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Possible Impact of Caspian Sea Level Rise on the Natural Habitat of the Anzali Lagoon in the North of Iran

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Abstract
Flooding due to Caspian Sea level rise (CSLR) resulting from climate change may have serious ecological and socio-economic consequences. According to estimates from the Caspian Environment Programme (CEP), global warming until 2016 may cause a relative CSLR in Iranian coastal area of 20–120 cm. Rising the Caspian Sea level will not only inundate low-lying coastal regions, but it will also contribute to the redistribution of sediment along sandy coasts. In the present paper the possible impact of a CSLR of this magnitude on coastal habitat types is discussed based on topography at the Anzali Lagoon area in the North of Iran. Coastal marshes are susceptible to accelerated CSLR because their vertical accretion rates are limited and they may drown. As the Anzali Lagoon convert to the Caspian Sea, tidal exchange through inlets increases, which leads to sand sequestration on tidal deltas, erosion of adjacent barrier shorelines, and change the ecological conditions. The CSLR is expected to cause a change in groundwater level, a horizontal displacement of vegetation zones and a reduction in area, depending on accretion rate (sedimentation), local topography and inland land-use.

Keywords: Caspian Sea, Anzali Lagoon, Sea-level rise, Inundation, Iran.

بررسی فشارهای احتمالی بالا آمدن آب خزر بر محیط‌های طبیعی تالاب انزلی در شمال ایران

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چکیده
بالا آمدن آب خزر در اثر تغییرات اقلیمی، پیامدهای اکولوژیکی و اجتماعی- اقتصادی زیان آوری را به دنبال خواهد داشت. بر اساس تخمین‌های برنامه محیط‌زیست خزر وابسته به برنامه توسعه سازمان ملل متحد، گرم شدن زمین باعث بالا آمدن آب خزر به میزان ۱۲۰-۲۰ سانتی‌متر در سواحل ایران تا سال ۱۳۹۵ هجری شمسی خواهد شد. بالا آمدن آب خزر نه تنها باعث آبگرفتگی مناطق پست ساحلی خواهد شد، بلکه سطوح مختلف شن و رسوبات بخش‌های وسیعی را در بر خواهد گرفت. در این مقاله، فشارهای احتمالی بالا آمدن آب خزر بر اکوسیستم‌های طبیعی و مکان‌های انسانی بر اساس توپوگرافی تالاب انزلی در شمال ایران مورد بررسی قرار می‌گیرد. تالاب‌های ساحلی خزر به دلیل محدودیت در عمق و ارتفاع، نسبت به بالا آمدن آب حساس می‌باشند. ورود آب خزر باعث باعث افزایش رسوب‌گذاری، فرسایش سواحل کناری و تغییر در شرایط اکولوژیکی تالاب انزلی می‌شود. اثرات بالا آمدن خزر بستگی به توپوگرافی منطقه و مناطق تحت استفاده دارد و منجر به تغییر در سطح آب‌های زیرزمینی، تغییر در ترکیب گونه‌های گیاهی و جایگزینی آن‌ها و کاهش محیط‌های طبیعی تالابی می گردد.

کلیدواژه‌ها: دریای خزر، تالاب انزلی، بالا آمدن آب، آب گرفتگی. ایران.

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Introduction

Increasing atmospheric concentrations of carbon dioxide and other gases are expected to cause a global warming that could raise sea level in the next century (Wigley, 2005; Brooks *et al.*, 2005). Many scientists consider global warming-forced climatic change as the most serious environmental threat facing the world today (IPCCa, 2007). Global warming has the potential to affect many humans dramatically and adversely as a consequence of both natural and anthropogenic changes to temperature, precipitation, sea level, storms, air quality, and other climatic conditions (Alley *et al.*, 2005; Rignot and Kanagaratnam, 2006; Fussel and Klein, 2006).

Sea-level rise (SLR) poses a particular threat because 10% of the world's population (634 million people) lives in low-lying coastal regions within 10 m elevation of sea level (Chen *et al.*, 2006; Miller and Douglas, 2006). Impacts of sea level rise vary from location to location and often lead to many physical changes to the coastal environment. These changes, in turn, affect human uses such as settlement, tourism, fishing, agriculture, as well as wildlife uses of the coast (Berkhout *et al.*, 2001; Francis *et al.*, 2005). The most serious physical impacts of sea level rise on coastal zones are inundation and displacement of wetlands and lowlands; coastal erosion; increased vulnerability to coastal storm damage and flooding; and the salinization of surface water and ground water. The Intergovernmental Panel on Climate Change (IPCC, 2007) predicts that global average sea level may increase by the year 2100, placing the lives and property of 46 million people at risk (Bruun, 1962; Galbraith, 2002; Crooks, 2004; IPCC 2007a,b).

The Caspian coast of Iran is about 740 km long, around the southern side of the Caspian Sea. The land descends from the lower slopes of the Alborz Mountains to the Caspian Sea, now about 26 m below global mean sea level (Meehl *et al.*, 2005; Nerem *et al.*, 2006). The surface of the Caspian Sea has shown long-term oscillations, and fell about 3 m between 1930 and 1977, since when it has risen about 2.5 m (Figure 1).

Coastal sensitivity to the Caspian Sea level rise has become a major issue in the north of Iran, and overview published by the Geological Survey by Caspian Environment Programme (CEP) in 2002-4 demonstrates that there are low, moderate, and high sensitivity regions. Some of the most severely threatened coastal areas in Iran are parts of the Anzali Lagoon district area in the north of Iran (UNOPS, 2003; Lowe, 2004).

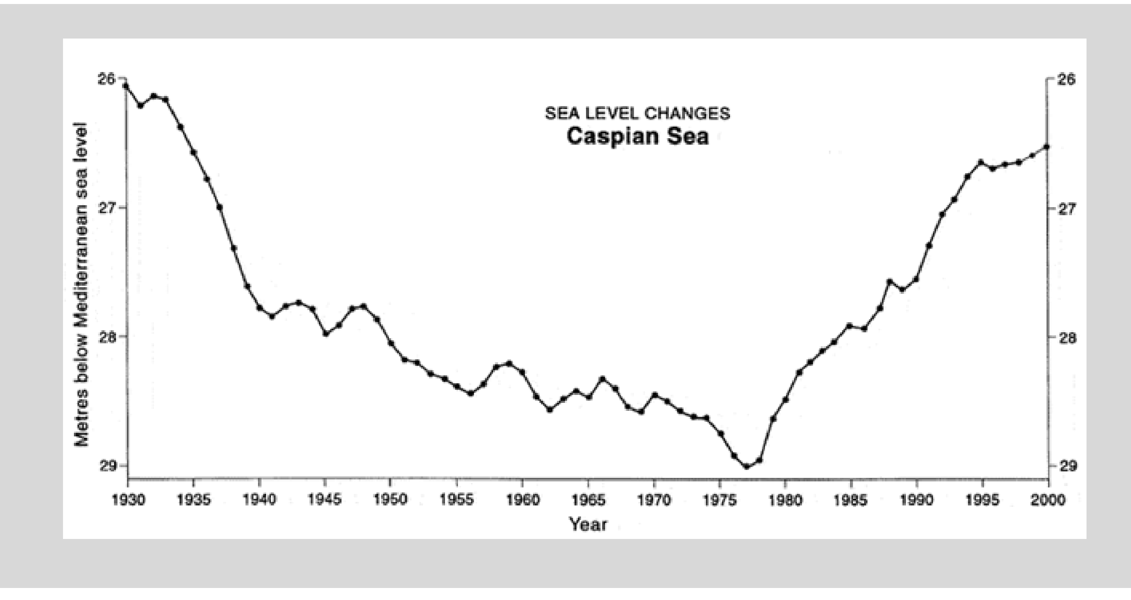

Figure 1. Changes in the level of the Caspian Sea from 1930. Sea level fell intermittently until 1977, and then rose fairly rapidly (The national Research and Study Center of the Caspian Sea, 2007).

Without coastal protection, sea-level rise would cause the landward migration of shorelines (Pethick, 2001; Crooks, 2004), inundating and displacing freshwater wetlands and lowlands, exacerbating coastal storm flooding, increasing estuary salinity, threatening freshwater aquifers and otherwise affecting water quality (Watson *et al.*, 1998; Nystrom *et al.*, 2000). Tidal deltas, low-lying coastal plains, beaches, islands (including barrier islands), coastal wetlands and estuaries would be most affected. From a societal perspective, according to (Klinke and Renn 2002; Klein *et al.*, 2003; Sarewitz *et al.*, 2003) the most important bio-geophysical effects are: (1) increasing flood-frequency probabilities, (2) erosion, (3) inundation, (4) rising water-tables, (5) saltwater intrusion and (6) biological effects.

One of the most important features of the Caspian Sea is its changing water level, a factor that has a significant effect on biodiversity and coastal management in the extensive shallow areas. These water level fluctuations change greatly the usual succession in water plants along beach front property along the coast (UNOPS, 2003).

The Anzali lagoon Adaptive Management Pilot Initiative Project as part of Caspian Environment Programme (CEP) was undertaken over a period of 2 years' (2005-7) activity related to Caspian Sea level fluctuations and their impact on both the natural and human activities.

The main objectives of this project were to:

(a) Provide flood risk maps for six different the CSLR scenarios of the study areas in Anzali Lagoon in the North of Iran between 2005 and 2007.

(b) Determine how much biodiversity of the Anzali Lagoon might be lost by a 1.20 m increase in the CSLR.

Material and Methods

Study Area

The Iranian Caspian frontage is found in Guilan, Mazandaran and Golestan Provinces; the combined coastline of these three provinces is about 630 km (René Jensen, 2003). The Anzali protected wetland is listed under the Ramsar Convention as a wetland of international importance. It is 35 km long and 12 km wide at its widest point, and covers an area of 18000 ha. The entire study area consists of the coastal region of Caspian Sea from the whole region of the Anzali Lagoon coastal, Anzali, Iran (Figure 2). The biodiversity of this wetland is very high and many rare species live in it.

The vegetative community of the Anzali Lagoon is largely classified into four groups: (i) submerged plants, (ii) free-floating plants, (iii) leaved floating and (iv) emergent plants. There are 18 species of submerged plants, 33 species of free-floating and floating leaved plants, and 74 species of emergent plants (Caspian Environment Programme, 2007).

There are 53 fish species in the Anzali Wetland, of which 8 species are non-native and 46 are native species. The Anzali wetland is important for a wide variety (240 species) of breeding, passage and wintering waterfowl. It has been reported that eight species of mammals in 8 families, four species of snakes, as well as 5 species of lizard are distributed thoughout the Anzali Wetland (Caspian Environment Programme, 2007).

Mapping Methodology

The need to predict and manage the potential impact of CSLR on the Anzali Lagoon in the north of Iran requires accurate models. A geographic information system (GIS) was used to map potential CSLR scenarios. This map provides an important tool for qualitatively highlighting coastal vulnerability associated with future changes in the Caspian Sea level. The maps generated in this process have also proven extremely useful in communicating the potential impacts of CSLR and initiating policy discussions with decision-makers.

Data Sources and Analytical Tools

Remote Sensing provided the data for Information Interchange. The data was split into two types; a

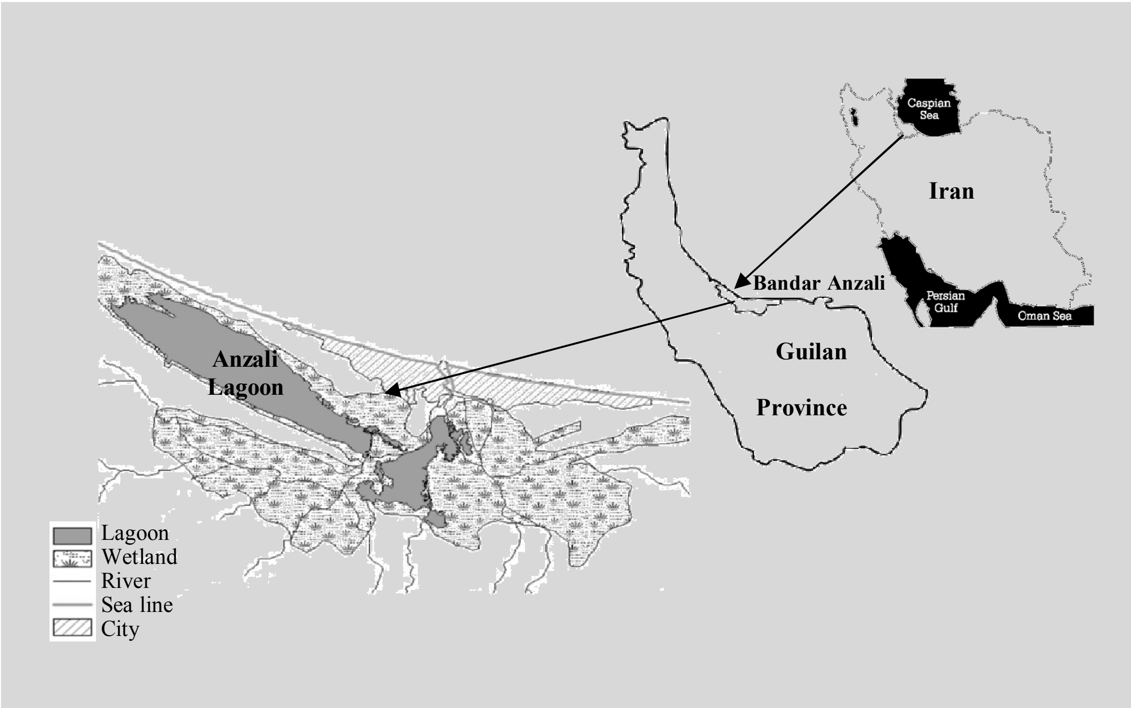

Figure 2. The Anzali Lagoon, Guilan Province, North of Iran.

ground-only hits file and a non-ground-only hits file, with each file containing the following data: GPS, Easting, Northing, orthometric height, and Ellipsoidal height. These information sources with high-resolution data that can be processed to produce an accurate representation of the topography, perfect for predicting areas that are at risk to coastal flooding associated with the CSLR. Data consists of a series of point measurements that consists of geographic location and height of both natural and man-made features, and can be processed to produce several different products and can be integrated into a GIS.

The separation of data allows for the construction of a digital surface model to providing a true ground digital elevation model (DEM).

GPS Validation data

GPS data was collected by members of the GIS section using a Garmin GPS System. Data was collected in the spring of 2006, spring, summer and fall of 2007. The data was processed and exported into an ESRI shape file format. The GPS data contained the following data: easting, northing, orthometric height, geoid separation, GPS time, standard deviations and field work related attributes such as photos numbers, and ground details.

Results

Floodplain Mapping

Currently some 1.4 million people live within Iranian coastal area which is threatened if the Caspian Sea level increases by 1.20 m. Over longer periods, the mean Caspian Sea-level rise is likely to exceed more than 1.20 m if no action is taken.

In an attempt to describe those changes, this study created a floodplain map for the Anzali Lagoon in the North of Iran. The map created in this study was designed to identify areas of potential vulnerability. They should not be used for specific site planning, construction decisions or high precision planning. The map is a valuable aid to local decision-makers and planners in the development of non-catastrophic of the CSLR response options (Figure 3).

The map colors showed the new shoreline under each of the CSLR scenarios. Initially the heavily armored shoreline limits the extent of the floodplain. A 0.20 m increase in the Caspian Sea level creates a commensurate 0.20 m increase in the base flood elevation. As the Caspian Sea levels increase, the floodplain expands, as does the area potentially vulnerable to large storms and major flood events. With a 0.60 m rise in the Caspian Sea level, the new flood zone is equivalent to the 1m inundation scenario. In each case, the infrastructure within the new flood zone is at risk to impacts from large storm events.

The most widely assessed effects of the future CSLR are inundation, erosion, increased flooding, and saltwater intrusion in the Anzali Lagoon area. Results of this study have estimated the inundation of dry land that would occur from a rise in the Caspian Sea level, to elevations where it is possible to estimate potential wetland loss in the areas of Anzali region. Topographic maps and remote sensing estimated that a 0.20 to 120 cm rise in the Caspian Sea level would result in a 50-90 percent loss of the Anzali Lagoon. It has been argued elsewhere that adverse environmental impacts could be diminished significantly if the area inland of the wetlands is abandoned to enable ecosystems to migrate landward (Titus, 1990, 1998; Schneider *et al.*, 2002).

Figure 3 shows that as a result of a CSLR of 0.20 m by 2010 and 1.20 m by 2016, and the inundation between the Anzali Lagoon, villages and cities could be affected. This figure illustrates that there are large areas within a 0.20-1.20 m elevation of present high water, partly reflecting the extensive areas of natural and claimed intertidal habitat around the Anzali Lagoon District. Above a 1-m elevation, the land area is almost linear as a function of elevation, although the threatened area does diminish slowly with elevation. Figure 3 shows that over 32440 km^2 lies within a 1.20 m inundation around the Anzali Lagoon. This illustrates the large areas that are threatened by the high-end the CSLR scenarios.

Economic Impacts of CSLR

The entire coastal area in the north of Iran, such as Anzali Lagoon area lies below 2 m, which without large-scale coastal protection, even an increase in sea-level of 1 m is expected to displace its 48,000 inhabitants. Project experts analysis based on current population values suggests that in the north of Iran at the study sites (Anzali Port Region), a CSLR of 50 cm would displace some 100,000 people, including over half the population of the city of Anzali Port, if no action is taken. Also, a 1m rise in sea-level would affect 2.5 million people in five Caspian countries, based on the population in coastal floodplains.

The results show economic assets to be a function of elevation above the Caspian Sea level in the form of GDP versus elevation, along with area and population. On the other hand, the concentration of economic activity and assets in coastal zones may be expected to increase due to the concentration of both population and economic activity in coastal areas, so these results might be viewed as representing a minimum value of assets at risk.

However, given the long timescales required for CSLR in excess of 1m to occur, and the finite lifetimes of the systems that make up a large proportion of these assets, it might realistically be anticipated that economic activity may gradually migrate away from areas at risk from a CSLR in excess of 0.20 to 1.20 m without severe economic losses on these longer timescales. The window of most concern should be that over which existing and projected near-term assets are directly threatened by lower CSLR values.

The economic impacts of CSLR will be much wider and more complex than the costs of relocating property, people, industry, agriculture and transport infrastructure from areas threatened by inundation. Relocation costs may be offset by coastal protection, although the costs of coastal protection are high (Yohe and Schlesinger, 1998; Darwin and Tol, 2001). To the costs of adaptation through coastal protection, relocation or resilience building must be added the costs of residual, un-avoided damages, including:

*Loss of productive land especially paddy fields that it is not deemed economically viable to protect

*Costs of relief and reconstruction after coastal storm and flood events

*Loss of livelihoods resulting from CSLR

*Impacts on trade and markets

Economic Costs of Increased Flood Risk

The economic assets at risk of coastal flooding in the North of Iran, Anzali Port region were assessed using a pre-existing flood risk analysis model by Hall *et al.*, (2003). The analysis combined relative CSLR scenarios of 0.20 m to 1.20 m in the North of Iran (Anzali Lagoon District) with the four socio-economic scenarios (Table 1).

Impacts of CSLR on Ecosystems

CSLR will have significant impacts on a number of wetland and terrestrial ecosystems, many of which are already threatened by human activities. Coastal wetlands are particularly at risk where coastal flood barriers and human settlement prevent their migration inland (Jackson *et al.*, 2001). The sensitivity of the coastal system and wetlands to flooding under the different CSLR, will cause the loss of wetland biodiversity in all scenarios (0.20-1.20 m).

Table . Impacts of the Caspian Sea level rise on the inundated areas, population, and assets of the Anzali Lagoon Project Area (km^2) population thousand persons assets billion US$.

Present			0.4 Sea Level Rise			0.8 Sea Level Rise			1.2 Sea Level Rise		
area	population	assets	area	population	assets	area	population	assets	area	population	assets
14345	7	1.43	25261	13	2.53	29478	17	2.8	32440	20	3.2

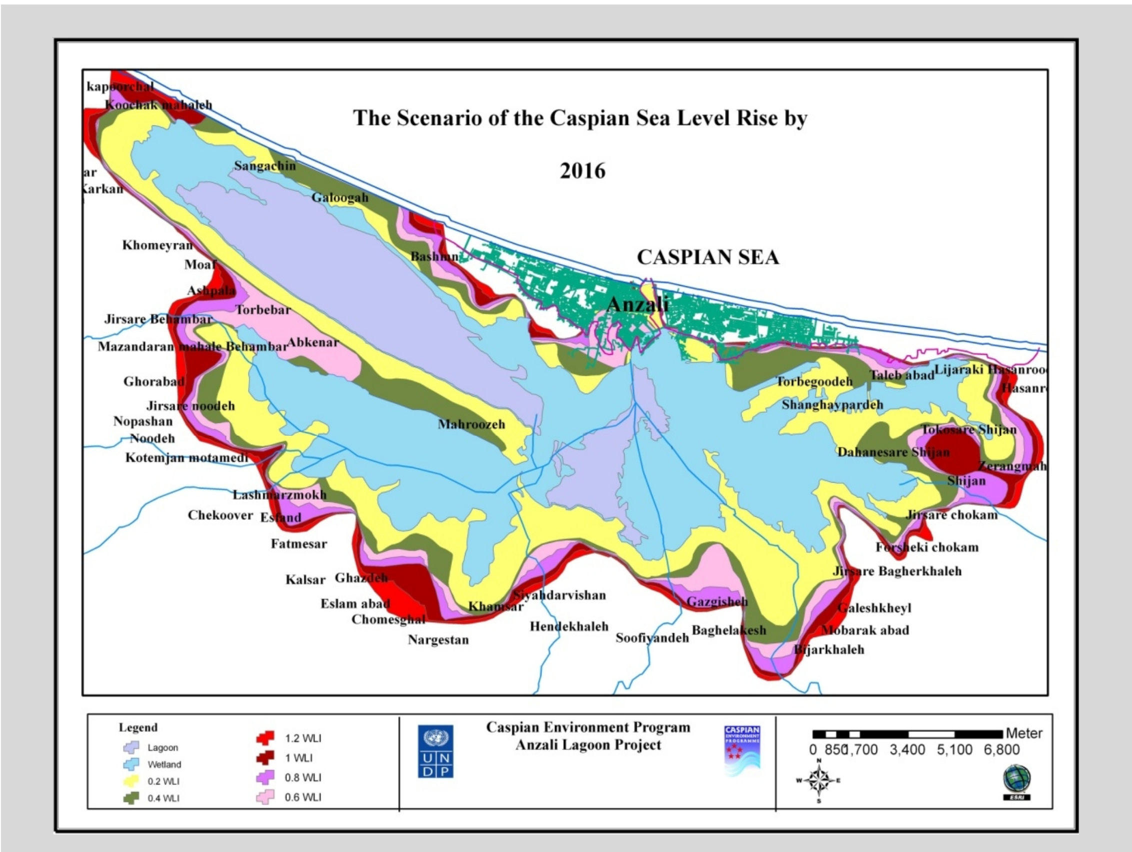

Figure 3. Predicted the Anzali Lagoon inundation scenarios (0.20 – 1.20 m) due to the Caspian Sea level rise by use of the Coastal Flooding Model.

Discussion

The greatest effect of CSLR will be the increased risk of inundation around the estuary, the lower rivers, and the Anzali Lagoon. For example, the estimated rise in Caspian Sea levels by 2016 would result in changes in water levels and the protection ability provided and ecological functions of the Anzali Lagoon. The existing protection provided by minimum ground and floor levels will also be progressively reduced.

An alternative way of assessing the effects of the CSLR is to compare the areas at risk for inundation in similar sized events, with and without CSLR. The indicative inundation areas for a 1% (10 year return period) tidal event associated with 1.20 m CSLR estimated that an additional 32440 km^2 mostly natural resource and paddy fields of land within the Anzali Port City could be potentially at risk by an event of this magnitude by 2016. In monetary terms, the costs of the additional assets at risk are significant, being estimated at approximately $3.2 billion. This represents approximately a 223% increase from the current value of assets at risk in this size event. While private assets make up 60% of the value of the addition assets at risk, the 1.92 billion total includes.

The CSLR predictions are a complex and multi-faceted issue. Response to this issue requires actions on a variety of fronts and at many levels of government. Only in combination will these semi-independent steps be enough to change the trajectory of climate change, allow societies to adapt to the unavoidable changes, and decrease climate change impacts (Walker *et al.*, 2004 and 2006; Tompkins and Adger, 2004; Cooper and Pilkey, 2004).

The research questions in this study focus on analyzing the regulatory and institutional structure surrounding coastal zone management and the CSLR issue. However, a detailed analysis of this framework and the viability of potential the CSLR response opportunities must be based on an understanding of CSLR science. It is apparent that the issue of the CSLR is complicated by the difficulties in understanding and modeling ice-sheet dynamics. It is not currently possible to make exact the Caspian Sea level rise predictions due to both the scientific uncertainty and the long-term sea level rise dependence on human responses to climate change. This embedded uncertainty means that decision makers are unable to wait for perfect information before taking action. Thus, it is important to develop a theoretical framework and tools that will allow decision-makers to take action in this uncertain environment.

Caspian Sea levels will continue to rise for many centuries and forward thinking decision-makers will have the ability to design proactive response strategies that will allow for adaptation to those changes. The concepts of resilience provide a framework for analyzing not only potential sea level rise impacts but also policy response options. The effort to determine effective policy response options is aided by the use of current mapping technology. High resolution data sources provide a powerful and useful tool with which to respond to the CSLR. Computing resources allow for the efficient generation of a variety of relative CSLR scenarios based on the local realities of vertical land movement and topography. The choice of scenarios can build community understanding and highlight areas of vulnerability. The availability of high resolution data allows for the creation of non-catastrophic scenarios that can be used to inform local decisions and initiate consideration of legal and regulatory opportunities for response.

Although erosion is more difficult to predict than inundation, applications of the Bruun (1962) rule and other simplified procedures suggest that a 30 cm rise in sea level would erode the shore by 1500-3000 cm. Flooding would increase both because storm surges would have higher bases to build upon (Klarin *et al.*, 1990; Klarin and Hershman, 1990) and because rainwater would drain more slowly (Watson *et al.*, 1998). Finally, the salinity of estuaries and aquifers would increase, threatening water supplies and aquatic life (Howat *et al.*, 2007; Hudgens, 1999).

Vast changes are expected in the Anzali Lagoon freshwater resources including in freshwater habitats, fish production, and water supply. Reactive approaches to environmental problems will lead to a more severe decline than proactive approaches. Fish populations are projected to be lost from some river basins due to the combined effects of climate change and water salinity (Gornitz and Lebedeff, 1987; Cooper and Pilkey, 2004). Other significant drivers of freshwater biodiversity loss include eutrophication, acidification, and increased invasions by alien species (Johnson *et al.*, 1992). According to the scenarios, the demand for fish and the risk of a major long-lasting collapse of fisheries will increase because of the human population, incomes, and preferences for fish are increasing.

An acceleration in the rate of sea-level rise, severely impact wetlands and tidal flats behind barrier island chains, in estuaries, and on lower delta plains (Fiorino, 1995; Church and *et al.*, 2004).

The Subbotina *et al.*, (2001) and Burkett *et al.*, (2005) relationship states that in the coastal zone, a one meter height of the free water table above is associated with a depth of freshwater below sea level of 40 m, indicating that a 50cm SLR will result in approximately a 20m reduction in the thickness of the freshwater layer. However, this relationship assumes a sharp, well-defined interface between sea and fresh water and must be treated as approximate. Relationships between sea-level and groundwater are modified by pumping and recharge activities, and the impacts of SLR on freshwater resources via geography, topography, and the geological and geomorphological characteristics of coastlines (Yohe and Neumann, 1997; Folke, 2006).

Any impacts on the availability of freshwater in coastal areas will interact with other factors, for example changes in runoff and recharge rates resulting from land management and climate change, as well as changes in demand resulting from population growth, urbanisation, industrialisation, the expansion of agriculture and increased affluence. Most of these factors are likely to increase water stress, compounding even modest decreases in freshwater availability (City of Olympia Public Works Department Policy and Program, 1993; Douglas, 1997; Tol, 2005). Water stress resulting from a combination of all of these factors is likely to be greatest in the rapidly growing coastal megacities of the developing world.

Results showed that the Electrical Conductivity (E.C.) of paddy fields around the Anzali Lagoon after the 1.20 m CSLR will change to damage level for agricultural crops (>4 mmhos/cm). Schallenberg *et al.*, (2003) find that even minor saline intrusions into wetlands can cause severe perturbations among plankton communities, water plants and fish diversity. Even in the absence of complete inundation, CSLR may therefore compromise existing coastal wetlands ecosystems via increases in the frequency and severity of saline intrusions.

Though not an initial goal, this study has found that concepts of resilience provide a valuable framework for addressing the CSLR. Resilience acknowledges the complex and potentially non-linear nature of the combined social-ecological system as well as the possibility of threshold responses and multiple equilibrium.

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