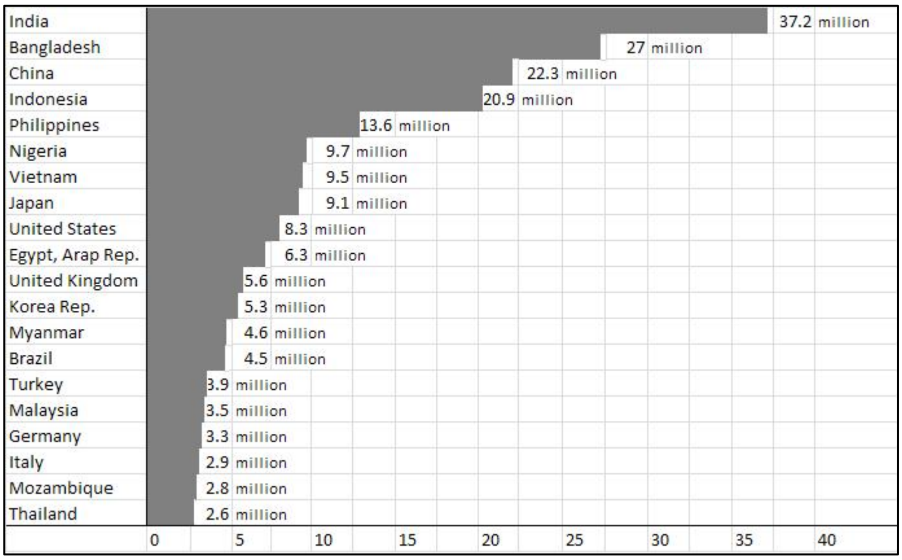
Mentioned in the book, High Tide On The Main Street (Englander, 2013), Greenland holds the potential to raise sea level more than 20 feet. Despite the revealed AR5 of IPCC (2013), the author states that the authorities missed some tipping points such as the destabilization of West Antarctica. He thinks that even the prominent authorities of IPCC (2013) do not want to be alarmist not to decrease the credibility.(Englander, 2013).

IMPACT OF SEA LEVEL RISE:

About 23% of the world population inhabit within a 100km distance of the coast and at an elevation less than 100m above sea level at present. Also, one third of the global average population densifies in coastal regions. It is foreseen to reach 50% of total population living within a distance of 100 km of the shores in the next two decades (Small and Nicholls, 2003) .

The projected number of population at risk by country by the year 2050 is given in Englander (2013). While 3.9 millions of people in Turkey will have to be displaced due to the risk, 37.2 millions of people from India will be exposed to the impacts of sea level rise by the year 2050.(Table 2.2).

Table 2.2: Population at Risk by Country (2050) (Englander, 2013)



Throughout the history, coastal areas are attractive with their aesthetical beauties to locate and build structures and live out for people. Those coastal beauties start to be threatened with the possibility of submerging underwater as a result of the rising sea level. Most of these population indicated in Table 2.2 have been living in coastal areas today. The population amount to be suffered from global sea level rise is not a value which can be ignored.

Englander (2013) also discussed the outcome of the impacts of rising sea level on coastal properties. The valuable investments may go bankrupt while the structures going underwater in a time period since the destruction of trillions of dollars of assets come into question. Beyond the property damage, the deeply rising sea level might affect sanitary and sewage systems, harbors, transportation facilities negatively. (Englander, 2013).

The accelerating sea level rise, as the most probable result of climate change, increases the probability of storm surges and coastal erosion in the world. As sea level exceeds its usual surging and waving and rises as a result of accelerating global warming, high amount of flows in rivers, land subsidence, coastal and estuarine floods occur especially in low-lying coastal areas vulnerable to this kind of flooding. (BALICA S., 2012)

IPCC (2014) in WG2AR5 states that the contributions of climate change impact in Europe will be observed on increasing coastal and catchment flooding driven by increasing sea levels, coastal erosion, river discharges and increasing urbanization. Coastal ecosystems and low-lying areas are projected to be exposed to adverse impacts of the climate change such as submergence, coastal floods due to extreme storms, and coastal erosion in the following decades due to population growth, urbanization.

The AR4 studied storm surge projections for Europe, Australia, the Bay of Bengal, based on limited dynamical model studies that the results gives surges with higher magnitude in future simulations (Christensen et al., 2007; cited in IPCC, 2007), these projections have low confidence. The results of dynamical and statistical methods on regional scale indicate that an increase in the occurrence of future sea level extremes will very likely be observed in some areas by the year of 2100. (IPCC, 2013). According to AR4, extremes will increase with MSL rise in high confidence level but there is low confidence in region-specific projections in storminess and storm surges. According to IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) published in 2012, the increase in MSL rise will very likely create and increase in future sea level extremes (Seneviratne et al., 2012; cited in WG1AR5 of IPCC, 2013)).

Most of the coasts have already been becoming face to face with high levels of coastal flooding, increased rate of coastal erosion, saltwater intrusion into freshwater resources due to the exacerbation of climate change and sea level rise. The rising level of oceans cause to erosion of sandy and gravel beaches and barriers, loss of dunes and wetlands, difficulty of removal in drainage on low-lying and mid-latitude area. (IPCC, 2001).

2.3 Vulnerability Assessment Model

Vulnerability refers to a level used for the determination of susceptibility of a system to any stressors such as global warming, sea level rise, storm surge, tsunami. Vulnerability can vary based on characteristic features, magnitude, susceptibility, adaptation capacity of the system under stress. (McCarthy, 2001)

Vulnerability assessment studies are conducted in the past by different researchers from different countries all around the world in order to assess climate change vulnerability for plants such as forests, for animal species such as fish stocks, birds and for natural resources such as groundwater, coastal ecosystems, coastal vulnerability to sea level rise, tsunami, storm surge, human vulnerability to environment, seismic vulnerability, social vulnerability to disasters, vulnerability to agricultural drought.

Hayhoe et al. (2001) stated that any kind of vulnerability assessment is a representation of a systematic response model which could be as ordinary as a conceptional model based on box-arrow diagrams or as complicated as a geospatial model considering the changes in distribution and types of elements. (Dubois et al., 2011)

It can be seen from recent studies that the popularity of global climate change assessments conducted in different types have been increasing (McCarthy et al., 2001) while the coastal catastrophe lies ahead for centuries (Englander, 2013) and is approaching with its probable devastating impacts on the planet.

2.3.1 Coastal VulnerabilityAssessments

Coastlines on low latitudes where a number of human population exists are more sensitive and vulnerable to the impacts of climatic changes. (IPCC, 2001). Different kinds of stressors of climate change such as sea level rise, storm surge, tsunami waves, water temperature and salinity and affected resources such as coastal system, freshwater, geomorphology, biodiversity are investigated and evaluated to direct the coastal communities in mitigation plans and adaptation measures. (EAE, 2011). Hence, the parameters used in the vulnerability models are strongly related to the natural resources imposed to stress by the impacts of climate change and sea level rise.

Beside its variable impacts on natural and social systems, there are several worldwide known techniques of assessing the vulnerability of coastal areas against climate change and sea level rise (Abuodha et al., 2006; cited in Mahapatra M. et al., 2013). Among these assessment techniques,

- IPCC Common Methodology (CM)
- Coastal Vulnerability Index (CVI)
- Global Vulnerability Assessment (GVA)
- Bruun rule
- The Synthesis and Upscaling of Sea-level Rise Vulnerability Assessment (SURVAS)
- Land and wetland loss assessment
- Dynamic Interactive Vulnerability Assessment (DIVA)
- Simulator of Climate Change Risks and Adaptation Initiatives (SimCLIM)
- Community Vulnerability Assessment Tool (CVAT)
- Coastal Zone Simulation Model (COSMO)
- South Pacific Island Methodology (SPIM)
- Shoreline Management Planning (SMP)

According to EAE (2011), four main prevalent methods are used to assess the coastal vulnerability to climate change. These are index-based methods, indicator-based approach also with GIS applications, GIS-based decision support systems, methods based on dynamic computer models. (EAE, 2011).

Index-based method uses one-dimensional technique to assess coastal vulnerability with a unitless vulnerability index in general. The final index does not allow you to understand the assumptions which lead to the calculations during process that a clear explanation to understand the methodology is needed in order to use it properly. Indicator-based method allows you to express the coastal vulnerability with independent elements (i.e.indicators). This method provides an opportunity to evaluate several aspects of coastal vulnerability in a steady condition. (EAE, 2011). Both index-based and indicator-based methods can be called parametric model. As the most famous parametric models in the world, DRASTIC (Aller et al., 1987; cited in Gaieb et al.,2013), GALDIT (Lobo-Ferreira et al., 2007; cited in Ivkovic KM. et al., 2012) can be considered. GIS based decision support systems are also used to assess the coastal impacts of climate change. DESYCO, DITTY-DSS are the two famous approaches for GIS-based decision support systems. The fourth method based on dynamic computer models are numerically developed tools for vulnerability analysis, mapping of vulnerability and risks of coastal mechanisms to climate change. (EAE, 2011). Dynamic computer models may belong to either numerical models (i.e.FVCOM, Delft3D, SWAN, XBeach, SLOSH, P-Surge, WAVEWATCH-III) or scenario-based models (i.e.NAMI-DANCE Tsunami Simulator, LUDAS Land Use Dynamic Simulator, CSIRO Storm Surge Simulator).

Vulnerability assessment models can be applied to any place in need of being protected around the world. While the geographical and antropogenical factors of a region due to human interaction in natural resources play salient role in the determination of vulnerability level, the consciousness of the authorities about the upcoming coastal crisis and the financial position of the country can be considered among the most critical issues for implementation of assessment studies and adaptation plans.

Although the coastal vulnerability assessment studies can be applicable all around the world, the most popular locations to implement the studies are the low-lying coasts due to the high risk of flooding and inundation and salinity intrusion as a result of seawater and freshwater interchange..

One such assessment focusing on shoreline response is that in the U.S. Geological Survey Open-File Report 00-179, a preliminary study for national assessment of coastal vulnerability to sea level rise is conducted by Thieler E.R. and Hammar-Klose E.S. (2000). In these studies, Thieler and Hammer-Klose made the assessment of U.S. coasts, Pacific, Atlantic and Gulf of Mexico, by using a six physical parameter based coastal vulnerability index model to sea level rise that is similar to that used by Gornitz V.M. et al. (1994) and Shaw J. et al.(1998). The following equation indicates the method of calculation used:

$$CVI = \sqrt{(a * b * c * d * e * f)/6}$$

where, a = geomorphology, b = coastal slope, c =relative rate of sea-level rise, d = erosion/accretion rate of shoreline, e =mean tide range, and f = mean wave height.

Table 2.3: Ranking of coastal vulnerability index variables for the U.S. Gulf of Mexico. (Thieler et al., 2000)

	Ranking of coastal vulnerability index				
	Very low	Low	Moderate	High	Very high
VARIABLE	1	2	3	4	5
Geomorphology	Rocky, cliffed coasts Fiords Fiards	Medium cliffs Indented coasts	Low cliffs Glacial drift Alluvial plains	Cobble beaches Estuary Lagoon	Barrier beaches Sand Beaches Salt marsh Mud flats Deltas Mangrove Coral reefs
Coastal Slope (%)	>0.115	0.115-0.055	0.055-0.035	0.035-0.022	<0.022
Relative sea-level change (mm/yr)	<1.8	1.8-2.5	2.5-3.0	3.0-3.4	>3.4
Shoreline erosion/ accretion (m/yr)	>2.0 Accretion	1.0-2.0	-1 - +1 Stable	-1.1 - -2.0 Erosion	< - 2.0
Mean tide range (m)	>6.0	4.1 - 6.0	2.0 - 4.0	1.0 - 1.9	<1.0
Mean wave height (m)	<0.55	0.55 - 0.85	0.85 - 1.05	1.05 - 1.25	>1.25

One of the most popular methods among vulnerability indexes for assessing impact on freshwater resources is GALDIT which is based on parametric model logic. Many researchers use GALDIT method which is the ringleader of vulnerability assessment methods in order to assess the vulnerability of a natural resource. Chachadi A.G. et al. (2002) carried out an impact assessment of coastal aquifer vulnerability to seawater intrusion in coastal area of North Goa, India. Moreover, based on GALDIT Index, Sundaram et al. (2008) conducted a vulnerability assessment of seawater intrusion and effect of artificial recharge in Pondicherry using GIS. Bhattacharya A.K. (2004) studied the coastal aquifers on a saltwater – freshwater intrusion model by using GALDIT vulnerability index method and following an integrated remote sensing and GIS approach to determine its vulnerability priority against sea level rise and excessive groundwater exploitation. Table 2.4 tables the weights, rates and parameter ranges of the model.

Table 2.4: GALDIT Model Weights, Rates and Parameter Ranges (Chachadi et al., 2002)

SUMMARY TABLE OF GALDIT MODEL WEIGHTS, RATES AND PARAMETER RANGES						
Parameters→	**G (Groundwater Occurrence) [Aquifer Type]**	**A (Aquifer Conductivity) [m/day]**	**L (Groundwater Levels bmsl) [m]**	**D (Distance from Coast) [m]**	**I (Impact of Existing intrusion) [epm]**	**T (Aquifer thickness) [m]**
Weights→ Rates↓	**1**	**3**	**4**	**2**	**1**	**2**
1		**00.0-04.0**	**>2.00**	**>1000**	**$Cl/HCO_3+CO_3<1.5$**	**<1.0**
2		**>04.0-12.0**	**>1.75-2.0**	**>800-1000**		**>1.0-2.0**
3			**>1.50-1.75**	**>700-800**		**>2.0-3.0**
4		**>12.0-28.0**	**>1.25-1.50**	**>600-700**		**>3.0-4.0**
5			**>1.00-1.25**	**>500-600**	**$Cl/HCO_3+CO_3<1.5-2$**	**>4.0-5.0**
6		**>28.0-41.0**	**>0.75-1.00**	**>400-500**		**>5.0-6.0**
7			**>0.50-0.75**	**>300-400**		**>6.0-7.0**
8	**Leaky confined**	**>41.0-81.0**	**>0.25-0.50**	**>200-300**		**>7.0-8.0**
9	**Unconfined**		**>0.00-0.25**	**>100-200**		**>8.0-10.0**
10	**Confined**	**>81.0**	**≤0.00**	**<100**	**$Cl/HCO_3+CO_3>2.0$**	**>10.0**

TOTAL GALDIT SCORE = Σ Weight(i) x Rate(i) ; where is a variable
TOTAL GALDIT SCORE = Σ1*G+3*A+4*L+2*D+1*I+2*T
It is an open ended additive semi-emprical model

Table 2.5 presents the calculation of the total score range by multiplying its weight and importance rating of each parameter and then attains the GALDIT Index by dividing total score into total weight value of parameters.

Table 2.5: Computation of GALDIT Index (Chachadi et al., 2002)

Computation of GALDIT-Index

S.no.	Indicator	Weight	Range of importance ratings				Range of scores (weight*Importance rating)			
			Minimum	In between		Maximum	Min	In between		Max
1	Groundwater Occurrence (Aquifer Type)	1	2.5	5	7.5	10	2.5	5	7.5	10
2	Aquifer Hydraulic Conductivity	3	2.5	5	7.5	10	7.5	15	22.5	30
3	Depth to Groundwater Level above Sea	4	2.5	5	7.5	10	10	20	30	40
4	Distance from the Shore	4	2.5	5	7.5	10	10	20	30	40
5	Impact of existing status of Seawater Intrusion	1	2.5	5	7.5	10	2.5	5	7.5	10
6	Thickness of Aquifer being Mapped	2	2.5	5	7.5	10	5	10	15	20
				Total Score (T.S)			37.5	75	112.5	150
				GALDIT-Index=T.S/15			2.5	5	7.5	10

Similar to the presented models given above, a simple index-based model is presented by Ozyurt, 2007. This preliminary model, combines the shoreline behavior with freshwater impacts to have an overall assessment of the region to prioritize for decision maker with limited data. (Ozyurt and Ergin, 2010).

To enhance the reliability of the preliminary model, a fuzzy logic based indicator model, the fuzzy coastal vulnerability assessment model (Ozyurt, 2010) is developed. In fuzzy logic based model, there are physical and human related parameters that describe the characteristics of the study area and affect the output of the vulnerability model after several parametric operations. In order to obtain more realistic results, the fuzzy concept is recommended to be introduced to the model instead of giving one representative value to each parameter for the whole shoreline as carried out in the preliminary vulnerability assessment. The shoreline in each independent parameter can be considered as a combination of many segmental pieces of which represent its own small strip of land. More detailed data is needed to assign a realistic value to each segment as representative of its land strip. Once the detailed information about the whole shoreline is obtained and the fuzzy vulnerability assessment model is conducted to determine the vulnerability priority against sea level rise. The model is applied to three vulnerable region of Turkey; Amasra, Gocek and Goksu and several EU locations (Ozyurt and Ergin, 2012)

The last two models are used in this study. Detailed information on these two models are given in methodology section.

Risk Models

The risk concept can be defined as the product of consequence of an event and probability of that event. (Pasche et al., 2010).

Although the risk management concept is known for centuries, ‘risk’ is started to be perceived as a serious influence of flood management decisions since 1950s following the coastal surge flood in 1953 in Europe (Delta Commission, 2008). Even the risk concept based on probability and consequence terms is started in 1990s to be a milestone for flood risk management. Later, in 2004, after tsunami disaster in Asia (Boxing Day), the vulnerability of coastal communities and the urgent need for better warning systems, emergency planning and spatial planning to be able to reduce the risk were recognized and taken into consideration. (Sayers P. et al., 2013).

There are different risk models applied to coastal areas throughout the literature. One of the most widely used risk model is Source-Pathway-Receptor-Consequences Model.

SPRC Model is a risk evaluation mechanism used to shape flood propagation and risk management studies. (Narayan S. et al., 2011) It is useful in the application of flood risk evaluations in light of the risk function. Risk function can be described as follows. (Schanze J. et al.,2006).

Risk = function (p, e, s, v)

p; the nature and probability of disaster,

e; the degree og exposure of receptors to disaster,

s; the susceptibility of receptors,

v; the value of receptors.

Although Institution of Civil Engineers (ICE, 2001) proposed the following diagram in order to represent the concept for risk of flooding (Schanze J. et al.,2006), the mechanism can be modified according to all kinds of hazards such as coastal erosion, inundation and saltwater intrusion.

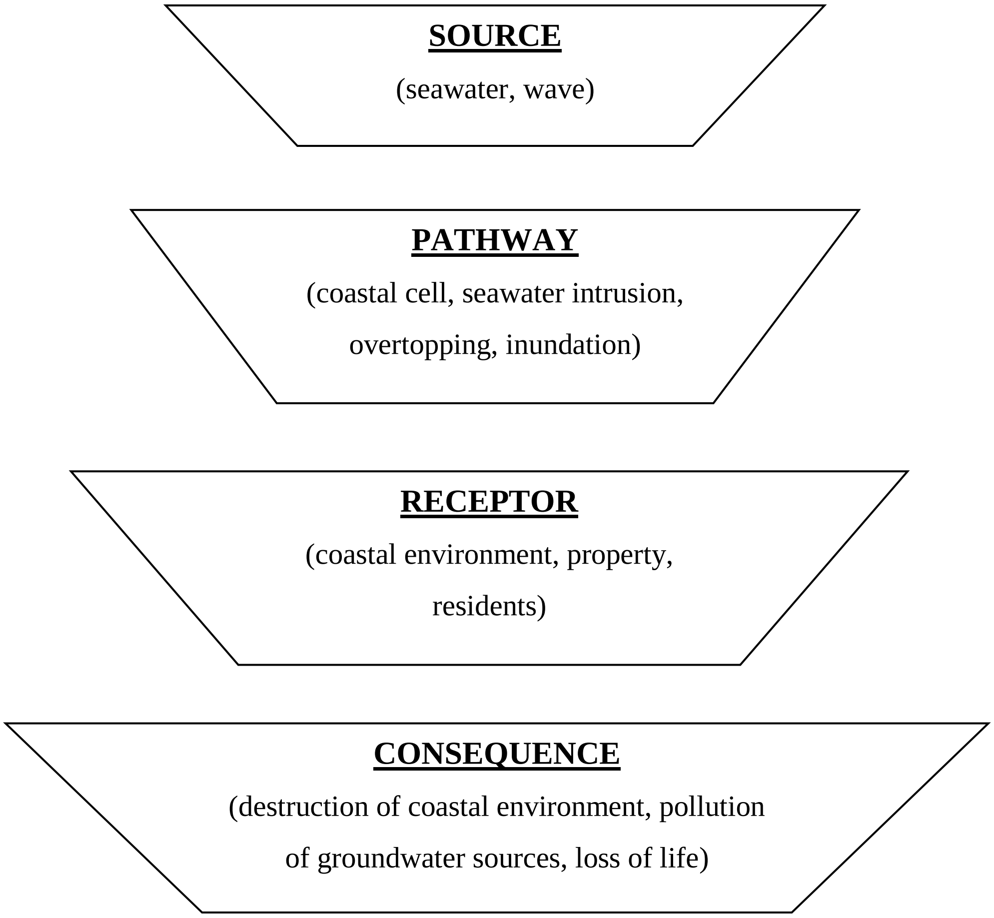


Figure 2.3: Source-Pathway-Receptor-Consequence-Model (ICE 2001, cited in Schanze (2006))

More specifically, the flood risk indicates a causal chain as represented in the diagram.

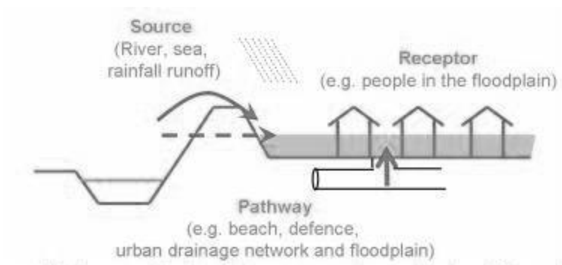


Figure 2.4: Source – Pathway – Receptor as the components od flooding system (modified from Sayers et al.2012; cited in Kellagher R. et al. 2008)

The flood risk can also be described as a causal chain system as in the following formula.

Flood Risk = f $[(p, m, w, t)_{source}, (I, a, c)_{pathway}, (s, r)_{receptor}, (v, d)_{consequence}]$

where ‘source’ can be detected by considering the probability of flood event (p) with an exact magnitude (m). Early warning (w) and retention capacity (t) of the source areas can be taken into account as risk reduction factors. Coastal overflow and inundation (i) with many attributes (a) and interferences to control (c) the flood can help to describe ‘pathway’.Vulnerability is taken into account under both ‘receptor’ and ‘consequence’ concepts, while the susceptibility (s) in order to increase the resilience (r) stands for ‘receptor’, the damage to values (v) and mitigation measures to decrease (d) these damages are the parameters defining ‘consequence’.

Risk models widely use vulnerability assessment models as one of the most important input elements. Throughout the model process, the vulnerable system is questioned and investigated. Finally, the vulnerability level of the vulnerable system is determined as the output element of the risk model that the result is the most salient guide in the sense of the Coastal Zone Management since these results bring the causative elements of the vulnerability problem into prominence. There are worldwide integrated risk assessment studies in which vulnerability maps are prepared to identify the hazard and vulnerable areas. As an example, Sayers P. et al. (2013) states that FEMA, one of the agencies in US, prepared an integrated hazard risk management (IHRM) plans about the preparations of hazard prevention activities, response plans, mitigation studies. As the output of the study, maps identifying hazards and vulnerable areas to hazards are prepared and risk assessments for the preparation of integrated mitigation plans are prepared. (Sayers P. et al., 2013).

CHAPTER 3

METHODOLOGY

As it is known, the coasts have such a sensitive nature that can be easily altered by any intervention or by an external factor compared to the inland geographies. Coastal systems are directly in a face-to-face interaction with a great amount of water mass confined in the oceans. Considering the interaction of saline water and freshwater within the system, the role of coastal strips comes into prominence as being boundary between freshwater and saltwater.

In addition to social impacts mostly occurred as the results of unconscious human activities, the coasts are directly exposed to the physical impacts of sea level rise that is one of the adverse outcomes of global climate change. The physical impact processes can be ordered as salinity intrusion to freshwater, coastal erosion, inundation of coastal lands, flooding due to storm surge. Both the social and physical impacts of sea level rise will directly affects the populations settled on the coastal lands.

The coastal vulnerability assessment models become more significant especially as the number of the scientific researches on the impacts of global climate change and the awareness of the decision makers for the upcoming coastal crisis have been increasing. The coasts especially exposed to more threatening external factors become more vulnerable to the impacts of sea level rise.

In this chapter, preliminary model and the fuzzy coastal vulnerability assessment model are explained.

3.1 Preliminary (Vulnerability Assessment) Model

Various types of vulnerability assessment studies can be found in the literature. The former studies based on the basic mathematical operations conducted using a representative value for each parameter of the whole coastline. Even some of those studies are just based on few parameters that can be misleading due to the ignorance of the other related parameters.

The preliminary vulnerability model utilized in this thesis not only provide output information to make vulnerability comparison of different regions for decision makers, but also help prioritize the vulnerability levels to different impacts of a specific region. The parameters used to calculate the vulnerability of the region to a specific impact are assigned by their vulnerability values between very low and very high (1-5). The coastal impacts consist of different physical and human-influenced parameters assigned by different ranges of vulnerability values prepared in consideration of local physical data and expert opinion.(Ozyurt, 2007). It is salient to assign a weight to each parameter with an equal value or not by analyzing the importance and the priorities of the parameters within the coastal impacts. Since the relation between the coastal impacts can make the situation more complex, the coastal impacts are weighted equal as 1 by taking into account as independent of eachother.(Ozyurt, 2010). Physical impact subindice (CVIimpact) for each coastal impact is calculated by dividing the sum of weight-assigned parameters into the least vulnerable case result which includes the related parameters ranked by very low vulnerability as 1. Finally, different types of CVI-SLR results are calculated depending on the physical characteristics of the study region. CVI-III is calculated for a study region including groundwater, estuary and river whereas CVI-II is for a study region which does not include river, estuary but groundwater. Furthermore, CVI-I is considered for a study region which does not include groundwater, estuary or river etc. (Ozyurt, 2007).

The preliminary coastal vulnerability assessment model of Fethiye, called initial vulnerability model in this thesis, is studied by using 13 physical and 7 human related socio-economic parameters. Each parameter has a single order value to represent the whole shoreline with a total length of 9742 meters. Although each order value is not representative for the whole strip of 9742 meters, they give an opportunity to generalize the situation and to realize the priority of the impacts. The values used in the preliminary vulnerability assessment model of Fethiye can be seen in the following tables; Table 6a and Table 7a as worst case scenario and Table 6b and Table 7b as common case scenario, respectively.

Table 3.1: Physical Parameter Ranges of Fethiye (worst case)

Rate of SLR	3	mm/yr
Geomorphology	Salt marsh, Sand beach	
Coastal Slope	1/50-1/100	%
Sign.Wave Height	0.5	mm/yr
Sediment Budget	>50% in erosion	%
Tidal Range	0.15	m/yr
Proximity to Coast	605.80	mm/yr
Type of Aquifer	unconfined	
Hydraulic Conductivity	12	m/day
Depth to GW level above sea	~5	m
River Discharge	2	m^3/s
Water Depth at downstream	2	m

Table 3.2: Human Related Parameter Ranges of Fethiye (worst case)

Reduction of Sediment Supply	0	%
River Flow Regulation	low affected	
Engineered Frontage	>50	%
GW Consumption	110	%
Land Use Pattern	Agricultural	
Natural Protection Degradation	0	%
Coastal Protection Structures	0	%

Table 3.3: Physical Parameter Ranges of Fethiye (common case)

Rate of SLR	1.7	mm/yr
Geomorphology	Cobble Beach	
Coastal Slope	1/10-1/20	%
Sign.Wave Height	0.5	m
Sediment Budget	10-30% in erosion/	%
Tidal Range	0.15	m/yr
Proximity to Coast	1237.75m	m
Type of Aquifer	unconfined	
Hydraulic Conductivity	12	m/day
Depth to GW level above sea	>5	m
River Discharge	3-5	m^3/s
Water Depth at downstream	0-1	m

Table 3.4: Human Related Parameter Ranges of Fethiye (common case)

Reduction of Sediment Supply	10	%
River Flow Regulation	low affected	
Engineered Frontage	50	%
GW Consumption	99.36	%
Land Use Pattern	Settlement	
Natural Protection Degradation	<20	%
Coastal Protection Structures	<5	%

Based on local physical data and expert opinion evaluated as “1” for the least vulnerable case and as “5” for the most vulnerable case, two different kinds of CVI values are obtained by classifying into five impacts in the coastal vulnerability matrix in order to find out the value of CVI impact and the overall vulnerability index with a vulnerability level ranging between 1 to 5 from least vulnerable to most vulnerable at last. (Ozyurt, 2010). CVI impact is obtained by dividing the sum of the parameter values to the least vulnerable case result. The vulnerability results can be interpreted according to the following criteria: (Ozyurt, 2007).

- Very low vulnerability : 1≤CVI(SLR)<1.5
- Low vulnerability : 1.5≤CVI(SLR)<2.5
- Moderate vulnerability : 2.5≤CVI(SLR)<3.5
- High vulnerability : 3.5≤CVI(SLR)<4.5
- Very high vulnerability : 4.5≤CVI(SLR)≤5

Table 3.5: Coastal Vulnerability Matrix for Fethiye Bay, Turkey (common case)

Impact	Physical Parameters							Human Influence Parameters							Impact Total	CVI impact
	Parameter	1	2	3	4	5	Total	Parameter	1	2	3	4	5	Total		
1. Coastal Erosion	P1.1 Rate of Sea Level Rise	0	1	0	0	0	2	H1.1 Reduction of Sediment Supply	0	0	0	0	1	5		
	P1.2 Geomorpholgy	0	0	0	1	0	4	H1.2 River Flow Regulation	0	1	0	0	0	2		
	P1.3 Coastal Slope	0	1	0	0	0	2	H1.3 Engineered Frontage	0	0	0	1	0	4		
	P1.4 $H_{1/3}$	1	0	0	0	0	1	H1.4 Natural Protection Degradation	0	0	0	0	1	5		
	P1.5 Sediment Budget	0	0	0	1	0	4	H1.5 Coastal Protection Structures	0	0	0	0	1	5		
	P1.6 Tidal Range	0	0	0	0	1	5									
	TOTAL	1	2	0	2	1	18	TOTAL	0	1	0	1	3	21	19.5	3.5
2. Flooding due to Storm Surge	P2.1 Rate of Sea Level Rise	0	1	0	0	0	2	H2.1 Engineered Frontage	0	0	0	1	0	4		
	P2.2 Coastal Slope	0	1	0	0	0	2	H2.2 Natural Protection Degradation	0	0	0	0	1	5		
	P2.3 $H_{1/3}$	1	0	0	0	0	1	H2.3 Coastal Protection Structures	0	0	0	0	1	5		
	P2.4 Tidal Range	0	0	0	0	1	5									
	TOTAL	1	2	0	0	1	10	TOTAL	0	0	0	1	2	14	12	3.4
3. Inundation	P3.1 Rate of Sea Level Rise	0	1	0	0	0	2	H3.1 Natural Protection Degradation	0	0	0	0	1	5		
	P3.2 Coastal Slope	0	1	0	0	0	2	H3.2 Coastal Protection Structures	0	0	0	0	1	5		
	P3.3 Tidal Range	0	0	0	0	1	5									
	TOTAL	0	2	0	0	1	9	TOTAL	0	0	0	0	2	10	9.5	3.8
4. Salt Water Intrusion to Groundwater Resources	P4.1 Rate of Sea Level Rise	0	1	0	0	0	2	H4.1 Groundwater consumption	0	0	0	0	1	5		
	P4.2 Proximity to Coast	1	0	0	0	0	1	H4.2 Land Use Pattern	0	0	1	0	0	3		
	P4.3 Type of Aquifer	0	0	0	0	1	5									
	P4.4 Hydraulic Conductivity	1	0	0	0	0	1									
	P4.5 Depth to Groundwater Level Above Sea	1	0	0	0	0	1									
	TOTAL	3	1	0	0	1	10	TOTAL	0	0	1	0	1	8	9	2.6
5. Salt Water Intrusion to River/Estuary	P5.1 Rate of Sea Level Rise	0	1	0	0	0	2	H5.1 River Flow Regulation	0	1	0	0	0	2		
	P5.2 Tidal Range	0	0	0	0	1	5	H5.2 Engineered Frontage	0	0	0	1	0	4		
	P5.3 Water Depth at Downstream	1	0	0	0	0	1	H5.3 Land Use Pattern	0	0	1	0	0	3		
	P5.4 River Discharge	0	0	0	0	1	5									
	TOTAL	1	1	0	0	2	13	TOTAL	0	1	1	1	0	9	11	3.1

CVI(SLR)-1	41	3.57
CVI(SLR)-2	50	3.33
CVI(SLR)-3	61	3.30

Table 3.6: Coastal Vulnerability Matrix for Fethiye Bay, Turkey (worst case)

Impact	Physical Parameters							Human Influence Parameters							Impact Total	CVI impact
	Parameter	1	2	3	4	5	Total	Parameter	1	2	3	4	5	Total		
1. Coastal Erosion	P1.1 Rate of Sea Level Rise	0	0	1	0	0	3	H1.1 Reduction of Sediment Supply	0	0	0	0	1	5		
	P1.2 Geomorpholgy	0	0	0	0	1	5	H1.2 River Flow Regulation	0	1	0	0	0	2		
	P1.3 Coastal Slope	0	0	0	0	1	5	H1.3 Engineered Frontage	0	0	0	0	1	5		
	P1.4 $H_{1/3}$	1	0	0	0	0	1	H1.4 Natural Protection Degradation	0	0	0	0	1	5		
	P1.5 Sediment Budget	0	0	0	0	1	5	H1.5 Coastal Protection Structures	0	0	0	0	1	5		
	P1.6 Tidal Range	0	0	0	0	1	5									
	TOTAL	1	0	1	0	4	24	TOTAL	0	1	0	0	4	22	23	4.2
2. Flooding due to Storm Surge	P2.1 Rate of Sea Level Rise	0	0	1	0	0	3	H2.1 Engineered Frontage	0	0	0	0	1	5		
	P2.2 Coastal Slope	0	0	0	0	1	5	H2.2 Natural Protection Degradation	0	0	0	0	1	5		
	P2.3 $H_{1/3}$	1	0	0	0	0	1	H2.3 Coastal Protection Structures	0	0	0	0	1	5		
	P2.4 Tidal Range	0	0	0	0	1	5									
	TOTAL	1	0	1	0	2	14	TOTAL	0	0	0	0	3	15	14.5	4.1
3. Inundation	P3.1 Rate of Sea Level Rise	0	0	1	0	0	3	H3.1 Natural Protection Degradation	0	0	0	0	1	5		
	P3.2 Coastal Slope	0	0	0	0	1	5	H3.2 Coastal Protection Structures	0	0	0	0	1	5		
	P3.3 Tidal Range	0	0	0	0	1	5									
	TOTAL	0	0	1	0	2	13	TOTAL	0	0	0	0	2	10	11.5	4.6
4. Salt Water Intrusion to Groundwater Resources	P4.1 Rate of Sea Level Rise	0	0	1	0	0	3	H4.1 Groundwater consumption	0	0	0	0	1	5		
	P4.2 Proximity to Coast	0	0	1	0	0	3	H4.2 Land Use Pattern	0	0	0	0	1	5		
	P4.3 Type of Aquifer	0	0	0	0	1	5									
	P4.4 Hydraulic Conductivity	1	0	0	0	0	1									
	P4.5 Depth to Groundwater Level Above Sea	1	0	0	0	0	1									
	TOTAL	2	0	2	0	1	13	TOTAL	0	0	0	0	2	10	11.5	3.3
5. Salt Water Intrusion to River/Estuary	P5.1 Rate of Sea Level Rise	0	0	1	0	0	3	H5.1 River Flow Regulation	0	1	0	0	0	2		
	P5.2 Tidal Range	0	0	0	0	1	5	H5.2 Engineered Frontage	0	0	0	0	1	5		
	P5.3 Water Depth at Downstream	0	1	0	0	0	2	H5.3 Land Use Pattern	0	0	0	0	1	5		
	P5.4 River Discharge	0	0	0	0	1	5									
	TOTAL	0	1	1	0	2	15	TOTAL	0	1	0	0	2	12	13.5	3.9

CVI(SLR)-1	49	4.26
CVI(SLR)-2	60.5	4.03
CVI(SLR)-3	74	4.00

In the preliminary model matrix, five salient coastal impacts in the case of probable sea level rise consist of different groups of parameters. Each rating for all parameters affects the related particular coastal impact .

In consideration of the parameter values, the following formula is used to measure the Coastal Vulnerability Index Ranges: (Ozyurt, 2007)

$$CVI = \frac{0.5 * \sum_{1}^{n} PP_n * CVRP_n \ + \ 0.5 * \sum_{1}^{m} HIP_n * CVRP_m}{CVI_{leastvulnerable}}$$

where, PP = Parameters for Physical Impacts

HIP= Parameters for Human Influence

CVRP=Parameters corresponding vulnerability range

$CVI_{leastvulnerable}$=Summation value of parameters for the least vulnerable case among given impacts

The results of the analysis are given in Chapter 4 Result and Discussion part.

3.2 Fuzzy Coastal Vulnerability Assessment Model

In the previous section, the preliminary vulnerability assessment model is presented with the application of Fethiye data. However, since it is considered that the representation of the entire coastline with a single value as in the preliminary model does not give accurate and realistic results, the fuzzy vulnerability assessment model is decided to apply for this study.

The aim of using the fuzzy concept in this study is to examine the whole body in detail by dividing into a number of small-scaled elements that contributes into sensitivity and accuracy in results.

The fuzzy logic coastal vulnerability assessment for this thesis is carried out by considering spatial information to assess the parameters on the basis of fuzzy logic in addition to the preliminary model study.

FCVAM (Fuzzy Coastal Vulnerability Assessment Model) evaluates different regions in terms of coastal vulnerability while these regions can be also evaluated for their vulnerability to different impacts. The FCVAM is run according to an analytical hierarchy process by integrating the opinion of stakeholders during decision-making, according to fuzzy expert system by integrating the expert opinion, the data, the knowledge on coastal engineering, geographical information systems so as to be able to display an integrated results of vulnerability assessment with the impacts of sea level rise. In the establishment of FCVAM (Fuzzy Coastal Vulnerability Assessment Model), uses database to develop parameter membership functions, rule base expert system to analyze numerical models used to define coastal process on climate change, fuzzy arithmetic to determine CVI, Maylab Fuzzy Logic Toolbox to provide the extension of the present model capability. (Ozyurt and Ergin, 2012).

In FCVAM (Fuzzy Coastal Vulnerability Assessment Model), the parameter ranges for the vulnerability level are determined by using Fuzzy C-Means. Therefore, the input data can be directly utilized in the model in order to assess the vulnerability of the region. The developed model (FCVAM- Fuzzy Coastal Vulnerability Assessment Model) (Ozyurt, 2010) processes the data and matches it according to the determined parameter ranges by using If-Then rules (Rule Base). Then, it calculates the vulnerability scores of the parameters and the impacts with the help of MAX/MIN/OR rules. The systematical work principle of the FCVAM (Fuzzy Coastal Vulnerability Assessment Model) is presented in detail in Ozyurt (2010).

To determine priorities of the vulnerable areas worldwide and to develop the vulnerability model content, the model should be implemented into more coastal regions. On the other hand, to contribute into mitigation plans for an impact or to develop an adaptation plan for a specific coastal region, site-specific implementations should be carried out. (Ozyurt and Ergin, 2012)

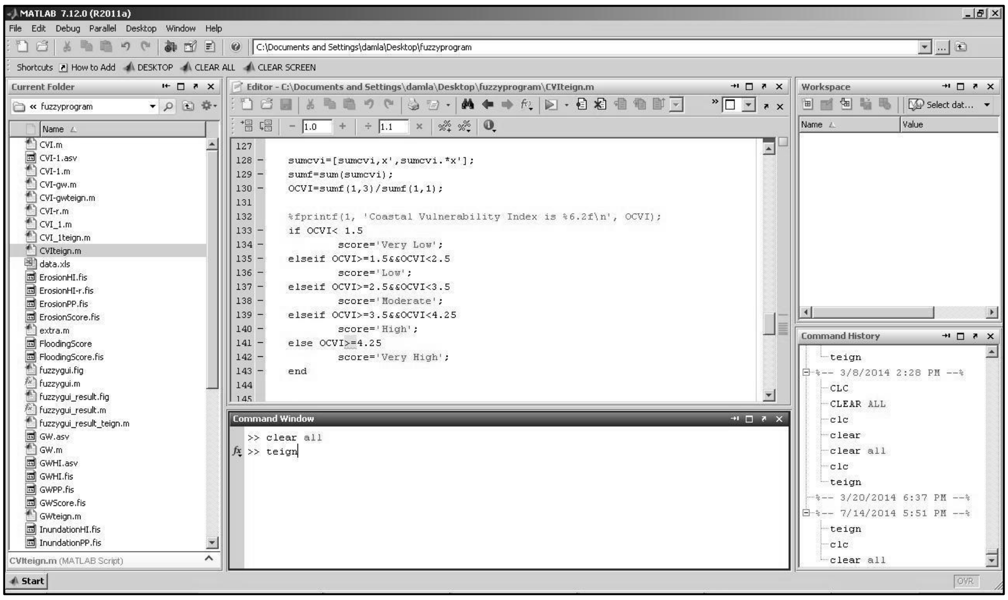
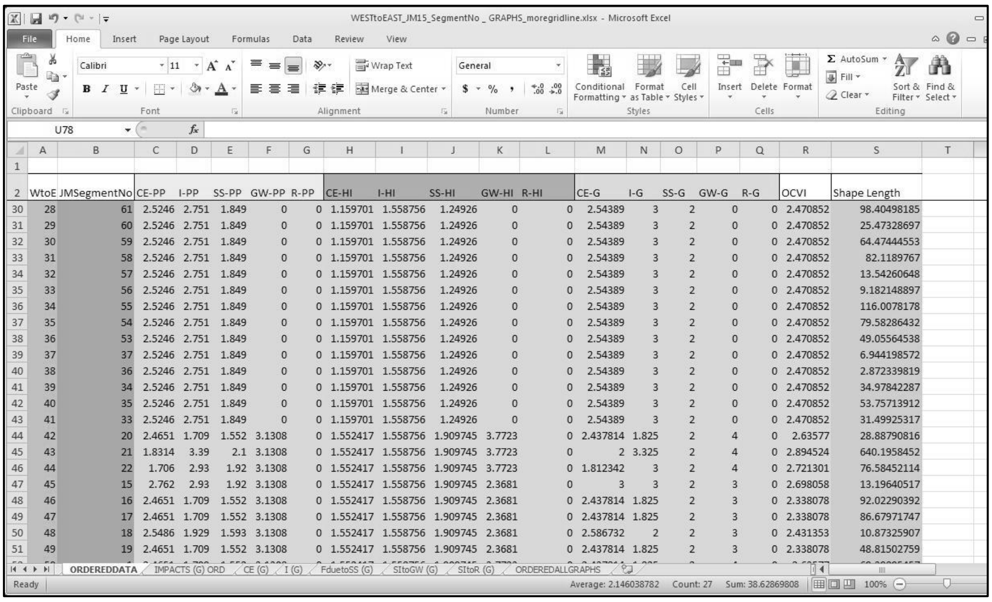


Figure 3.1: Matlab Environment for Coastal Vulnerability Index (CVI)

Vulnerability level results of the coastal segments to the coastal impacts based on FCVAM can be transferred from Matlab environment, and displayed on Excel or ArcGIS environment.



	WtoE	JMSegmentNo	CE-PP	I-PP	SS-PP	GW-PP	R-PP	CE-HI	I-HI	SS-HI	GW-HI	R-HI	CE-G	I-G	SS-G	GW-G	R-G	OCVI	Shape Length
30	28	61	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	98.40498185
31	29	60	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	25.47328697
32	30	59	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	64.47444553
33	31	58	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	82.1189767
34	32	57	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	13.54260648
35	33	56	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	9.182148897
36	34	55	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	116.0078178
37	35	54	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	79.58286432
38	36	53	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	49.05564538
39	37	37	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	6.944198572
40	38	36	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	2.872339819
41	39	34	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	34.97842287
42	40	35	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	53.75713912
43	41	33	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	31.49925317
44	42	20	2.4651	1.709	1.552	3.1308	0	1.552417	1.558756	1.909745	3.7723	0	2.437814	1.825	2	4	0	2.63577	28.88790816
45	43	21	1.8314	3.39	2.1	3.1308	0	1.552417	1.558756	1.909745	3.7723	0	2	3.325	2	4	0	2.894524	640.1958452
46	44	22	1.706	2.93	1.92	3.1308	0	1.552417	1.558756	1.909745	3.7723	0	1.812342	3	2	4	0	2.721301	76.58452114
47	45	15	2.762	2.93	1.92	3.1308	0	1.552417	1.558756	1.909745	2.3681	0	3	3	2	3	0	2.698058	13.19640517
48	46	16	2.4651	1.709	1.552	3.1308	0	1.552417	1.558756	1.909745	2.3681	0	2.437814	1.825	2	3	0	2.338078	92.02290392
49	47	17	2.4651	1.709	1.552	3.1308	0	1.552417	1.558756	1.909745	2.3681	0	2.437814	1.825	2	3	0	2.338078	86.67971747
50	48	18	2.5486	1.929	1.593	3.1308	0	1.552417	1.558756	1.909745	2.3681	0	2.586732	2	2	3	0	2.431353	10.87325907
51	49	19	2.4651	1.709	1.552	3.1308	0	1.552417	1.558756	1.909745	2.3681	0	2.437814	1.825	2	3	0	2.338078	48.81502759

Figure 3.2: Output Values obtained from MatLab CVI Code based on Fuzzy Logic

CHAPTER 4

DATASETS AND PREPROCESSING

Upon the need of segmental analysis of the coastal vulnerability to be more precise and real-like, the fuzzy coastal vulnerability assessment model is used on the GIS environment for this study.

4.1 STUDY SITE INFORMATION

The study area, including low-lying coast and indented coast with high levels of human activity, is an attractive touristic destination with a shoreline of 9742 meters in the southwestern coast of Turkey. This coastal strip constitutes the surrounding of the bay that population mostly settled in this area due to the convenience and accessibility of such a low-lying area. Considered geomorphological features in detail, a significant amount of agricultural area exists on the east side of the bay. The west coast of the bay has mostly indented cliffs with a few pocket beach with a slope range of 20°~44°. Fethiye met many seismic events and tsunamis during the historical periods.(Erel and Adatepe, 2007). The most significant problem of Fethiye indicated in the first earthquake zone in the Map of Earthquake Regions in Turkey is the positioning of a significant amount of the settlement area on made ground, marshy land, the foundation including a certain amount of groundwater level as a foundation condition which decreases the carrying capacity and increases liquefaction potential. The plain of Fethiye includes artesian wells mostly range in the coastal strip with a confined aquifer. Unconfined aquifer is located in the east and northeast of the Fethiye plain and also observed shallowly above the confined aquifer layer. The flowing of groundwater through the plain is towards the bay with a water level profile going upward when approaches to the bay. (METU, 2001).

Greenhouses are in the forefront as the region-wide agricultural and economical activity. According to METU (2001), the surface area of greenhouses covers a 5.5 km^2. These greenhouses are irrigated with surface runoff and groundwater resources. It is stated in METU (2001) that annual feeding of the groundwater aquifer of Fethiye plain is around $22X10^6$ m^3. A volume of 17.5X10^6 m^3 discharges into the Aegean Sea from a wide range area while $5.04X10^6$ m^3 of the total volume is drawn for drinking and irrigational use. There is a decrease of $0.54X10^6$ m^3 in the reservoir. (METU, 2001). Although it is estimated in METU (2001) that the aquifer of Fethiye can afford the water demand with a plenty of groundwater resource by the year of 1999, the river discharge values and precipitation values which feed the groundwater significantly change in a negative manner due to the global warming and increasing temperatures of the region as well as antropogenic factors especially overexploitation of the natural resources and increasing construction facilities. According to online meteorological sources (Accuweather, 2014), the temperature in Fethiye reaches peak values in July-August with 35°C-38°C and drops to the bottom in January with 10°C-15°C. (http://www.accuweather.com/tr/tr/fethiye/319475/month/319475?monyr=8/01/2014).

The population study is conducted by the State Institute of Statistics. (retrieved from http://www.citypopulation.de/php/turkey-mugla.php?cityid=966 , available on August 2014)

Table 4.1: Population Trend of Fethiye (http://www.citypopulation.de/php/turkey-mugla.php?cityid=966)

District	Dec 2009	Dec 2010	Dec 2011	Dec 2012	Dec 2013
Fethiye	72003	77237	81467	84053	82000

It is seen that a sudden increase in population between the year of 2009-2011 is observed in the center of Fethiye.(Table 4.1).

Fethiye, ancient Telmessos on the coast between Karia and Lycia (Ashton, 2004), has many archaeological site that during the history the region was under the domination of different civilizations such as Persians, Romans, Byzantine since 3rd Century B.C. In Fethiye Museum founded in 1960s, archaeological monuments and artifacts of Bronze Age, Archaic, Hellenistic, Roman, Byzantine and ethnographic work of art of Mentese, Ottoman and recent period is exhibited.(The Ministry of Culture and Tourism, 2014). Fethiye hosts many endangered species (i.e. Caretta *caretta*, Chelonia *mydas*). In accordance with the agreement of BERN and CITES, Fethiye region is protected as one of the 12 important Caretta caretta nesting beaches in Turkey. Since the Fethiye includes several archaeological sites, it is taken under protection in accordance with Barcelona Agreement in 1988. The region also hosts Liquidambar orientalis forests and Lyciasalamandra fazilae as endemic species.(Ministry of Environment and Urban Planning, 2014). After these international agreements, Fethiye has been declared to be in the list of “Specially Protected Areas” also by The Ministry of Environment and Urban Planning.

(http://www.csb.gov.tr/projeler/ockb/index.php?Sayfa=sayfa&Tur=webmenu&Id=7781)

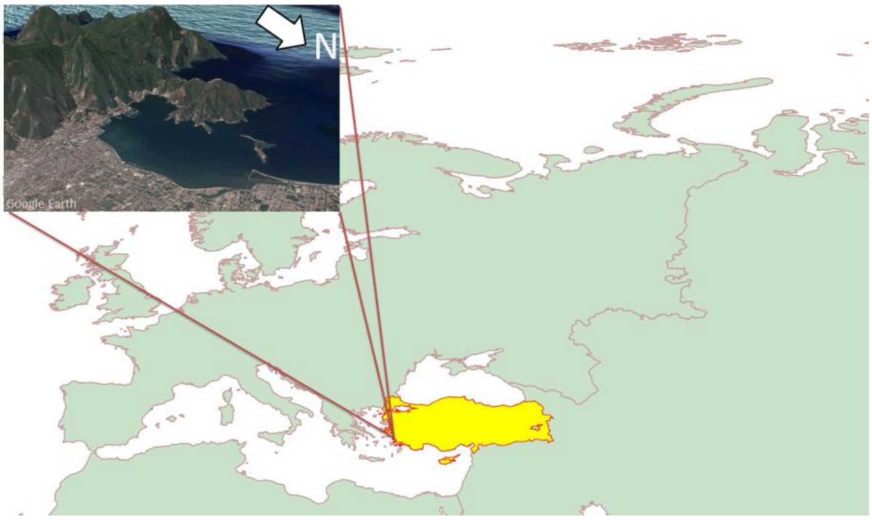


Figure 4.1: The Location of Fethiye (Atalay et al., 2013)

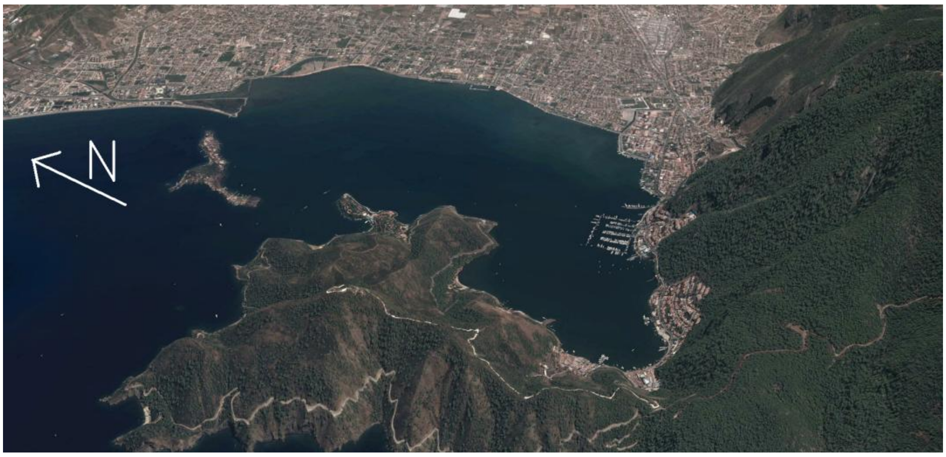


Figure 4.2: The Study Area (Google Earth 3D View)

In terms of the fuzzy vulnerability model, the study area is suitable due to its diverse geomorphology, land use, beach slope as physical parameters. To give an example of its diversity, the study area includes indented cliffs, alluvial plains, estuary, salt marsh, sand beach as geomorphological diversity; as well as its agricultural, settlement, protected land use types with a wide range of coastal slope between 0°~44°.

4.2 INPUT PARAMETERS

The data obtained from institutions as in raw format are processed and converted into the required format type. The data format used within the scope of the thesis is ArcGIS Shape (.shp)format. The projection system is UTM (Universal Transverse Mercator) and the datum is ED50 while the study area corresponds to 35th zone in UTM system (Zone 35).

The Quickbird Satellite images of Fethiye Bay were in mosaics taken from two different dates as 2004 and 2005. Two groups of mosaics are merged to generate the final map of the study area as an entire map.

The study region, Fethiye, is examined on the GIS environment in terms of its physical parameters mostly. The study is performed at a 150 meter of buffer zone to represent the coastal area of the bay. Each polygon (pixel polygon) forms a value and enhances the variety of each coastal segment since each polygon contains data different than others for the relevant parameter.(Figure 4.3).

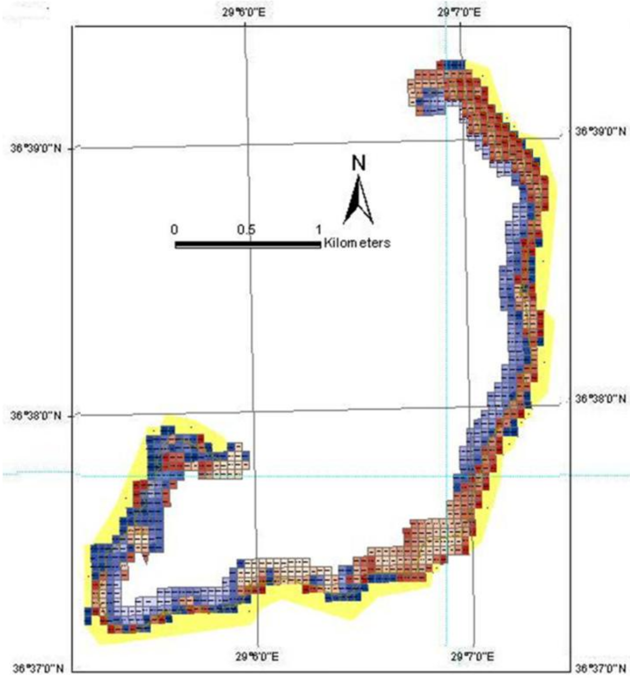


Figure 4.3: The Coastal Strip on GIS Environment (ArcGIS)

The unprocessed raw data has undergone several process in ArcGIS environment using the toolbexes within the ArcMAP software. The data is processed in order to create a raster data in which every pixel has much more meaningful information. Then, the pixels having the same or very similar data has been classified into condensed subgroups. The following figure (Figure 4.4) includes a small-scaled representation of a segmental analysis that the coastal segment confined in one pixel (square) and highlighted in cyan having a characteristic value different than that of its neighbours. Each pixel being represented by a value dominant in all points of that pixel has been under the influence of other neighbours (pixels) in weighing the average. Each data in pixel is re-calculated statistically within the zones of another dataset (ArcMap Zonal Statistics Tool).

The blue segmental line in Figure 4.4 contains a representative information related to the polygon inside. The larger polygon is obtained by using weighted average methodology and neighborhood analysis as a combination of smaller pixels within each comprising polygon. These polygons contain the data about the physical parameters such as coastal bathymetry, water depth at specific points, slope values, geomorphological characteristics etc. For the human related parameters, expert opinion will be needed to consult later.

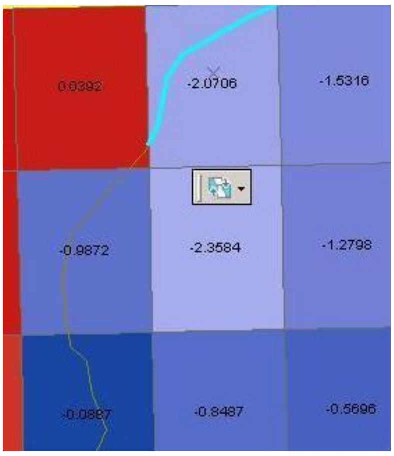


Figure 4.4: Sample Coastal Segment Used in Fuzzy Model

Datasets can represent one or more numbers of pixels. Some physical or human based parameters' data groups are reclassified into more organized group of dataset in order to prevent the data from being messy. After reclassification to obtain a similar and well-ordered groups of data, each mass of data group is assigned to the related part of shoreline. A whole shoreline for one layer has now various groups of datasets which directly determine the coastal segments' characteristics. Starting from the beginning, shoreline of each layer as a representative of physical or human based parameter is onebyone joined spatially in another. After each spatial join operation which combines the two shorelines related to the different parameters into one joined shoreline, the number of segments formed within the joined shoreline increases. Totally 20 layers are spatially joined and form one shoreline at the end as an output which is splitted into many segmental pieces having different characteristics than the others (ArcMap Spatial Join Tool). The principle of creating a segment is to make it unique by its parameter values so that there must be at least one different parameter value among 20 parameters in each segment.

Totally 13 physical and 7 human based parameters for each coastal segment are recorded in a database builded in ArcGIS software. The principle of creating a database is to keep data secure and compact together, to establish a statistical environment, to understand the distribution of a specific parameter, and to provide comfort in matching the coastal characteristics with one another.

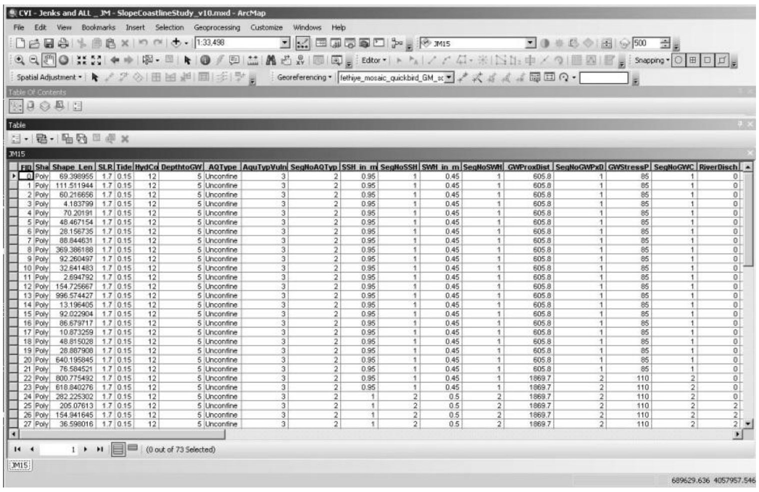


Figure 4.5: Database View on ArcMap for Coastal Segments

Some parameters need to be analyzed in a ArcGIS Model Builder environment.The raw data obtained from an institute, municipality or academic unit is processed by using several tools and then converted into a desired format at the end of model run. As an example, the procedure followed for slope layer is given in Figure 4.6.

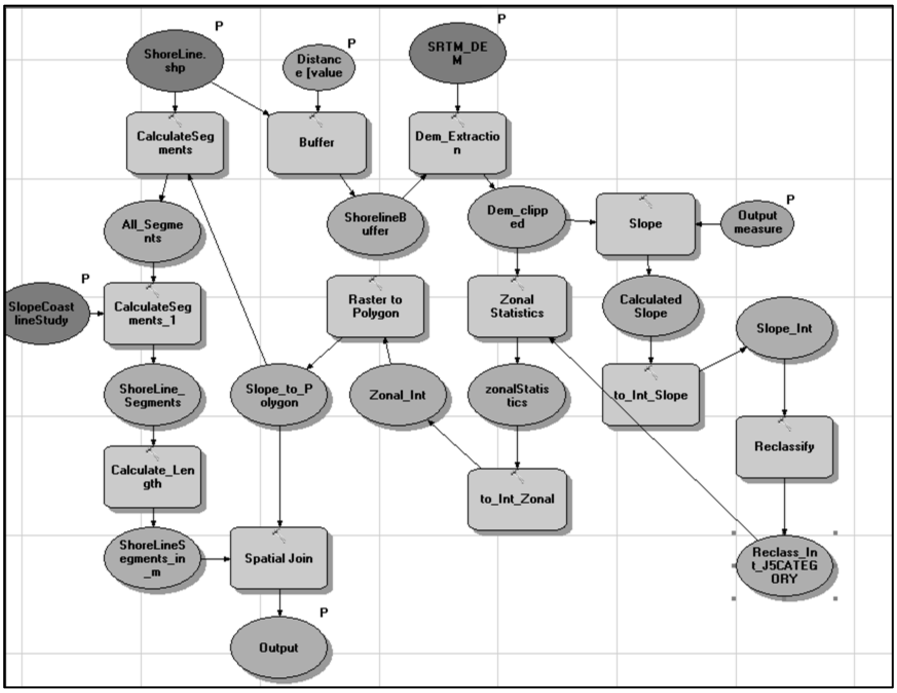


Figure 4.6: Model Builder for Slope layer

4.2.1 The Physical Impact Parameters

The physical impact processes which are studied are Coastal Erosion, Flooding due to Storm Surges, Inundation of Lands, Salt Water Intrusion to Groundwater Resources, and Salt Water Intrusion to River/Estuaries. 13 physical parameters were obtained and processed. In light of these processes, vulnerability assessment is conducted and indicated as the vulnerability levels for each segment of the shoreline. These impact process will be discussed in Chapter 5.

P1. Rate of Sea Level Rise

Even a small amount of increase in sea level poses a risk in the long term, not an instantaneous risk like tsunami phenomena. It brings out the impacts gradually in the long term with domino effect. The more increase in the rate of global warming means the higher degree in sea level.

As mentioned in the Literature Review part in Chapter 2, there are many studies dealing with the estimation and projections based on observation, statistical data in order to estimate the rate of sea level rise in near future.

According to the thirteenth chapter of WG1AR5 (5th Assessment Report Working Group-I) which is not an approved assessment report yet but published as one of the working group meetings' report, "it is most likely that global mean rate of sea level rise was determined as 1.7 [1.5 to 1.9] mm/yr between 1901 and 2010 for a total sea level rise of 0.19 [0.17-0.21] m. (Church J.A. et al., 2013). Although it is claimed in WG1AR5 (Church J.A. et al., 2013) that the rate was most likely higher at 3.2 [2.8 to 3.6] mm/yr between 1993 and 2010, the rate calculated for the period between 1901-2010 as 1.7 mm/yr is used in the model due to the convenience of the data and being a representation of long period of time.

Due to being a semi-closed basin connected to the ocean through the Strait of Gibraltar, rate of sea level changes in Mediterrenean basin is always different than the global rate. The study based on tide gauge data and conducted by Tsimplis and Baker (2000) gives an increasing trend in Mediterranean basin with a 1.2-1.5 mm/yr until 1960 and an decreasing trend in the period of 1960 and 1998. (Carillo et al., 2012). Due to these fluctuations caused by local temperature and salinity differences of Mediterranean from global trend, and the lack of site-specific information for Fethiye, as a reasonable rate level of 1.7 mm/yr is used for Fethiye Bay in the vulnerability assessment model.

P2. Geomorphology

Geomorphology is one of the important parameters which determines the coastal evolution and relative resistance of a landform to erosion or the relative erodibility of different types of landforms. (Pendleton et al., 2004).

The study area includes carstic, carbonate rocks and alluvial cone deposits mostly in addition to estuary, salt marsh on the north and indented cliffs on the west as geomorphological characteristics.(Figure 4.7).

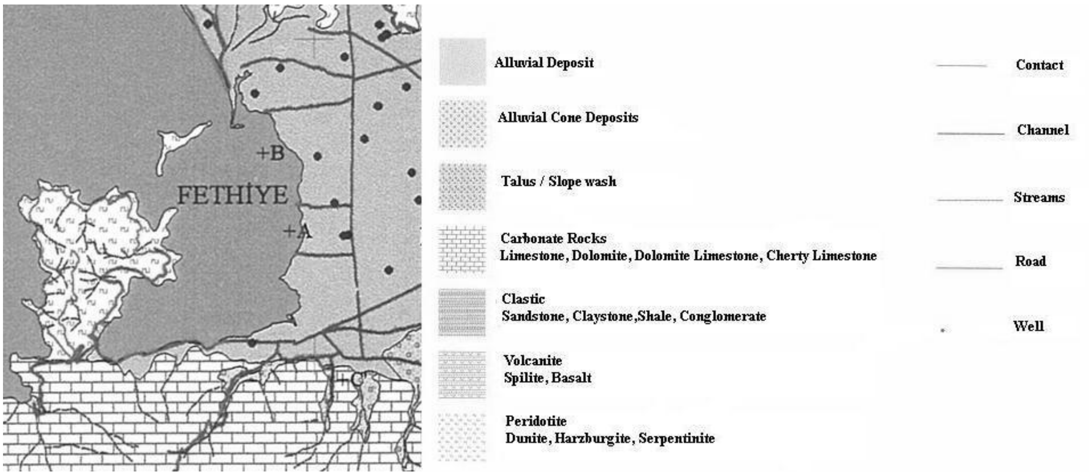


Figure 4.7: The geomorphological characteristics (METU, 2001)

Settlement can be observed on the east and on the south part of the bay in front of medium cliffs going towards south. Antropogenic facilities above the reclamation area are prevalent without any doubt of locating on an artificial landform.(Figure 4.8)

Figure 4.8: Antropogenic facilities on reclamation area

The Island of Sovalye which lies on the northwestern part protects the inner bay like a shell from wind or storm wave or any tsunamigenic event. The island includes both beach and low cliffed rock together that increases the geomorphological variety. A few settlement exists on the island that remains unprotected against hazard waves. (Figure 4.9).

Figure 4.9: Sovalye Island

Medium cliffs indented coast with rocks are seen on the west coast of the tip of the bay as well as green area on the hill. (Figure 4.10) No settlement is observed on these geomorphology due to constructional difficulty.

Figure 4.10: Medium cliffs indented coast

A few settlement can be seen in front of coastal forest in a Specially Protected Area of the Ministry of Environment and Urban Planning. These antropogenic facilities are an obvious proof of a reckless control mechanism of the authorities that allow to construct in a specially protected area. (Figure 4.11).

Figure 4.11: Settlement in front of a coastal forest

All the data is combined into the dataset of geomorphology layer in ArcGIS shown in Figure 4.12.

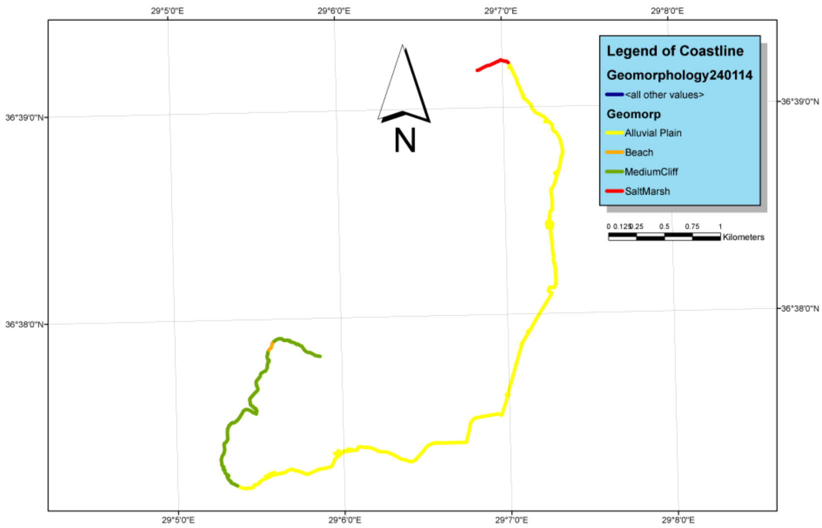


Figure 4.12: Database View for Geomorphology Layer

P3. Coastal Slope

In the geology report of METU (2001), slope ranges is given in degree with low resolution due to being hardcopied map. In this map, the slope values ranging between 0°-40° are classified into five categories for the whole Ölüdeniz, Fethiye, Göcek, Dalaman plains.(Figure 4.13).

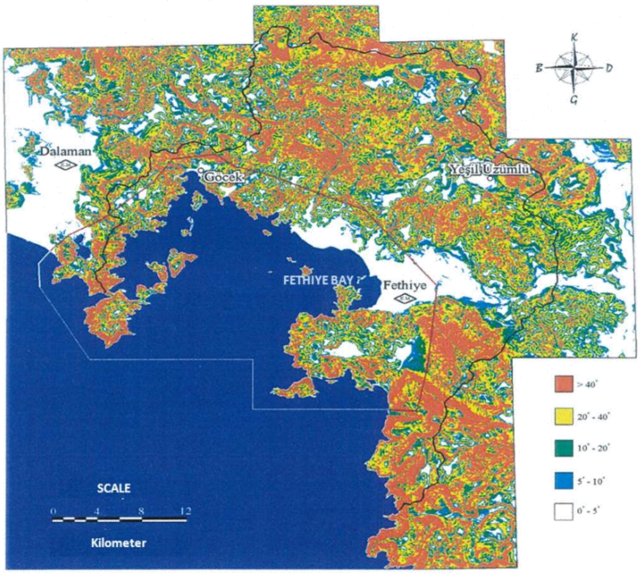


Figure 4.13: Representative Slope of Fethiye Plain (METU, 2001)

In order to have an accurate slope data, National-scale Shuttle Radar Topographic Mission (SRTM) 1-second (30 m) Digital Elevation Model (DEM) data is collected free from USGS website (http://gdex.cr.usgs.gov/gdex/) to study the coastal area within the 150 meter buffer. Geographical slope in a 150 meters of buffer zone on the sea side of the shoreline is extracted from DEM in percent rise. After converting raster features to polygons, shoreline is exploded and broken into shorter segments having its own average slope value obtained from the neighboring pixels by using Zonal Statistics Tool. The length of each segment calculated automatically with different tools and assigned to the related segment piece of the shoreline by joining spatially.(Figure 4.14).

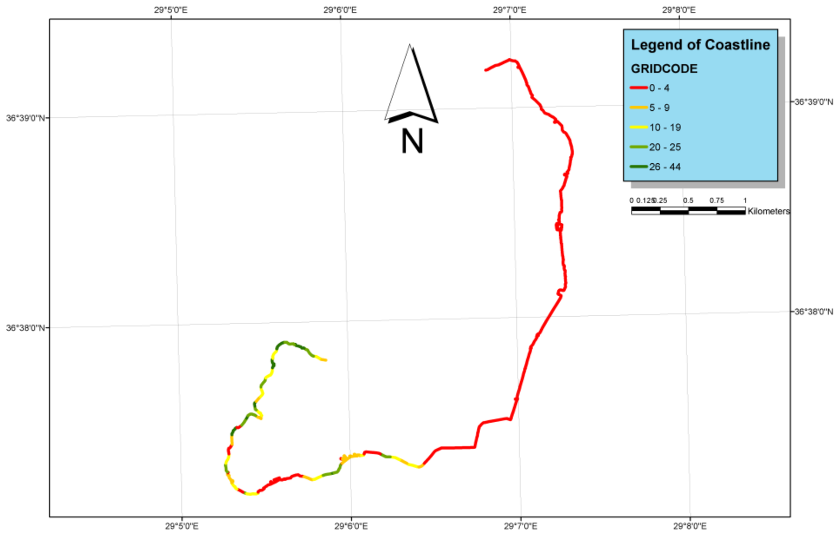


Figure 4.14: Database View for Coastal Slope (%) Layer

P4. Significant Wave Height

The significant wave height calculated based on SMB Method (Akbasoglu, 2011) is obtained. A significant wave height of 0.5m (0.4m-0.6m) is used for the upper part which is directly imposed to coming waves from open-sea without any obstacle. The lower part of the inner bay is evaluated with a value of 0.45m since the Island Sovalye is considered being a protective shell which meets the coming wave at the entrance of the bay and breaks it before entrying into the bay.(Figure 4.15)

Figure 4.15: Sovalye Island at the entrance of Fethiye Bay

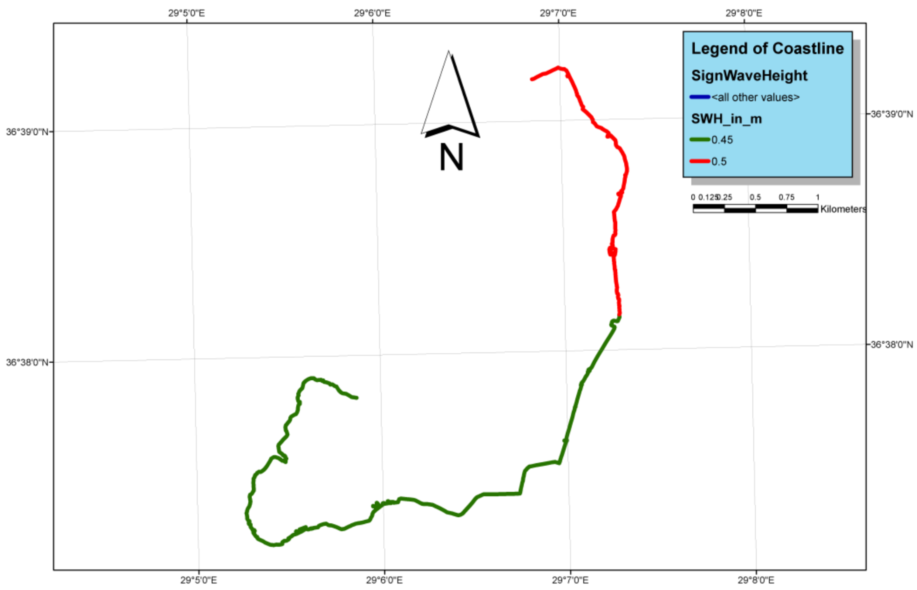


Figure 4.16: Database View for Significant Wave Height Layer

P5. Storm Surge Height

Even though extreme events occur once in the return period for a short duration, the affected area always gives an effort to recover itself by balancing an equilibrium in a longer period of time. Loss of land suddenly occurred by erosion due to extreme events like storm surge sometimes may have higher importance than establishing coastal equilibrium in a longer time period. In this case, it is feasible to solve the problem by using numerical modeling. The FCVAM assesses the flooding due to storm surge although the time scale of flooding assessment may extend to several decades based on its return period (1, 10, 100, 1000 years). (Ozyurt and Ergin, 2012). Since the lower part of the bay is in a protected area, the storm surge height is taken 0.95m for the lower part while it considered as 1m for the upper part of the bay.(Figure 4.17).

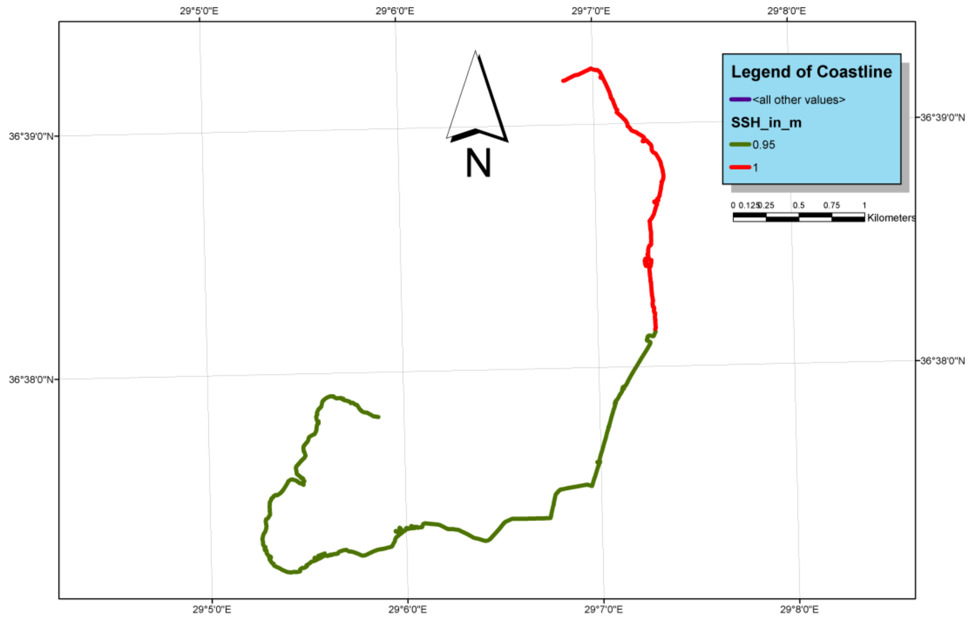


Figure 4.17: Database View for Storm Surge Wave Height Layer

P6. Sediment Budget

Formation of beaches is controlled by coastal processes which carry or take away loose sediment such as sand, gravel, silt or cooble. Among the elements shaping the shores, waves, currents, weather can be considered. While sediment causing the beach to grow may accrete, it may also erode the beach by taking away its elements from the shore. Erosion can be defined as the corroding of the land by natural movements, specifically sweeping away of fine-graded material by waves, tides, whereas accretion can be described as accumulation of sediment on a beach, wetland, saltmarsh by the action of water or air which creates an increase in elevation or profile. (Johannessen et al., 2014)

This parameter gives an idea about erosion/accretion condition of the study area. The bathymetry files are found for the years of 1956 and 2007. The shoreline formed according to these years' bathymetry is compared on GIS environment. There are three types of sediment budget condition such as erosion, accretion as well as the segments which are not changed in terms of sediment budget. For each condition, the pixels are charged with representing accretion, erosion, or neutral condition. After the Spatial Join operation for other layers is completed, these charged pixels are assigned to the splitted segments. New Split Operations are obtained with a more number of coastal segments. For example, a coastal segment may be formed by a combination of four different pixels of erosion, accretion and neutral sediment condition.. In accordance with the occupied length of shoreline, the coastal segments are assigned by different percentages of pixels representing erosion, accretion and neutral sediment condition. (Figure 4.18).

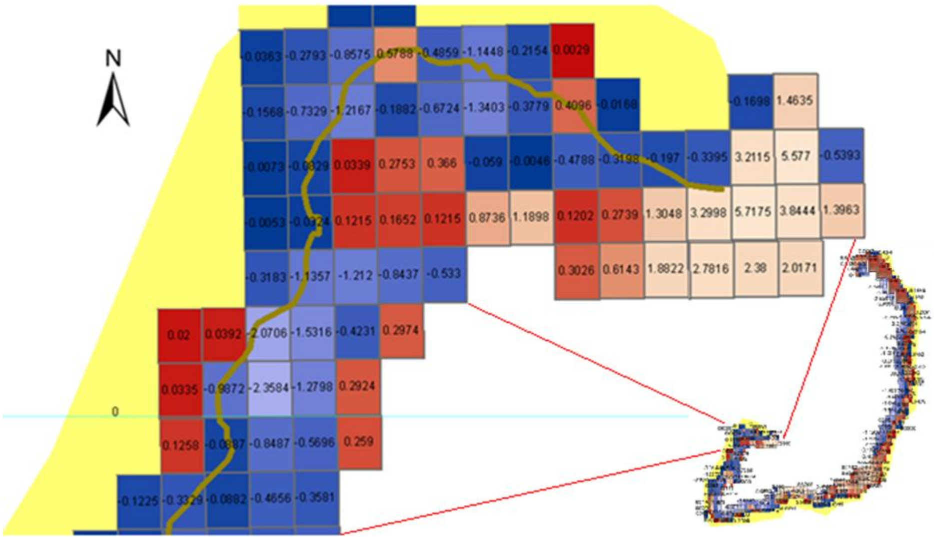


Figure 4.18: Representative Pixel Polygons of Bathymetric Difference between 1956-2007

Sediments are mainly accumulated at the sea bottom due to two main reasons. Rivers can cause sediment accumulation at the river mouth since they carry suspended materials while flowing through river bed. On the other hand, waves can cause sediment accumulation through the sea bottom especially in the vicinity of the coastal structures. Accretion areas are formed mainly due to these two reasons. In Fethiye Bay, accretion spots due to river discharging are distributed in small amounts especially in the east and in the north shore of the bay. (Figure 4.19). There was an active river discharging in the past on the southeast, but it is used as irrigation canal which does not have a regular flow today.

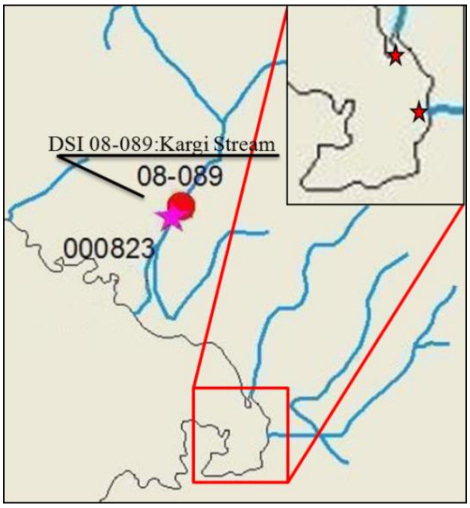


Figure 4.19: Representative River Distribution Network of DSI (Akbasoglu, S., 2011)

Considering the river distribution network map above and comparing the erosion-accretion condition of the study area, nearshore accretion area at the river mouth is pointed out on the east and north of the bay. A large accretion spot is observed between these two river mouth through the river discharging point on the north coast and the small scale fishing port on the east of the bay. The naturally accumulated zone due to alluvial sediment carried by rivers and wave action poses a risk for the bay as well as small boats. The other most visible accretion area are around the accumulation point currently used as irrigation-drainage canal in the southeast and wave action around the breakwater in the south. This larger accretion area on the southeast is estimated due to the past accumulation zone of the old river that is currently just used as canal for excessive irrigational water sources from hydroelectrical power plant and also possibly due to residual construction material from the reclamation projects in recent past since no information exists about the amount of discharge of the point on the southeast. The only information obtained from the sources is that in 1991 sample sediment is taken from that point, called T2 discharging canal of DSI (Akbasoglu, 2011).

Considering the accretion area on the south, coastal structures are mostly exposed to erosion on one side and deposition on the other side due to the driven action of the waves.(Figure 4.20). As a result of this, there accumulates a huge amount of sediment in the vicinity of the breakwater. Furthermore, the sediment is accumulated at the central locations due to the wave action at the sea floor of Fethiye Bay.

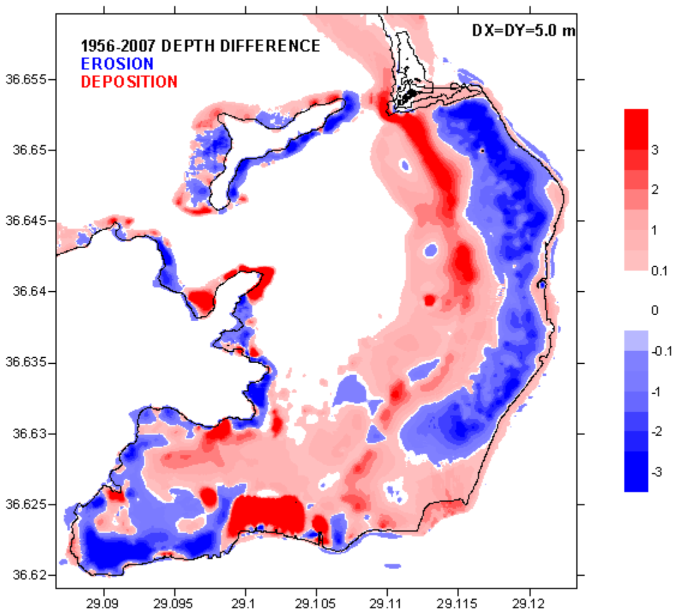


Figure 4.20: Depth Difference (1956-2007) (Akbasoglu, S., 2011)

Since 1960s, several reclamation and dredging activities are taken place by permission of the authorities in Fethiye Bay. One of the large-scaled reclamation activities surrounded by yellow line (Figure 4.21) is conducted in 1968 under the name of coastal rehabilition while the other small-scaled reclamation project enclosed by red line (Figure 4.21) is put into practice in 1994.

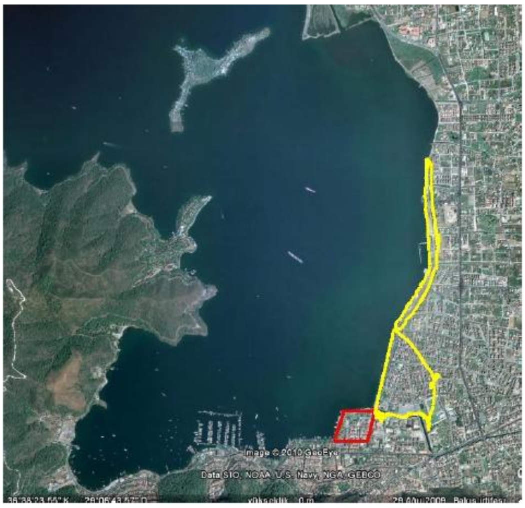


Figure 4.21: Reclamation Areas in Fethiye Bay (Akbasoglu, 2011)

Upon these artificial embarkments, dredging projects (blue shaded area in Figure 4.22) performed between the years of 1990s-2000s is to prevent navigation problems of boat, yacht and ships by protecting their drop keels from sea bottom. Especially in recent years, dredging activities to clean the northeast shores of the bay have been carried out with the participation of non-governmental organizations under the municipal support. Since the nearshore zone on the northeast of the bay encounter a significant decrease in water depth as a result of alluvial sediment discharging through the rivers around Murt Stream (Sample Sediment Location-1) and T3 canal of DSI (Sample Sediment Location 2).(Akbasoglu, 2011).

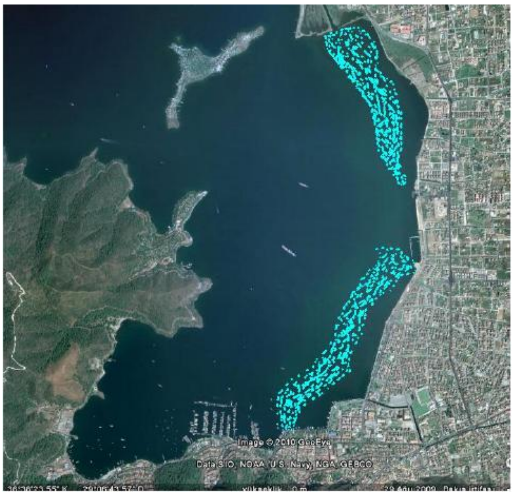


Figure 4.22: Dredging Areas in Fethiye Bay (Akbasoglu, 2011)

In the following database view, the segments faced with erosion is shown by blue line and those faced with accretion is shown by red line. The coastal strips which do not change is represented by yellow line. (Figure 4.23).

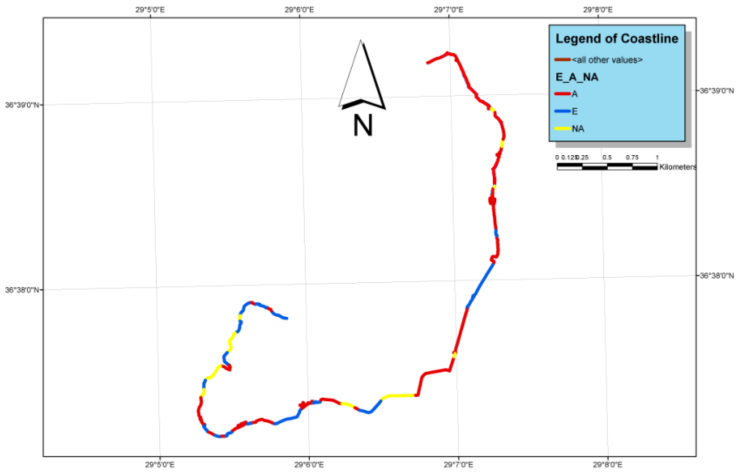


Figure 4.23: Database for Sediment Budget Layer (E:erosion, A:accretion, NA:no change)

P7. Tidal Range

The lower tidal level means the higher vulnerable to sea level rise. Tidal level values vary by region. Based on the reference source of Intergovernmental Panel on Climate Change, it is accepted as 0.15 meter for Mediterranean Region in this study. (IPCC, 2007). Such a small height does not constitute a risk for tide but for the coastal impact incase of salinity intrusion into freshwater. Coasts faced with lower tide show higher vulnerability against impacts due to the absence of familiarity with saline water for the ground.

P8. Proximity to Coast

Since groundwater body plays an important role in the vulnerability assessment about sea water intrusion, it is taken into consideration. Proximity to Coast refers to the distance of the central point of the groundwater basin to the shoreline. It is calculated as the perpendicular distance between shoreline and the central point of the groundwater body. This distance represents the effect of the groundwater on the coast. At the same time, it considers the impact of seawater on groundwaters in the case of seawater intrusion.

Based on METU (2001), the groundwater basin of Fethiye Plain has two main parts that it almost affects the whole shoreline. In light of conducted studies on GIS to determine the boundaries of the aquifers based on the reference source, the nearest distances between the centroid of the polygons and the shoreline are found. Two polygons around the Fethiye Bay are created to represent the upper and lower basins around the shoreline.(Figure 4.24).

Figure 4.24: Representative aquifer boundaries affecting the Bay

From the centroid of the geometries determined by Zonal Geometry in ArcMap, the distances to the shoreline are calculated. These values are assigned to the corresponding shoreline segments in front of the related geometries by Spatial Join Tool.

The distance of the centroid of the upper basin to the shoreline is found as 1869.7 meters while the lower one’s is 605.8 meters. At the left end point of the lower basin, the groundwater resources disappear. Hence no proximity distance exists for the western land of the bay.

The proximity distances of the aquifers to the shoreline is represented in meters by green line for the upper aquifer and by yellow line for lower aquifer in the following map. (Figure 4.25).

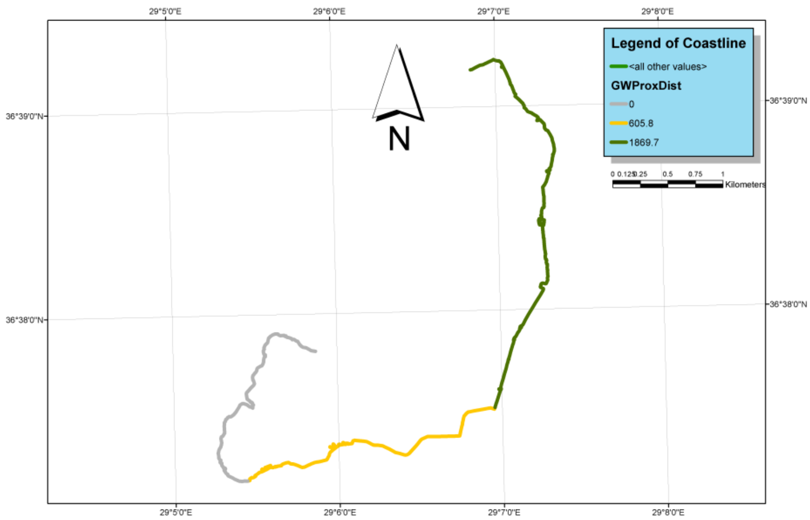


Figure 4.25: Database View for Proximity Distance Layer

P9. Type of Aquifer

An aquifer is such a formation that includes adequate saturated element to provide considerable amount of water to wells and springs. An aquifer that was used by O.E.Meinzer, 1945; cited in Lohman S.W. et al., 1988) to classify the water bodies in line with stratigraphical data include the unsaturated units of permeable formations.(Lohman S.W. et al., 1988)

In terms of vulnerability, coastal aquifers can be mainly classified into two types. An aquifer with an impermeable layer at the bottom boundary and a free surface as phreatic surface at the top is called unconfined aquifer. (Turcotte, Schubert, 2005). The most critical aquifer type is unconfined aquifer since it’s open to all kinds of leakages due to the lack of an impermeable layer. Contrary to confined aquifers, they’re the main concern to be in danger of contamination, under the threat of leaking or spilling of anything into the soil above the unconfined aquifers. Furthermore, to access drinking water, unconfined aquifers are not preferable to drill wells on them. (Kaiser and Skiller, 2001).

Monitoring coastal aquifers plays a significant role in the study of sea-water intrusion in terms of being helpful in the determination of the characteristics of salt/fresh water interface. Saltwater and fresh water is quite miscible that in uncontrolled pumping cases, saltwater may proceed inland until a new interface is established. (Wu et al. 1993).

Springs as natural formations related to phreatic flows from elevated geographies to lower elevations flows through permeable structured aquifer. Naturally occurring springs are usually due to the flow of groundwater from a high elevation to a low elevation. The flow takes place through an aquifer or permeable formation. (Turcotte, Schubert, 2005). Fethiye plain has a large distribution of aquifer as in Figure 4.26 (METU, 2001). In the green strip in Figure 4.26, effusive artesian range is represented with a great deal of artesian wells on it.

In the Figure 4.26 (METU, 2001), the contour lines represent the groundwater levels in the aquifer of Fethiye Bay. The green propagation area symbolizes the effusive artesian range with orange colored artesian wells inside. (METU, 2001).

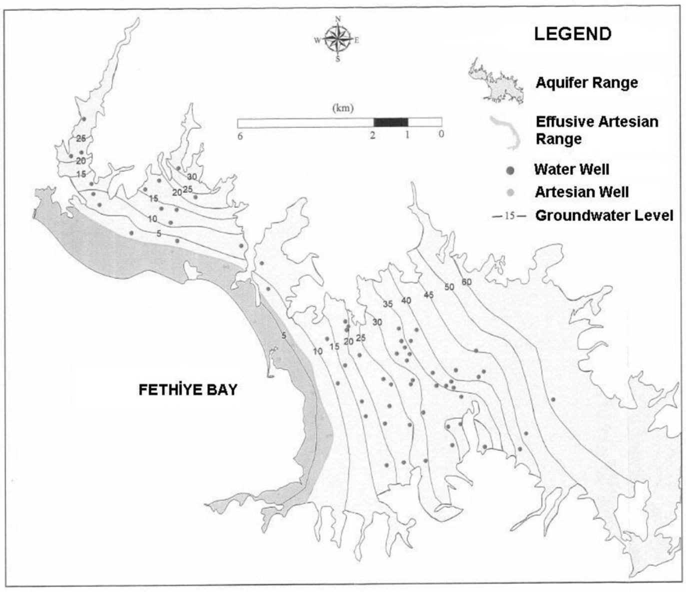


Figure 4.26: Aquifer Range and Groundwater Levels of the bay (METU, 2001)

As can be seen from Figure 4.7, the alluvial deposits are prevalent on the eastern and southeastern part that represents the populous settling region. Artesian flowing wells are common in these areas. On the south coast of the bay, going towards inland, a transition is observed from a short strip of alluvial deposits to carbonate rocks. On the high-cliffed west shore partaking of a peninsula, peridotite type of geological formation is prominent. Furthermore, alluvial cone deposits are rare as representatives of a noteless share in the study area whereas this type of formation is noticeable in clusters out of the study region (Figure 4.7). Although artesian wells mostly range in the coastal strip with a confined aquifer in the Fethiye plain, unconfined aquifer is located in the east and northeast of the Fethiye plain and also observed shallowly above the confined aquifer layer. (METU, 2001). Due to the existence of carbonate rocks towards inland, and due to the lack of a certain boundary for the aquifer types specified in METU (2001), the type of aquifer of the study field is taken as unconfined in order to be on the safe side, for all coastal segments which the groundwater reaches to.(Figure 4.27).

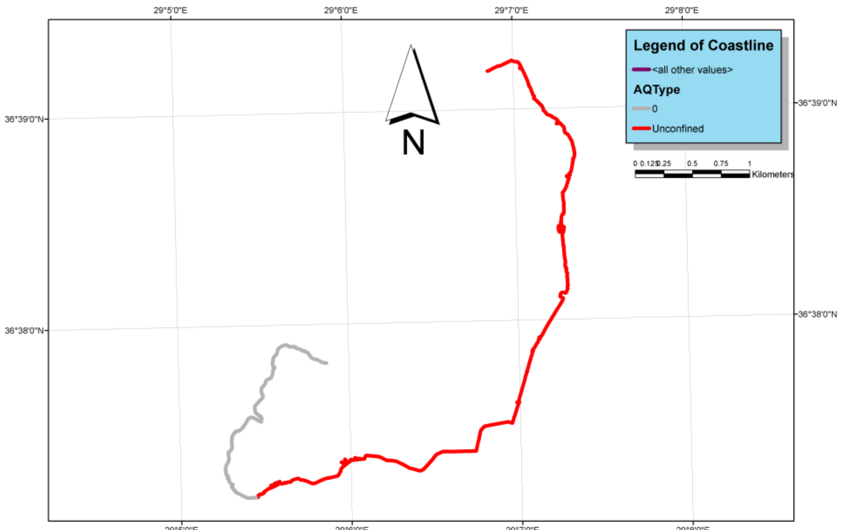


Figure 4.27: Database View for Aquifer Type Layer

P10. Hydraulic Conductivity

A general value for hydraulic conductivity (K) is obtained from the reference source (Table 4.2). Although Fethiye region is classified into three aquifer zones, the study area corresponds to the third coastal strip (Figure 4.28) with a hydraulic conductivity value of 12 meters per day. (METU, 2001).

Table 4.2: Hydraulic Conductivity Ranges for Fethiye (modified, METU, 2001).

Coastal Strip No.	Width Of Coastal Strip (m)	Hydraulic Conductivity K (m/day)	Hydraulic Gradient i	Aquifer Width (m)	Groundwater Discharge Per Unit Width (m^3/day/m)	Total Groundwater Discharge (m^3/year)
1	5600	40	0.0035	25	3.5716	7.300.000
2	3500	20	0.0066	25	3.2110	4.100.000
3	4500	12	0.0100	30	3.7270	6.100.000

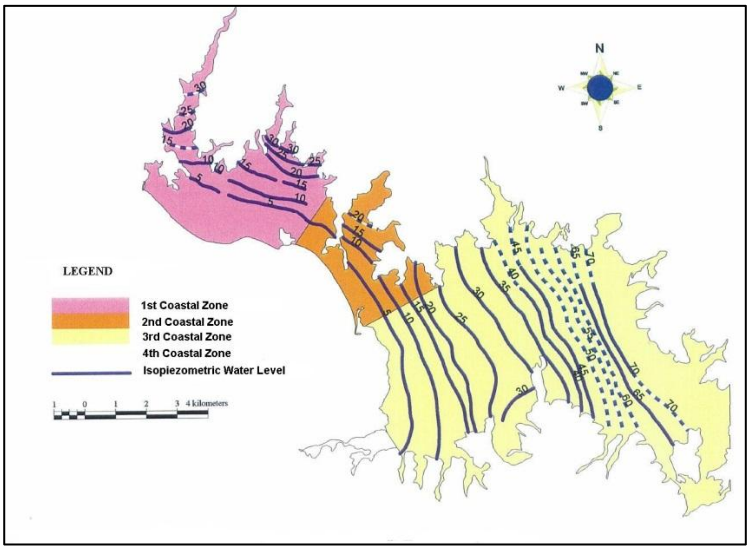


Figure 4.28: Isopiezometric Water Level Through Three Coastal Zones (METU, 2001)

P11. Depth to Groundwater Level Above Sea

In view of the reference source (METU, 2001), an effusive artesian range is commonly observed with artesian wells on it through the coast (Figure 4.26). In addition, isopiezometric water level through these effusive artesian range seems to be more than five meters.

P12. River Discharge

Based on the Stream Flow Year Book (EIE, 2010), three rivers have been investigated. While the name of the old discharging point on the southeast is known as DSI T2 canal (for irrigation purposes), the sources of two current discharging stream able to reach into the bay are not clear according to DSI and EIEI database. Due to the uncertainities on the discharge data, the worst case scenario is taken into account. The discharge values of Kargi Stream, Esen Stream, and Karacay (Kayadibi) Stream are evaluated but only the data of Kargi Stream in Yanıklar region is found and used due to its discharging point as the closest data station to Fethiye Bay. Among the other known sources, Esen Stream is flowing from north to south through the eastern part of Fethiye Bay without approaching the bay area. The Oren Regulatory is located on Esen Stream discharging through the eastern side of the bay area. In the meantime, the irrigation canal, ended at DSI T2 canal downstream point, is fed by a branch which springs from water outlet of Oren Regulatory. As can be seen, the branches are collected and splitted in different points. Therefore, regular discharge measurement is needed to be recorded by the institutions such as DSI, EIEI etc.(Figure 4.29).

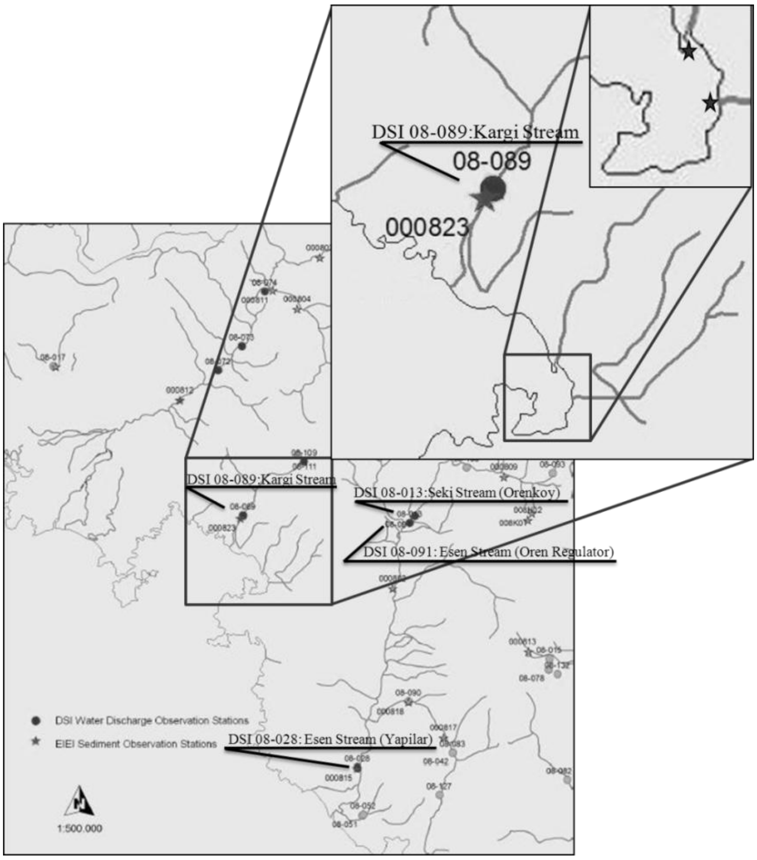


Figure 4.29: River Discharging Points (modified, Akbasoglu, 2011)

Although the discharging point of Kargi stream is 8 km far away on the northwestern direction of Fethiye Bay, it is the closest data station to Fethiye Bay whose data can be used.

Table 4.3: Max.-Min.Flow Rates of Kargi Stream discharging into the north of the outside bay (EIEI, 2003-2007)

YEAR	AVERAGE FLOW (m^3/s)	MAX FLOW (m3/s)	MIN FLOW (m3/s)
2003	7.23	138.00	1.98
2004	5.71	76.30	2.20
2005	3.87	60.10	2.20
2006	4.11	49.30	2.20
2007	3.02	62.70	1.89

Table 4.4: Average Flow Rate of Kargi Stream (EIEI, 2003-2007)

STATION NAME:			KARGI ÇAYI-YANIKLAR
STATION CODE:			EIE_8-823
COORDINATE:			36°44'46'',29°04'07''
PRECIPITATION AREA:			194km^2
ELEVATION:			55m
AVE. OF FIVE YEARS' AVERAGE:			**4.789 (m3/s)**

The annual average values ranges between 2 m^3/s (June-October) and 6 m^3/s (November-May) (EIEI, 2003-2007) (Table 4.3) depending on the season. To be on the safe side in the vulnerability model studies, the minimum values around 2 m^3/s are taken into consideration for each stream flowing into the bay area since the the vulnerability model is based on the minimum flows as the poor condition.

Although the Kargı Stream on the north flows with an mean discharge rate of 4.789 m^3/s between the years of 2003-2007 (Table 4.4), the data about the river discharging point on the eastern coast, which corresponds to around Sediment Sample Location-2 in Figure 4.29, lacks due to the absence of data of DSI. This situation deprives of a comparison opportunity between the two rivers discharging into Fethiye Bay.

In current map sources, an irrigation channel, connected to Oren Regulatory System near Seki Stream, is observed on the east and southeast of the bay. Although the downstream point of this channel corresponds to Sample Location-3 (Akbasoglu, 2011), it is an artificial channel used for irrigation. Throughout the year, the discharge of the canal continuously changes depending on the season and storage ratio of the reservoir. In the yearly books of DSI and EIEI, no discharge data about this downstream point of the shoreline exists. Even it is ambiguous whether any discharge flows or not. (Stream Yearly-Book of EIEI, 2007).

The river discharge locations colored by red line are shown in the following figure. Considering the worst case scenario, the discharge values are taken similar with 2 m³/sec for the two different discharging point.(Figure 4.30).

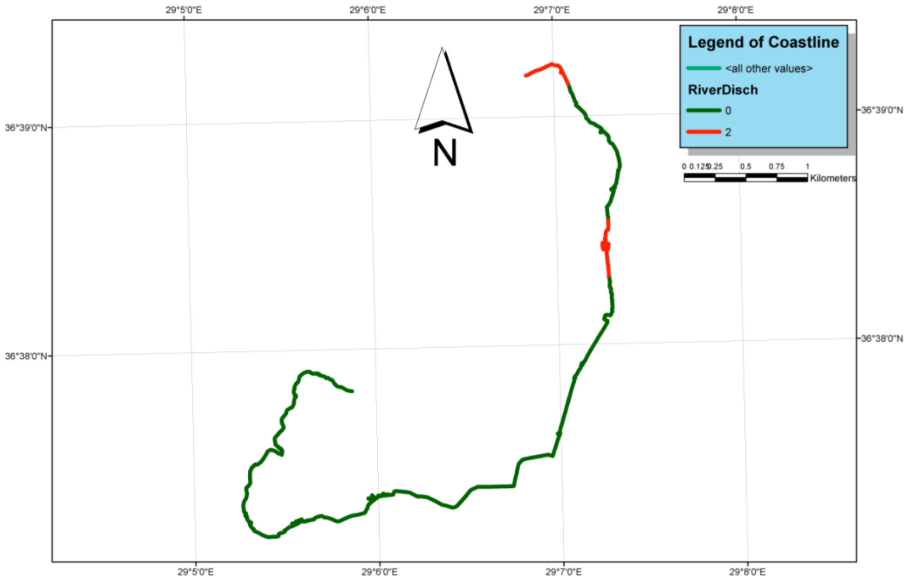


Figure 4.30: Database View for River Discharge Layer

P13. Water Depth at Downstream

It is very common for local sea level to rise in the vicinity of rivers' mouth due to the accumulation of different size of sediments coming from rivers into the open-seas (Chachadi, 2002) as in the northern and eastern parts of the coast of Fethiye Bay.

The higher depth of seawater at downstream, the lower velocity of the fresh water through the river bed. (as cited in Ozyurt, 2007). In the vicinity of downstream of rivers, sediment coming through rivers accumulates at the river mouth. Accretion areas that occur at river mouth prevent freshwater to flow fast. Flowing water on river bed with a velocity lower than the limit value causes suspended sediment to accumulate more on channel bed. This is a loop that initiates eachother.

To find the water depth at downstream of the rivers around Fethiye Bay, bathymetry data (right map in Figure 4.31) and river map (left map in Figure 4.31) have been overlapped on ArcGIS. Accretion areas are apparent in reddish color on GIS environment whereas the blue colored polygons represents the eroded zones. At the zone of river mouth, the bathymetry data interpolated through the surrounding pixels by Zonal Statistics is assigned to the corresponding shoreline segments.

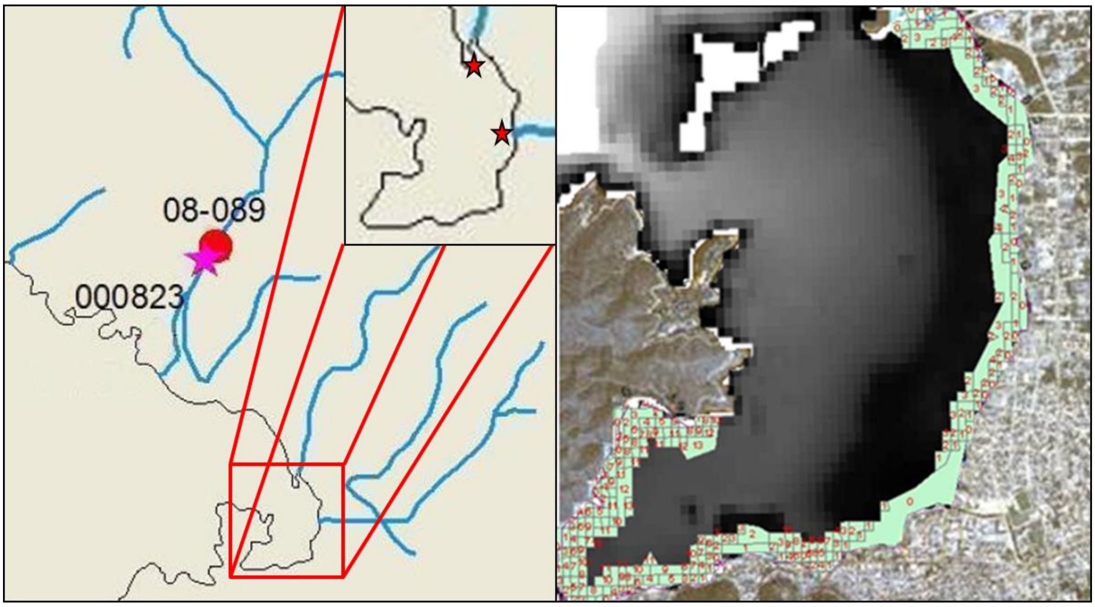


Figure 4.31: Layers to be overlapped for Water Depth (with Polygonal Bathymetry)

It is obvious on the figure above that water depth at the downstreams of rivers changes between 0 meter and 2 meters through the shoreline. After the locations the rivers fall into the sea are marked, the water depth values interpolated with the adjacent pixels, and assigned the resulting water depth values to the corresponding segments of the shoreline. The rivers discharging into the north of the bay and into the east of the bay are taken into consideration in calculation. The values of these rivers range between 0-2 meters by pixel.

The water depth values are assigned to river discharging zones from the bathymetry map. The variation in depth values around river mouths is due to being a zone not a point.

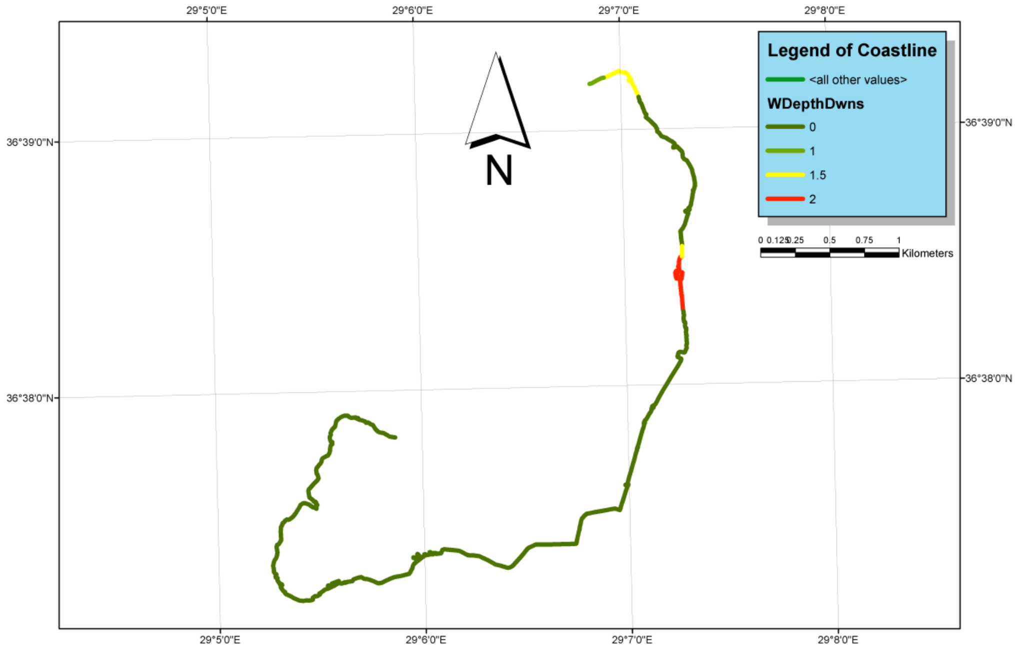


Figure 4.32: Database View for Water Depth Values at Downstream Layer

4.2.2 The Human Related Parameters

In this part, the remaning 7 human based factors of totally 17 parameters will be clarified.

H1. Reduction of Sediment Supply

There are many agents that should be considered in reduction of sediment supply. Building a dam or channel on the edge of the upstream of the rivers plays important role since these types of human interventions cause the sediment supply of coasts to decrease one of the major elements in reduction of sediment supply. Wave action coming from open sea also provides sedimentary material towards the shoreline. Constructing a breakwater or sea gate may also reduce the sediment deposition at the downstream of a river or at the entrance of the harbor. Change in land use type may also influence the sediment supply by altering the climate (rainfall etc.) in the long term.

The parameters that can change the condition of reduction of sediment supply are the sediment particles trapped in dams constructed near the upstream point of rivers, any alteration in land use, or any digging facility due to mining or construction works (Ozyurt, 2010). Reduction in Sediment Supply refers to the ratio of the amount of the sediment particle transported through the river into the coast to the equilibrium state of the coastal region (Ozyurt, 2007).

As can be seen from the two figure below (Figure 4.33 and Figure 4.34), one of the stream poured near Fethiye basin, Kargi Stream, has no significant sediment load. With the help of the data obtained between the years of 1993-1996 and 2005-2010, it is obviously seen that there is no considerable amount of transported sediment except spikes. These spikes are due to probable flood events at related years.

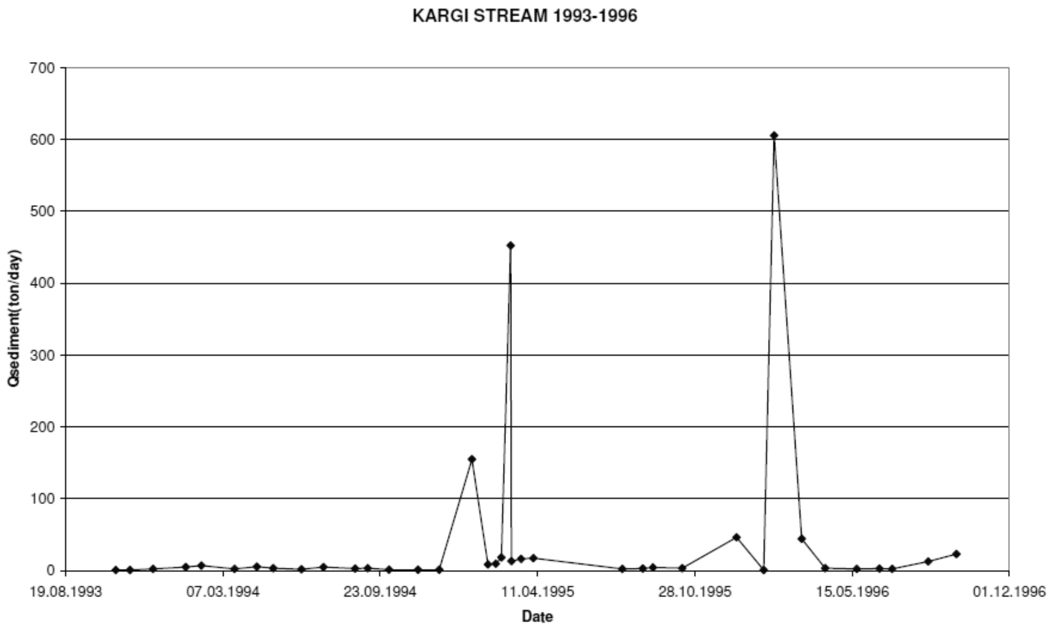


Figure 4.33: Daily transported sediment amounts vs. date. (Akbasoglu, 2011)

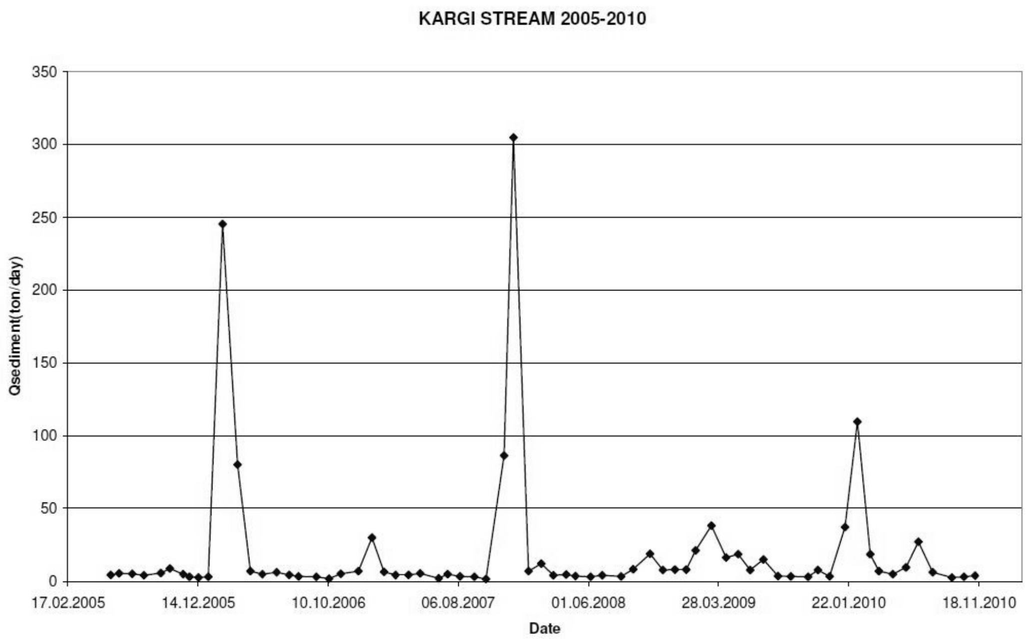


Figure 4.34: Daily transported sediment amounts vs. date. (Akbasoglu, 2011)

The rate of the sediment supplies of rivers discharging the bay reduces a bit due to the existence of dams and stream restoration near the north, east and southwest of the bay. Although these sediment preventive structures are not so close to especially the upper river, they can trap the sediment upto a certain degree. On the other hand, the accumulation still continues on the northeast zone with the contribution of Murt Stream branching out Susambeleni, Pasaarki, Cerci, Eldirek, Kosebuku. Especially during flood season, Murt Stream and its branches carry natural sediment and contaminated materials into the bay (Yilgor, 2003; cited in Akbasoglu and Yalciner, 2011). Some construction materials have been removed and the sediment stability of the stream has been destroyed.(Akbasoglu and Yalciner, 2011). Although dredging activities to remove the sediment from sea bottom have been carried out as an artificial intervention by non-governmental organizations each year, the northeast zone of the bay is observed to be naturally accreted. The parameter of reduction of sediment supply is taken as ±80% for the shoreline affected by Murt Stream in view of expert opinion.(around Sample Location-1 and Sample Location-2 in Figure 4.35). The sediment accumulation expands in the region from the north tip towards the fishing port on the east. Sample location-3 (Akbasoglu, 2011) is used to take sample sediment in 1991 but it is currently not a natural river, just a canal that no current discharge data is found in DSI or EIEI archive. (See Figure 4.29 for River Discharging Points).

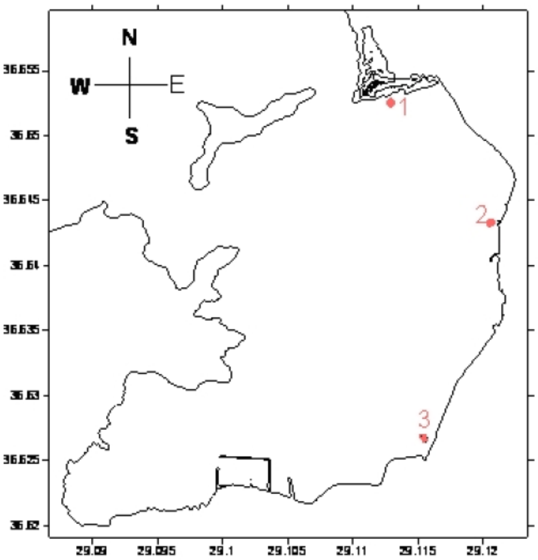


Figure 4.35: Sediment sample locations (DSI, 1993) (Akbasoglu, 2011)

The percentage values for reduction of sediment supply are determined as 80% and shown in the database by red lines for the locations which corresponds to the river discharging zones. (Figure 4.36).

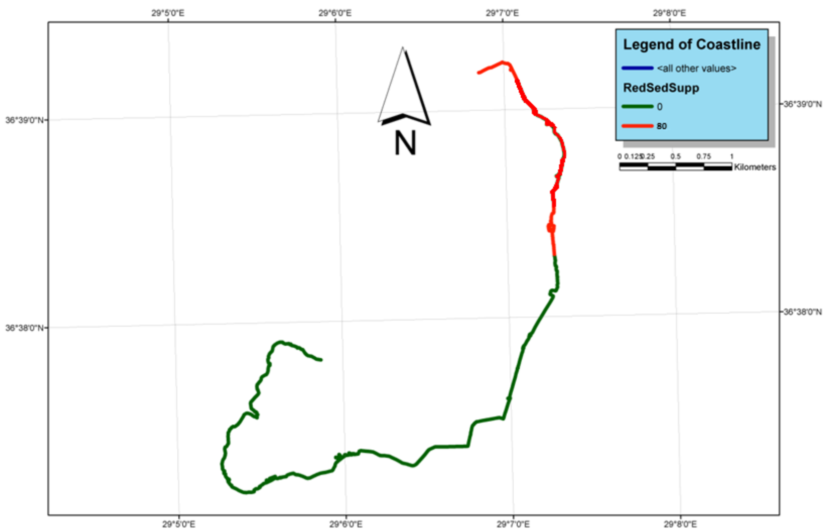


Figure 4.36: Database View for Reduction of Sediment Supply Layer

H2. River Flow Regulation

Although rivers regulated by a structure allow stable rate of water flows, these regulated rivers have lower capacity to carry the sediment to the coastal area by creating a condition to make the sediment settle along river channels although these regulated rivers allow stable rate of water flows. On the other hand, rivers which are not regulated have higher capacity to carry sediment load due to the lack of a dam to trap the sediment transported in river channels with the flushing of it especially during floods.(Ozyurt, 2010).

The existence of sediment preventive structures affect the sediment loads of the two natural rivers upto a certain degree that these two river discharging points around Sample Location-1 and Sample Location-2 are indicated in Figure 4.29. Due to the long distance of regulative structures to river discharging points on the coast, the effect of silting weir and base belt on the north and the silting weir and check dams on the east of the bay are similar and taken as Low Affected which corresponds to the vulnerability level of 2. If the effect of these structures were high, the sediment amount carried by rivers would be almost zero at all time.(Figure 4.37).

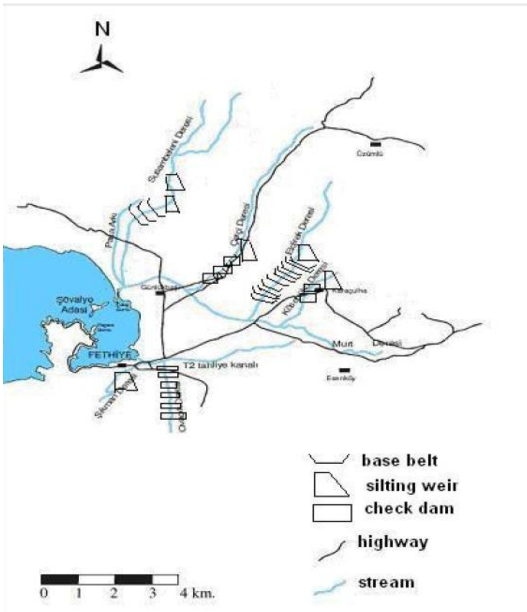


Figure 4.37: Sediment Preventive Structures on Streams Discharging Fethiye Bay (Akbasoglu, 2011)

The downstream locations expected to be affected by the regulative structures are shown by red line in the following map. (Figure 4.38).

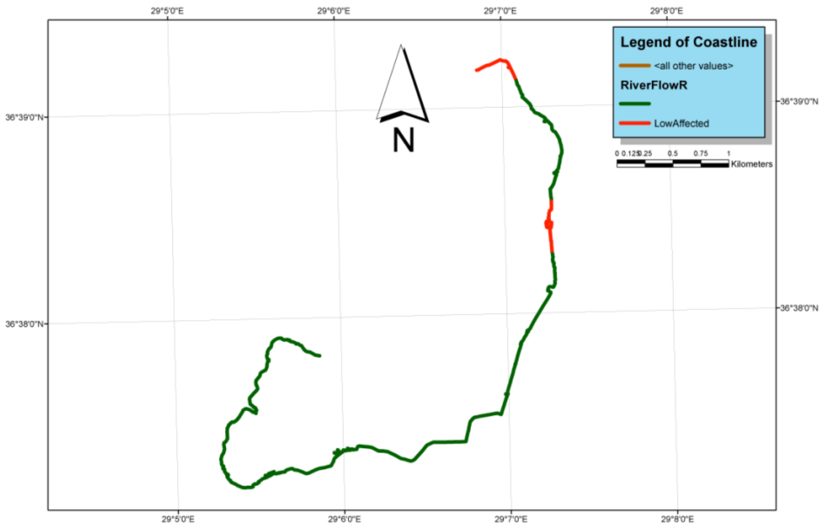


Figure 4.38: Database View for River Flow Regulation Layer

H3. Engineered Frontage

This parameter is related to the amount of the structures not naturally exist, but antropogenically located there. Natural structures are not included in engineered frontage. Structures built in favor of human use and landscaping is called engineered frontage. In the construction of such structures, protection concern is not taken into consideration or at least does not become in the first priorities. The observations prove the miserable condition of the coastline due to antropogenical interventions.(Figure 4.39).

Figure 4.39: Wall in front of the east coast

Such short walls (Figure 4.40) can be observed on the south and east coast of the bay that no measure against storm surge, tsunami or other marine hazards is considered in the design of the structure. The only concern in design period of this wall is related to antropogenic and aesthetical factors .

Figure 4.40: East Coast of the inner bay

The entrance of the canal which is closed at the upstream side with human-made wall is designed for yachts, boats to be moored inside. The canal with a hundred meter length towards the land is seen on the east coast of the bay (Figure 4.41).

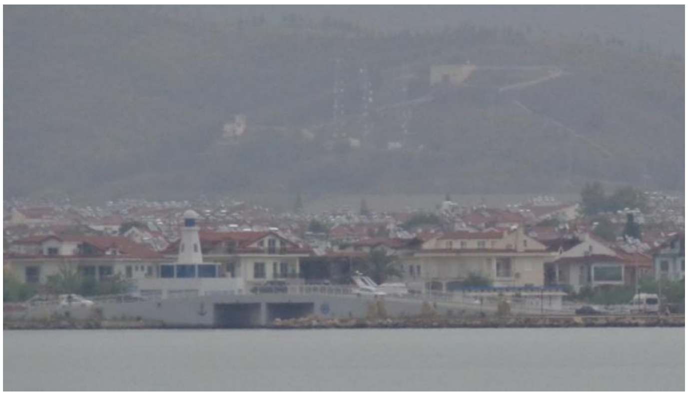


Figure 4.41: Entrance of the mooring canal on the east

Hotel constructions (Figure 4.42) can be seen on the coasts of the bay which adversely affects the natural ecosystem and increases the vulnerability of the region.

Figure 4.42: West coast of the inner bay (Hotel Front)

Considering Figure 4.41, Figure 4.42 taken in 2014, the coastline mostly surrounded by human-made structures which will decrease the resilience and increase the vulnerability of the bay against sea level rise.

The engineered frontages through the coastline of the bay are represented by red line in the following map where 1 means there is engineered frontage.(Figure 4.43).

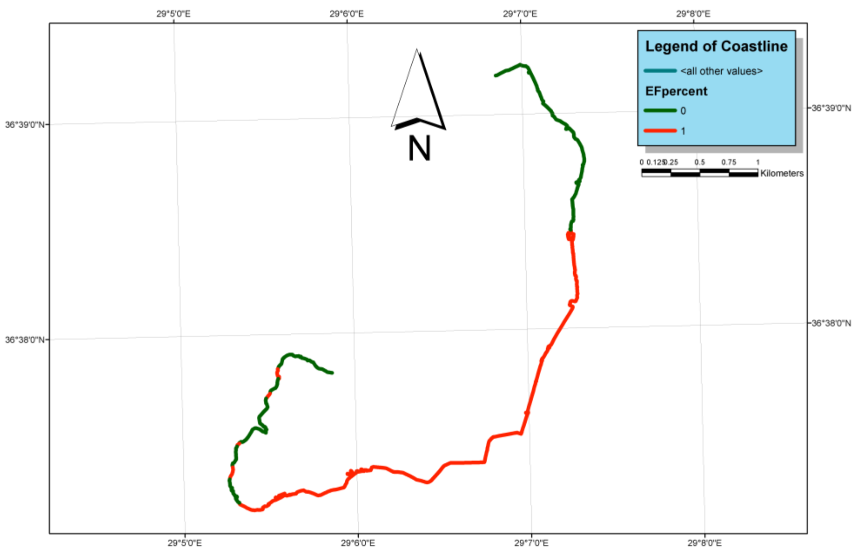


Figure 4.43: Database View for Engineered Frontage Layer

H4. Groundwater Consumption

Sea-water intrusion was caused by the excessive pumping of groundwater from the coastal aquifer. (Wu et al., 1993. Sea-Water Intrusion in the Coastal Area of Laizhou Bay,China).

As mentioned in ‘Depth of Groundwater above Sea’ part, artesian range is so prominent through the shoreline that water is widely flowing through the green strip. In Figure 4.44, the contour lines represent the groundwater levels in the aquifer of Fethiye Bay. The green propagation area symbolizes the effusive artesian range with orange colored artesian wells inside. (METU, 2001).

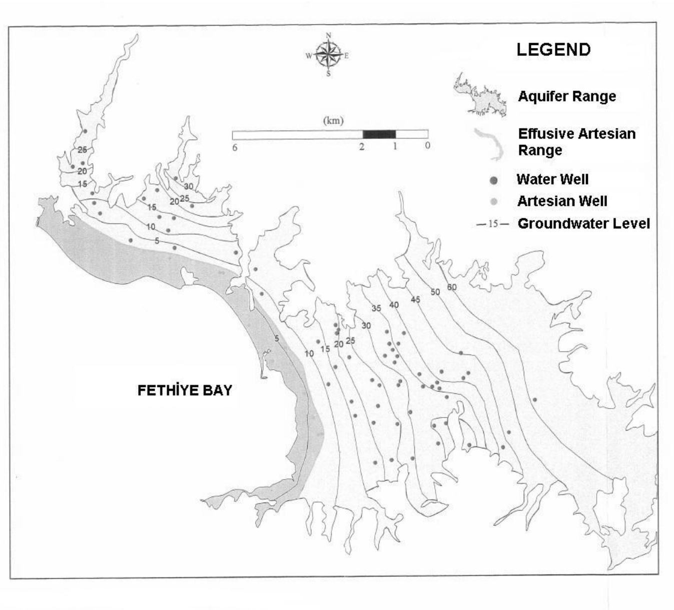


Figure 4.44: Isometric Levels of Groundwater (February1999) (METU, 2001)

Groundwater use from Fethiye plain aquifer is mainly for three main reasons; industrial, agricultural and domestic use. According to the report “Inventory of Groundwater Potential and Use in Turkey“ prepared by State Hydraulics Works (DSI) in 1995, the annual amount of groundwater drawings is $4.45x10^6$ m^3/year except agricultural use. Agriculture is very common as one of the main sources of income for local people.

Groundwater drawings for irrigational purpose is performed in greenhouses. When these groundwater drawing amount for irrigational purpose is added, total drawing amount becomes around 5 x10^6 m^3/year. A groundwater supply/demand distribution for inner side forming Alluvial Aquifer of Fethiye Plain can be seen as follows.(Table 4.5).

Table 4.5: Groundwater Consumption (METU, 2001)

RECHARGE		DISCHARGE	
Components	**Amount(10^6 m^3/year)**	**Components**	**Amount(10^6 m^3/year)**
Precipitation	12.00	**Discharge to sea**	17.50
Surface Runoff	10.00	**Drawing for domestic and irrigation**	5.04
TOTAL AMOUNT	22.00	**TOTAL AMOUNT**	22.54
CHANGE IN RESERVE: 0.54x10^6 m^3/year			

As can be seen from the table, water discharge amount from the aquifer is a little bit higher than the recharge amount value. This difference can create big problems over the years. The decrease in groundwater resources means an increase in salinity water intrusion toward inland. This decrease also affects the movement of the plates due to the tectonic movements beside representing a decrease in water supply of the region.

Groundwater drawings should be taken under control in terms of drawing amount and drawing points to prevent a permanent loss of the natural resources.

Groundwater Consumption of each aquifer is determined as 110% for the eastern part of the aquifer which underlies the agriculture and settlement area and as 85% for the southern part of the aquifer which lies down under the settlement and unclaimed area, respectively. The upper part of the aquifer located on the east is indicated by red line while the lower part on the south is represented by yellow line in the following map.(Figure 4.45).

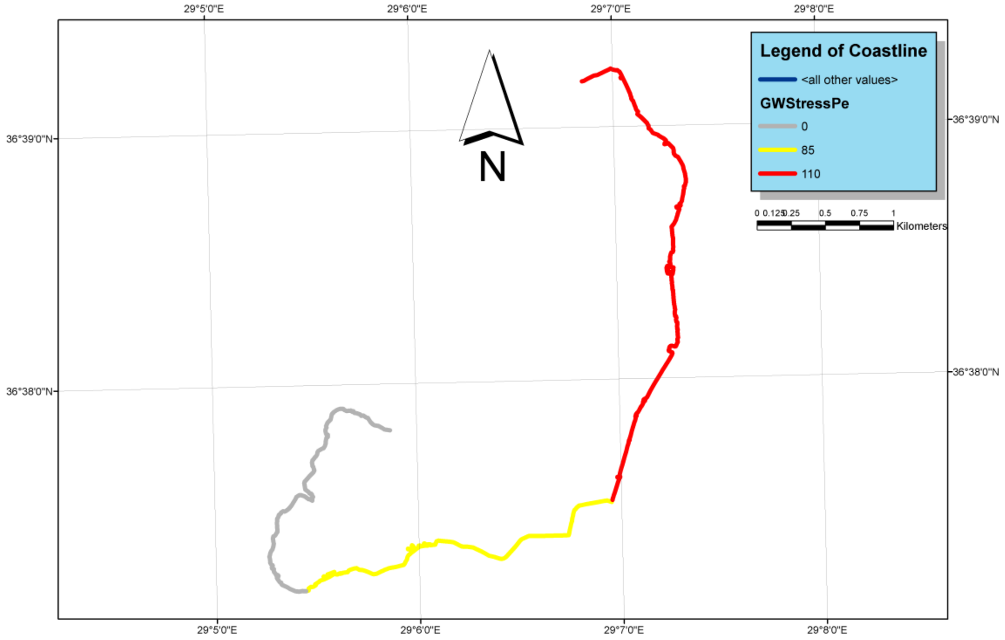


Figure 4.45: Database View for Groundwater Consumption Layer

H5. Land Use Pattern

The study area includes a variety of land use patterns. On the west and southwestern part of the bay (Figure 4.46), there are protected reclamation areas while the settlement and agricultural areas are observed on the whole east side of the plain. In satellite images, settlements enlarging towards the southern coast can be pointed out.

Fethiye including the whole study area has been declared to be in the list of “Specially Protected Areas” by The Ministry of Environment and Urban Planning in the late 1990s. (Ministry of Environmental and Urban Planning, 2014).

Although the study area is legally declared to be under the classification of protected area, a wide range of human made structures is observed around the bay. Therefore, settlement, agricultural and industurial area classifications are used when considered necessary beside protected area for the land use parameter.

Figure 4.46: Southwestern coast of the bay

The study region has a wide range of landuse patterns through the coastline which represented by different colors on the following map. (Figure 4.47).

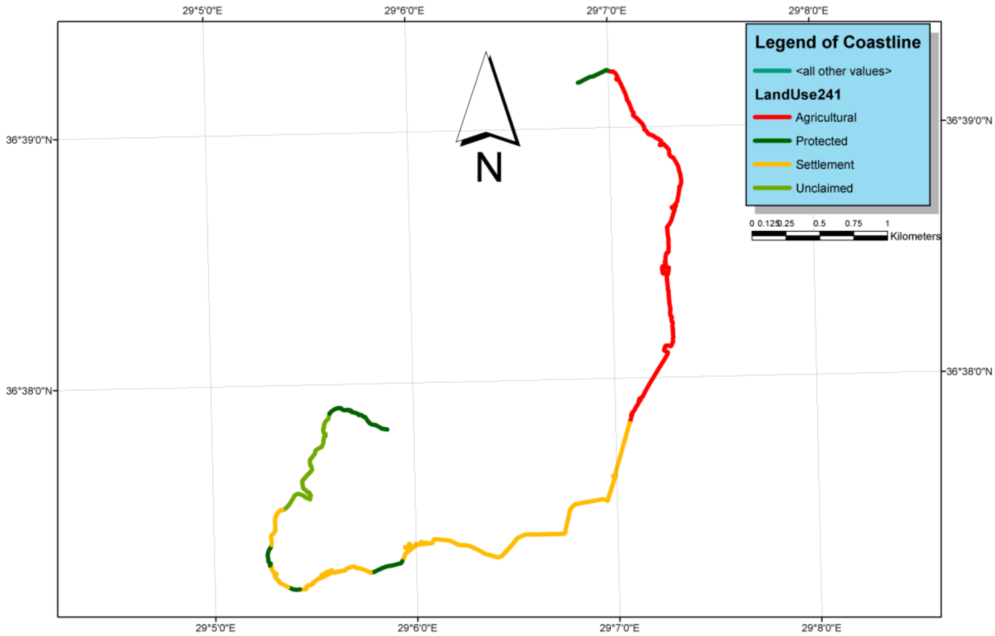


Figure 4.47: Database View for Land Use Layer

H6. Natural Protection Degradation

This parameter gives information about the condition of natural protection structures such as dune, wetland, and salt marsh. (Ozyurt, 2007). The existence of undisturbed natural protection systems is an indicator for steady and powerful coastal systems. The existence of natural protection systems alive prove the protection of the coast against any hazards and natural phenomena. Natural protection systems such as dunes, wetlands, marshes are very limited in the study area. Salt marsh is observed on the north tip while a pocket beach takes part on the northwest of the bay as undisturbed natural protection systems.

In the case of human interference on these systems, natural protection systems are disturbed and at least one chain of the system is broken. For instance salt marsh provides stability in sediment binding and trapping beside being food sources for aquatic and terrestrial animals. In the case of constructing a coastal structures instead of protecting them, the fauna and flora of that environment get starved since enough nutrients can not be delivered to the ecosystem. Then, local people who earn their life from fishing will get hungry and poor in the region in addition to the complete destruction of the ecosystem. Moreover, the sediment equilibrium can not be balanced anymore.

Since salt marshes can be entangled firmly with the soil and can prevent coastal erosion upto a certain degree, they are considered as a natural protection element against sea level rise. The west part of the study area is covered with coastal forests while the whole study region is declared as one of the Specially Protected Environmental Areas by Ministry of Environment and Urban Planning. However, these forests do not act as a protection mechanism against sea level rise and are not taken into consideration as natural protection element. It is still being discussed whether coastal forest may stand as a preventive element against tsunami or not.

The study region is quite poor in terms of natural protection degradation except salt marsh on the north tip and the pocket beach on the west tip as shown by dark green and light green colored line in the following map. (Figure 4.48).

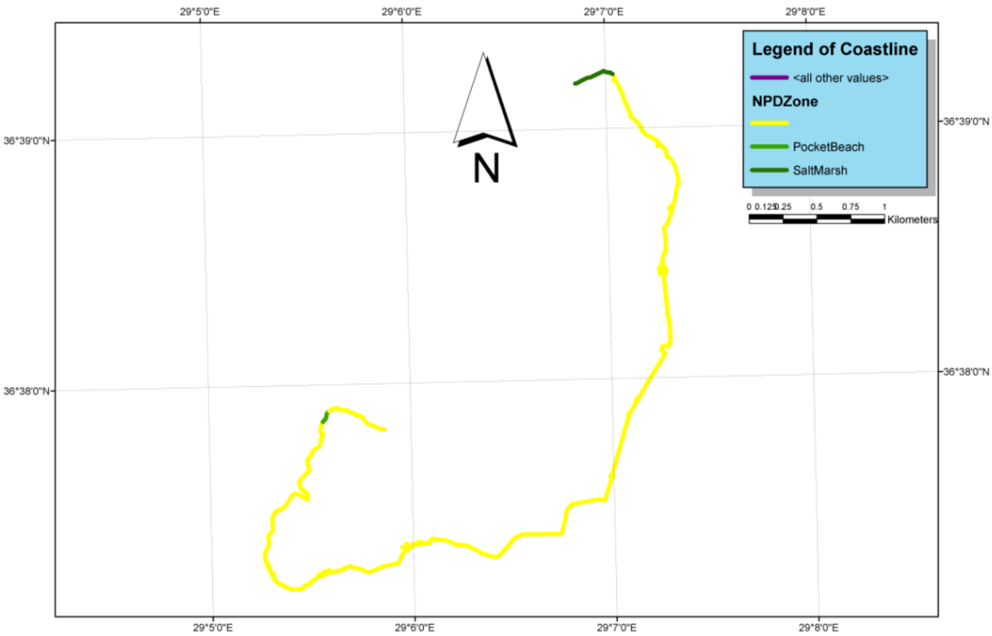


Figure 4.48: Database View for Natural Protection Degradation Layer

H7. Coastal Protection Structures

Coastal protection structures are built in order to protect the coastal ecosystem and the settlements behind it. However, the percentage of the coastal protection structures in Fethiye Bay is much ignorable that the existence of the only structure can not mitigate the impacts of sea water.

Considered the bay as a whole, several human made structures are built in favor of tourism. Most of the marine structures are made of floating type breakwater or just T-fingers without a main breakwater except one protective structure on the east. Since other marine structures except the one on the east side of the bay can not provide a protection against waves or probable sea level increase, they are not included in coastal protection structures in the model. On the other hand, seawalls built in the southeastern and southern side of the bay area are supposed not to be designed for coastal protection against overtopping of the waves in storm surge condition but for landscaping since their elevation is almost the same with the sea level. Although these seawalls may be considered as a partial protection element for coastline against erosion or short-term sea level rise to some extent, no coastal protection structure except that in the frame in Figure 4.49 exists inside the bay as the worst case scenario in the vulnerability model.

Figure 4.49: Coastal Protection Structure as breakwater

The study field has a poor condition from the point of coastal protection structure that such a structure shown in red color on the following map is just located on the small part of the coastline. (Figure 4.50).

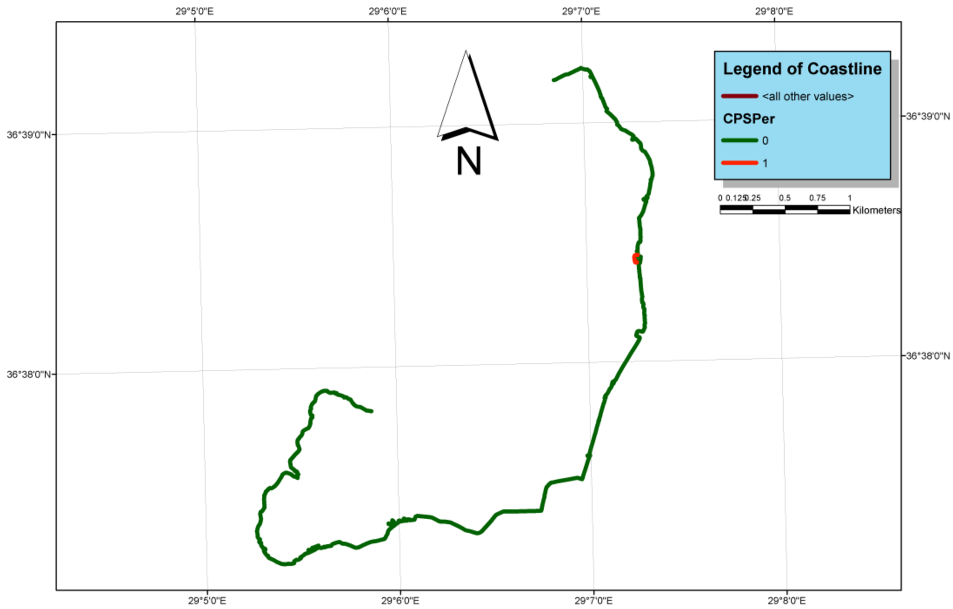


Figure 4.50: Database View for Coastal Protection Structure Layer

4.2.3 Summary

The twenty parameters have different reference sources (Table 4.6) and process methods to obtain their output values. The parameters of Rate of Sea Level, Tidal Range, Type of Aquifer, Hydraulic Conductivity, Depth to Groundwater level above sea directly get their physical values constant throughout the shoreline from various sources in the literature. The height of significant wave, storm surge wave is obtained from the previous studies carried out in METU (Akbasoglu, 2011), but the distribution of these two parameters is determined considering the direction of the coming waves into the bay area.

The parameters of Geomorphology, Sediment Budget, Proximity to Coast, River Discharge, Water Depth at downstream of the river is clarified, combined with necessary maps and finally calculated in pixel scaled and assigned to the related coastal segments.

For the determination of defuzzified values of the human related parameters requires to apply expertise to some degree. To identify the amount of reduction of sediment supply, bathymetry maps of 1956 and 2007 are compared, formulated in GIS environment before assigning to coastline. River Flow Regulation is determined by considering the closeness of the human-made structures (silting weir, check dam etc.) which is built around the bay area. Engineered frontage, Land Use Pattern, Natural Protection Degradation and Coastal Protection Structures are investigated in light of the satellite images. Groundwater Consumption are calculated for each aquifer section separately.

Table 4.6: Model Parameters and References

Physical Parameters	**Reference Sources**
Rate of SLR	IPCC (2013), Chambers et al. (2012), Church and White (2006), Bindoff et al. (2007)
Geomorphology	METU (2001)
Coastal Slope	USGS DEM (30m) (2013)
Sign.Wave Height	Akbasoglu S. (2011)
Storm Surge Wave Height	Akbasoglu S. (2011)
Sediment Budget	Akbasoglu S. (2011)
Tidal Range	IPCC (2007)
Proximity to Coast	METU (2001)
Type of Aquifer	METU (2001)
Hydraulic Conductivity	METU (2001)
Depth to GW level above sea	METU (2001)
River Discharge	METU (2001)
Water Depth at downstream	METU (2001)
Human-Related Parameters	**Reference Sources**
Reduction of Sediment Supply	Akbasoglu S. (2011), Akbasoglu S.and Yalciner A.(2011)
River Flow Regulation	Akbasoglu S. (2011)
Engineered Frontage	Quickbird (200X), Google Earth (2014)
GW Consumption	METU (2001)
Land Use Pattern	Quickbird (2004), Google Earth (2014), OCKK (2014)
Natural Protection Degradation	Quickbird (2004), Google Earth (2014), OCKK (2014)
Coastal Protection Structures	Quickbird (2004), Google Earth (2014)

Apart from 19 parameters, the parameter of coastal slope is handled in two different manner. The first model run for coastal slope is performed according to such a classification including five categories of slope range in terms of Jenks Method whereas the second model is studied considering four categories. From the viewpoint of defuzzification, totally 51 pieces of coastal segments are generated with the first model run of coastal slope. On the other hand, less coastal segmental pieces of 41 are generated as defuzzified outputs with the latter 4 categoried slope model run which means including coarser slope data compared to the first run. At the end of these two model run for coastal slope parameter, both results are not so much different than eachother in terms of the coastal impacts. Both model runs give almost similar coastal impacts on coastal segments except in the number of coastal pieces.

At the end of the spatial join operations of all layers, total number of coastal segments splitted is 73 for the first run though 63 for the second run. Considered five coastal impacts, the histogram at left stands for the first model run results including 5-categoried coastal slope, whilst the one at right for the second model run results which include 4-categoried coastal slope.

Considered another experimental thing in this study, totally twenty layers of parameters are spatially joined according to an ascending or descending order. In the first run with ascending order, layers are joined starting with the layer including the least number of coastal segment ending with the layer having the highest number of segment. In the second run, the layers are joined in reverse manner, starting with the one having the highest number of coastal segment ending with the layer containing the least number of segment corresponding to descending order.

CHAPTER 5

RESULTS AND DISCUSSION

The preliminary vulnerability model and the vulnerability model based on fuzzy logic are analyzed and the results are compared.

5.1 Results

5.1.1 Preliminary Coastal Vulnerability Model Results

The initial model study based on basic mathematical operations clarifies the coastal impacts by grading the parameters and averaging the sum of them (=impact total) and then dividing into the half number of parameters of the related impact. This gives the CVI result which corresponds to coastal vulnerability level index.

As an overall vulnerability index, the CVI Matrix (Table 5.1) including five coastal impacts calculates CVI impact value which defines the overall vulnerability levels by using numerical intervals. Coastal erosion and Flooding has a vulnerability level of 3.5 and 3.4 over 5.0, respectively, which corresponds to moderate-high vulnerability range. Inundation impact has the highest value of vulnerability with 3.8 over 5.0 corresponding to moderate-high range. Salt water intrusion into groundwater has the lowest vulnerability value of 2.6 over 5.0 as low-moderate range while salt water intrusion into river has a value of 3.1 over 5.0 as moderate vulnerability level.

Table 5.1: Preliminary Model Results (Coastal Vulnerability Index)

Impact	Physical Parameters							Human Influence Parameters							Impact Total	CVI impact
	Parameter	1	2	3	4	5	Total	Parameter	1	2	3	4	5	Total		
1. Coastal Erosion	P1.1 Rate of Sea Level Rise	0	1	0	0	0	2	H1.1 Reduction of Sediment Supply	0	0	0	0	1	5		
	P1.2 Geomorpholgy	0	0	0	1	0	4	H1.2 River Flow Regulation	0	1	0	0	0	2		
	P1.3 Coastal Slope	0	1	0	0	0	2	H1.3 Engineered Frontage	0	0	0	1	0	4		
	P1.4 $H_{1/3}$	1	0	0	0	0	1	H1.4 Natural Protection Degradation	0	0	0	0	1	5		
	P1.5 Sediment Budget	0	0	0	1	0	4	H1.5 Coastal Protection Structures	0	0	0	0	1	5		
	P1.6 Tidal Range	0	0	0	0	1	5									
	TOTAL	1	2	0	2	1	18	TOTAL	0	1	0	1	3	21	19.5	3.5
2. Flooding due to Storm Surge	P2.1 Rate of Sea Level Rise	0	1	0	0	0	2	H2.1 Engineered Frontage	0	0	0	1	0	4		
	P2.2 Coastal Slope	0	1	0	0	0	2	H2.2 Natural Protection Degradation	0	0	0	0	1	5		
	P2.3 $H_{1/3}$	1	0	0	0	0	1	H2.3 Coastal Protection Structures	0	0	0	0	1	5		
	P2.4 Tidal Range	0	0	0	0	1	5									
	TOTAL	1	2	0	0	1	10	TOTAL	0	0	0	1	2	14	12	3.4
3. Inundation	P3.1 Rate of Sea Level Rise	0	1	0	0	0	2	H3.1 Natural Protection Degradation	0	0	0	0	1	5		
	P3.2 Coastal Slope	0	1	0	0	0	2	H3.2 Coastal Protection Structures	0	0	0	0	1	5		
	P3.3 Tidal Range	0	0	0	0	1	5									
	TOTAL	0	2	0	0	1	9	TOTAL	0	0	0	0	2	10	9.5	3.8
4. Salt Water Intrusion to Groundwater Resources	P4.1 Rate of Sea Level Rise	0	1	0	0	0	2	H4.1 Groundwater consumption	0	0	0	0	1	5		
	P4.2 Proximity to Coast	1	0	0	0	0	1	H4.2 Land Use Pattern	0	0	1	0	0	3		
	P4.3 Type of Aquifer	0	0	0	0	1	5									
	P4.4 Hydraulic Conductivity	1	0	0	0	0	1									
	P4.5 Depth to Groundwater Level Above Sea	1	0	0	0	0	1									
	TOTAL	3	1	0	0	1	10	TOTAL	0	0	1	0	1	8	9	2.6
5. Salt Water Intrusion to River/Estuary	P5.1 Rate of Sea Level Rise	0	1	0	0	0	2	H5.1 River Flow Regulation	0	1	0	0	0	2		
	P5.2 Tidal Range	0	0	0	0	1	5	H5.2 Engineered Frontage	0	0	0	1	0	4		
	P5.3 Water Depth at Downstream	1	0	0	0	0	1	H5.3 Land Use Pattern	0	0	1	0	0	3		
	P5.4 River Discharge	0	0	0	0	1	5									
	TOTAL	1	1	0	0	2	13	TOTAL	0	1	1	1	0	9	11	3.1

CVI(SLR)-1	41	3.57
CVI(SLR)-2	50	3.33
CVI(SLR)-3	61	3.30

The histogram (Figure 5.1) enlightens five different coastal impacts by ordering their vulnerability levels in accordance with the source parameters as physical or human-related. The weighted parameter factor of coastal erosion, flooding, inundation and salt water intrusion into groundwater is antropogenic except salt water intrusion into river. Specifically, human-related factors play a very significant role for inundation impact. From the viewpoint of saltwater intrusion into river, physical parameters are responsible for the increasing of the vulnerability. (Figure 5.1).

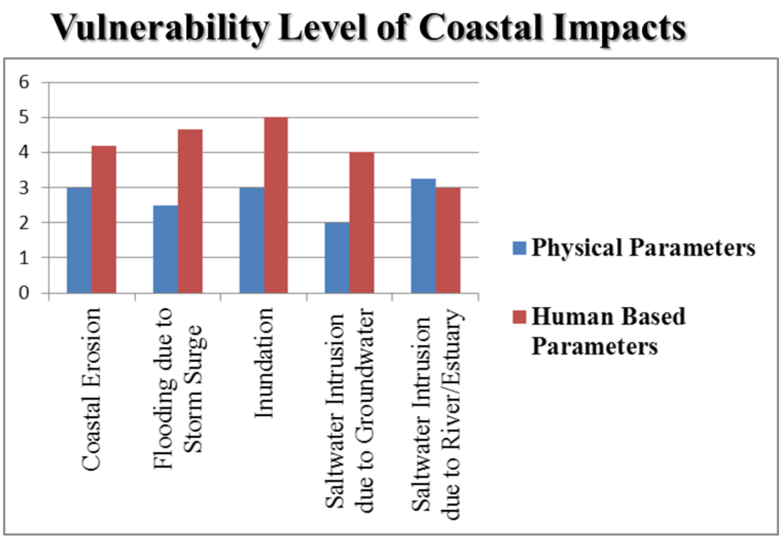


Figure 5.1: Vulnerability Level of Coastal Impacts against Sea Level Rise

The pie-chart (Figure 5.2) gives an idea about the distribution of physical and human related parameters as the result of preliminary vulnerability index for Fethiye. The red part with greater percentage in pie-chart represents the antropogenic factors as the dominant resource of the vulnerability problem by decreasing the resilience of the coast.

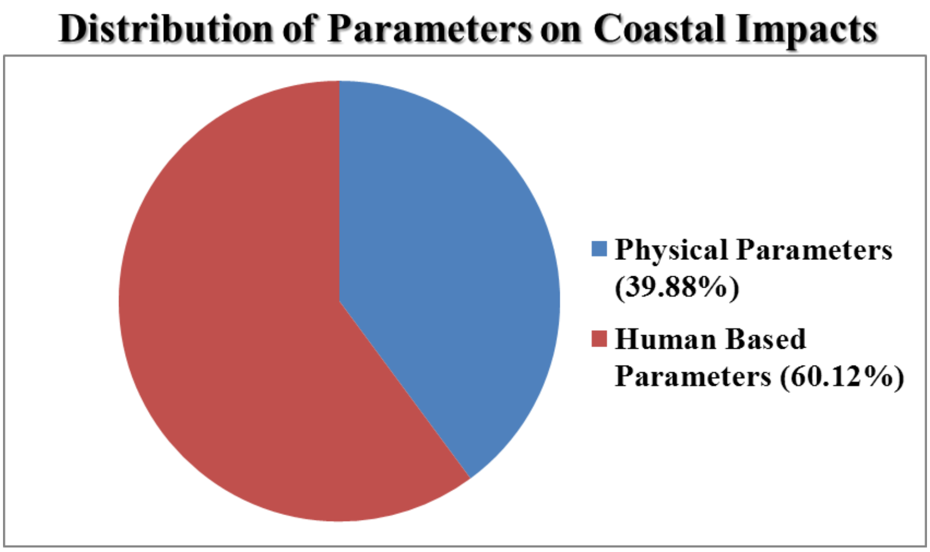


Figure 5.2: The Percentages of the Impacts in the Preliminary Model

5.1.2 Fuzzy Coastal Vulnerability Assessment Model Results

To be more realistic and precise, fuzzy logic is used in the vulnerability analysis upon the preliminary model studies. All data acquired from different sources (see Table 4.6) are processed.

5.1.2.1 Overall Coastal Vulnerability Index

Overall Coastal Vulnerability Index is calculated with defuzzification technique which makes fuzzy output set turn into crisp values by using centroid method.

The FCVAM results indicate that the overall vulnerability of the region is low-moderate fluctuating within the moderate range along the northern part of the shoreline.(Figure 5.3). The fluctuations of the result signifies that the application of the localized solutions could enhance the success of generalized coastal zone management (CZM) plans.

Figure 5.3: Overall Coastal Vulnerability

In the following figure (Figure 5.4), Overall Coastal Vulnerability Index classified by Jenks-5 methodology ranges between 2.30 and 3.09 over 5.00 even as the level for the most critical scores between 2.94 and 3.09. The red colored line represents for the most critical vulnerability levels whereas the dark green line stands for the least vulnerable. The vulnerability level around large-scaled coastal structures is continuously changing as up ad down due to the existence of an artificial element in a natural environment.

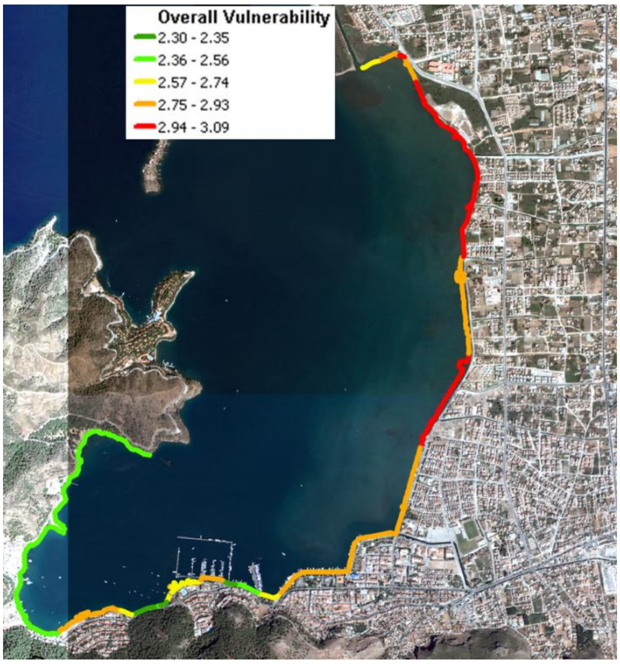
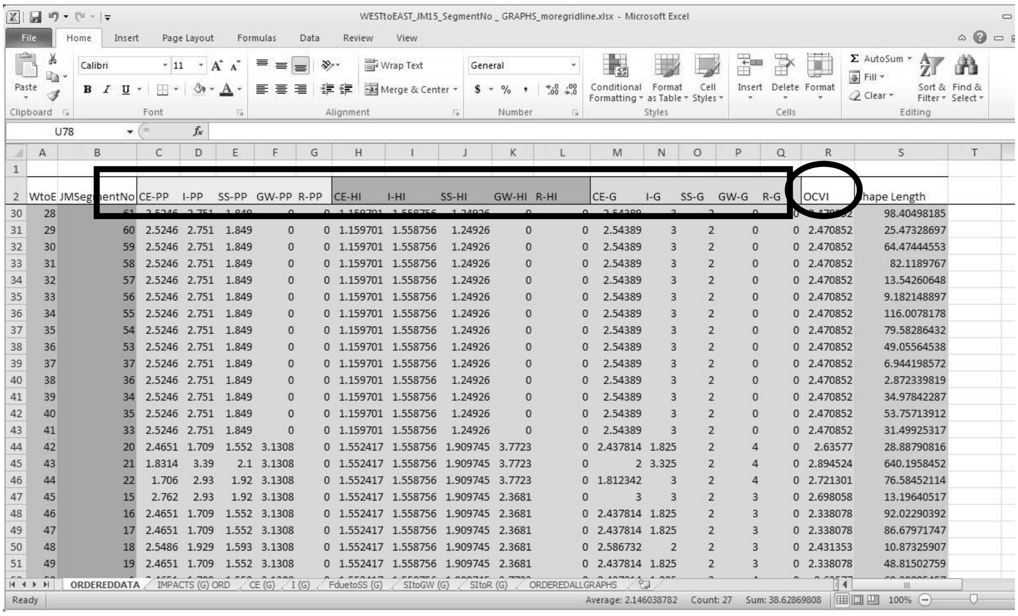


Figure 5.4: Overall Coastal Vulnerability Index

As being on such a sheltered zone compared to the upper part, the lower part located on west and southwest of the bay gives milder results corresponding to low vulnerability level. Beside, the upper part on the east and southeast of the bay is evaluated as moderate vulnerable against sea level rise.

5.1.2.2 Overall Coastal Vulnerability Impact

Overall impact score is the result of the individual coastal impacts. Coastal erosion, Inundation, Flooding due to Storm Surge, Salinity Intrusion into Groundwater, Salinity Intrusion into River are the five main impacts which are all investigated in three categories as general, physical, human-related. (Figure 5.5)



	WtoE	JMSegmentNo	CE-PP	I-PP	SS-PP	GW-PP	R-PP	CE-HI	I-HI	SS-HI	GW-HI	R-HI	CE-G	I-G	SS-G	GW-G	R-G	OCVI	Shape Length
30	28	61	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	[illegible]	98.40498185
31	29	60	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	25.47328697
32	30	59	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	64.47444553
33	31	58	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	82.1189767
34	32	57	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	13.54260648
35	33	56	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	9.182148897
36	34	55	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	116.0078178
37	35	54	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	79.58286432
38	36	53	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	49.05564538
39	37	37	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	6.944198572
40	38	36	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	2.872339819
41	39	34	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	34.97842287
42	40	35	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	53.75713912
43	41	33	2.5246	2.751	1.849	0	0	1.159701	1.558756	1.24926	0	0	2.54389	3	2	0	0	2.470852	31.49925317
44	42	20	2.4651	1.709	1.552	3.1308	0	1.552417	1.558756	1.909745	3.7723	0	2.437814	1.825	2	4	0	2.63577	28.88790816
45	43	21	1.8314	3.39	2.1	3.1308	0	1.552417	1.558756	1.909745	3.7723	0	2	3.325	2	4	0	2.894524	640.1958452
46	44	22	1.706	2.93	1.92	3.1308	0	1.552417	1.558756	1.909745	3.7723	0	1.812342	3	2	4	0	2.721301	76.58452114
47	45	15	2.762	2.93	1.92	3.1308	0	1.552417	1.558756	1.909745	2.3681	0	3	3	2	3	0	2.698058	13.19640517
48	46	16	2.4651	1.709	1.552	3.1308	0	1.552417	1.558756	1.909745	2.3681	0	2.437814	1.825	2	3	0	2.338078	92.02290392
49	47	17	2.4651	1.709	1.552	3.1308	0	1.552417	1.558756	1.909745	2.3681	0	2.437814	1.825	2	3	0	2.338078	86.67971747
50	48	18	2.5486	1.929	1.593	3.1308	0	1.552417	1.558756	1.909745	2.3681	0	2.586732	2	2	3	0	2.431353	10.87325907
51	49	19	2.4651	1.709	1.552	3.1308	0	1.552417	1.558756	1.909745	2.3681	0	2.437814	1.825	2	3	0	2.338078	48.81502759

Figure 5.5: Output Values of the coastal impacts based on FCVAM

Consequently, main impact scores as shown in Figure 5.6 show that the region could be more vulnerable to certain impacts such as inundation and salt water intrusion into groundwater resources. The result considering the individual impacts are discussed in the next section.

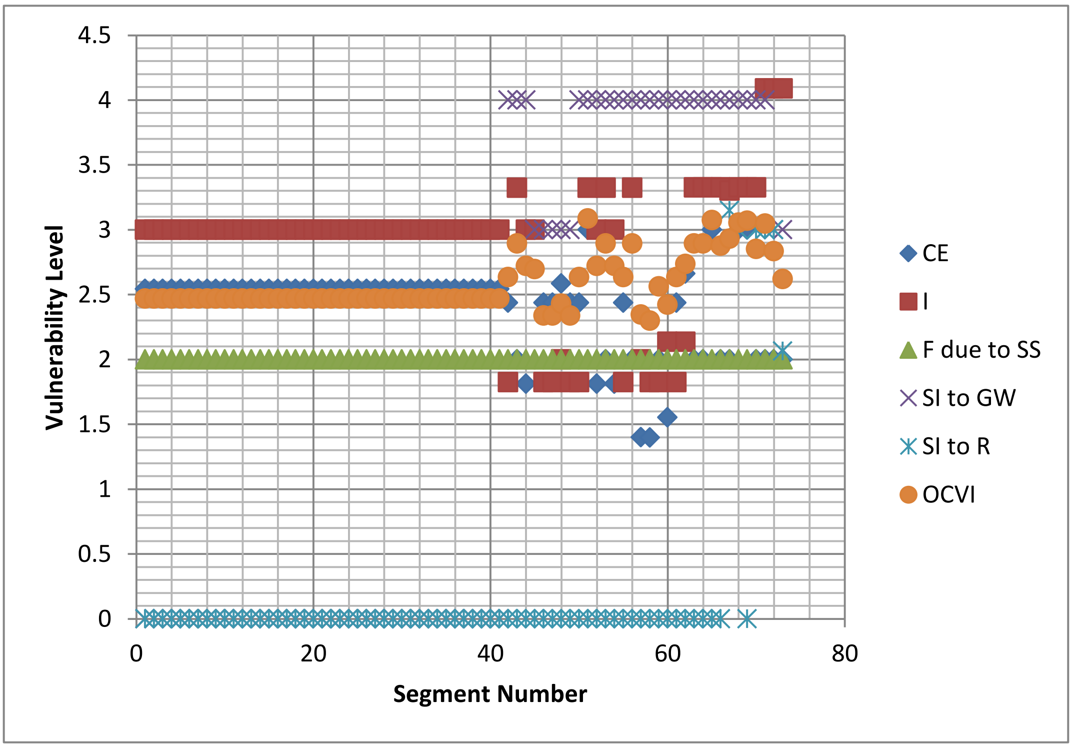


Figure 5.6: Overall Coastal Vulnerability Levels of All Impacts

The output figure (Figure 5.7) taken from ArcGIS gives the details of the potential coastal impacts along the coastline. Coastal erosion, flooding and salinity intrusion risk come into the picture in each strip whereas the risk of salinity intrusion into river comes into prominence at downstream points only. Inundation risk plays a salient role along the low-lying topography of the study area which corresponds to the east and southeast part of the coastline.

The defuzzified results the overall vulnerability refer to moderate vulnerability range for Fethiye Bay.

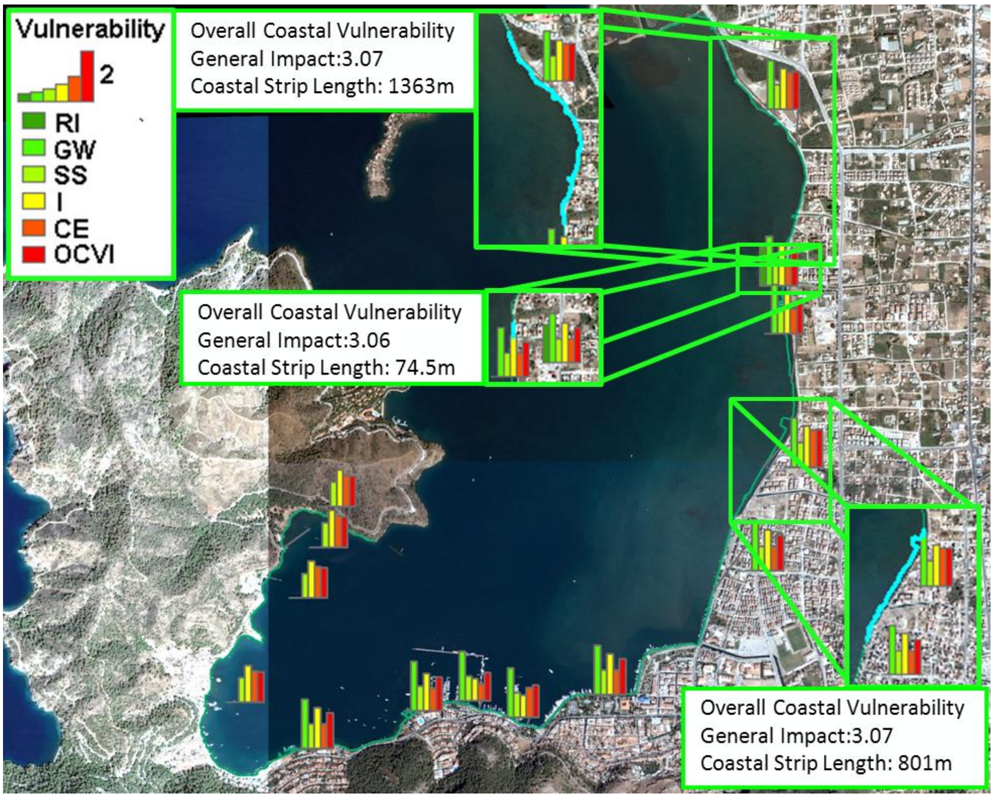


Figure 5.7: Overall Coastal Vulnerability Impact

5.1.2.3 Coastal Erosion

As a long term coastal impact, coastal erosion is determined in light of the combination of various parameter outputs. Rate of SLR, Geomorphology, Coastal Slope, Significant Wave Height, Sediment Budget, Tidal Range physically influences coastal erosion while Reduction of Sediment Supply, River Flow Regulation, Engineered Frontage, Natural Protection Degradation, Coastal Protection Structures are the human related factors affecting this impact. As can be seen, there is a number of parameters leading the equilibrium formation and change of the shoreline.

In consideration of the physical and human related parameter in fuzzy model, the vulnerability of the Fethiye Bay in terms of coastal erosion as an impact is observed mostly as 2.38 (Figure 5.9) which corresponds to a low-moderate vulnerability range.

Additionally, the vulnerability range specific to Fethiye Bay is classified according to Jenk-5 methodology to prioritize the coastal segments of the region. While all the segments vary between vulnerability scores of 1.40 and 3.00 for coastal erosion impact, the yellow lines in Figure 5.8 represent the most vulnerable coastal strips of the bay corresponding to moderate vulnerable range.

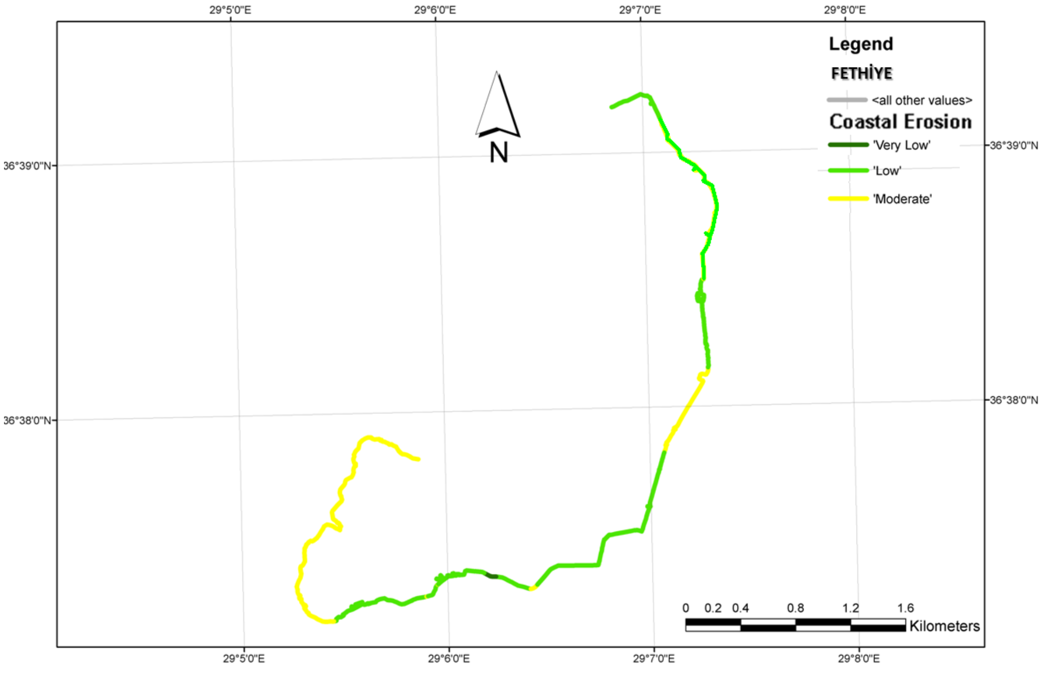


Figure 5.8: Vulnerability Map for Coastal Erosion

Through the west and southwest coast, the vulnerability level is stable while it is fluctuating towards the north. Physical parameters are more changeable throughout the south, the east and the north coast compared to human-influenced parameters (Figure 5.9).

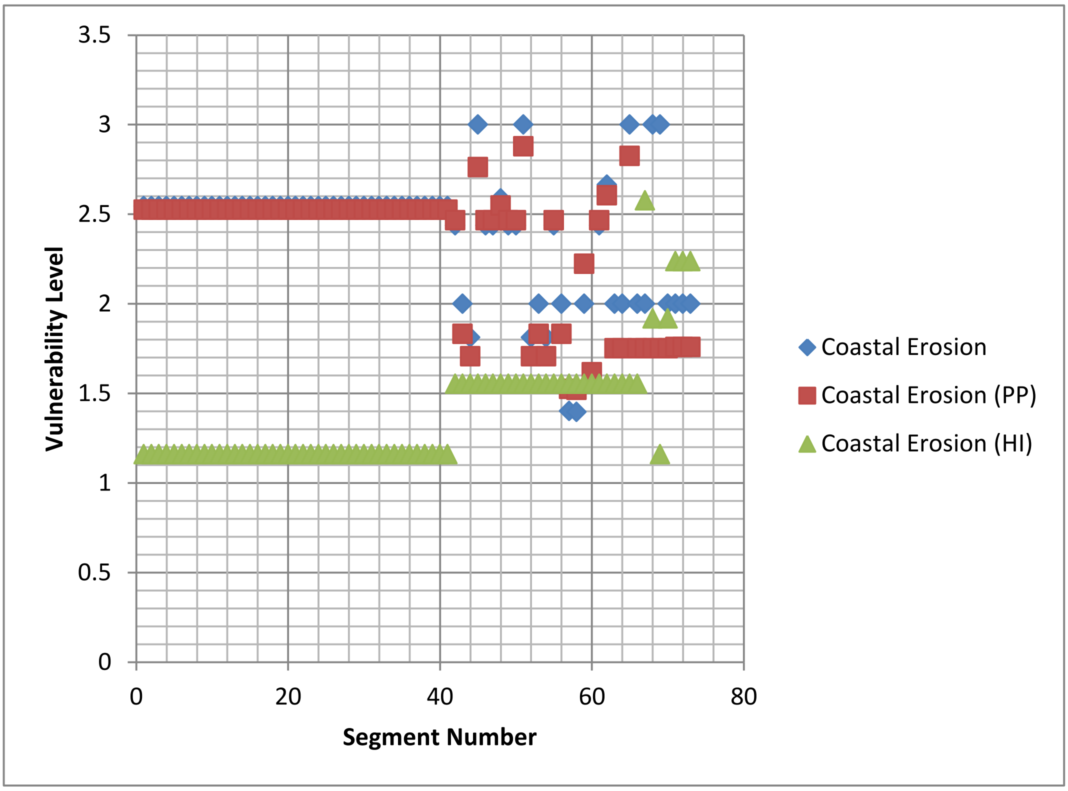


Figure 5.9: Coastal Vulnerability Level of Coastal Erosion

Going from south to the north (in counterclockwise direction), although coastal slope, geomorphology, significant wave height, engineered frontage have higher vulnerability scores, the sediment accumulation is widely observable. Therefore the vulnerability level for coastal erosion is mostly evaluated as low for this part of the coastline..

Considering Figure 5.10, it is anticipated that physical parameters are more effective compared to the human influenced ones in the determination of general coastal erosion impact.

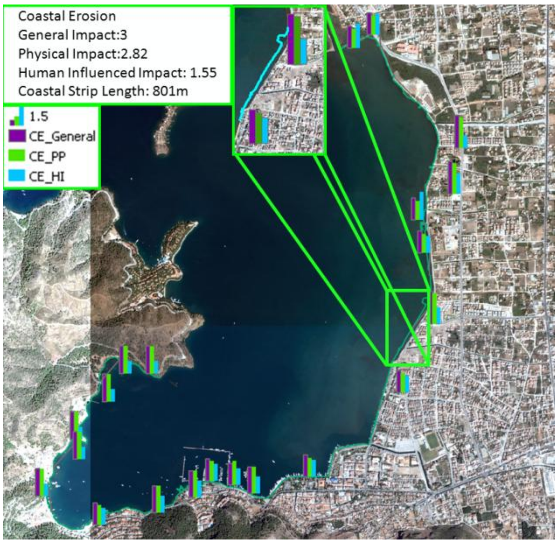


Figure 5.10: Coastal Erosion Impact Distribution

The most important factor in the determination of sediment budget is to compare and clarify erosion and accretion condition of the bay. The coastal erosion on the eastside of the bay has been increasing since at least 1956. It is widely observed that accretion dominated regions are gradually enlarging due to river deposition and wave action on the northeast side and central parts of the bay as well as due to the construction of coastal structures on south side of the bay.Although the sediment deposition continues on the northeast coast, the dredging activities to remove the sediment from sea bed of this part have still been carried out each year as an artificial intervention by the municipality cooperated with non-governmental organizations.(Figure 5.11).

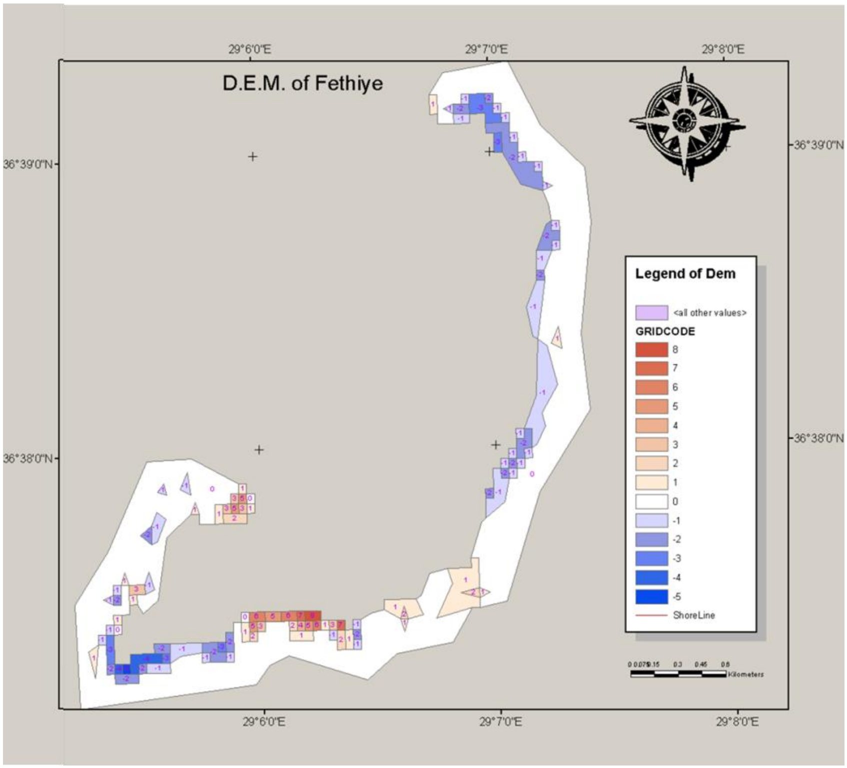


Figure 5.11: Erosion-Accretion Change between 1956-2007

As mentioned in previous chapters, rivers carry the sediment and accumulate at downstream points. For the study area, another zone onwhich sediment deposition is observed is on the southeastern part of the bay. This specific area is deposited by sediment due to previous discharges and also wave action after the reclamation application. An irrigation channel reaching at downstream of the bay but with no discharge data currently available in DSI or EIEI yearly books for that point. Even if the discharge data were available, the amount of that would be changing by season, by the demand for irrigation water, by the growth rate of crops etc. Furthermore, marine structures deposite a huge amount of sediment around the structure in the direction of incoming waves whereas this phenomena results in erosion problem inside part of the marine structure. The incoming wave accumulates sediment in one side of the artificial element and takes the sediment away from the other side and causes to coastal erosion there. In light of the observations mentioned above, a partly propagation of sediment deposit is pointed out around the breakwater at the south side as well as small-scaled coastal structures in the bay.

5.1.2.4 Inundation

Rate of sea level rise, coastal slope, and tidal range are the physically affecting factor, whereas coastal protection structures and natural protection degradation are the two human-influencing factors for inundation as one of the coastal impacts.

In fuzzy logic model, the general vulnerability level of inundation is calculated around 3.00 as moderate except the coastal segments around the north tip which correspond to the most vulnerable geography of salt marsh area. In salt marshes, the vulnerability level can ascend over 4.00 mostly by reason of the degradation of natural protection systems around the north tip.(Figure 5.12).

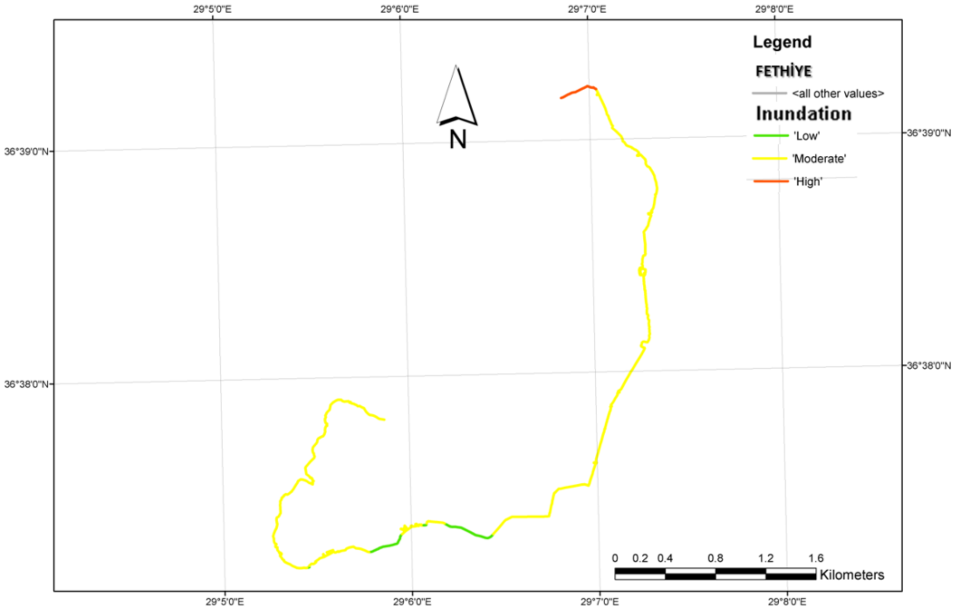


Figure 5.12: Vulnerability Map for Inundation

While the common world-wide vulnerability level of 3.00 prevails as the general value of inundation impact, the following figure classified according to Jenks-5 methodology indicates the vulnerability range within itself (range specific to the event). The vulnerability levels vary between 1.82 and 4.09 while the most critical shoreline range are in red-colour with the value of 3.65-4.09.(Figure 5.13).

Figure 5.13: Inundation Impact

Fethiye plain hosts a large settlement area in the center on a low-lying topography that is prone to inundation.

Physical parameters play more deterministic role than human related ones that they fluctuate especially in the second half of the shoreline whereas human based parameters follow more smooth manner. The second half of the shoreline contains the only coastal protection structure on the first spike of human related factors (green marks). The last peak point is due to the saltmarshes at the north tip of the bay.(Figure 5.14).

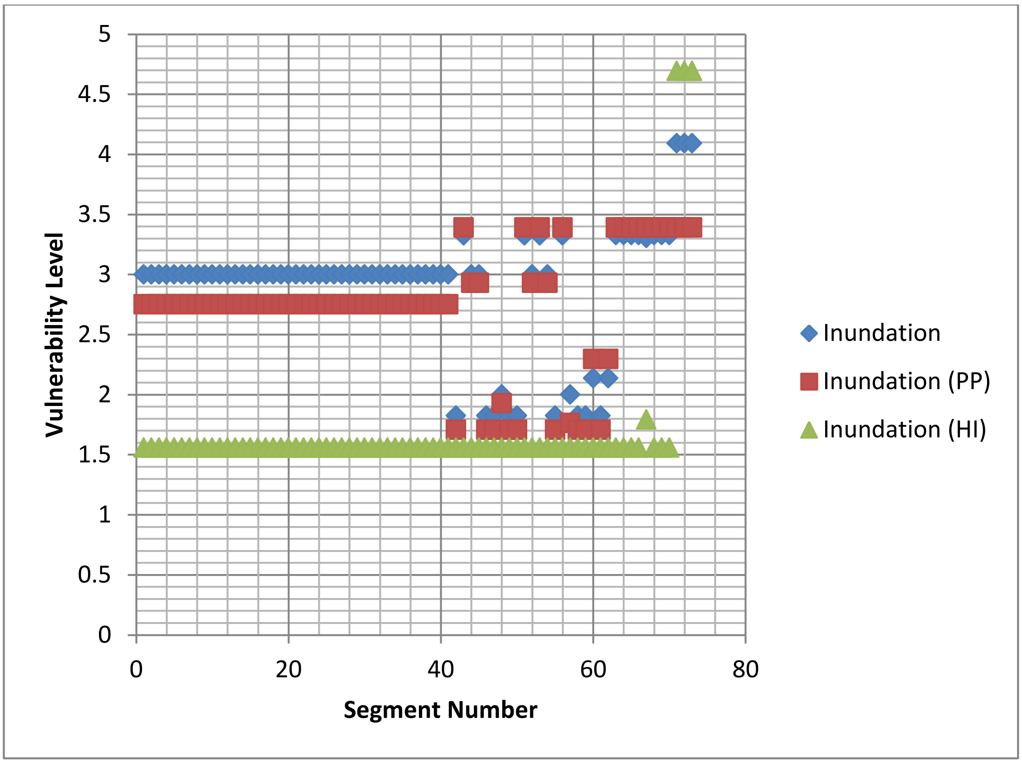


Figure 5.14: Coastal Vulnerability Level of Inundation

All remaining coastal structures available to be moored on both side are floating type or fingers and have no main rubble mound breakwater to mitigate the coming waves.(Figure 5.15).

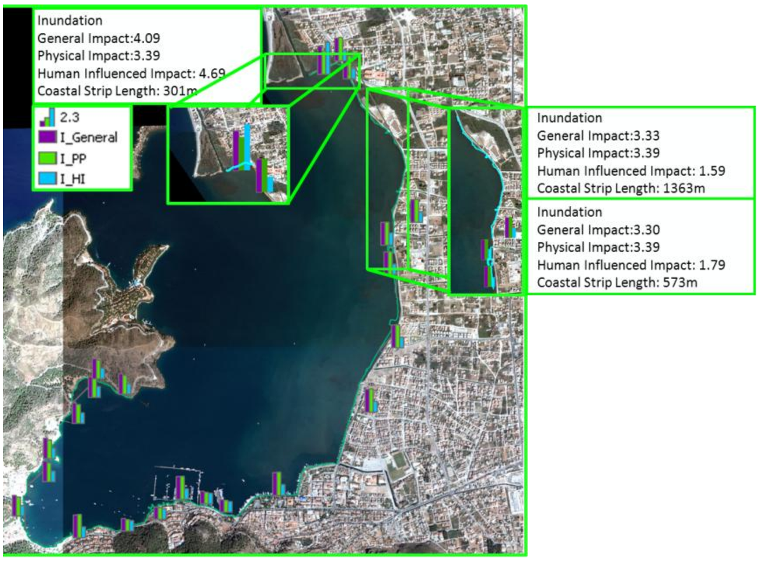


Figure 5.15: Inundation Impact Distribution

5.1.2.5 Flooding

Flooding as one of the coastal impacts mainly depends on rate of sea level rise, coastal slope, significant wave height, tidal range among physical parameters and on engineered frontage, natural protection degradation, coastal protection structures among human related factors.

When considered the contributory factors, vulnerability level against storm surge flooding is fluctuating around 2.00 as physically but sticks to 2.00 as low moderate in general. Therefore, the unique range is displayed as 2.00 throughout the bay.(Figure 5.16).

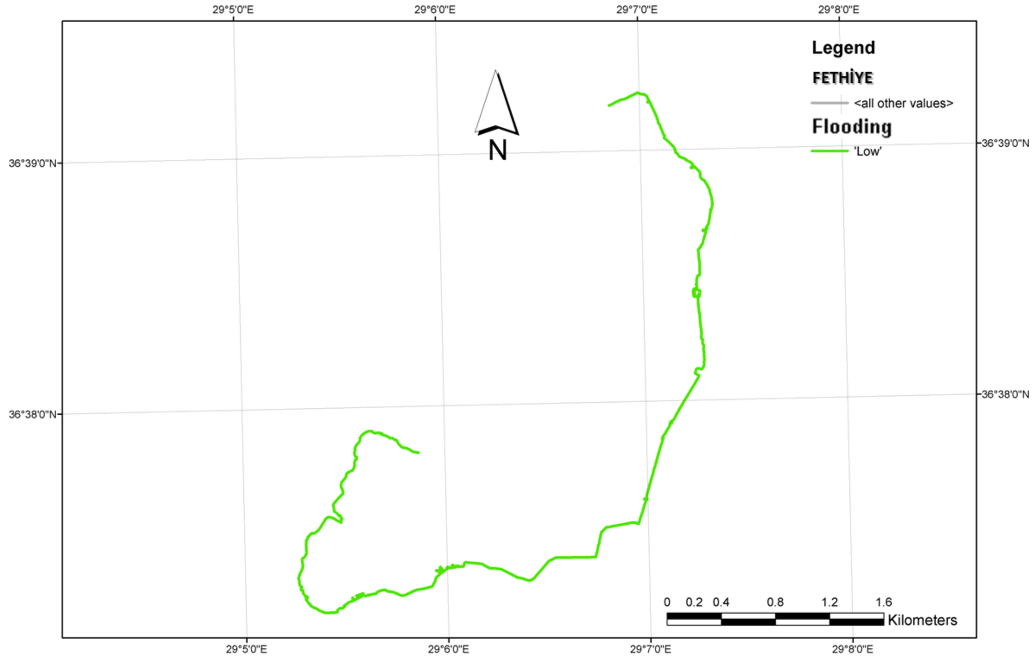


Figure 5.16: Vulnerability Map for Flooding due to Storm Surge

Based on fuzzy model, vulnerability level ranges between 1.5-2.5 but mainly concentrates around 2.0 against flooding due to storm surge despite the less value of human related factors. Since especially the current circumstances of engineered frontage on the southeast and east coast is much widespread, the higher values of vulnerability depending on human influence is pointed out towards the end of the graph.(Figure 5.17).

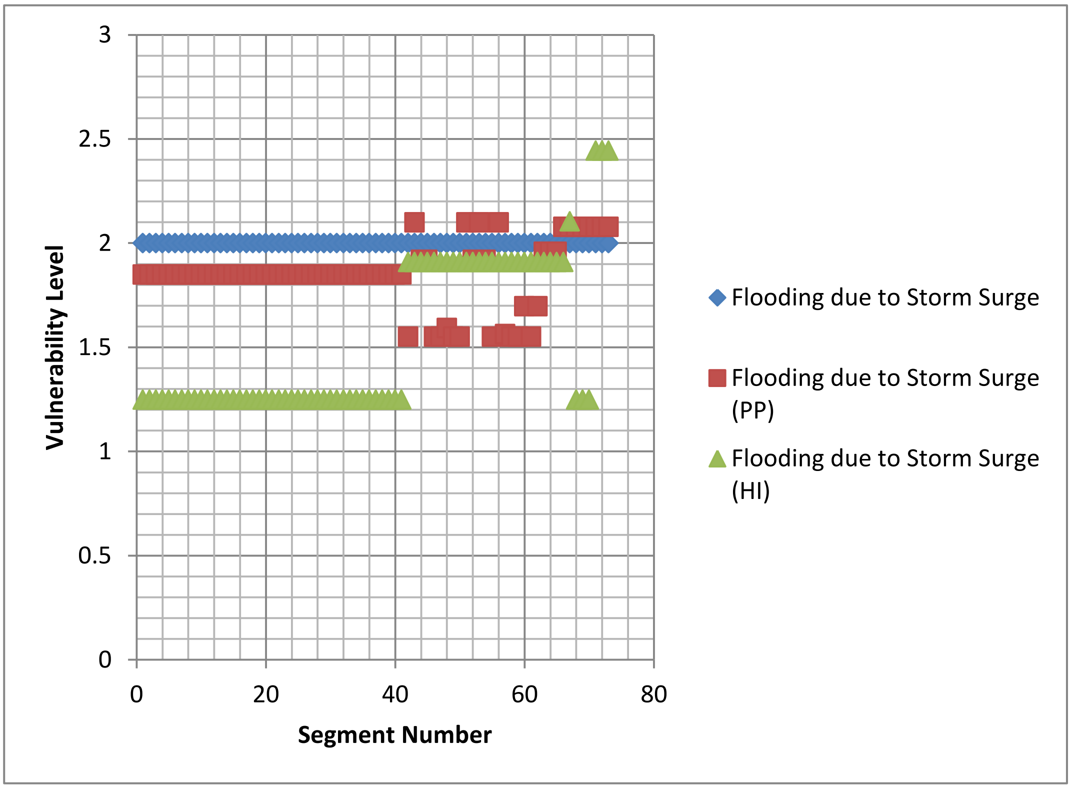


Figure 5.17: Coastal Vulnerability Level of Flooding due to Storm Surge

From the viewpoint of impact ratio, physical and human-related factors are pretty much the same that means human activity is much to be emphasized. For the aesthetical concern, not protection concern, seawalls constructed through the south, east and north shores. These seawalls (Figure 5.18) are not supposed to be designed by considering the coastal protection concern such as storm surge wave height, significant wave height etc. They are only supposed to be constructed for landscaping concern. Furthermore, engineered frontage, as human-serving coastal structures, are constructed in favor of human, so they can not be taken into consideration as coastal protection structure.

Figure 5.18: Seawall landscaping (Buba marina on the east of the bay)

Towards the west coast, the risk of flooding is reducing since the topography is becoming steeper compared to the east side. Although rate of sea level rise and tidal range is taken constant for the whole Fethiye bay, significant wave height and storm surge height for the west inner part is relatively less than that of east coast. Considered the antropogenic factors included in the flooding impact, rate of engineered frontage decrease while going to the west-northwest direction through the coastline. As a natural protection degradation, the existence of a pocket beach on the northwestern coast of the bay decreases the vulnerability of this part of the coastline to flooding impact.

5.1.2.6 Salinity Intrusion into Groundwaters

Coastal groundwater systems are under high risk especially near coasts since they are confronted by the overexploitation problems. When the risk of salinity intrusion into groundwater is considered, various parameters such as rate of sea level rise, proximity of aquifers to coast, type of aquifer, hydraulic conductivity, depth to groundwater level above sea, groundwater consumption and land use pattern are taken into account.

The level of the overall vulnerability to this impact ranges between 3.0 and 4.0 as moderate-high throughout the coastline.(Figure 5.19).

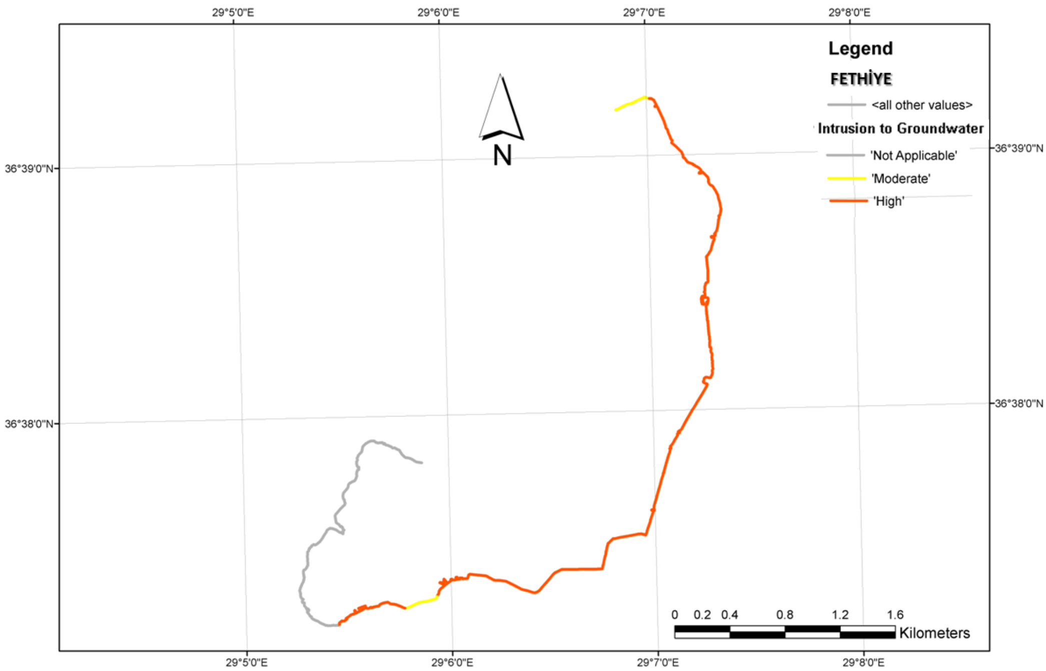


Figure 5.19: Vulnerability Map for Salinity Intrusion to Groundwater

No aquifer system exists near shoreline located on the west-southwest part of the bay. Due to the lack of an aquifer system, the following graph (Figure 5.20) gives zero for the vulnerability to salinity intrusion into groundwater of the part corresponding to the related segment number (1-40), from the northwest to west-southwest of Fethiye Bay. The level of overall vulnerability to this impact ranges between 3.0 and 4.0 throughout the southern, the eastern, the northern part of the coastline, even it increases upto a level of 4.0 at the north tip. While physical factors keep going constant, the human-influenced impact and general overall impact value for salinity intrusion into groundwater fluctuate from south towards the north.

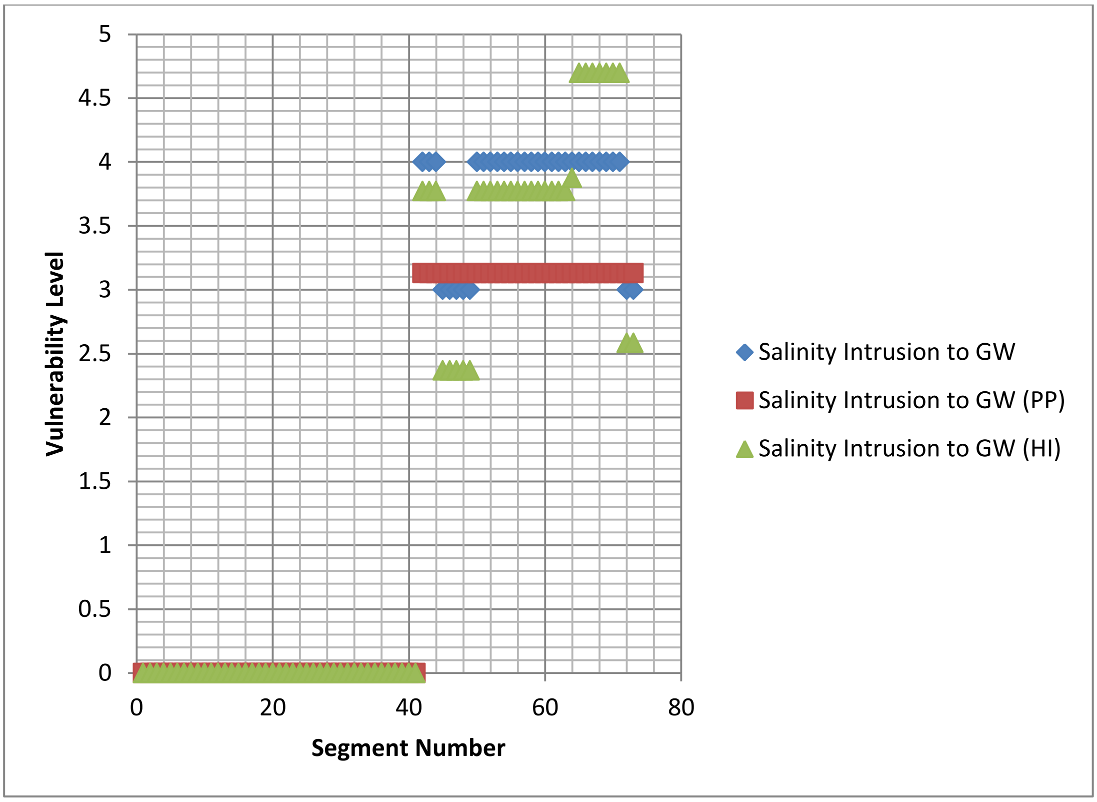


Figure 5.20: Coastal Vulnerability Level of Salinity Intrusion to Groundwater

While a constant value of 3.2 for physical parameters, the human based parameters vary between the levels of 3.7 and 4.7 as the most critical at a certain time.(Figure 5.21). Human-influenced parameters have higher number of values in vulnerability compared to physical parameters that human activity plays a prominent role in the overexploitation of the groundwater resources.

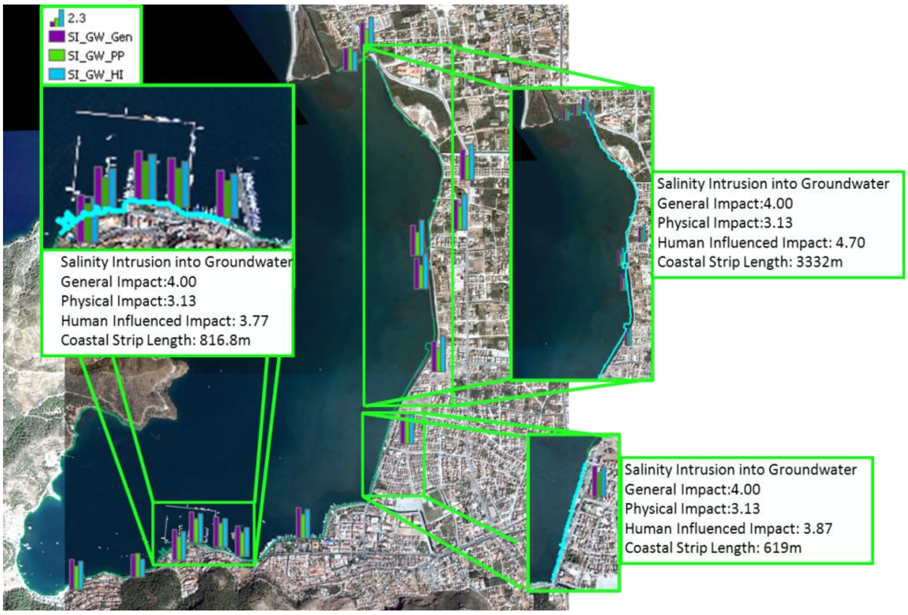


Figure 5.21: Salinity Intrusion due to Groundwater Impact Distribution

5.1.2.7 Salinity Intrusion into Rivers

Salinity Intrusion into the river/estuary mechanism depends on rate of sea level rise, tidal range, water depth at downstream, river discharge as physical factors, and river flow regulation, engineered frontage, land use pattern as human-influenced factors.

The area hosts only a few discharge points of natural rivers. The main stream, called Kargi Stream (DSI 08-089), comes from the north and follows a route ended up at the sea. The discharging point is outside of the study area at the north. Of the study area, discharging point of a stream which is supposed to branch out from Kargi Stream is observed at the north coast around saltmarsh. The second discharging point from a stream is observed on the east coast but no data is available. There exists only the data of DSI station called DSI 08-089 around the study area. Taking the advantage of DSI river map which is digitized for this study (Akbasoglu, 2011), and using the discharge data of this DSI station, stream discharging points are marked. After several processes, the layer is joined spatially to investigate the effect of river discharge in the vulnerability model study.

In accordance with the map obtained from the State Hydraulics Work (DSI), the vicinity of the locations where active rivers have been discharging are investigated. Within 150-200 meters around river discharging locations, various parameters which play active roles in the(i.e. rate of sea level rise, tidal range, water depth at downstream, river discharge, river flow regulation, engineered frontage, land use pattern) are studied in order to clarify the vulnerability priorities of these zones to sea water intrusion into freshwater in the long term.

The main river data belongs to two different river discharging on the north and on the east coast. Due to the lack of a discharging river, the impact score gives zero for the vulnerability to salinity intrusion into river of the parts corresponding to the related segment numbers (1-65) through the coastline from northwest to the east of Fethiye Bay in counterclockwise direction. (Figure 5.22).

Fuzzy model gives the following map (Figure 5.22) as the result of the analysis which ranges between 2.1 and 3.2 which corresponds to low-moderate vulnerability range around the north-northeast shores of bay.

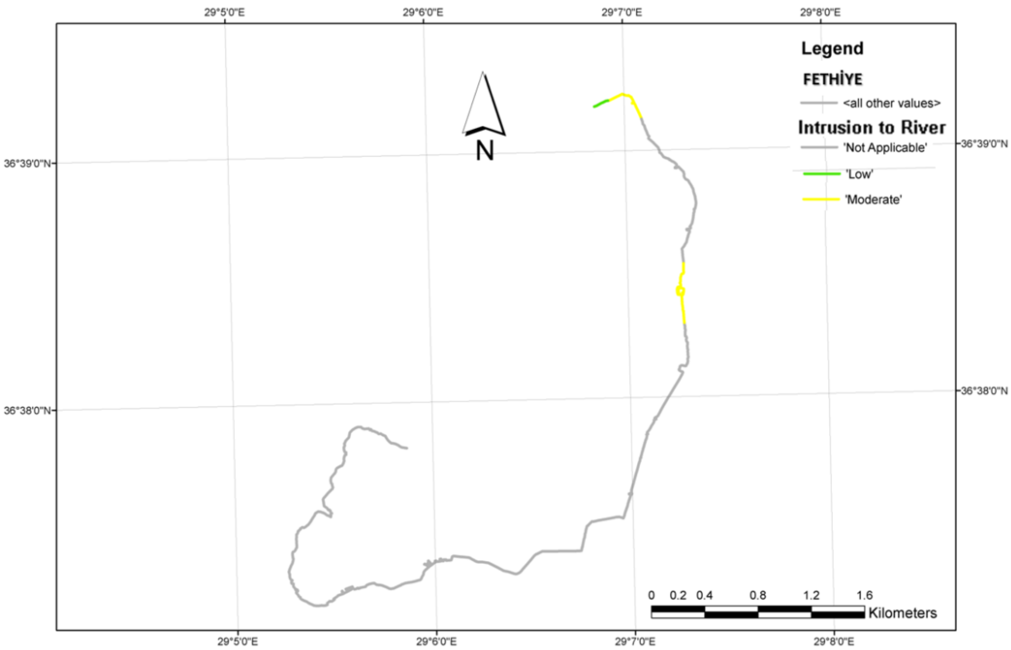


Figure 5.22: Vulnerability Map for Salinity Intrusion to River

According to the graph of vulnerability level vs segment number (Figure 5.23), despite the moderate vulnerability level as 3.3, equivalent of moderate vulnerable, for physical parameters, the number of discharging points limited by two reduces the overall vulnerability level of this impact.

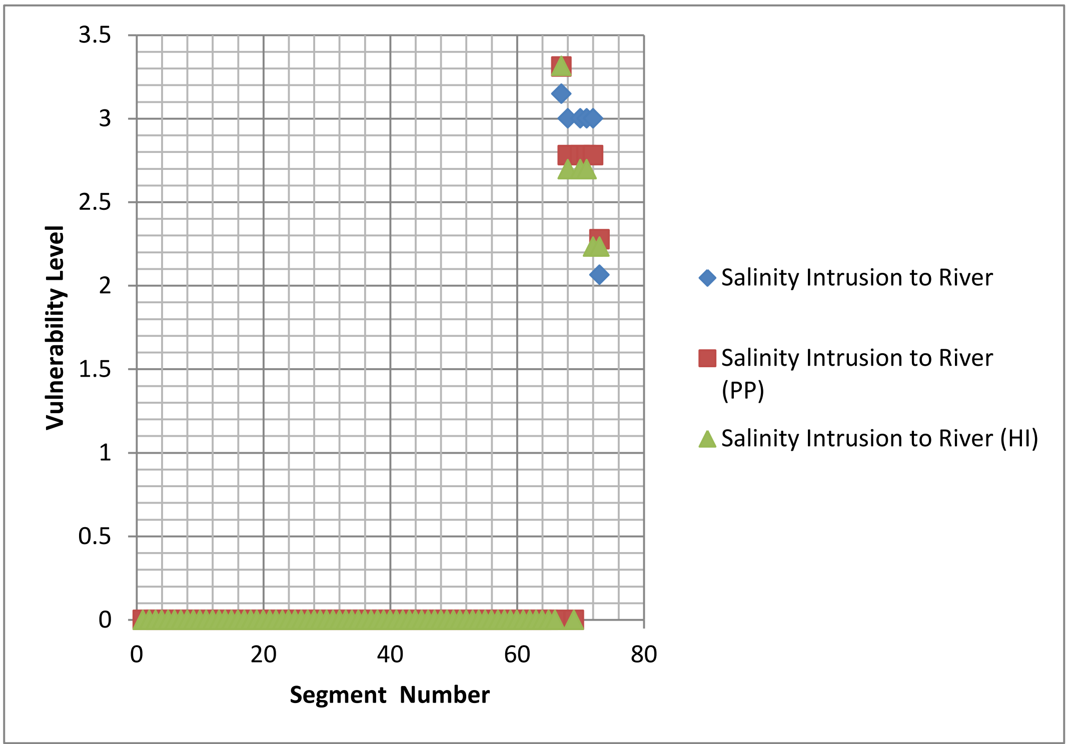


Figure 5.23: Coastal Vulnerability Level of Salinity Intrusion to River

Land use also changes the vulnerability level. Unless the type of land use would be settlement near these river discharging points, the vulnerability of the region would be less critical than now. Through the coast, engineered frontage for human use also endangers the coastal environment and increases the vulnerability level against salinity intrusion into river/estuary.

Due to the lack of tidal risk for Fethiye Bay, the coast is not familiar with the saline water. Incase of any intrusion, the shoreline will negatively affect more than a coast under tide risk.

5.1.3 Comparison of the Two Model

The results of the two coastal vulnerability assessment model of preliminary and fuzzy logic are compared and discussed. The comparison of the two model will have the feature of being a control point for the reliability and convenience of fuzzy model. The preliminary model results are a bit more exaggerated due to misleading representation of the whole coastline with a single parameter value whereas the fuzzy vulnerability assessment model conducted on GIS environment gives real-like results due to the detailed investigation of each segment in itself . In general, the results of the model based on fuzzy logic are provides more detailed, realistic and accurate values compared to the preliminary vulnerability model.

In the initial model, each parameter for the entire coastline in the bay might take only one value corresponding to the range it belongs in between 1 to 5 within the meaning of least vulnerable to most vulnerable, respectively. Nonetheless, the number of segments assembling the entire coastline of the bay depends on the diversity of the features representing that part of the coastline. The more the variety of the physical and human related parameters, the higher number of segments representing coastal line sections and the more detailed examination/investigation of that coastline.

Overall Coastal Vulnerability Index

Overall Coastal Vulnerability Index is calculated with defuzzification technique which makes fuzzy output set turn into crisp values by using centroid method.

In preliminary model study, OCVI is calculated using all the impacts that needs to be considered for the assessment. CVI-III, weighted averaging of all five impacts, is calculated as 3.30 out of 5.00 which signifies that the region is moderately vulnerable.

Similarly, the FCVAM model calculates within a range of 2.30 as low and 3.09 as moderate over 5.00 for the different segments of the region.

Although the worst case scenario of the preliminary model results approach to high level of vulnerability with a value of 4.00 over 5.00, the common case scenario remains in moderate range. Both model results, preliminary based (common case) and fuzzy logic based coastal vulnerability model give moderate vulnerability level for Fethiye Bay.

Moderately vulnerable means that within a global assessment although the region does not require immediate intervention, certainly significant importance has to be given for future planning to take mitigation measures.

Although a value is assigned to describe the overall vulnerability of the region, impacts have different ranges of vulnerability. This should be considered in the planning since it means that some impacts should be given higher priority for mitigation. For this reason, impact scores are also discussed for both models.

Coastal Erosion

The preliminary model study gives a CVI impact value of 3.5 for coastal erosion. On the other hand, in consideration of the physical and human related parameter in fuzzy model, all the vulnerability levels vary between 1.40 as low and 3.00 as moderate vulnerable for coastal erosion impact, the most vulnerable coastal strips of the bay represents with the values, whereas most of the segments have 2.38 over 5.00 as low-moderate vulnerability score for coastal erosion impact considering all other coastal vulnerability studies in the world.

To sum up, preliminary model result with 3.5 over 5.0 as high-moderate vulnerable, calculates a bit higher values of overall vulnerability than fuzzy coastal vulnerability assessment model with the values between 1.4 and 3.00. This results from the representation of the entire shoreline with a single value.

Inundation

The preliminary model calculates the vulnerability level with the value of 3.8 for the coastal impact of inundation.

In fuzzy logic model, the general vulnerability level of inundation ranges segments between 1.8 as low and 4.1 as high over 5.0. As the most vulnerable segments are in salt marsh area. The vulnerability score is calculated as 4.1 over 5.0 by reason of the degradation of natural protection systems in the north tip which corresponds to high vulnerable.

All in all, although the result of the preliminary model is in between the upper and lower limit of the fuzzy logic based model, preliminary model gives higher values than fuzzy coastal vulnerability assessment model in general.

Flooding due to Storm Surge

In the previous study, the preliminary coastal vulnerability model gives a 3.4 value for inundation as the third coastal impact. Nevertheless, the model based on fuzzy logic allows the user to perform a more detailed analyses and mostly gives less vulnerable results. Based on fuzzy model, the vulnerability score of physical and human-related impacts ranges between 1.5-2.5 over 5.0 as low-moderate vulnerable but the general impact score mainly concentrates on 2.0 over 5.0 as low vulnerable to flooding due to storm surge.

Since especially the current circumstances of engineered frontage on the southeast and east coast is much widespread, the vulnerability level based on human influence increases a bit higher towards the end of the graph.

The preliminary model result gives higher values as 3.4 which corresponds to moderate-high vulnerable, the fuzzy logic based model calculates the impact of flooding due to storm surge as 2.0 over 5.0 which corresponds to low vulnerable. This indicates that the preliminary model results overestimates the results compared to the model based on fuzzy logic.

Salinity Intrusion into Groundwater

Preliminary model study calculates the vulnerability level of salinity intrusion into groundwater basically as 2.6 which corresponds to low-moderate vulnerable, whereas the fuzzy model study gives different levels for different segments.

The reason for the lack of salinity intrusion impact score on the west and the southwest coast is the absence of an aquifer system on the west and southwest of Fethiye plain. The vulnerability values of fuzzy logic based model range between 3.0 as moderate and 4.0 as high vulnerable throughout the south, the east, the north of the coastline. The human-influenced impact scores suddenly increases to 4.0 on the north tip including the salt marsh area. Although the physical factors keep going constant, the general impact score is changing in accordance with the human-influenced factors while going from southwest to east and from the east to the north towards the shoreline. The human-influenced factors comes into prominence at the north tip where the impact scores increase around the salt marsh area.

The preliminary model result gives lower values with moderate vulnerable than the fuzzy coastal vulnerability assessment models with high vulnerability values. This difference results from the variety of groundwater consumption values and land use patterns.

Salinity Intrusion into River

In the preliminary model, the impact score for salinity intrusion into river is calculated 3.1 over 5.0 as moderate vulnerable. Fuzzy model gives the impact scores ranging between 2.1 as low vulnerable and 3.3 as moderate vulnerable as the result of the analysis.

According to the data obtained, the impact scores of the fuzzy coastal vulnerability assessment model are given within a range between 2.1 as low vulnerable and 3.3 as moderate vulnerable over 5.0, the preliminary model result is calculated as moderate vulnerable with 3.1 over 5.0. This shows the fuzzy coastal vulnerability assessment model results calculate similar impact scores in accordance with the preliminary model results.

Summary of Comparison

The main aim while applying two different model is to obtain a certain result, to minimize the errors, to compare the results and to verify the credibility of the fuzzy coastal vulnerability assessment model (FCVAM).

Considered the vulnerability priorities of the two model, preliminary (common case) and fuzzy coastal vulnerability assessment, the inundation is the uppermost coastal impact which is followed by coastal erosion and then flooding due storm surge impacts.

For the vulnerability priority order, the following table (Table 5.2) summarizes the case of Fethiye Bay for coastal vulnerability assessment.

Table 5.2: Vulnerability Priorities with Impact Scores of the two model studies

Priority Order	Coastal Impacts and Impact Scores			
	Preliminary Model		FCVAM	
1	Inundation	3.80	Inundation	2.90
2	Coastal Erosion	3.50	Coastal Erosion	2.40
3	Flooding due to Storm Surge	3.40	Flooding due to Storm Surge	2.00
4	Salinity Intrusion into River	3.10	Salinity Intrusion into GW	1.66
5	Salinity Intrusion into GW	2.60	Salinity Intrusion into River	0.24
Total	CVI (SLR)-III	3.30	OCVI	2.58

In consequence of the comparison of model results, the model results bring the vulnerability priority of the study area into prominence since the region is in the range of moderate and high-moderate vulnerability ranges. The overall result of the preliminary model gives a bit higher vulnerability value with high-moderate range than the fuzzy coastal vulnerability assessment model with moderate range. CVI(SLR)-III which includes the groundwater and river, estuary case calculates 3.30

over 5.00 as high-moderate while OCVI obtains the value of 2.58 over 5.00 which also corresponds to moderate vulnerable.

The priority order is almost the same for both models except the last two coastal impact. According to both model, the vulnerability priority indicates that inundation, coastal erosion, flooding due to storm surge are in the forefront.(Table 5.2). For the remaining two coastal impacts, salinity intrusion into groundwater and salinity intrusion into river take place interchangeably in the priority list. The most approximate impact result belongs to inundation impact with 3.80 and 2.90 for preliminary and fuzzy coastal vulnerability assessment models, respectively. Towards the end of the priority list, the difference between impact scores are becoming higher especially for flooding due to storm surge, salinity intrusion into groundwater and salinity intrusion into river, respectively. The big difference between the scores of salinity intrusion into river impact as 3.10 and 0.24 for preliminary and fuzzy vulnerability models respectively is due to the influence area of rivers which are discharging into a certain zone on the coastline. However, the preliminary model assumes that the entire coastline is under the influence of the discharging rivers due to the representation of shoreline with a single value instead of diversifying and examining in detail. When considered the causative factors of flooding, such as rate of sea level rise, coastal slope, significant wave height, tidal range, engineered frontage, natural protection degradation, coastal protection structures, one of the reasons of it is due to the misleading representative coarse data of coastal slope, engineered frontage, natural protection degradation and coastal protection structures. This is the overestimation of preliminary model for the salinity intrusion into river impact.

5.2 Sensitivity of Model Results to Resolution of Data

To understand the sensitivity of the model to resolution of data, slope parameter is preprocessed in two different ways and the results of vulnerability is obtained.

The first model run, the ordinary case, is performed according to such a classification including five categories of slope range in terms of Jenks Method whereas the second model is studied considering four categories of slope range.

In the coastal slope model generated using ArcGIS tools, firstly digital elevation model is being used to form a zonal map for the area of interest to investigate the slope changes over the zones having the same altitudes. Slopes are reclassified further to overcome the too many different slope classification in the end.

Zonal Statistics tool blends the slope categories that have been reclassified prior to implement within this tool. Final outcome of the tool gives us the mean average of the reclassified slope values having the same or similar elevation information.

From the viewpoint of defuzzification, 51 coastal segments are generated within the first model run of coastal slope whereas 41 segments are obtained as outputs of the second model run which gives coarser slope data compared to the first model run.

With the participation of these two types of slope model runs in spatial join operations, the impact scores are very similar to eachother with different numbers of coastal segments. At the end of the spatial join operations, totally 73 coastal segments are obtained with the first type model run of coastal slope parameter which is categorized into 5 classification at the preprocess procedure. On the other hand, totally 63 coastal segments are produced at the end of the second type model run of coastal slope which is categorized into 4 classification at the end of the preprocess procedure.

The two types of coastal slope model runs slightly affect the impact scores as in the follows.(Table 5.3).

Table 5.3: Average Impact Scores of Different Data Resolution for Slope Parameter

Coastal Impacts	Coastal Slope Model Run	
	Type I	Type II
Coastal Erosion	2.40	2.40
Inundation	2.90	2.94
Flooding due to Storm Surge	2.00	2.00
Salinity Intrusion to Groundwater	1.66	1.76
Salinity Intrusion to River	0.24	0.27
Overall Coastal Vulnerability Index	2.58	2.60

Coastal impacts obtained with the first type coastal slope model is given in the following graph.(Figure 5.24).

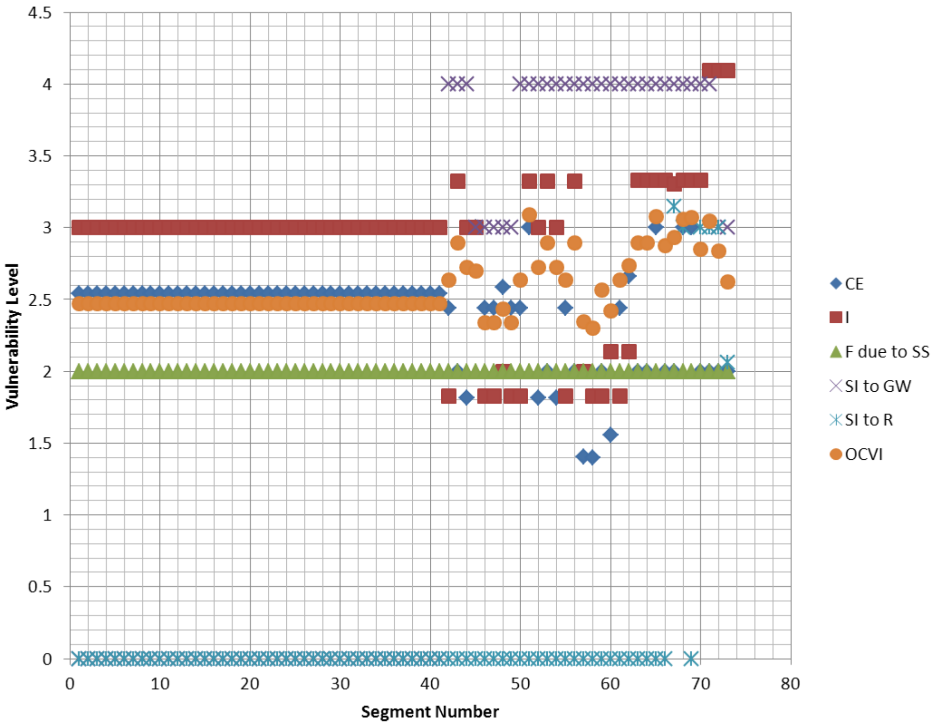


Figure 5.24: Coastal Impacts with the first type slope model

Coastal impacts obtained with the second type of coastal slope model is given in the following graph.(Figure 5.25).

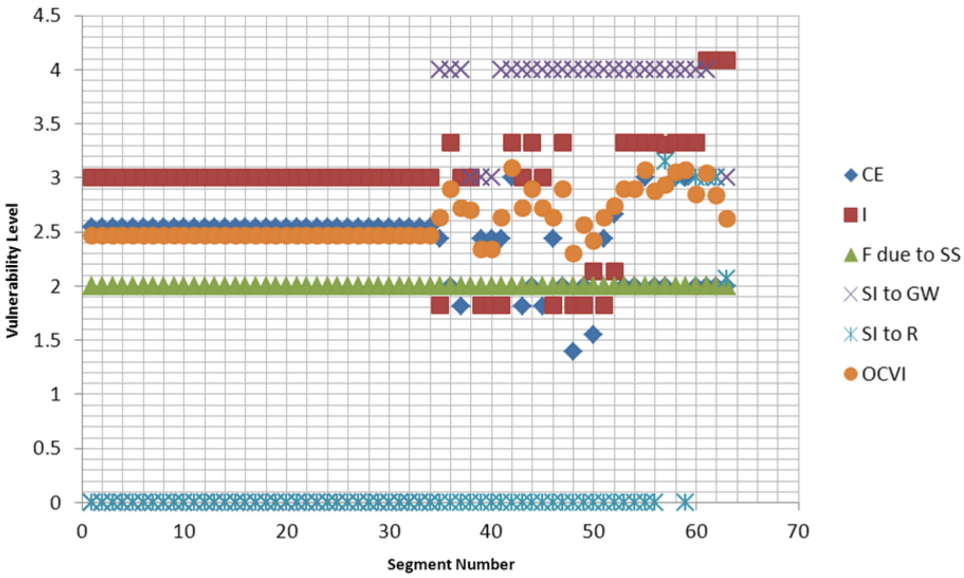


Figure 5.25: Coastal Impacts with the second type slope model

At the end of the spatial join operations, the coastal impact scores of the two model results are compared. The impact scores of coastal erosion and flooding due to storm surge are the same while the scores of inundation, salinity intrusion into groundwater and salinity intrusion into river can be considered as similar with a slight difference between the first type and the second type coastal slope models. The score differences between the first type and the second type of slope models are 2.90 and 2.94 for inundation impact, 1.66 and 1.76 for salinity intrusion into groundwater, 0.24 and 0.27 for salinity intrusion into river, respectively. The score of salinity intrusion into river is too low due to the narrowness of the influence area of two river discharging point throughout the shoreline.

Considered the maximum and minimum values of the two types of slope models (Table 5.4), the differences between the scores of coastal impacts are originated from the length differences of the coastal segments splitted in accordance with the coastal slope category specified in slope model.

Table 5.4: Maximum vs Minimum Impact Scores of Different Data Resolution for Slope Parameter

Coastal Impacts	Type - I		Type - II	
	Maximum	Minimum	Maximum	Minimum
Coastal Erosion	3.00	1.40	3.00	1.40
Inundation	4.09	1.82	4.09	1.82
Flooding due to Storm Surge	2.00	2.00	2.00	2.00
Salinity Intrusion to Groundwater	4.00	0.00	4.00	0.00
Salinity Intrusion to River	3.15	0.00	3.15	0.00
Overall Coastal Vulnerability Index	3.09	2.30	3.09	2.30

5.3 Sensitivity of Model Results to Segmentation Procedure

To understand the impact of segmentation procedure on the results, two different methodology is used to implement the process. Totally twenty layers for twenty parameters are spatially joined successively according to a certain order, but in two different manner. In the first case, each shoreline layer overlapped starting with the layer possessing the least number of segment ending with the layer having the highest number of segment. In the second case, the layers are joined in reverse manner, starting with the one having the highest number of segment ending with that possessing the least number of segment.

Considered the results of the two model, reverse and unreverse runs, the outputs such as the number of coastal segments and the impact scores are completely the same with eachother. In the reverse run case of the model, the shoreline consists of 73 coastal segments which is utterly the same with the unreversed case.

This sensitivity analysis indicates that there is no difference between the outputs in the reverse processing of the layers.

5.4 Discussion of the Results in light of Coastal Zone Management

This study is an indicator to determine the priority of Fethiye region for its vulnerability against sea level rise. By implementing two versions of the coastal vulnerability assessment model into Fethiye Bay, the vulnerability levels to global sea level rise on both versions are identified as moderate vulnerable.

Since the region is not ready to the consequences of a sea level rise scenario, a very coordinated adoptation study must be carried out. An adoptation process would be painful to get used to it unless no implementation has been conducted. On the other hand, if the policy makers and decision takers can come to an agreement on common issues, Fethiye would be able to prepare for a possible sea level rise scenario.

As one of the human related factors of coastal erosion, river flow regulation has a significant role in the circulation of sedimental materials. Regulative structures trapped sediments within their pathway can be dangerous due to preventing sediment to reach at the downstream of the river, successively reducing sediment and increasing coastal erosion risk on the coast. In Turkey, unplanned distribution of dam projects also increases the vulnerability level of the regions. According to the report (2011) sent to The Grand National Assembly of Turkey reveals that totally 34 HES project in different design phases have been waiting for the approval. For 30 years, marketing economy is being applied instead of planned economy in Turkey, the number of HES projects are planned to be increased.(TBMM 2011,)

Although salinity intrusion into groundwater is on the fourth rank in the priority order list prepared in light of fuzzy coastal vulnerability assessment model results, groundwater resources might be exposed to reduction risk since climate change is projected to very likely reduce water quality due to temperature increase, sediment and pollutant concentration in freshwater coming from intense rainfall, insanitary treatment facilities during floods. (IPCC, 2014). Considering the pressure on freshwater resources, local drawings might be taken under control by legislating drawing volumes and drawing locations to prevent a permanent loss of the natural resources with the rising of global sea level.

The study area, Fethiye Bay, is legally and completely under the jurisdiction of OCK (Institute for Specially Protected Environmental Areas) (OCK, 2014). Nevertheless, there is a wide range of human made structures around the bay. Urbanization interacting with economic development and population growth causes to alter land use pattern. Freshwater resources might adversely affect from this alteration due to the concretion of the region, and might not feed by rainfall due to reducing permeability of the ground. This artificial land use pattern may increase the impact of extreme natural hazards.

According to WG2AR5 IPCC (2014), the reduction in marine biodiversity as one of the projections of climate change will pose a threat fishery productivity and other marine species. (IPCC, 2014). Despite these pressures on the coastal ecosystem, the shipyard constructions and operations severely threaten and cause the severe habitat destruction and nesting decline documented in the Specially Protected Area of

Fethiye. If conservation measures to prevent sea turtle population decline are being enforced, irreversible ecological degradation and further decrease of nesting will be occur in near future.(MEDASSET Report, 2011).

Even if the region is legally under protection by the Institution for Specially Protected Areas, people are still degradating the flora, fauna of the region by using concrete, by exploiting natural resources even in scarce. This shows the absence of an inspection-punishment mechanism in the society. Unfortunately this overexploitation may last throughout the human history unless the stakeholders raise the awareness of their own society and the authorities take logical and applicable measures, and make mitigation policies.

As being responsible of leading the politicians and decision makers, scientists have a dominant role to explain the environmental process in a more scientific way. International Institute for Sustainable Development (2013) states that mentoring of scientific people to the government and private sector clients on the analysis and evaluation of international climate policy contributes to the development of the country in terms of environment, science and technology. (IISD, 2013).

In order to emphasize the importance of protection measures and the sustainability of the vulnerable areas, it is appropriate to enlarge the application area of Coastal Vulnerability Index to Sea Level Rise (CVI-SLR) Model (Ozyurt, 2007) and the Fuzzy Coastal Vulnerability Assessment Model (Ozyurt, 2010).

The results gave an idea for authorities and decision makers on the optimal resource allocation and adaptation plans about coastal zone management. Since the sea level rise is a global problem, it is vital to put into practice promptly for mitigation and adaptation plans. For the future studies, fuzzy coastal vulnerability assessment model conducted by integrating geographical information systems to obtain more accurate results about the region can be enlarged more as well as the vulnerable regions studied in Ozyurt (2010) and the study area of this thesis. Hereby, coastal vulnerability maps against sea level rise can be formed to better understand where the communities are of the vulnerability range, what kind of preparations do the communities need and what the damage level will be. All these parameters will certainly guide for adaptation plans to decision makers and the volunteers of non-governmental organizations.

CHAPTER 6

CONCLUSION

The main subject in this study is the determination of the vulnerability priority of Fethiye Bay to global sea level rise and the implementation of fuzzy coastal vulnerability assessment model (FCVAM) in the study area.

6.1 Summary and Conclusion

Turkey, with a 8333km of coastline is under threat against sea level rise due to its geological location. The coastal vulnerability assessment is focused on Fethiye Bay due to its closeness to the center of settlements and the population density settled around the bay.

The study performed depends on the parametric model of fuzzy coastal vulnerability model (FCVAM) with two main initiatives; physical and human influenced parameters. Coastal impacts based on physical and antropogenic parameters can be classified into five main categories. Coastal Erosion, Flooding due to Storm Surge, Inundation, Salt Water Intrusion to Groundwater Resources, Salt Water Intrusion to River/Estuary. Outside of the bay towards Mediterranean Sea, high cliffs with very steep slopes can be observed that no settlement is formed in those areas due to the difficulty of constructing transportation facilities onto such a steep sloped geography. Thus, the suburban zones around Fethiye are not considered in this vulnerability assessment model study.

Although it is difficult to change the physical characteristics, human activity is the controllable parameter by implementing coastal zone management policies to mitigate the negative consequences of the coastal impacts.

All in all, the preliminary and fuzzy coastal vulnerability assessment model results put the vulnerability priority of the study area to forefront. The inundation impact is in the first priority in accordance with both model results. The causative factors of inundation impact include coastal protection structures and natural protection degradation as human related, rate of sea level rise, coastal slope and tidal range as physical. The two human related parameters, Natural Protection Degradation and Coastal Protection Structures, also play salient roles in other two impacts which have priorities in the vulnerability level list as well as inundation impact. The mitigation policies and adaptation plans to reduce the impact of these two parameters will be to the point decisions in terms of coastal zone management practices.

Appropriately well-designed coastal protection structures will be very effective long term controlling measures to mitigate the negative consequences of the first three impacts. Increasing the natural protection areas will be convenient due to its key role in inundation, coastal erosion and storm surge flooding impacts.

From the coastal erosion viewpoint, wave action coming from Mediterranean may provide sedimentary material to deposit towards the shoreline as another influencing factor. The Island will also be protective to some degree for the wave height and sediment budget as the causative parameters of coastal erosion. In the cases where badly-designed coastal protection structures are constructed, the wave action may cause to erosion in one part of coast and to accretion in other part as the influencing physical impact of coastal erosion. Human-made structures (i.e. dam, channel, silt weir, badly designed breakwater) make permanent changes in the characteristics of natural resources. Building a dam or channel on the edge of an upstream of a river plays significant role in the decrease of sediment supply of coasts. This also affects the regulation of river flow in a negative manner. Engineered frontage is very prevalent along the coastal strip starting from the north tip towards the southwest coast of the bay as the risk increasing factor for coastal erosion.

Acccording to IPCC (2013), the increase in MSL rise will very likely create and increase in future sea level extremes (Seneviratne et al., 2012; cited in WG1AR5 of IPCC (2013)). Storm surge flooding depending on the coastal slope, wave height and rate of sea level rise as physical parameters can also be a potential danger that it can be mitigated by implementing policies in favor of increasing coastal protective structures, minimizing natural protection degradation and engineered frontage. From the viewpoint of physical impacts of storm surge flooding, the Island Sovalye has also a protective role in minimizing the wave height. The Island Sovalye protects the bay to a certain degree from coming waves from the Mediterranean Sea. Engineered frontage around the river discharging points at the north and on the east coast also negatively affects the flooding impact.

According to IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) published in 2012, the increase in MSL rise will very likely create and increase in future sea level extremes (Seneviratne et al., 2012; cited in WG2AR5 of IPCC (2014)).

Both the rate of sea level rise and tidal range as physical parameters have prominent roles in the top three impact ranks of vulnerability priority of Fethiye Bay; inundation, coastal erosion and flooding, respectively.

Although its impact score is in the range of low vulnerability, salinity intrusion into groundwater may pose a slight threat for the study area in case of the rise of sea level. To take measures by implementing coastal zone management policies, groundwater consumption rates and alteration of land use patterns should be under control.

Physical properties of the confined aquifer provide resistance to a certain degree. Artesian well range is also observed throughout the coast. However, there are shallowly unconfined aquifers located on confined aquifers in the study area. Yet, saltwater intrusion might slightly be a potential threat for groundwater in the future. This can be avoided by taking under control of groundwater drawings. Land use pattern also plays a salient role that agriculture, industrial or settlement areas need more freshwater to sustain itself. The land use also regulates the climatic events.

Salinity Intrusion into River is the final rank of the priority list. Although the discharge rates of rivers flowing into the bay are very low, the human-made structures also play salient role in controlling the impacts of salinity intrusion to river. Constructing a breakwater or any structure may also reduce the sediment deposition and consecutively the water depth at the downstream of a river.

6.2 Recommendation

Considered the results of fuzzy coastal vulnerability assessment model as moderate vulnerable, local people and the authorities are expected to pay more attention to develop a master plan. In order to mitigate the effects of human-related factors while decreasing the total impact of inundation; increasing the natural protection areas and appropriately well-designed coastal protection structures will be very convenient and to the point. Since these two parameters have key roles in inundation as well as coastal erosion and storm surge flooding as the top three ranks in vulnerability priority of Fethiye Bay.

Physical and economic preperation for the catastrophic levels of the rise completes the half of the adaptation procedure against the situation. Distribution of reading materials, different practical action drills in schools, and public places may contribute to raise the awareness of the community. The other half is the action part that will create innovative engineering solutions to sustain the life in particular region. Englander (2013) claims that creative and sustainable large-scale civil engineering projects may help to solve the desperate complexities, to sustain the environment and to improve the economy. (Englander, 2013).

As future recommendation for the vulnerability assessment model studies, coastal structures can be classified into subgroups and integrated into the model in addition to an integrated analysis for the impacts of these structures on behalf of improving the fuzzy coastal vulnerability assessment model (FCVAM). For the future studies,the effects of coastal forest to mitigate the impacts of sea level rise can be further investigated in terms of coastal erosion and inundation as well as integrating them into the model.

Even though the ICZM suggestions given are towards the problem of sea level rise, some of them can be applied for other coastal hazards. For instance, tsunami phenomena had been observed at least 6 times throughout the history of Fethiye (Altinok, 2011). Similar to the rising of sea level, tsunami may also result in inundation problems. In this manner, the impacts of sea level rise such as flooding and inundation can be considered similar for tsunami. Therefore, the mitigation and adaptation plans for the rising of sea level problem can be applicable to tsunami hazards in this region.

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