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Determining the Spatial Vulnerability Levels and Typologies of Coastal Cities to Climate Change: Case of Turkey

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***Abstract*—**One of the important impacts of climate change is the sea level rise. Turkey is a peninsula, so the coastal areas of the country are threatened by the problem of sea level rise. Therefore, the urbanized coastal areas are highly vulnerable to climate change. At the aim of enhancing spatial resilience of urbanized areas, this question arises: What should be the priority intervention subject in the urban planning process for a given city. To answer this question, by focusing on the problem of sea level rise, this study aims to determine spatial vulnerability typologies and levels of Turkey coastal cities based on morphological, physical and social characteristics. As a method, spatial vulnerability of coastal cities is determined by two steps as level and type. Firstly, physical structure, morphological structure and social structure were examined in determining spatial vulnerability levels. By determining these levels, most vulnerable areas were revealed as a priority in adaptation studies. Secondly, all parameters are also used to determine spatial typologies. Typologies are determined for coastal cities in order to use as a base for urban planning studies. Adaptation to climate change is crucial for developing countries like Turkey so, this methodology and created typologies could be a guide for urban planners as spatial directors and an example for other developing countries in the context of adaptation to climate change. The results demonstrate that the urban settlements located on the coasts of the Marmara Sea, the Aegean Sea and the Mediterranean respectively, are more vulnerable than the cities located on the Black Sea's coasts to sea level rise.

***Keywords*—**Climate change, coastal cities, sea level rise, urban land use planning, vulnerability.

I. INTRODUCTION

SEA level rise is one of the most serious effects of climate change. In the *Fifth Assessment Report* of IPCC [1] it was mentioned that the rate of global mean level rise (GMSL) during the 21st century will very likely exceed the rate observed during 1971-2010 for all RCP scenarios and the median projections for GMSL in all scenarios lie within a range of 0.05 m until the middle of the century. Also, in the various projections made for 2010 based on different scenarios, rising values varying between 0.44-0.74 m have been calculated [1]. Coastal systems consisting of both natural and human systems are particularly sensitive to sea level rise [2]; so the world's coastal urban settlements are threatened by sea level rise. The attractiveness of the coastal area has resulted in rapid expansion of settlements and migration of people in these areas is common in both developed and developing countries [3]. Sea level rise threatens especially low elevation coastal zones (LECZ). "LECZ defined as a contiguous coastal area which is less than 10 meters above sea level and covers 2% of the world's land area. On the other hand, LECZ contains 10% of the world's population and 13% of the world's urban population" [4]. There is high and growing population exposure to LECZ [5]. Therefore, adaptation of coastal settlements to climate change became one of the important policies.

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In addition to coastal urban settlements hosting ever-increasing populations, the reason of their being vulnerable to climate change could be listed according to each city's own characteristics under such headings as: Geographical location, socio-economic structure, spatial development characteristic, and infrastructure. This paper focuses on spatial development and structural characteristics at the urban scale. Spatial settlement pattern is the most important factor when considering the interaction between urbanization, climate dependent risks and vulnerability [6]. Therefore, urban land use planning is an important tool for the implementation of adaptation policies [7]-[12].

In general, the term of spatial vulnerability is used for showing the spatial distribution of vulnerability levels of cities (e.g. [13], [14]). However, this term is used to mention the vulnerability that is based on morphological characteristics of urban settlements in this study. In other words, spatial development pattern and structure (morphological characteristics such as location of housing, distance of housing from the sea, coastline built length etc.) are considered as factors in determining the vulnerability of a given central cities. So, at the aim of enhancing spatial resilience of urbanized coastal areas and adaptation of them to climate change, these questions arise: Which spatial-morphological characteristics are important for determining of the vulnerability of an urban settlement to sea level rise? How can we decrease the spatial vulnerability via urban land use planning? And, which intervention is crucial in the first phase for a given city. To answer these questions, this study aims to determine spatial vulnerability typologies and levels of Turkey coastal cities to sea level rise, based on morphological, physical, social and economic characteristics. Thus it was purposed to provide a base for future adaptation-based urban land use planning processes.

II. Coastal Urban Settlements in Turkey and Sea Level Rise

Turkey is surrounded by four seas: Mediterranean Sea, Aegean Sea, Black Sea and Marmara Sea (Marmara Sea is an internal sea) (Fig. 1). So, Turkey is a peninsula with an 8,333 km coastline. In the last century, sea levels in the Mediterranean and Black Sea Region have been increased by 12 cm [15]. The sea level along the Turkish coastline was monitored several times between 1922 and 1985 [16]. Currently, there are 20 tide gauge stations which were established under Turkey National Sea Level Monitoring Network (TNSLMN) and the data are shared with the Global Sea Level Observation System (GLOSS) and Permanent Service for Mean Sea level (PSMSL). According to the results of the measurements carried out by TNSLMN, there is an obvious rise in average sea level.

The potential for economic opportunities such as tourism, agriculture, transportation, industry in the coastal cities of Turkey is a strong attractive force. Low-lying coastal areas constitute 3% of the surface area of the country [17]. In Turkey, 28 provinces from 81 provinces are located in coastal areas and 14 central cities of these provinces are located on LECZ (Fig. 1). Rize, Trabzon, Ordu, Samsun and Sinop are located on the Black Sea coast of northeastern Turkey; Istanbul, Tekirdağ are located on the Marmara Sea coast of northwestern Turkey; Çanakkale and İzmir are located on the Aegean Sea coast of western Turkey and Antalya and Mersin are located on the Mediterranean Sea coast of southern Turkey. Some of these coastal cities are one of Turkey's major tourism (Antalya, İzmir, Istanbul) and industry (Istanbul, Kocaeli, İzmir) centers. For example, Istanbul which is located on the coast of the Marmara Sea is the biggest city of Turkey with 14 million inhabitants (18% of the country's population). İzmir is the third biggest city of Turkey with 4 million population as well. Briefly, the problem of sea level rise also threats the coastal areas of Turkey and a large part of the country population will be faced with the risks resulting from this problem in the future [18].

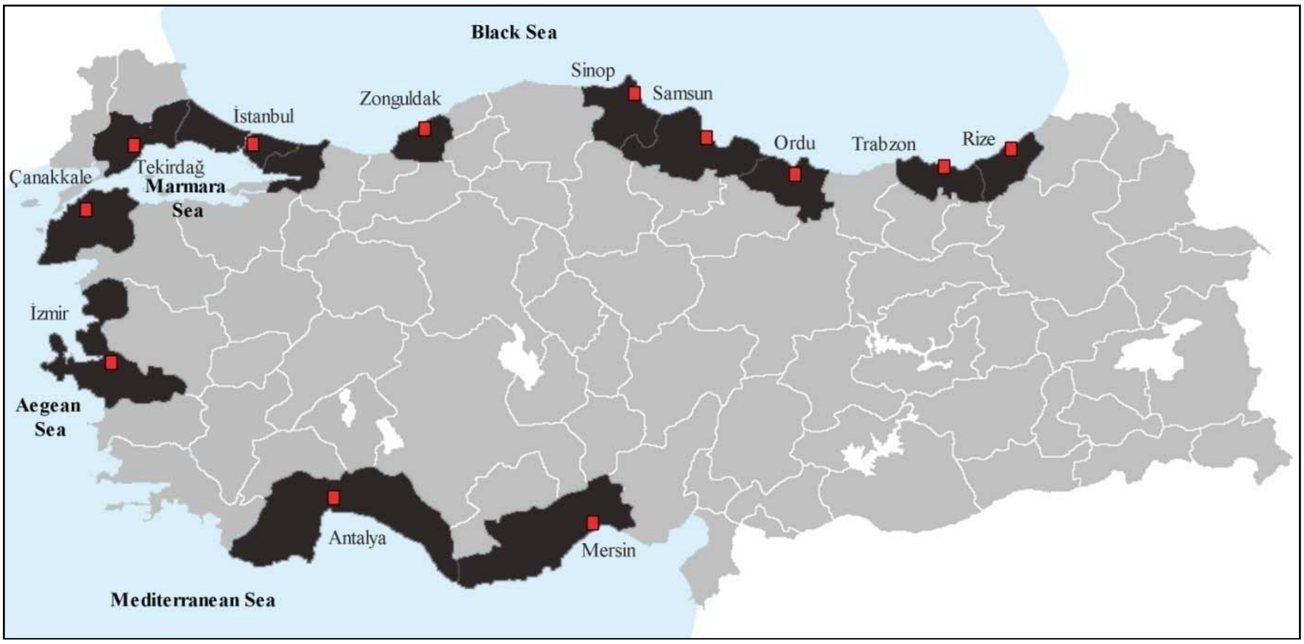

Fig. 1 Coastal cities in Turkey (n=14) (produced by Aydın and Kahraman)

III. Method

According to IPCC, vulnerability to climate change is "the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change" [18]. Therefore, both the factors which have positive effects and the factors which have negative effects gain important in determining of vulnerability. So, vulnerabilities are defined with different equations including these terms: Exposure, susceptibility and resilience or coping capacity. Social, economic, physical, morphological, hydro-geological and politico-administrative characteristics of cities were distinguished according to the condition of being exposed, susceptible or resilience.

De Leon and Carlos [19] mentioned a formulation of vulnerability proposed by Disaster Reduction Institute (DRI). According to DRI, vulnerability is the portion of number calculated by multiplication of exposure and susceptibility to coping capacity, which is the capacity, including existing institutions, people, organizations and resources that face to adverse effects of disasters. Similar to DRI formula, Flood Vulnerability Index (FVI) Equation which provides comparisons between various geographical scales was conducted to present FVI by using all components (exposure, susceptibility and resilience). This equation allows a dimensionless platform for comparing FVI, FVI's with related indicators in different cases [20].

$$FVI = \frac{E \times S}{R} \tag{1}$$

Different components of settlement characteristics were standardized (normalization) based on the formula used by [21]-[23]. Balica et al. [23] developed the FVI for coastal cities. In their methodology, each indicator transformed into a standardized number (0 to 1) to allow quantifying different dimensions together by using:

$$FVIs = \frac{FVIscale}{FV\ \mathrm{Im}\, ax} \tag{2}$$

FVI Equation was used in this study as Coastal Vulnerability Index (CVI) to compare spatial vulnerability levels of Turkey's coastal cities which have different physical, morphological, social characteristics. CVI is;

$$CVI = CVIphy + CV\ \mathrm{Im}\, orp. + CVIsoc. \tag{3}$$

$$CVIphysica\ l = \frac{(\mathrm{ALR} \times SLR \times \mathrm{LECZ})}{FOR} \tag{4}$$

$$CV\ \mathrm{Im}\, orp. = \frac{(\mathrm{LECZ/C} \times \mathrm{CA} \times \mathrm{COAST} \times \mathrm{DFS})}{(\mathrm{PAR} \times \mathrm{INFRAS})} \tag{5}$$

$$CVIsoc. = \frac{(\mathrm{POP} \times \mathrm{POPD} \times \mathrm{POPG} \times \mathrm{AGE} \times \mathrm{DIS} \times \mathrm{FM})}{(\mathrm{INCOM})} \tag{6}$$

A. Explanation of Physical Indicators

Turkey signed the UNFCCC in 2004 and thus efforts related to climate change have been started after that year. So there are limited scientific data about regional mean sea level rise that can be used in this research. According to *First National Communication of Turkey on Climate Change*, "average sea level relative linear change is calculated by harmonic analysis of sea level change measurements obtained in 20 years' time in Antalya-II (Mediterranean), Bodrum-II and Mentes (Aegean) mareographic stations and in 21 years' time in Erdek (Marmara Sea) mareographic station are 7.4±0.6 mm/year, 3.8±0.6 mm/year and 7.7±0.7 mm/year, respectively" [24]. Sea level rise in the Black Sea was calculated by Avşar et al. [25] and the result shows 3.19 ± 0.81 mm/year for the period of 1993–2014. Thus, the values obtained from the 4 mareographic station were generalized according to station's location to the sea for each one.

Sea level rise, LECZ, altitude and forest area were used as physical indicators. Except sea level rise, other physical indicators have a close relation with the location decisions which are produced in urban land use planning processes. For example, LECZ is very vulnerable to sea level rise and thus become an important factor in assessment of vulnerabilities. However, if there were no housing or sectoral building in LECZ, then we could not consider it as an important indicator in determining of the vulnerability to sea level rise of an urban settlement. Therefore, these factors which are called as physical indicators also refer the characteristics of spatial and morphological development of a given coastal urban settlement in this study (see Table I).

B. Explanation of Morphological Indicators

A distinctive feature of this study is that measurement of morphological data was limited with LECZ. In this frame, urbanized area, forest area and park area were measured in 0-10 meter LECZ. The rate of urbanized area located at 0-10 meter LECZ gives us information about growth pattern of urban macro form. The length of built-up area of along the coast is related to vulnerability. Thus, if the urbanized area in LECZ and the length of the built-up area will increase, the population and urbanized area in the coastal zone will be threaten by the sea level rise.

Forest area and park area, measured in 0-10 meter LECZ, were the indicators that determine the resilience of the urbanized area. Urban voids are important for enhancing resilience of the city to disasters caused by climate change [26]. Likewise, if the urban voids in the LECZ are high, the resilience of the coastal city against to sea level rises.

Due to the advantages, coastal zones have the most valuable urban lands in the city. Turkey coastal zones fulfilled by high rise buildings which are located close distances from the sea because of the desire to gain benefit from the high land values. For example, in Istanbul, there are coastal zones which are fulfilled by the buildings which were located a 1 m distance from the sea. Thus, mean distance of built-up area from the sea were taken as another important exposure indicator to calculate CVI morphological. If the buildings are built close to the sea, the vulnerability of the city will increase. Distances of the buildings to the sea were calculated by 3 km intervals and the mean values were included into the CVI morphological (see Table I).

C. Explanation of Social Indicators

Number of people exposed to climate change and annual growth rate of the population 2014-2015 are the exposure indicators of social vulnerability. Income and wealth index is calculated as the resilience indicator for social vulnerability. Number of people who are 65 years old and older, number of people who have any kind of disabilities and number of female people live in urbanized areas in coastal zones are the susceptibility indicators of social vulnerability (see Table I).

IV. Results

The results demonstrate that the urban settlements located on the coasts of the Marmara Sea (Kocaeli, İstanbul, Çanakkale), the Aegean Sea (Izmir) and the Mediterranean (Antalya, Mersin) respectively, are more vulnerable than the cities located on the Black Sea's coasts (Ordu, Zonguldak, Sinop, Rize and Trabzon) to sea level rise (Fig. 2). According to the results, Kocaeli is the most vulnerable urban settlement. Following this value of vulnerability, Istanbul and Izmir cities are more vulnerable than the other coastal settlements. Kocaeli and Istanbul are located on the coasts of the Marmara Sea.

TABLE I
INDICATORS OF PHYSICAL, MORPHOLOGICAL AND SOCIAL CHARACTERISTICS

Indicator	**Abbr.**	**Factor**	**Vulnerability component**	**Unit**	**Definition**	**Relationship with vulnerability**	**Data Source**
Altitude	ALT	exposure	physical	m	mean height above sea level of a given city	Higher altitude, lower vulnerability	[23]
Sea level rise	SLR	exposure	physical	mm/ year	projections of the sea level increase in a year	Higher sea level rise, higher vulnerability	[14], [22]
LECZ	LECZ	exposure	physical	ha	urbanized area located in 0-10 meter low elevation coastal zones	Higher lecz, higher vulnerability	[24]
Forest area	FOR	resilience	physical	ha	forest area located in 0-10 meter low elevation coastal zones	Higher forest area, lower vulnerability	[25]
City area	CA	exposure	morphological	ha	Built-up area	Higher city area, higher vulnerability	[26]
LECZ in city ratio	LECZ/C	exposure	morphological	%	The ratio of built-up LECZ in city area	Higher lecz in city ratio, higher vulnerability	[24]
Parks	PAR	resilience	morphological	ha	parks located in 0-10 meter low elevation coastal zones	Higher parks, lower vulnerability	[25]
Coastline	COAST	exposure	morphological	km.	built-up coast length along the city	Higher coastline, higher vulnerability	[26]
Infrastructure	INFRAS	resilience	morphological	%	access to infrastructure	Higher infrastructure, higher vulnerability	[27]
Distance from the sea	DFS	exposure	morphological	km	mean distance of built-up area from the sea	Higher distance from the sea, lower vulnerability	[26]
Population	POP	exposure	social	people	number of people exposed to climate change	Higher population, higher vulnerability	[28]
Income and wealth index	INCOM	resilience	social	%	income and wealth index	Higher income and wealth index, lower vulnerability	[27]
Population growth rate	POPG	exposure	social	%	annual growth rate, 2014-2015	Higher population growth rate, higher vulnerability	[28]
Age ≥ 65	AGE	susceptibility	social	people	Number of people who are 65 years old and older	Higher age ≥ 65, higher vulnerability	[29]
Disable people	DIS	susceptibility	social	people	Number of people who have any kind of disabilities	Higher disable people, higher vulnerability	[30]
Female population	FM	susceptibility	social	people	Number of female people	Higher female population, higher vulnerability	[29]

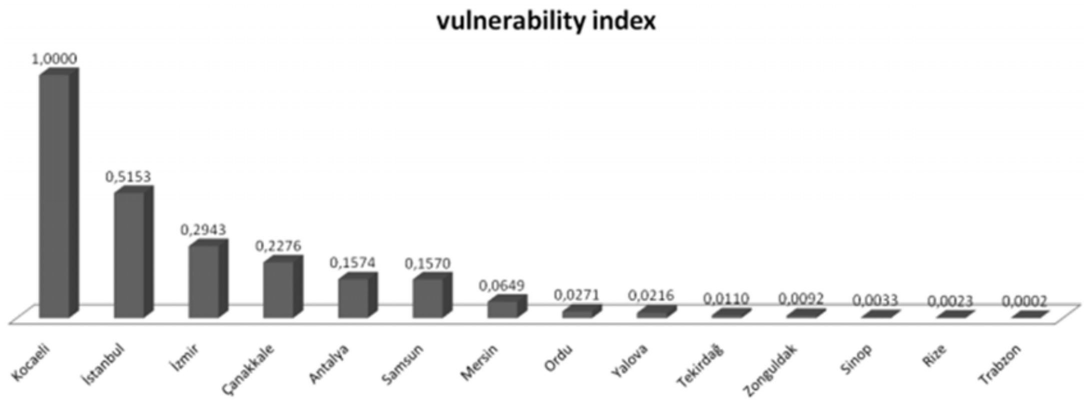

Fig. 2 CVI of cities in Turkey

According to the results, 6 types were determined for the coastal cities in Turkey as; (1-p) physical vulnerable coastal cities, (2-m) morphological vulnerable coastal cities, (3-s) social vulnerable coastal cities, (4-p-m) physical and morphological vulnerable coastal cities, (5-p-s) physical and social vulnerable coastal cities, (6-m-s) morphological and social vulnerable coastal cities (see Table II).

When we compare the vulnerability assessments individually made for each component by using CVI equation, 6 types were determined for coastal cities in Turkey. Priority interventions against to climate change should be organized according to vulnerability types. Especially physical and morphological vulnerable coastal cities could be more resilient to climate change affects as sea level rise by urban land use planning strategies. More research is on call.

TABLE II
VULNERABILITY TYPES

T1	T2	T3	T4	T5	T6
p	**m**	**s**	**p-m**	**p-s**	**m-s**
Ordu	Çanakkale	İstanbul	Kocaeli	İzmir	Antalya
Yalova	Samsun	Mersin		Sinop	
Tekirdağ		Trabzon			
Zonguldak					
Rize					

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