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Caspian Sea level fluctuation and Determination of Setback Line

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ABSTRACT

In the past 25 years, rising of the Caspian Sea level, part of a natural treat to the sea, has inundated and destroyed many buildings and arable lands and threatened many inhabitations in coastal areas. The main reason for these damages is that the law-setback has lost its efficiency and human activities have proceeded seaward. The goal of this study is to introduce a proper setback line for the southern coast of Caspian Sea on the basis of critical water elevation and the results of coastal vulnerability assessment to sea level rise. This setback contains vertical and horizontal buffers. The Coastal vulnerability index (CVI) method is used for coastal vulnerability assessment and is also used in the Geographic Information System. Five variables in two sub-indices were used in this method. The final map obtained from coastal vulnerability assessment divided the coastal zone into low, moderate, high and very high risk categories based on quartile ranges and visual inspection of data. A mean distance of very high risk category of vulnerability map from a second vertical buffer in each rural district was then proposed as a width of horizontal buffer in the same rural district.

Keywords: *Caspian Sea, Coastal area, Geographic Information System, Horizontal buffer, Sea level rise, Setback line, Vertical buffer, Vulnerability assessment.*

INTRODUCTION

The southern coast of the Caspian Sea is currently experiencing two events; the rising of sea levels on one side (which started in the year 1977), and an increase in human activity and development on the other side that is indicated by Mirasadi (1995). Many reports and studies carried out on the southern coast of the Caspian Sea (in Iran) reveal that the low lying coastal zone has been severely and increasingly impacted by the rising of sea levels from 1977. Shamsi (1994) reported that this rising continued until 1995. In this term (1977-1995) the rate of rising was nearly 13 cm per year as reported by Mansuri (1995) and (Klaus & Leroy, 2007). Although today the retrogression phase of the Caspian Sea has started, these fluctuations are important phenomena in the natural threat to the sea. According to the jurisdiction of Iran indicated by the Minister of Energy (2002) the width of law setback is determined as 60 m from the elevation of sea level in 1963, but the Caspian Sea level in this year was -27.8 m (the Caspian Sea level is one of the lowest in the world. From 1961 the average level of the Baltic Sea was introduced as a datum plane for measuring the Caspian Sea levels). This level increased from -28.5 m (in 1977) to -26.0 m (in 1995) (Figure 1). Recently some studies in Iran have led to the introduction of these two scenarios as the critical Caspian Sea elevations on the basis of the past threat to the Caspian Sea in three terms (Caspian Sea National Research Center, 2006, unpublished data). These terms included long term (historical changes), middle term (instrumental observation) and finally short term (that contains of storm surge and seasonal changes). At least two levels were proposed as the critical levels of the Caspian Sea that will probably threat the coastal zone. These levels are -24.7 m and -23.5 m (Caspian Sea National Research Center, 2006, unpublished data).

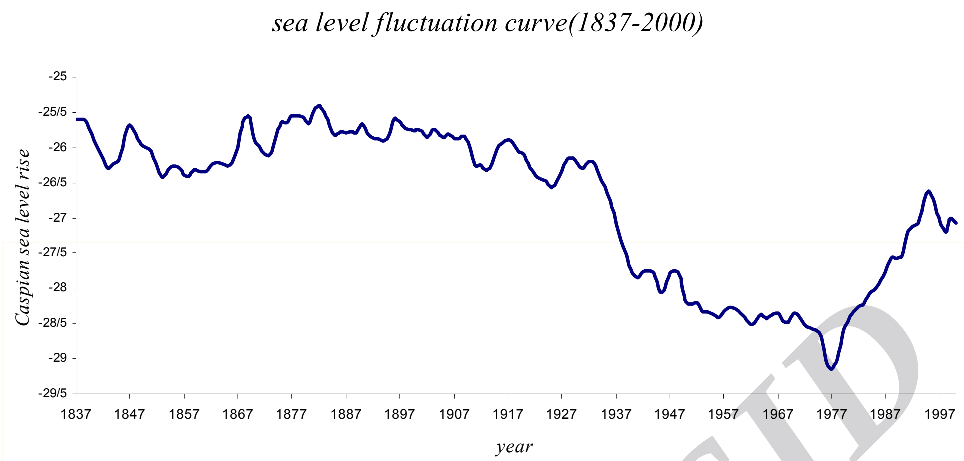

Fig 1. Caspian Sea level fluctuations from 1837 to 2000

The coastal zone usually has three basic adaptation strategies to coastal hazards which are often used (IPCC, 1990, 1992 & Ferreira et al., 2006) which are as follows; Protect, reducing the risk of event; accommodate, increasing the societies ability to cope with effects of event; retreat, reducing the potential effects of events. The most common response to coastal hazards has been to protect by rising sea walls, dikes and other hard protection structures. To accommodate and retreat are however, better options among the approaches (Ferreira et al., 2006).

A possible response to avoid the effects of coastal hazards is to determine the proper setback line in order to manage occupations or activities. It is critical, wherever possible, to leave the entire littoral active zone intact and locate all development landward of this line. Haines (2005) reported that one of the most important elements of zoning and planning for future development in coastal areas is to ensure that development is kept a sufficient distance away to allow it to continue functioning naturally. In total there are three general approaches used to establish buffer width (CBPDS[1] & BI[2], 2007).

i. Fixed-width approach

The benefit of this approach is that it is very simple in establishing, applying and administrating. Sometimes it is established at two, three or four different fixed widths. Fixed width approach may not provide sufficient protection to ecologically sensitive areas or conversely, may deprive landowners of activities in the areas that are more suited to development. Determination of fixed width setback needs a detailed evaluation in all of coastal areas.

ii. Variable-width approach

The width of this setback is varied according to specific conditions of the coastal area for example topography, slope, kind of land use or landform and the sensitivity of a specific part of the coastal area. Although this approach is more accommodating to the local condition, it is more difficult and expensive in establishing, developing and administrating.

iii. Multi-zone approach

This approach establishes the strict setback nearest to the water body (a limited or prohibited developing zone) and a controlled development zone along the far edge of the water body. This approach provides strict protection in some parts of the coastal area that is more likely to be affected from natural hazards of sea level fluctuations and also controls the intensity of uses in the coastal area.

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2- Biohabitats, Inc.

Since the scientific principles in coastal zone management plans are zoning, vulnerability mapping and determination of setback line (Arulraj et al, 2006), it is necessary to first prepare a coastal vulnerability map for sea rise. The goal of this study is to introduce proper setback line for the southern coast of the Caspian Sea on the base of critical fluctuations of sea levels and the results of coastal vulnerability assessment to sea level rise.

MATERIAL AND METHODS

Study area

The coastal zone in the southern coast of The Caspian Sea is similar to a crescent. It has a subtropical climate characterized by warm summers and mild winters (Radionov 1994; Kosarev & Yablonskaya 1994). Its length is nearly 890 km. According to national jurisdiction, the southern coast of the Caspian Sea (in Iran) falls into three provinces (Gilan, Mazandaran and Golestan). The study area is located in Mazandaran Province located at latitude between N 36° 33' 36" and 36° 57' 43" and at longitude between E 50° 35' 42" to 54° 00' 03". This part covers a band of coastal area with the length of 487 km. This part of Mazandaran Province includes 12 townships, 19 districts and 37 rural districts (RD) on the base of national civil jurisdictions (Figure 2). The elevation of the study area is from-30 m (below the mean sea level of the oceans) to 0 m.

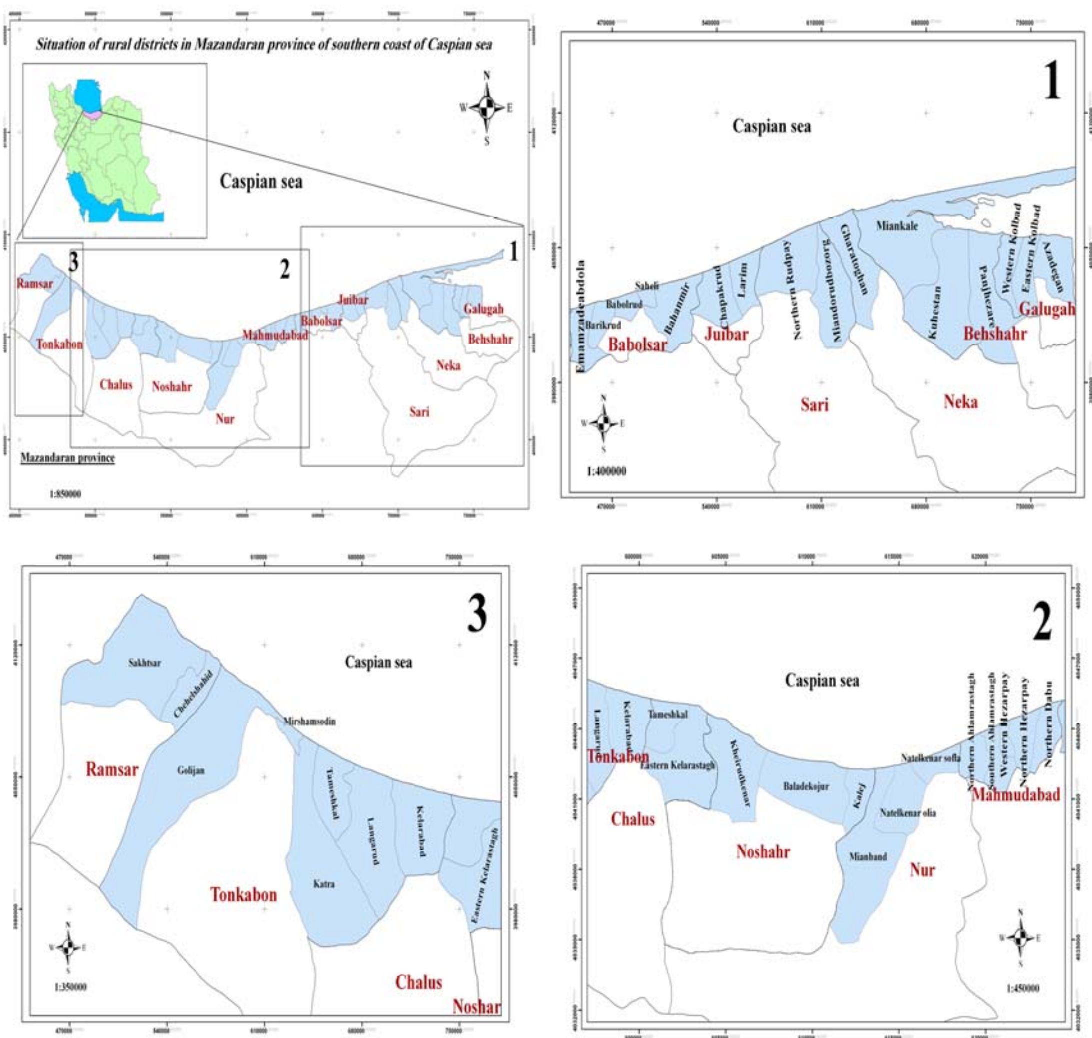

Fig 2. Situation of rural districts in Mazandaran Province in south Caspian Sea region.

Methodology

Determination of a setback line is based on this opinion that setback should be provided landward from the boundary of the water body to allow natural ecosystem functioning and natural interaction between estuarine and terrestrial environments. Therefore, in definition of appropriate setbacks from many intermittently closed and open lakes and lagoons the concept of two buffers that is pointed by Haines (2005) can be employed. First a vertical buffer should be established to allow the natural expansion and future fluctuations of the sea. Second, a horizontal buffer should be established landward from the lateral extents of the vertical buffer to protect the coastal environment from the many potential impacts associated with adjacent urban development. This width will not be fixed, but will vary on the basis of local sensitivity.

i. <u>Vertical buffer</u>

The vertical buffer is defined on the basis of the critical scenarios for the Caspian Sea level. These scenarios were -24.7 m (based on the highest sea level in 1995 that is compared with 100-year period plus the amount of storm surge with 100-year return period and seasonal changes) and -23.5 m (base on the highest sea level in the last 170 years that is related to sea level in 1882 plus amount of storm surge and seasonal changes) since there are two scenarios for the Caspian Sea level, in practice there are two areas as the vertical buffers. The area that is below -24.7 m is suggested as the first vertical buffer and the area that is between -24.7 m and -23.5 m is suggested as the second vertical buffer.

The first step required in definition for vertical buffer is to produce a base map for contouring law-setback line and each sea level rise scenario. Two types of data are used, topographic contours and topographic points. This information is extracted from topographic and bathymetric maps prepared at a scale of 1:25000 with 5m contour interval (about topographic map) and scale of 1:100'000 (about the bathymetric map). DEM (digital elevation model) is then produced by interpolation among topographic information in 10 m resolution. Finally law setback and two proposed vertical buffers are extracted from DEM for subsequent analysis.

ii. <u>Horizontal buffer</u>

Horizontal buffer, beyond the limit of vertical buffer is provided to protect the coastal environment from the many potential impacts associated with development. Because this width varies on the basis of local sensitivity or vulnerability and for the reason that in scientific principles of coastal zone management plans, definition of setback is done after definition of vulnerability mapping (IMO, 2003). The vulnerability assessment may be the first step for determination of horizontal buffer. There are diverse methods of coastal zone vulnerability assessment (Gornitz, 1990; Gornitz et al., 1994; Thieler & Hammer-Klose, 1999) and Szlafstein (2005) reported that most of the scientists agree on this point that it is necessary to integrate several different kinds of information for vulnerability definition and the results have to provide a valid instrument for the proper coastal area management. CVI (coastal vulnerability index) is one of the methods for definition of vulnerability. This method could be defined as a mean to combine a number of separate variables to create a single indicator. Szlafstein (2005) reported that in this method, variables may reflect natural and human-induced characteristic that contribute the coastal vulnerability to natural hazards. In this study, five variables in two dimensions are used. These dimensions are natural coastal vulnerability index (NCVI) and human-induced coastal vulnerability index (HCVI). Topography, slope and landform are the natural dimensions (table 1), distance of road and land use are the human-induced dimensions (table 2).

Each variable is ranked on a scale of 1 to 6, 6 showing the most vulnerability and 1 the least. With respect to vulnerability dimensions, the variables that set in a single dimension composed together on the basis of the following formula:

$$CVI = \sqrt{(a_1 * a_2 * \dots a_n)/n}$$

For example for the NCVI a_1, a_2 and a_3 are topography, slope and landform, respectively and for the HCVI a_1, a_2 are distance of road and land use. Total coastal vulnerability index (TCVI) is defined as the combination of both them. For final analysis TCVI scores are divided into low, moderate, high and very high risk categories based on quartile ranges and visual inspection of data. The primary land use and landform data that is used in this study was acquired from the Port and Maritime Organization and then updated using the digital images from IRS-1C pan sensor related to 2004. Topographic maps (at scale of 1:25000) are used for geo referencing of the digital image on the basis of image to map method.

Table 1. Natural dimension (Natural sub-index)

Variables	Variables Vulnerability Classes					
	1	2	3	4	5	6
Topography (m)	> -23.5	-23.5 to -24.5	-24.5 to -25.5 m	-25.5 to -26.5 m	-26.5 to -27.5 m	< -27.5
Slope°	10.40 - 54.14	5.10 - 10.40	2.55 - 5.10	1.06 - 2.55	0.21 - 1.06	0 - 0.21
Land form	Sea	Mountain	Alluvial plain, Flood plain, River bed, Oxbow	Estuary, Lagoon, Coastal plain	Bar, Spit, Bay	Beach, Barrier island, Mud flat, Sand dune, Delta plain

Table 2. Human-induced dimension (Human-induced sub-index)

variables	Variables Vulnerability Classes					
	1	2	3	4	5	6
Land use	Sea	Sparsely vegetated area, Wetland, Marsh, Water bodies, vegetated or non vegetated salt land	Grassland, Naturalness coastal area	Forest	Agriculture	Urban and industrial infrastructure
Distance of road (m)	Sea	> 500 m landward distance of the main road	500 m landward distance of the main road	300 m landward distance of the main road	100 m landward distance of the main road	Seaward side of the main road

RESULTS

i. Law-setback

According to the shoreline position in 1963 (-27.8 m) and the jurisdiction of Iran about setback, 88.87 % of coastline in Mazandaran Province is inundated by sea level rise. Unfortunately in spite of civil law about prohibition of destruction or ownership, from total lands that are located in law-setback area, 451000 m² of cultivation land and 2466300 m² of residential and industrial infrastructures are inundated by sea level rise. It should be brought to attention that use of the lateral fixed approach for determination of law setback and the difference in slope or topography, created some problems and contrasts in this area. Law-setbacks are located in various elevations from -29.5 m to -23.5 m. Nearly all elevations that are less than -27.5 m are inundated by sea level rise. According to the consideration of the topographic situation of the law-setback area in every rural district (RD), as the smallest civil and managing unit, the mean elevation of lands that are located in the Kheirudkenar RD is between -23.5 m to -24.5 m, in Baladekojur, RD is between -24.5 m to -25.5 m, in Barikrud, Babolrud, Chehelshahid, Northern Dabu, Northern Hezarpay and Kelarabad RDs are -25.5 m to -26.5 m, in Bahanmir, Miankale, Miandorudbozorg, Larim and Northern Ahlamrastagh RDs are -26.5 m to -27.5 m and in Emamzade-abdollah and Gharatoghan RDs are -27.5 m to -28.5 m.

ii. Vertical buffers

Table 3 shows the area of land use that is located in each vertical buffer. According to the results, the most area of land use in the first vertical buffer is related to natural structure (25.12 km²) and orchard (16.06 km²). In the second vertical buffer the most area of land use is related to agriculture and cultivation lands (53.75 km²) and natural structure (50.36 km²). Consideration for the concentration of high human occupancy points in each vertical buffer showed that there are 4 villages and 3 animal husbandries (with 516 inhabitants) located. Shahidrejaii with a population of 450 inhabitants is the most populated. Also there are 17 villages, 20 animal husbandries and 4 hunting areas (with 7719 inhabitants) in the second vertical buffer. Valiabad, with a population of 2191 inhabitants, is the most populated. Considering the situation of the roads it was seen that 3 km of the length of the main road is located in the first vertical buffer. The greatest length is located in the northern Rudpay RD (955 m) and the least length of it is located in the northern Ahlamrastagh RD (15 m). Total length of the main road in the second vertical buffer is 8 km. Most of its length is located in Golijan RD (3 km) and the least length of it is located in Miankale RD (20 m).

Table 3. Area and percentage of land uses in each type of vertical buffer

Land use	Details	Area Km 2 & percentage (In the first vertical buffer)	Area Km 2 & percentage (In the second vertical buffer)
Residential and Industrial Infrastructure	Includes built area, single building, industrial unit, dike, breakwater, earthwork area	5.4 (8.75 percent)	15.00 (8.28 percent)
Cultivation land	Includes aquaculture area, fish cultivation pond, irrigation farming	2.20 (3.57 percent)	53.75 (29.68 percent)
Orchard	Includes orchard and wood, wood rangeland, orchard and forest	16.06 (26.00 percent)	16.98 (9.38 percent)
Natural terrain	Includes sand dune, vegetation and unvegetation salt land	25.12 (40.65 percent)	50.36 (27.81 percent)
Rangeland	Includes dense and semi dense rangeland	3.04 (4.93 percent)	12.75 (7.04 percent)
Forest	Includes dense and semi dense forest, manmade forest	9.95 (16.11 percent)	32.26 (17.81 percent)

iii. Horizontal buffer

The calculated TCVI values for the study area range from 0 to 16.43. The mean TCVI value is 3.3; the standard deviation is 1.23. The 25th, 50th and 75th percentiles are 2.6, 3.16 and 4.47 respectively. TCVI values are divided into low, moderate, high and very high vulnerability categories based on quartile ranges and visual inspection of data. TCVI values below 2.6 are considered in the low category, values from 2.6 to 3.16 are assigned to the moderate category, values from 3.16 to 4.47 are laid in the vulnerability category and values above 4.47 are considered as being in the high vulnerability category. Figure 3 shows the percentage of vulnerability categories. According to the vulnerability assessment from the second vertical buffer, 23 percent of the study area is at very high risk from the effects of rising sea level. With this assumption that the area located in elevations higher than 0 m is not affected by the Caspian Sea level fluctuations, consideration of TCVI values in each RD, with respect to the area of each RD shows that the mean vulnerability in Miankale, Larim, Saheli, Chapakrud and Bahanmir RDs is very high and that in Babolrud, Barikrud and Western Kolbad RDs is high. Figure 4 shows the mapped TCVI values. Also for each RD the specification of very high vulnerability category was determined (Table 4). For comparing the strength of each kind of sub-index in total vulnerability the profiles are presented in Figure 5. Therefore, it is possible to distinguish the relative strength of each sub-index in total vulnerability to sea level rise. Gornitz (1993) and McLaughline et al (2002) had studied this before. According to this study conducted on 19 RDs, HCVI has more strength in total vulnerability to sea level rise. Also the results of calculation of the mean distance from second vertical buffer boundaries to high vulnerability category in TCVI map that is used for determination of horizontal setback in each RD are shown in table 5. Results show that the greatest distance is 2180 m in Larim and the least one is 170 m in Kalej.

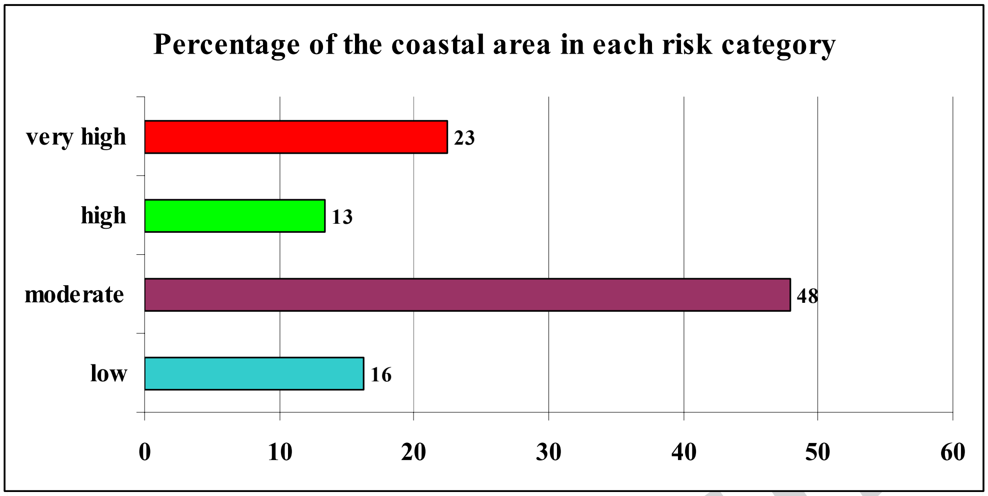

Fig 3. Bar graph showing the percentage of coastal area in each risk category

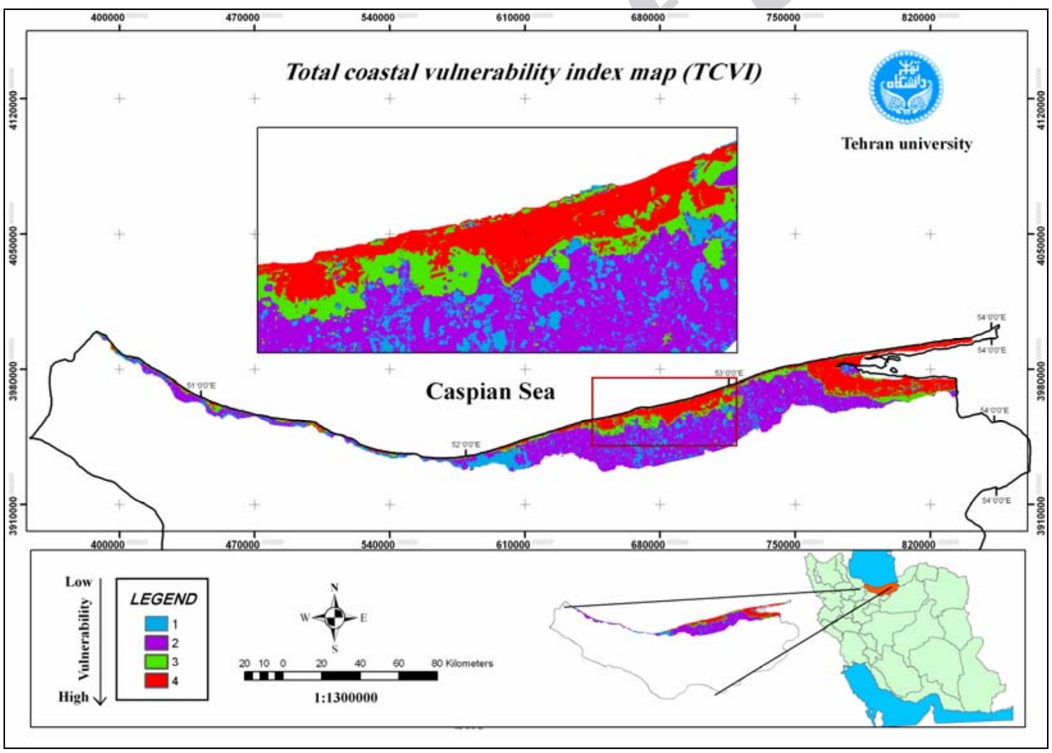

Fig 4. Total Coastal Vulnerability Index (TCVI) map

Table 4. The specification of high vulnerability category in each rural district

Rural district	The specification of high vulnerability category		
	topography	Land form	Land use
Mianband, Kalej	> -23.5 m	Coastal plain	Coastal area
Eastern kelarastagh	> -23.5 m	Coastal plain	Cultivation area
Sakhtsar, Chehelshahid, Golijan, Kelarabad, Katra, Kheirudkenar	> -23.5 m	Coastal plain	Residential and industrial infrastructure
Eastern kolbad	-23.5 to -24.5 m	Mud flat	lagoon, vegetaded and unvegetated salt land
Miandorudebozorg	-23.5 to -24.5 m	Flood plain	Cultivation area
Northern rudpay, Northern hezarpay, Western hezarpay, Northern ahlamrastagh	-23.5 to -24.5 m	Coastal plain	Cultivation area
Gharatoghan, Langarud, Saheli, Mirshamsodin, Babolrud, Western kelarastagh, Northern dabu, Southern ahlamrastagh, Natelkenar olia, Natelkenar sofla, Mianband, Baladekojur	-23.5 to -24.5 m	Coastal plain	Residential and industrial infrastructure
Western kolbad	-24.5 to -25.5 m	Sand dune	lagoon, vegetaded and unvegetated salt land
Azadegan	-24.5 to -25.5 m	Mud flat	Cultivation area
Tameshkal	-24.5 to -25.5 m	Flood plain	Cultivation area
Larim, Bahanmir, Barikrud, Emamzade abdolah	-24.5 to -25.5 m	Coastal plain	Cultivation area
Chapakrud	-24.5 to -25.5 m	Coastal plain	Residential and industrial infrastructure
Kuhestan	-25.5 to -26.5 m	Mud flat	lagoon, vegetaded and unvegetated salt land
Panjhezare	-26.5 to -27.5 m	Mud flat	lagoon, vegetaded and unvegetated salt land

Table 5. The length of horizontal buffer in each rural district

Rural district(RD)	Horizontal buffer (m)	Rural district (RD)	Horizontal buffer (m)
Miankale	1106	Bahanmir	1450
Sakhtsar	494	Langarud	506
Chehelshahid	246	Saheli	1423
Golijan	344	Babolrud	1002
Gharatoghan	607	Kelarabad	539
Miandorudebozorg	389	Barikrud	2132
Northern rudpay	1892	Emamzadeabdollah	1654
Kuhestan	1310	Western kelarastagh	449
Panjhezare	1000	Northern dabu	795
Western kolbad	508	Northern kelarastagh	445
Eastern kolbad	269	Northern hezarpay	690
Azadegan	403	Kheirudkenar	352
Mirshamsodin	599	Western hezarpay	850
Larim	2182	Southern ahlamrastagh	737
Katra	366	Northern ahlamrastagh	444
Chapakrud	1700	Natelkenar sofla	635
Tameshkal	907	Baladekojur	484
Natelkenar olia	391	Mianband	344
Kalej	171		

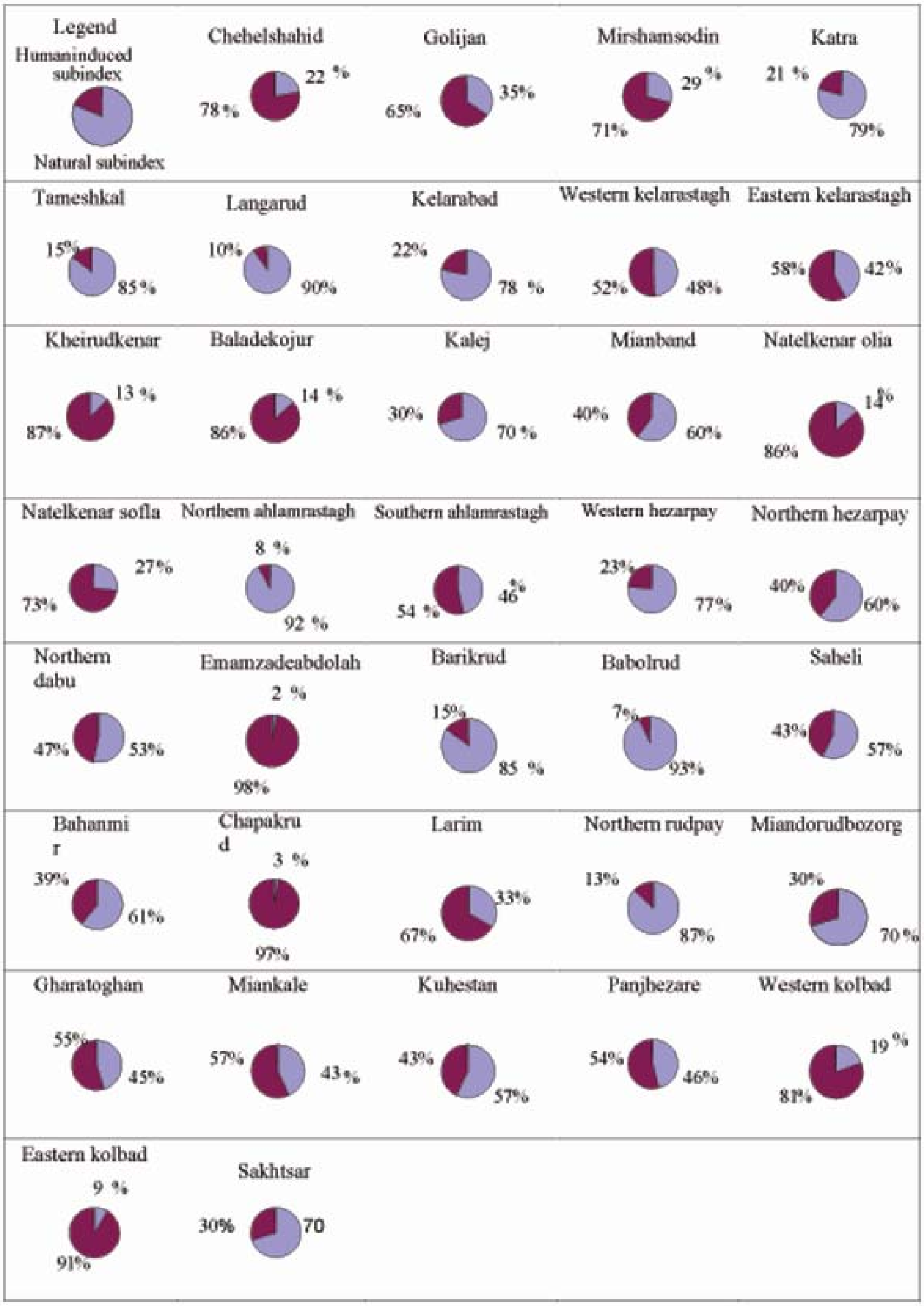

Fig 5. Vulnerability profile that compares the strength of each kind of sub-index in total vulnerability in rural districts of Mazandaran Province

DISCUSSION

There is no doubt that law-setback line has lost its efficiency due to Caspian Sea level rise. Also according to the primary principles of integrated coastal zone management, it is necessary to introduce the potential boundary that is influenced by sea level rise in order to introduce it as a common public right. In coastal zone, land use planning is based on strategic environmental program and for better development, definition of setback line in which the private ownership is forbidden on it is necessary. Unfortunately, there is a concentration of human activity on the southern coast of the Caspian Sea (in Iran) because of its potential and capability for development. This causes a twofold aspect in the execution of ordinances related to prohibition of occupation or construction in this area. So we should try to seek balance between development and conservation. Also a coastal area is contained of many types of land uses, such as cultivation land, human structures, natural terrains and etc. Each type of land use has a sensitive degree to sea level rise. This aspect has not been considered (sensitive degree to sea level rise) in determination of law-setback that is determined just as a lateral width. Furthermore we know that land elevation plays an important role in determination of vulnerability to sea level rise. Proper attention has not been given to land sensitive elevation to sea level fluctuation in the determination of law-setback. Various and different elevations in this lateral width (law-setback) are the reason that makes some locations of law-setback vulnerable to sea level rise. Introduction of two types of buffer and two types of vertical buffers are in direction of seeking this goal. on the basis of a multi zone approach we introduce two types of buffers; vertical and horizontal. In the vertical type we introduced two parts, the area that is below -24.7m (first vertical buffer) and the area that is between -24.7m and -23.5m (second vertical buffer). Results showed that except for 4 villages and 3 animal husbandries there is no urban point in the first vertical buffer, therefore this boundary is suggested as a prohibitive area that could be replaced as the present law-setback. It is suggested that any construction will be cleared from this area. Subdivision, construction, earthwork, vegetation clearance and all activities that are against natural character of the coastal environment will be forbidden in this area. Since most of the land use in this area is earmarked as natural structures, we could use from these natural opportunities for protection of coastal areas.

After the specification of vertical buffers it was revealed that there are no vertical buffers in parts of the coastal area in RDs that are located up to -23.5m e.g. Tameshkal, Golijan, Langarud, Katra, Mirshamsodin and western Hezarpay). Since they are located far from the effect of sea level rise they have the appropriate conditions, but there are other aims in determining the setback like providing or preserving amenity (including landscape values, aesthetic values, future recreational uses and etc) and generally the protection of coastal character that is pointed by Eghtedari (1997). Coastal character means to preserve the harmony with the natural and local environment of the coastal area and avoiding constructions that are against the coastal spirit. Therefore, horizontal buffer especially when there is no vertical buffer provides other purposes for setback. The Coastal Vulnerability Index (CVI) that is used in the definition of horizontal buffers provides insight into the relative potential of coastal change due to sea level rise. Knowing what specifications every part of the very high risk category (that is located in each rural district) has, helps to manage the coastal area properly. For example in 17 RDs (Table 4) most of the area of high risk category includes residential and industrial infrastructure. Therefore, in this case managers know what aspect of the coastal area in each rural district should be paid more attention.

CONCLUSIONS

In this paper after reviewing the problems associated with sea water level rise of the Caspian Sea along the southern Iranian coastlines, the insufficiency of the existing laws regarding the setback areas have been discussed and the need for introducing new setback lines based upon vulnerability and sensitivity issues has been emphasized. The Coastal vulnerability index (CVI) method is used on a GIS-based platform. Five variables in two sub-indices were used in this method. The obtained map has divided the coastal zone into low, moderate, high, and very high risk categories based on quartile ranges and visual inspection. Then a mean distance of very high risk category of vulnerability map from a second vertical buffer in each rural district was proposed as a width of horizontal buffer in the district. The new proposal for the set-back line has the advantage of preserving the sensitive ecological areas. At the same time, opportunities for land development face less limitation.

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نوسانات سطح آب دریای خزر و تعیین حریم

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چکیده

در ۲۵ سال اخیر، بالا آمدن سطح آب دریا که بخشی از رفتار طبیعی آن است، ساختمان ها و زمین های زراعی زیادی را به زیر آب برده و بخش های زیادی از نواحی مسکونی و مناطق ساحلی را دستخوش تخریب و تهدید قرار داده است. به نظر می رسد که دلیل اصلی این خسارات از بین رفتن کارائی حریم قانونی دریای خزر و نیز گسترش و پیشروی رو به دریا فعالیت های انسانی در این نواحی باشد. هدف از این مطالعه معرفی حریم مناسب برای سواحل جنوبی دریای خزر بر پایه ارتفاعات بحرانی آب دریا و نتایج حاصل از ارزیابی آسیب پذیری ساحلی نسبت به بالا آمدن آب دریا است. این حریم شامل دو بخش(محدوده حائل) عمودی و افقی است. برای ارزیابی آسیب پذیری ساحلی از روش شاخص آسیب پذیری ساحلی و نیز سیستم اطلاعات جغرافیائی استفاده شده است. در این روش از ۵ متغیر در قالب دو زیر شاخص استفاده شده است. نقشه نهائی حاصل از ارزیابی آسیب پذیری ساحلی بر پایه طبقه بندی چارکی ارزش های موجود در نقشه نهائی به چهار طبقه با شدت آسیب پذیری کم، متوسط، بالا و بسیار بالا طبقه بندی شده است. در نهایت متوسط فاصله طبقه دارای آسیب پذیری بسیار بالا از محدوده حائل عمودی ثانویه در هر دهستان ساحلی به عنوان پهنای حریم افقی در آن دهستان معرفی شده است.