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Application of Sea Level Rise Vulnerability Assessment Model to Selected Coastal Areas of Turkey

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ABSTRACT

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Climate change and anticipated impacts of sea level rise such as increased coastal erosion, inundation, flooding due to storm surges and salt water intrusion to freshwater resources will affect all countries but mostly small island countries of oceans and low-lying lands along coastlines. Turkey having 8333 km of coastline including physically, ecologically and socio-economically important low-lying deltas should also prepare for the impacts of sea level rise as well as other impacts of climate change while participating in mitigation efforts. Thus, a coastal vulnerability assessment of Turkey to sea level rise is needed both as a part of coastal zone management policies for sustainable development and as a guideline for resource allocation for preparation of adaptation options for upcoming problems due to sea level rise. As a scientific approach to coastal vulnerability assessment a coastal vulnerability matrix and a corresponding coastal vulnerability index of a region to sea level rise are developed. In the development of the matrix and the index, indicators of impacts of sea level rise which use commonly available data are used. The developed coastal vulnerability assessment model is used to determine the vulnerability of three different coastal areas of Turkey; Göksu Delta (Specially Protected Area), Göcek (Specially Protected Area) and Amasra to present the sensitivity of the model to regional properties.

ADDITIONAL INDEX WORDS: *Coastal Zone Management*

INTRODUCTION

Coastal areas are the vital locations for the communities throughout the history due to vast amount of resources available for survival and development. It is estimated that 50% of world's population will live within 100 km of the coast by 2030 and population densities in coastal areas are three times the global mean(SMALL and NICHOLLS, 2003). Anticipated impacts of global warming and climate change will alter many of the systems including coastal ecosystem and population which will also be affected by sea level rise. The impacts of sea level rise will be most profound on the small islands of the oceans and the low-lying coastal areas around the world (Intergovernmental Panel on Climate Change Staff, 2001).

Turkey, having 8333 km of coastline is also under threat. Although sea level rise on coastal areas of Turkey is not expected to be as high as the oceans, there will be consequences especially on low-lying areas and estuaries, which are also Turkey's most productive agricultural areas, urban centers and tourism zones. Thus, a vulnerability assessment of coastal areas of Turkey to sea level rise is needed both as a part of coastal zone management policies for sustainable development and as a guideline for resource allocation for preparation of adaptation options for the upcoming problems due to sea level rise.

There are many different levels of vulnerability assessments which can be classified as strictly quantitative to semi-quantitative, non-adaptive to perfectly adaptive, science-driven to policy driven, simplistic to sophisticated, etc. (FÜSSEL and KLEİN, 2006). Each assessment needs data with different levels of detail and accuracy. In Turkey, one of the main limitations of a vulnerability assessment, most probably, will be due to the lack of data for a particular region. Most of the available data belongs to major urban centers or there exists no data at all on some of the parameters. Thus in this study, a coastal vulnerability matrix and a corresponding coastal vulnerability index – CVI (SLR) of a region to sea level rise using indicators of impacts of sea level rise which use commonly available data are developed. The results of the matrix and the index enable decision makers to compare and rank different regions according to their vulnerabilities to sea level rise, to prioritize impacts of sea level rise on the region according to the vulnerability of the region to each impact and to determine the most vulnerable parameters for planning of adaptation measures to sea level rise (ÖZYURT, 2007).

The developed model is used to determine the vulnerability of three different coastal areas of Turkey; Göksu, Göcek and Amasra, to present the local effect on the impacts of sea level rise and how the model presents these differences successfully.

METHODOLOGY

In order to develop a method of coastal vulnerability assessment to sea level rise using indicators for both physical and socioeconomic vulnerabilities; first, the physical impacts were studied.

The physical impacts of sea level rise on coastal areas included in this study are;

Table 1: Coastal vulnerability matrix for Göcek Specially Protected Area

Location Göcek (Specially Protected Area)

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		1				2	H1.1 Reduction of Sediment Supply	1					1		
	P1.2 Geomorpholgy			1			3	H1.2 River Flow Regulation	1					1		
	P1.3 Coastal Slope			1			3	H1.3 Engineered Frontage				1		4		
	P1.4 $H_{1/3}$		1				2	H1.4 Natural Protection Degradation			1			3		
	P1.5 Sediment Budget			1			3	H1.5 Coastal Protection Structures					1	5		
	P1.6 Tidal Range					1	5									
	TOTAL	0	2	3	0	1	18	TOTAL	2	0	1	1	1	14	16	2.9
2. Flooding due to Storm Surge	P2.1 Rate of Sea Level Rise		1				2	H2.1 Engineered Frontage				1		4		
	P2.2 Coastal Slope			1			3	H2.2 Natural Protection Degradation			1			3		
	P2.3 $H_{1/3}$		1				2	H2.3 Coastal Protection Structures					1	5		
	P2.4 Tidal Range					1	5									
	TOTAL	0	2	1	0	1	12	TOTAL	0	0	1	1	1	12	12	3.4
3. Inundation	P3.1 Rate of Sea Level Rise		1				2	H3.1 Natural Protection Degradation			1			3		
	P3.2 Coastal Slope				1		4	H3.2 Coastal Protection Structures					1	5		
	P3.3 Tidal Range					1	5									
	TOTAL	0	1	0	1	1	11	TOTAL	0	0	1	0	1	8	9.5	3.8
4. Salt Water Intrusion to Groundwater Resources	P4.1 Rate of Sea Level Rise		1				2	H4.1 Groundwater consumption				1		4		
	P4.2 Proximity to Coast				1		4	H4.2 Land Use Pattern			1			3		
	P4.3 Type of Aquifer			1			3									
	P4.4 Hydraulic Conductivity			1			3									
	P4.5 Depth to Groundwater Level Above Sea				1		4									
	TOTAL	0	1	2	2	0	16	TOTAL	0	0	1	1	0	7	11.5	3.3
5. Salt Water Intrusion to River/Estuary	P5.1 Rate of Sea Level Rise		1				2	H5.1 River Flow Regulation	1					1		
	P5.2 Tidal Range					1	5	H5.2 Engineered Frontage				1		4		
	P5.3 Water Depth at Downstream	1					1	H5.3 Land Use Pattern			1			3		
	P5.4 Discharge					1	5									
	TOTAL	1	1	0	0	2	13	TOTAL	1	0	1	1	0	8	10.5	3

CVI(SLR)-1		
CVI(SLR)-2		
CVI(SLR)-3	59.5	3.2

a) Increased coastal erosion
b) Inundation
c) Increased flooding due to increased storm surge
d) Salinity intrusion to groundwater and estuaries

The model aims to determine the vulnerability of the region by defining the governing physical and human influence parameters of the phsyical impacts of sea level rise mentioned above using the available local data. To determine the indicators, the governing parameters that are believed to represent the physical processes of the impacts of sea-level rise were determined. THIELER and HAMMAR-KLOSE (2000) method for analyzing vulnerability of U.S. coasts was used as a baseline model however several other models were also considered to define each of these parameters, such as the Bruun rule for predicting coastal erosion and the Ghyben-Herzberg principle for salinity intrusion to groundwater resources. On the other hand, direct human activities in the coastal areas, such as settlement (land use that directly influences the evolution of coastal areas), as well as indirect activities, such as regulation of rivers by dams and reservoirs, were considered to determine the level of influence of anthropogenic actions. In light of these discussions, it was decided that 12 physical parameters and 7 human influence parameters would be appropriate without reducing the quality of the assessment. (ÖZYURT and ERGIN, 2009)

Vulnerability ranges determining the ranks of each parameter according to the regional data were based on distribution of avaliable data related to each parameter at locations around the world. Using regional data, each parameter is assigned a vulnerability rank of very low to very high vulnerability(1-5). For example, wave height parameter ranges from less than 0.5m (very low vulnerability) to more than 8.0m (very high vulnerability) around the world. Regional data of Göcek assigns wave height parameter a value of 2.0m meaning low vulnerability class.

The developed coastal vulnerability matrix (Table 1),using vulnerability ranks of regional data, calculates the impact sub-indices and the overall vulnerability index applying the formulas presented below. (ÖZYURT, 2007)

Physical impact sub-indices (CVI_{impact}) are the results of ratio of the sum of weighted parameters to the least vulnerable case result for the impact studied (Formula 1). The calculated indices ranges between 1 and 5 indicating the level of vulnerabiltiy accordingly.

$$CVI_{impact} = \frac{\left(0.5 * \sum_{1}^{n} PP_n * R_n\right) + \left(0.5 * \sum_{1}^{m} HP_m * R_m\right)}{CVI_{leastvulnerable}} \quad (1)$$

CVI_{impact}: Physical impact sub-index
PP: Physical parameters
HP: Human influence parameters
R: Rank of parameters
$CVI_{leastvulnerable}$: Calculated least vulnerable case for a particular physical impact

Coastal Vulnerability Index (CVI(SLR)) is calculated according to the group the region is in which depends on the likelihood of the existence of the types of physical impacts (Formula 2). The index is given as the ratio of the total value of parameter

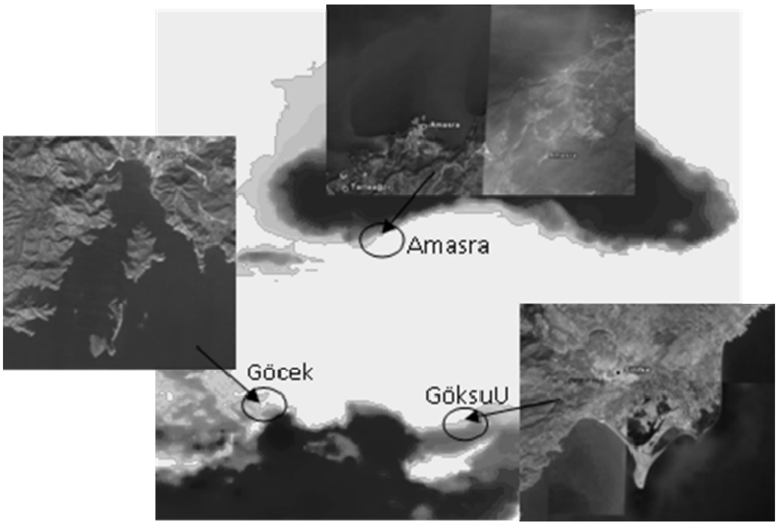

Figure 1. Case study locations. (Google Earth)

vulnerability ranks to the least vulnerability value of the corresponding group.

$$CVI(SLR)_n = \frac{\sum \text{Parameters of Impacts of group}}{\sum \text{Least Vulnerable Case of the group}} \quad (2)$$

One of the main assumptions of the model is the weighting system. The weights are assumed to be equal to 1 for all the parameters and 0.5 for the effect of physical and human influence parameters on the overall vulnerability as a baseline analysis until further research on comparison judgements at different levels are available .

CASE STUDIES

Using the available regional data from literature reviews of previous research on case study sites, studies of management plans by Authority of Specially Protected Areas and Ministry of Environment and data gathered during technical trips to Göksu delta, Göcek and Amasra (ÖZYURT, ERGIN and ESEN, 2008) (Figure 1); the coastal vulnerability matrices were prepared for all of the regions.

The results for all the regions are given in Table 2 and Table 3 as a summary showing the vulnerability ranks for each parameter, impact vulnerability scores and overall vulnerability of the regions.

As can be seen from the results, different levels of vulnerability are observed around the coastline of Turkey. This result underlines the necessity for an overall evaluation of the coastline of Turkey in terms of vulnerability to sea level rise. The results of the model are also in accordance with the literature of sea level rise such that coastal deltas are more vulnerable to impacts of sea level rise as is the case in Goksu Delta.

Another important outcome of the model results is that, the model taking into consideration of local properties in terms of parameters clearly represents the influence of these properties on the overall vulnerability. Thus the sensitivity of the model to local properties can be seen from the results of three different coastal area studies such that although the rate of sea level rise is same for Göksu and Göcek, the vulnerabilities to different impacts shows significant change.

Table 2: Vulnerability scores of each parameter for case study areas

Parameters	**Regions**		
	Amasra	**Gocek**	**Goksu**
Physical Parameters			
Rate of Sea Level Rise	3	2	2
Geomorpholgy	1	3	5
Coastal Slope	2	3	5
H1/3	5	2	4
Sediment Budget	3	3	4
Tidal Range	5	5	5
Proximity to Coast	3	4	4
Type of Aquifer	3	3	3
Hydraulic Conductivity	3	3	1
Depth to Groundwater Level Above Sea	1	4	2
Water Depth at Downstream	-	1	2
Discharge	-	5	4
Human Influence Parameters			
Reduction of Sediment Supply	1	1	3
River Flow Regulation	1	1	3
Engineered Frontage	2	4	2
Natural Protection Degradation	2	3	5
Coastal Protection Structures	3	5	5
Groundwater consumption	1	4	4
Land Use Pattern	3	3	5

Table 3: Vulnerability scores of impacts and overall vulnerability of case study areas

	Regions		
	Amasra	**Gocek**	**Goksu**
Coastal Erosion	2.5	2.9	3.9
Flooding due to Storm Surge	3.1	3.4	4
Inundation	3	3.6	4.4
Saltwater Intrusion to Groundwater	2.9	3.3	3
Saltwater Intrusion to Rivers/Estuary	-	3	3.3
VULNERABILITY	**2.8 Low**	**3.2 Moderate**	**3.7 High**

Not only physical influences but inclusion of human factors increases the significance of the model results such that a region that is considered as low vulnerable becomes high vulnerable due to these human factors which can be regulated through implementation of measures to decrease the impact of sea level rise.

Determining the vulnerability of coastal area to each impact of sea level rise is also another important property of the model which is also clearly validated through these case studies. Although a coastal area can be classified as low vulnerable to sea level rise as is the case in Amasra, the location can be more vulnerable to some impacts than the others, i.e., flooding due to storm surge has the highest vulnerability score (higher than overall vulnerability).

CONCLUSION

By implementing the developed coastal vulnerability assessment model (CVI (SLR)) to three geologically different coastal areas, the sensitivity of the model is tested.

The results show that the model can successfully incorporate the local properties with the expected impacts of sea level rise and give important information on the vulnerability of the region especially for the decision makers for optimum resource allocation and adaptation planning.

Integration of geographical information systems will increase the accuracy of the model by eliminating the spatial restricts of determining the study area using one matrix. It is important that compilation of detailed data should be considered for better results as well as accurate prediction.

The sensitivity of the model will also increase as the level of accuracy of data increases. Use of weights for parameters will also have a considerable effect on the accuracy of the results as well. In order to achieve this, fuzzy logic implementation can be considered.

The results of the model can also be used for coastal zone management practices since the impacts of sea level rise are also the main problems of coastal areas whether significant sea level rise is observed or not. Thus the use of the developed model can be broadened for other management practices. Integration of social vulnerability parameters is expected to finalize the development of the model in the future.

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