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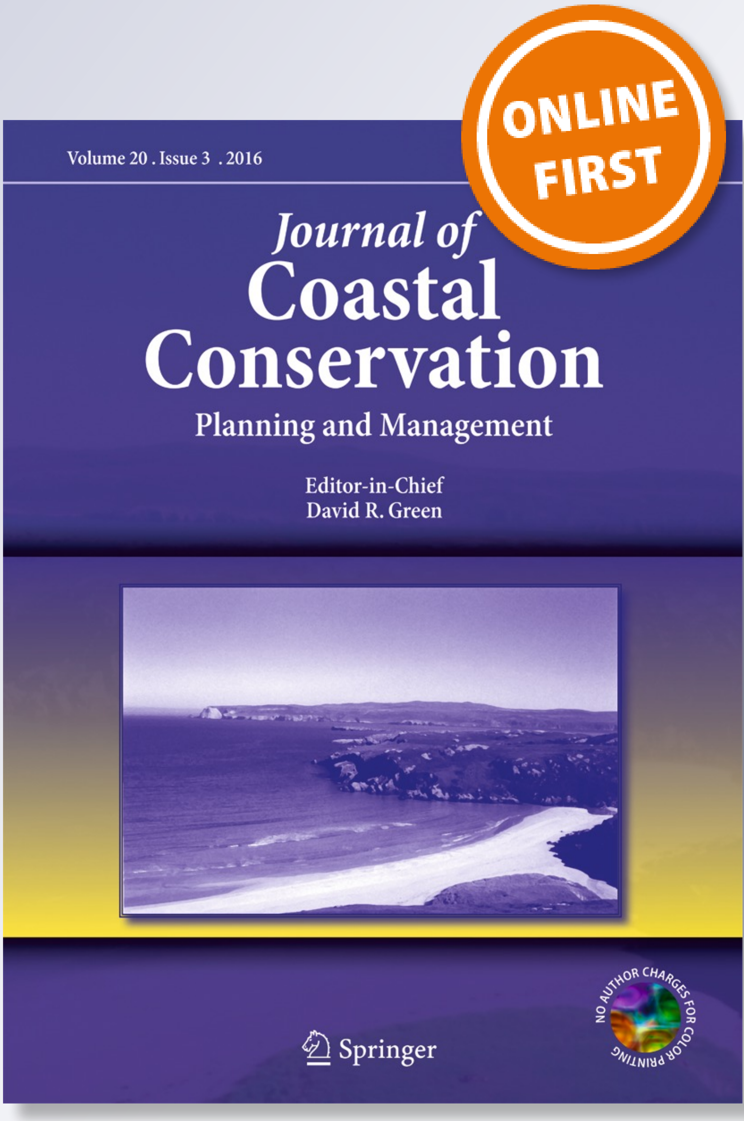

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Hazard, vulnerability and coastal erosion risk assessment in Necochea Municipality, Buenos Aires Province, Argentina

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Abstract This contribution determines the coastal erosion risk of Necochea and Quequén cities, Necochea Municipality, Buenos Aires Province (Argentina). Both risk components, hazard and vulnerability, were assessed by the construction of indices. The hazard index is composed of four indicators: the erosion or accretion rate, coastal geomorphology, storm waves effects, and sediment supply. The vulnerability index is comprised of land use/cover, demographic, life conditions, and work and consumption indicators, and includes population census data such as demographic, education, health, sanitary, economic, production, work and population exposure aspects. The analysis concluded that coastal erosion risk ranges from very low to high along the study area, Quequén yielding the highest values. Risk levels vary in both cities based on the uneven spatial distribution of hazard. The risk assessment developed herein constitutes a practical and adequate tool that can be utilized with other elements and tasks in the elaboration of a coastal management program.

Keywords Hazard · Vulnerability · Risk · Coastal erosion · Necochea · Quequén

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Introduction

The increasing complexity of the social-ecological systems due to the continuous expansion of cities and human activities, together with the accumulation of deleterious effects on the environment, has intensified natural disasters in certain areas and their consequences on the population. Coastal areas are especially vulnerable to changes in storm regimes related to global climate change, that increase hazard levels (Wu et al. 2002; Dolan and Walker 2006; Frazier et al. 2010). In this sense, the implementation of urban planning policies and coastal management programs has become increasingly critical. Nevertheless, risk assessment in coastal areas considered challenging in view of the physical, environmental, social and administrative complexity they entail (Lins de Barros and Muehe 2013).

Over recent decades, studies on environmental issues and natural disasters have incorporated the concept of risk. This approach has been improved with methodological and conceptual contributions from applied and social sciences, incorporating the analysis of the physical and human environments and their interactions (Montz and Tobin 2011). Risk assessment of natural disasters is a valuable tool for coastal management, being useful in the identification of areas susceptible to a particular environmental problem. The concept of risk constitutes a fundamental approach in the study of natural disasters and social interactions (Perry and Montiel 1996), since

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without human presence there would be no risk, just a natural phenomenon (Cardona 1993; Masgrau 2004). In this regard, risk assessment provides the appropriate understanding to develop prevention and mitigation programs (Cutter et al. 2000).

The Natural Disasters and Vulnerability Analysis report (UNDRO 1979) unified terms and definitions in a conceptual framework of risk. Total risk (Rt) is the number of lives lost, persons injured, damage to property and effects on economic activity due to a natural phenomenon event. Specific risk (Rs) is the expected degree of loss due to a natural phenomenon event and is a function of both natural hazard and vulnerability. Natural hazard (H) is the probability of occurrence of a potentially damaging natural phenomenon within a specific period of time in a given area. Vulnerability (V) is the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon; and Elements at risk (E) are the population, buildings and civil engineering works, economic activities, public services, utilities and infrastructure, etc. at risk in a given area. The following equation expresses risk assessment:

$$Rt = E.Rs = E.H.V$$

Cardona (1993) proposed to include the elements at risk in the concept of vulnerability, given that an element is vulnerable only if it is exposed; and therefore, risk is composed of two components: hazard and vulnerability. In recent years, vulnerability as part of risk has assumed great relevance, especially in environmental and sustainability sciences (Cutter et al. 2003). Moreover, it is considered a key factor when it comes to an effective risk management (Cutter 1996; Masgrau 2004; Hegde and Reju 2007; Yan and Xu 2010). Vulnerability has been defined, in different ways, by several authors. In this work it is considered as the conditions or characteristics of a person or community, based on their capacity to anticipate, survive, resist, absorb, and recover from the impact of a natural event (Blaikie et al. 1996).

Risk assessment requires the analysis of both of its components: the physical variables and particularities of the hazard, and the society and infrastructure characteristics exposed to the hazard (Bennett and Doyle 1997; Boruff et al. 2005; Birkmann 2007; Del Río and Gracia 2009). By combining both elements, the risk of a given area to a particular hazard is determined. Risk setting is obtained by mapping the spatial distribution of risk (Cardona 1993). One of the main advantages of risk maps is that they offer the possibility of identifying different areas under different degrees of risk, providing tools to discuss the root causes of the risk and formulate policies according to the needs of each area (Birkmann 2007).

The most commonly adopted methodology to evaluate risk consists in the development of quantitative hazard and vulnerability indices comprising selected indicators (Cutter et al. 2000; Wu et al. 2002; Boruff et al. 2005; Birkmann 2007; Hegde and Reju 2007; Szlafsztein and Sterr 2007; Del Río and Gracia 2009; Yan and Xu 2010; Furlan et al. 2011; Martins et al. 2012). The analysis and evaluation of coastal risks is very complex due to the large number of physical and socioeconomic variables that interact in the coastal environment (Del Río and Gracia 2009). A wide range of indicators have been proposed for the development of coastal hazard indices such us erosion rates, the presence and degree of dune occupation, coastal and beach slope, wave concentration, wave height, tide range, geomorphology, lithology, sediment supply, sea level oscillations, storm impacts, among others (Gornitz 1991; Wu et al. 2002; Boruff et al. 2005; Garcia et al. 2005; Hegde and Reju 2007; Del Río and Gracia 2009; Mahendra et al. 2011; Mujabar and Chandrasekar 2013; Aydın and Uysal 2014; Kunte et al. 2014), though they should be carefully selected. Regarding vulnerability indices, indicators are based on population and economic census data (Cutter et al. 2000; Wu et al. 2002; Boruff et al. 2005; Hegde and Reju 2007; Del Río and Gracia 2009; Lixin et al. 2014). Nevertheless, the difficulties arising from data acquisition somehow discourage the use of a large number of socioeconomic indicators.

The coast of Buenos Aires province is affected by different environmental hazards such as saltwater contamination of the phreatic aquifer, floods, relative sea level rise, storm surges and coastal erosion (Pousa et al. 2007). Anthropogenic activities such as construction of coastal defenses (breakwaters, jetties, etc.), urban growth and the consequent dune fixation, sand mining and exploitation of aquifers without an adequate management program, have worsen the natural hazards and increased the coastal risks. Coastal erosion constitute a significant environmental problem in several urban centers (Fiore et al. 2009; Merlotto and Bértola 2009; Pousa et al. 2013; Merlotto et al. 2014). Nevertheless, the study of these coastal problems from a risk perspective is scarce in Argentina. The existing studies constitute either first approximations or give relevance to hazard (Kokot and Otero 1999; Monti 1999; López and Marcomini 2004; Merlotto et al. 2008). Many studies that have assessed the vulnerability of a specific coastal sector to a particular phenomenon would constitute studies of the hazard component of the risk (PNUD and SECYT 1998; Kokot et al. 2004; Diez et al. 2007). On the other hand, some studies have determined social vulnerability in different urban centers (Natenzon et al. 2005; Natenzon 2007).

The study area corresponds to the coastal area of Necochea and Quequén cities, located in the south of Buenos Aires province, Argentina (Fig. 1). In Quequén, Kokot and Otero (1999) made a preliminary estimate of the geological risks. Among other phenomena they identified: coastal erosion, sea level rise, and storm wave floods. Other papers evaluated physic vulnerability of the coast of Necochea to a natural phenomenon. Diez et al. (2007) estimated the vulnerability to sea level rise on the coast of the Buenos Aires

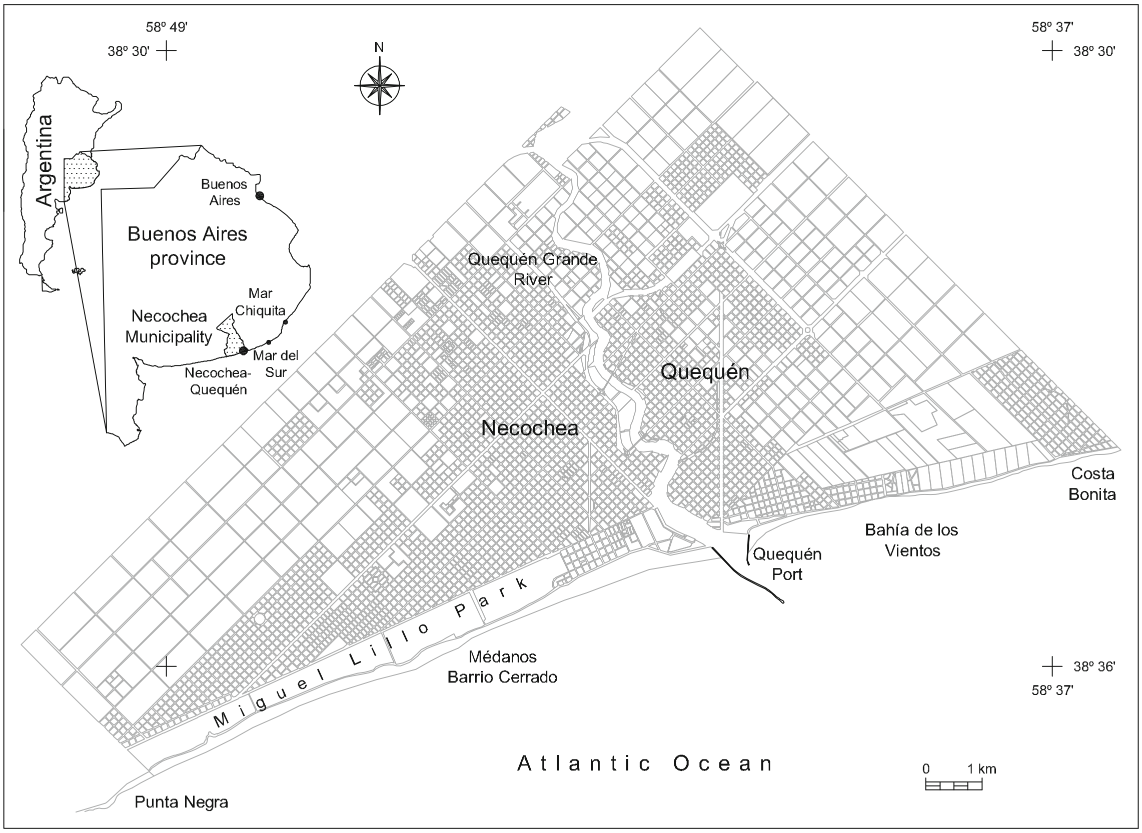

Fig. 1 Location of the study area

province assigning a moderate vulnerability to Necochea. While Marcomini et al. (2007) established from geomorphological indicators the susceptibility to coastal erosion of Necochea. The present work determinates the coastal erosion risk of the urban area of Necochea Municipality by assessing hazard and vulnerability. Therefore it constitutes one of the first studies focusing on a coastal environmental problem from the risk perspective in Argentine. The study contributes to a better understanding of the coastal environment and considers a holistic perspective, including natural and human issues and urban planning.

Study area

The study area covers the coastal area of Necochea and Quequén cities (Fig. 1). Both urban centers are separated by the Quequén River and the Quequén Port. The area lies on vast dune fields (Southern Dune Barrier) fixed by natural or induced vegetation mainly presented in Miguel Lillo Park. The dunes have also been urbanized to different degrees. They developed on quaternary sediments which constitute brownish silt cliffs of different heights. There are also inactive cliffs partially or totally covered by dunes and sand ramps, and less frequently active cliffs. The predominant littoral drift direction is SW-NE (Perillo et al. 2005) along the coastline.

The tide is mixed, mainly semidiurnal, with a mean tidal amplitude of 0.98 m (SHN 2009). Wave height presents a seasonal behavior, the highest in winter (1.26 m) and the lowest in summer (0.96 m), with a mean significant wave height of 1.18 m. Wave direction is ESE to SW with a predominance of waves from the SSE in all seasons (Merlotto et al. 2013). Mean wind speed is 17.8 km/h and the winds blow predominantly from the N and NW (Merlotto et al. 2013). Highest speeds correspond to winds from the SW and S, in concordance with the prevailing largest storm surges and wave storms direction. These storms are considered a main natural cause of morphodynamic changes in the beaches of the study area (Merlotto et al. 2013).

According to the predominant morphodynamic state the Quequén beaches are intermediate and the Necochea beaches are dissipative (Merlotto et al. 2013). The Necochea beaches are composed of well-sorted fine sands, whereas the Quequén beaches are composed of poorly- or moderately-sorted medium to coarse sands. Different behaviors of the beaches at both sides of the harbour were observed. The study of the coastal evolution showed that the coastline at Quequén has retreated, and also in the short term, the negative sedimentary balances indicate an accentuated erosion process. On the other hand, at Necochea the coastline has remained stable or advanced; while in the short-term the sedimentary balances showed an incipient erosion process (Merlotto et al. 2014).

The total urban area, comprised by the two localities, constitutes a medium-sized city of 80,845 inhabitants (INDEC 2005). The main economic activity is grain agriculture and the exportation of this commodity and its by-products, which are manufactured in the port's facilities. Due to the national economic crisis that the country suffered in the past decades; the service sector has become the main source of employment. Based on the weather and landscape characteristics of the region, coastal tourism constitutes a significant economic activity, although the agricultural sector remains the main source of income.

In sum, the urbanization of the coastal area of Necochea and the economic activities interact with the natural processes resulting in environmental issues, one of them being coastal erosion. Ever since the construction of the port breakwaters at the beginnings of twentieth century, the sand supply has been affected due to the partial retention of the sediments transported by the littoral drift. This process has had negative consequences on the port operation given the sandbanks that formed at the port mouth, and even caused coastal erosion in Quequén beaches (Isla et al. 2009). To develop a comprehensive coastal management program, it is necessary to establish areas of different degrees of hazard, vulnerability and risk.

Methodology

The coastal erosion risk assessment is based on the aforementioned definition of risk, considered as the combination of two components: the hazard and the vulnerability. For each component specific indices were developed, selecting indicators considered to be determinant to study the physical variables and particularities of the hazard, and the society and infrastructure characteristics exposed to the hazard. The categories of each indicator were established specifically according to the characteristics of the study area. Finally, the results were represented as a risk map.

The hazard index is composed by four indicators. The selected indicators are erosion or accretion rate, coastal geomorphology, storm waves effects and sediment supply (Table 1). Their study was accomplished based on field surveys and previously published data. The vulnerability index (Table 2) comprises demographic, education, health, sanitary, economic, production, labour and population exposure aspects. These aspects were grouped in ten variables selected to build the four indicators that compound the index: demographic indicator, life conditions indicator, work and consumption indicator, and land/use cover indicator. All these variables determine the capability of the elements exposed to the hazard to absorb losses and recover (Blaikie et al. 1996; Wu et al. 2002). For instance, extreme ages (0–14 and >65 years) require more time and money to move and could need special care, wealth enables communities to recover more quickly, education levels are linked to socioeconomic status, and lower education diminishes the possibilities of understanding warning information (Blaikie et al. 1996; Wu et al. 2002; Cutter et al. 2003; Lixin et al. 2014). In sum, higher vulnerability entails slower recovery from an event.

For both indices, each indicator was divided into five categories. The categories were established on a numerical basis when possible, but a qualitative description was adopted for those that could not be quantified (Tables 1 and 2). The categories were ranged in a scale from 1 to 5. Then, the variables were combined and the value of each index was derived from:

$$\text{Index} = (i_1 + i_2 + i_3 + i_4)/4$$

where i corresponds to the indicator. Equal-size intervals were produced to obtain the value of the indices that were scaled from 1 to 5 and from very low to very high hazard or vulnerability: 1: very low hazard or vulnerability, 2: low hazard or vulnerability, 3: moderate hazard or vulnerability, 4: high hazard or vulnerability, and 5: very high hazard or vulnerability.

No weights were attributed to the indicators of both indices. All indicators were treated equally as suggested by Cutter et al. (2000) and Boruff et al. (2005), considering that they all have the same relative importance in the indices and in their contribution to risk. The spatial distribution of coastal erosion risk was calculated by overlapping the hazard and vulnerability indices. The quantitative value was derived from:

$$\text{Risk} = \text{hazard index x vulnerability index}$$

The score was reclassified into five categories ranged from very low to very high risk. Finally, the results were mapped.

Hazard index

In the construction of the coastal erosion hazard index, the selected indicators acquire a different value along the study area. The commonly used indicators such us tide range and wave height were not selected because they are measured only at Quequén Port. Therefore those indicators present the same value for the whole study area and do not allow identifying distinguished sectors with different characteristics. The indicators (Table 1) used are defined below:

- Erosion or accretion rate (m/year): it represents the advance or retreat of the coastline and indicates the evolution of the erosion process. The erosion and accretion rates of the study area were obtained from Merlotto et al. (2014). Based on aerial photographs from 1967 to 1984, and satellite images from 2004, and using the dune or cliff toe as coastline indicator and the end point rate method, they estimated the erosion or accretion rates between 1967 and 1984, and 1984 and 2004. Therefore according to

Table 1 Indicators and categories of the hazard index

Indicator	Hazard				
	Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
Erosion or accretion rate (m/year)	< 0	0	−0.01 to −0.40	-0.41 to −0.80	> −0.81
Coastal geomorphology	Foredune	Cliff partial o totally covered by dunes	Cliff with aeolian ramp	Active cliff and sandy beach	Active cliff without sandy beach
Storm waves effects	Minor changes	Minor changes in foreshore	Poor lost of volumes and minor changes in foreshore	Lost of volumes and moderate morphologic changes	Lost of volumes, intense morphologic changes and coastline retreat
Sediment supply	Increase	Without changes	Minor decrease of aeolian and litoral drift supply	Moderate decrease of aeolian and litoral drift supply	Intense decrease of aeolian and litoral drift supply

these results, if the coastline advanced or remained stable, it will correspond to a very low or low category, whereas if the coastline retreated, the erosion rates will be moderate, high or very high category (Table 1).

- Coastal geomorphology: as a complex result of the interaction of several factors, the costal geomorphology indicates the landscape evolution and expresses the relative erodibility of the different landform types (Kokot et al. 2004; Hegde and Reju 2007). To construct the indicator the vulnerability to erosion of the landforms was especially considered. Reflecting the range of landforms within the study area, the categories were established from a cliff coast to a dune coast (Table 1). The identification of the coastal geomorphology was derived of topographic sheets, aerial photographs from 1967 to 1984, satellite images from 2004, and field surveys.
- Storm waves effects: storm waves constitute a significant erosion factor in the study area (Merlotto et al. 2013) and their impact could increase in the coming years. Changes in frequency, duration, and wave height during storms were observed in Argentina (D'Onofrio et al. 2008; Fiore et al. 2009; Dragani et al. 2010) as well as in other coastal regions related to the global climate change (Wu et al. 2002; Dolan and Walker 2006; Frazier et al. 2010). The categories of the indicator (Table 1) were established based on the morphological and volumetric changes registered in the beaches (Merlotto et al. 2013). By means of seasonal beach profiles carried out during 2006–2009, positive, stable or negative sedimentary balances of five beaches of the study area were estimated. Also, the morphologic changes in relation to storm waves were studied (Merlotto et al. 2013).

Table 2 Indicators, variables, and categories of the vulnerability index

Indicator	Variable	Vulnerability				
		Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
Demographic	Population	81 to 425	426 to 770	771 to 1115	1116 to 1460	1461 to 1805
	Children dependency ratio	19 to 27.91	27.92 to 36.82	36.83 to 45.73	45.74 to 54.64	54.65 to 63.55
	Olderly dependency ratio	4.08 to 38.02	38.03 to 71.96	71.97 to 105.9	105.91 to 139.84	139.85 to 173.78
Life conditions	Households with UBN (%)	0 to 5.13	5.14 to 10.26	10.27 to 14.4	14.41 to 20.53	20.54 to 25.66
	Population without health insurance (%)	12.84 to 26.19	26.2 to 39.54	39.55 to 52.89	52.9 to 66.24	66.25 to 79.59
	Householder with low education level (%)	0 to 1.81	1.82 to 3.62	3.63 to 5.43	5.44 to 7.24	7.25 to 9.05
Work and consumption	Unemployment ratio (%)	4.88 to 10.66	10.67 to 16.44	16.45 to 22.22	22.23 to 28	28.01 to 33.78
	Population without pension fund deduction (%)	13.89 to 23.3	23.31 to 32.71	32.72 to 42.12	42.13 to 51.53	51.54 to 60.94
	Households without PC (%)	39.91 to 51.31	51.32 to 62.71	62.72 to 74.11	74.12 to 85.51	85.52 to 96.91
	Households without cell phone (%)	57.94 to 65.74	65.75 to 73.54	73.55 to 81.34	81.35 to 89.14	89.15 to 96.94
Land use/cover		Non urban use	Green space	Urban use of low occupation	Urban use of moderate occupation	Urban use of high occupation

- Sediment supply: the presence of beaches depends on the stability of sediment supply sources, therefore if the supply is modified, variations in beach characteristics can be observed in the short-term. Due to the lack of data about sediment supply measurements, qualitative aspects were considered to estimate the changes of sediment supply by littoral drift and aeolian transport. Isla et al. (2009) evaluated the sand availability in the submerged beach in front of the study area through a side-scan sonar and drag samples. The study concluded that the submerged beach is composed by fine sands in front of Necochea, and that wide sand ribbons get narrow towards the East and alternate with compacted silts extending as submerged platforms. In front of Bahía de los Vientos coarse sands and gravels predominate as the submerged abrasion platform in front of Costa Bonita. The grain size composition of beaches was also considered. Merlotto and Bértola (2012) estimated that beaches are composed in Quequén of medium to coarse sands and gravels, and in Necochea city of fine sands. They observed an increase in average grain size since the mid-twentieth century. Finally, the observations made during field surveys and the degree of urbanization and vegetation on dune fields were considered. Based on the information cited above the five categories of the indicator were established in a decreasing scale in both aeolian and littoral supplies (Table 1).

Vulnerability index

The vulnerability index was created based on the Natenzon et al. (2005) and Natenzon (2007) methods. It is composed of four indicators: demographic indicator, life conditions indicator, work and consumption indicator, and land/use cover indicator. The demographic, life conditions and work and consumption indicators were developed based on ten demographic, education, health, sanitary, economic, production, and labour variables (Table 2). Data were obtained from the 2001 National Census of Population, Households and Housing (INDEC 2005); which are available in a census radius scale. It is defined as an administrative division of the geographic space and its size is determined by the quantity of housing units it contains. In average, a census radius contains a number of 300 housing units (INDEC 2005). Therefore the coastal census radius was considered as the analysis unit along the study area. Between Bahía de los Vientos and Costa Bonita there is no data because it is considered as a rural area by the census. The fourth indicator was based on the land cover/use of the study area (Merlotto et al. 2012). This indicator considers the predominant land use/cover in a resolution of a hectare.

The data of the eleven variables extracted from the census were normalized so that higher values indicate higher level of vulnerability. For the variables in which an increase implies a higher vulnerability, the formula employed was:

$$v_i = (a - \text{minimum})/(\text{minimum} - \text{maximum})$$

For the variables in which an increase implies a lower vulnerability, the formula employed was:

$$v_i = 1 - ((a - \text{minimum})/(\text{minimum} - \text{maximum}))$$

where v_i represents the standardized value of the variable and a represents the collected value. The maximum and minimum represent the extreme values of the observed range of values for each variable. Through the normalized procedure the observed values acquire a standardized value between 0 and 1 so higher scores indicate a higher vulnerability. Based on the maximum and minimum values for each variable, equivalent intervals were determined establishing categories ranging from 1 to 5. The value of each indicator was obtained from:

$$\text{Indicator} = (V_1 + V_2 + \ldots\ldots V_n)/n$$

where V is the variable and n is the number of variables that compound each indicator. The data processing and spatial distribution of the indicators values were performed using the gvSIG software.

The vulnerability index includes the following indicators and variables:

- Demographic indicator: population that needs preventive measures as well as assistance to recover from an event. The variables of the indicator are (Table 2): population, children dependency ratio (0–14 years old), and elderly dependency ratio (more than 65 years old).
- Life conditions indicator: percentage of housing and households with greater or lesser deficiencies in housing and sanitary conditions, education level, and health insurance. The selected variables are (Table 2):
  - Households with Unsatisfied Basic Needs (UBN): households with one of the following variables: overcrowded homes (more than 3 people per room), unsuitable housing conditions (rented room or hotel room; hovel; mobile home; premises unsuitable for human habitation; excluding houses, apartments and huts), sanitary conditions (without any kind of bathroom); school attendance (households with a 6 to 12 year old child who does not attend school), subsistence capacity (households with 4 or more dependents per working person, who have not finished third grade of primary education) (INDEC 2005).

  - Population without health insurance: people with no health coverage (obligatory affiliation of salaried workers) or private health insurance plan (voluntarily affiliation and health plan paid by the beneficiary). It excludes medical emergency services (INDEC 2005).
  - Householder with low education level: households with householders who have never been part of the formal education system or who have not completed primary education.

- Work and consumption indicator: based on job stability and household consumption level, this indicator allows estimating the current economic situation of the household and the capacity to recover from material goods and property loss and damages. The selected variables are (Table 2):

  - Unemployment ratio: 14–65 year old unemployed individuals. An unemployed is a person who did not do any activity (whether paid or unpaid) to produce goods or services commercialized in the market the week before the census (INDEC 2005).
  - Population without pension fund deduction: workers whose pension fund is not deducted from their wages. Two situations are contemplated: a) the deduction made by the employer from the worker's wage to pay the statutory pension fund, and b) the voluntary contributions made by the worker.
  - Households without PC: it considers households with no PC.
  - Households without cell phone: it considers households with not even one cell phone.

- Land use/cover indicator: potential loss of buildings, parks and infrastructure exposed to coastal erosion, on the basis of land use and degree of occupation of the coastal area. In view of the elements at risk, five categories were established (Table 2) (Merlotto et al. 2012). The coastal areas with no urban use, intended for quarrying activities or occupied by dune fields, belonged to the lowest category. Green spaces, such as parks, with recreational infrastructure, were considered as low category. The areas with urban use/cover were classified as moderate, high and very high categories based on urban use of low (0 to 15 %), moderate (15.1 to 60 %) or high occupation (more than 60 %), respectively (Merlotto et al. 2012).

Results and discussion

Hazard

The spatial distribution of the hazard index indicates different degrees of coastal erosion in the study area (Fig. 2). Zones from low to very high hazard were found in Quequén city, whereas zones from very low to moderate hazard were reported in Necochea.

Erosion or accretion rates yielded the lowest values in Necochea. Most of the coast is stable and in accretion in some sectors, corresponding to very low and low categories, respectively. Coastline retreat was registered only in particular sites, and it was attributed to the construction of beach resorts and to the presence of a rain drain (Merlotto et al. 2014) (Fig. 2). On the other hand, the coastline in Quequén remained stable only in few sectors (Fig. 2). High and very high values from −0.41 m/y to 0.8 m/y and higher than 0.81 m/y were reported in Bahía de los Vientos and Costa Bonita. Between these sectors, moderate erosion rates were registered (from −0.01 m/y to −0.4 m/y) (Fig. 2).

The coastal geomorphology varies significantly and both cities present different geoforms. Active cliffs with or without sandy beaches (high and very high values) predominate in Quequén. Low values were obtained in the east of the port and in the east of Costa Bonita. In those sectors a coastal dune or a low cliff covered by dunes has developed (Fig. 2). A low coast with dunes is found in the urbanized sector of Necochea, whereas toward the west, a cliff with an aeolian ramp predominates. Nearby Punta Negra, the coast belongs to the very high category owing to the location of active cliffs without sandy beaches (Fig. 2).

Quequén beaches are more vulnerable to storm waves than those of Necochea. They have undergone significant volumetric and morphological changes. Abrupt scarps, intensive sediment loss or a decrease in the topographic beach level with a beach foreshore slope reduction were observed, mainly at Bahía de los Vientos. A very high value was assigned to this site and a high value to Costa Bonita (Fig. 2). Conversely, a very low value was assigned to the west of the port breakwaters. Beaches present stable or positive sedimentary balances and have shown minor changes due to wave storms. Westward in front of Miguel Lillo Park, beaches experiment poor loss of volumes and storm waves have caused small changes in the foreshore such as sediment movement from the berm toward the sea, in some cases forming a small bar and trough (Merlotto et al. 2013) (Fig. 2).

Sediment supply to the beaches has changed in most part of the study area since a few decades ago. Quequén and Necochea lie on an area previously occupied by extensive live dune fields. The presence of Miguel Lillo Park and both cities has caused the decline of aeolian continental sediments supply to the beaches, particularly regarding Quequén (Merlotto et al. 2012). Quequén beaches are further affected by the decrease in the sediment supply by the littoral drift. Isla et al. (2009) postulated the breakwaters of Quequén Port obstruct the littoral drift, interrupting the main source of sediments. Therefore the indicator reflects a very high value in Quequén. On the other hand, near the port in Necochea, the beaches registered a

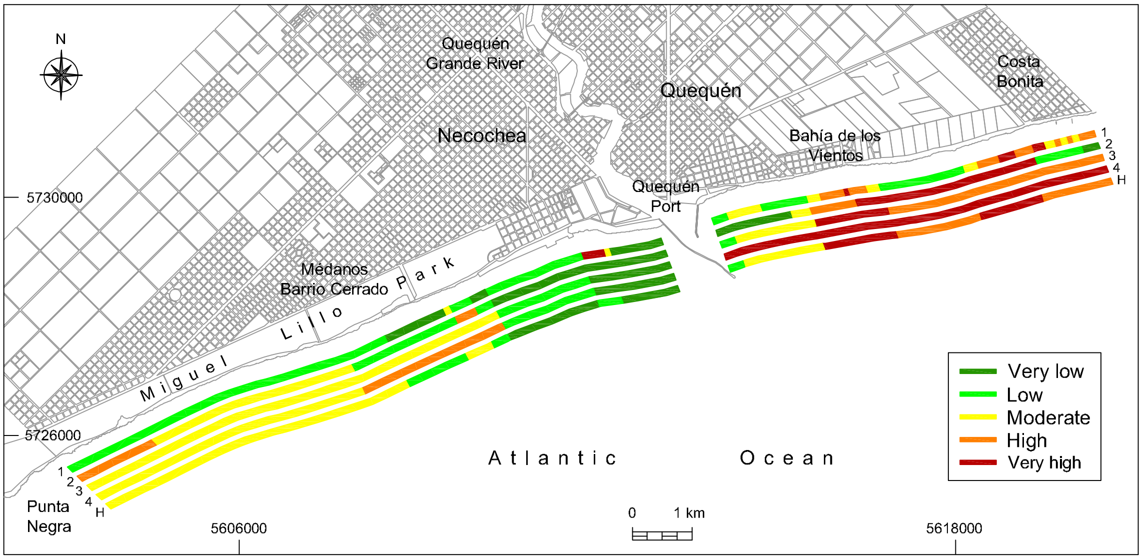

Fig. 2 Spatial distribution of the coastal erosion hazard index. The numbers designate the indicators of the index: 1) erosion or accretion rates, 2) coastal geomorphology, 3) wave storms effects, and 4) sediment supply

volumetric increase and fine sands and the coastline advanced, so the sediment supply by littoral drift has increased. Westward, the supply by the littoral drift is considered to have remained constant based on the positive or stable sedimentary balances. In this sector, the slight decrease in aeolian supply due to dune field occupation would have been compensated by the increase in the sediment supply by the littoral drift. To the west of the urbanized area, in front of the park, the decrease in the sediment supply is evidenced by the negative sedimentary balances (Merlotto et al. 2013).

Finally, according to the spatial behavior of the selected indicators, the hazard index presents the highest values to the west of Costa Bonita and in front of Bahía de los Vientos (Fig. 2). The hazard diminishes to the high category in Costa Bonita due to the geomorphologic characteristics of the area, and between Costa Bonita and Bahía de los Vientos, given coastline stability. In the port vicinity, the low hazard values can be ascribed to a decline in the erosion rates and to the presence of coastal dunes. In Necochea, the urbanized sector features the most favorable characteristics of the indicators, and hence the hazard is very low (Fig. 2). Toward the west, in front of Miguel Lillo Park, the coastline retreats and cliffs development increases the hazard index to the moderate category. In front of Barrio Cerrado Médanos (gated neighborhood), the hazard descends, in part due to coastline advance.

Vulnerability

The indicators of the vulnerability present a different spatial distribution in the studied cities. The demographic indicator displays a very low value in Quequén while, in Necochea, it is low (Fig. 3). Occupation in the coastal front of both cities is low. In Necochea this is explained by Miguel Lillo Park presence and, in Quequén, by unoccupied houses used as second or summer homes.

The life conditions indicator (Fig. 3) reveals more diversity than the demographic indicator. The highest values (poorer home conditions) are located on the coast in front of Miguel Lillo Park, and include the Barrio Cerrado Médanos with the highest value. Westward the indicator descends to the moderate category and, near the port in the most urbanized sector, households present the best conditions. In Quequén, the indicator yields lower values, therefore, life conditions are comparatively better. With respect to the labour and consumption indicator (Fig. 3), it yields higher values in Quequén. Moderate categories were determined in Bahía de los Vientos and, toward the port, the values decrease. The low values in the coastal front of Necochea city low values indicate a good current economic situation of the households and a higher capacity to recover or absorb material goods and property loss and damages.

The land use/cover indicator presents more diversity in Quequén than in Necochea (Fig. 3). Next to the port, very high occupation urban use was registered, while Bahía de los Vientos, like Costa Bonita, presented an urban use of moderate to high occupation. To the coastal sector with non-urban correspond a very low value. This sector is occupied by dune fields partially fixed by vegetation. There are also abandoned quarries. In Necochea, the very high category was assigned to most part of the coastal front due to high occupation density. Except for the Barrio Cerrado Médanos, with high urban occupation, the Miguel Lillo Park belongs to the low category.

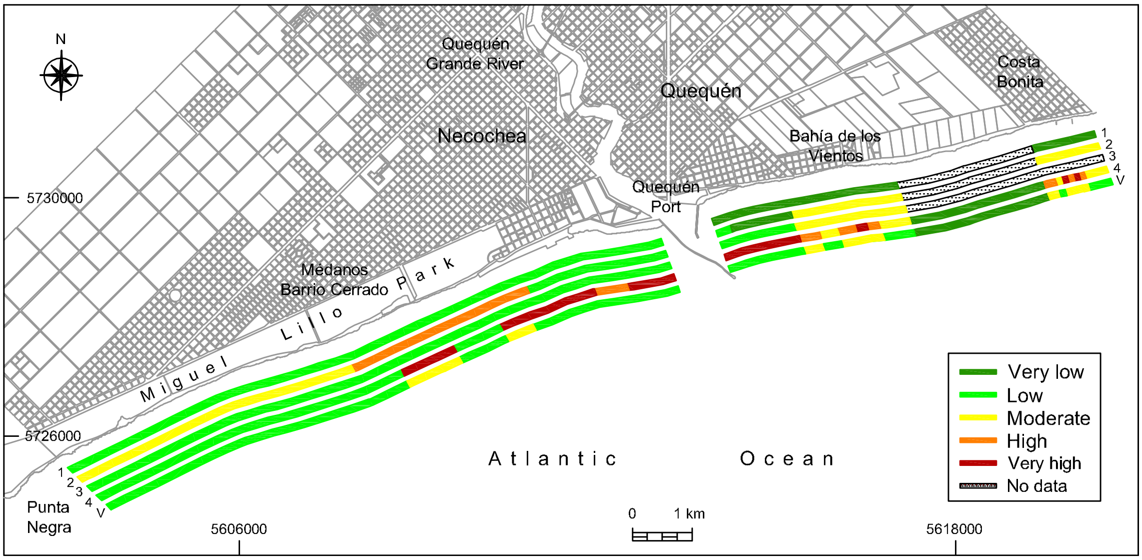

Fig. 3 Spatial distribution of the vulnerability index. The numbers designate the indicators of the index: 1) demographic, 2) life conditions, 3) work and consumption, and 4) land/cover use

To sum up, the vulnerability index presents very low to moderate values in Quequén and low to moderate in Necochea (Fig. 3). In Quequén, the sectors in the most urbanized areas belong to the moderate category. The non-urban use represents very low vulnerability and the rest of the area, low. In Necochea, the low vulnerability results from a different behavior of the indicators in the urbanized sector and in Miguel Lillo Park. The urbanized sector accounts for low values of the socioeconomic indicators and high and very high urban occupation. On the other hand, in Miguel Lillo Park, the low vulnerability corresponds to a low land use/cover and high values of the life conditions indicator. The sectors that belong to the moderate vulnerability displayed the highest values of both indicators.

Coastal erosion risk

The study area presents a very low to high coastal erosion risk (Fig. 4). In Necochea, the more urbanized zone has a very low risk while, toward the west, it reaches the low value. Quequén city presents a high and moderate risk in Bahía de los Vientos (Fig. 5a) and moderate in Costa Bonita (Fig. 5b). In the rest of the coastal front, the risk is low and very low (Fig. 4). The different risk levels in both cities are explained by the spatial distribution of the hazard. In Quequén, it is larger. This city is mostly settled on cliffs which have registered coastline retreat, significant changes due to storm waves and a decrease in the sediment supply of beaches. Instead, Necochea presents a significant lower hazard than Quequén (Fig. 4).

Mitigation and other policy initiatives must be place-specific and flexible in order to adjust to variability in physical parameters of hazard (Boruff et al. 2005). The main factors that influence the coastal evolution in the study area are anthropogenic: dune field fixation by urbanization and forestation, and the obstruction of the littoral drift by the breakwaters of Quequén Port. Infrastructure expansions such as roads and drainage systems have also caused coastal erosion processes in some sectors. Regarding the natural factors, the erosion generated by wave storms is significant. Coastal erosion risk is significant mainly in Quequén hence the development of the risk management program should include prevention and mitigation measures for this place. Mitigation measures can be structural or non-structural, such as seawalls or others rigid infrastructure and beach nourishment. Further, prevention and mitigation measures will be different for areas that are not urbanized or that are urbanized in different degrees. Likewise, areas with low or very low coastal erosion, due to the coastline stability or advanced, would not require mitigation measures. In these places, it would be necessary prevention measures. For the whole study area, a periodic monitoring environmental plan as part of a management program is essential.

Regarding socioeconomic issues such as population welfare and quality of life as components of the vulnerability, they depend in great part on the political and socioeconomic situation of the country. Nevertheless, numerous prevention measures can be adopted to diminishing vulnerability from exposure. Two important non-structural measures are land use/cover planning and education. They encompass legal regulations, land use/cover zoning, urban growth planning and land policies, environmental education and risk communication, among others.

Actions carried out in Bahía de los Vientos exemplify the lack of management program policies. During 2006 and 2007, several real estate projects were developed in Quequén, one of them next to the cliff toe line in Bahía de los Vientos (Fig. 5c and d). The zone was assessed as a very high hazard area

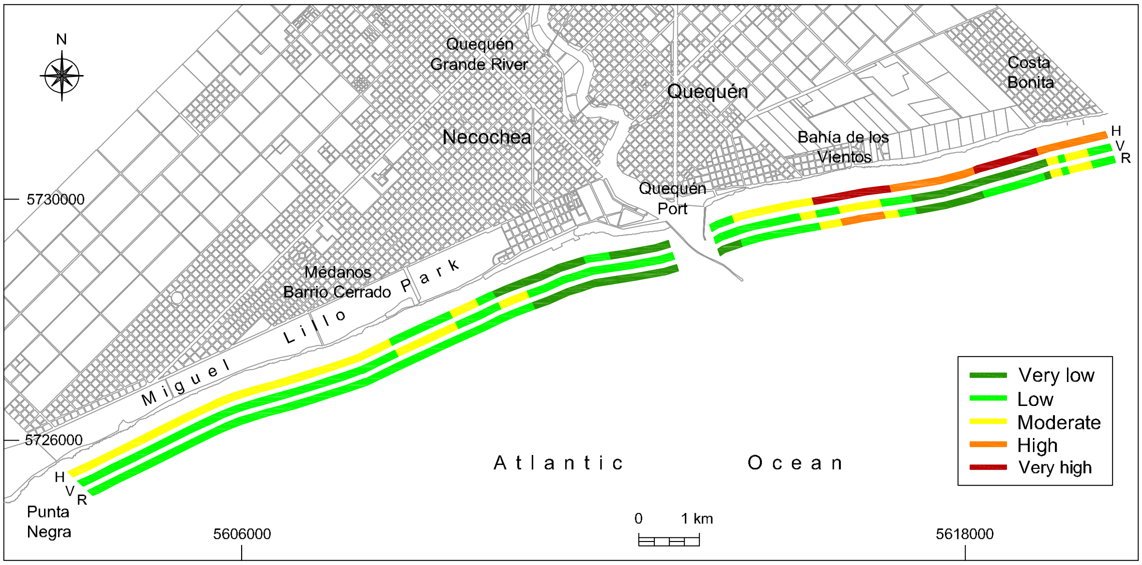

Fig. 4 Spatial distribution of coastal erosion risk

where the erosion effect by storm waves could be significant (Fig. 5a). This area presented coastal defenses in some sectors. Still the project was approved by the authorities, and once the building was finished, new coastal defenses (rip-rap structures) had to be built along the coast. This evidences that real estate speculation with the entrepreneurial rationality of maximizing economic benefits is privileged over the possibility of reducing coastal erosion risk.

Fig. 5 Areas with high coastal erosion risk. **a** Waves reach the urbanized cliff toe during storms in Bahía de los Vientos (22-07-12) **b** A rigid structure in front of a sector in Costa Bonita at low tide (18-03-08) **c** Construction of building close to the coastline in Bahía de los Vientos (11-27-06) **d** Building finished (12-07-07)

Similar actions to those described above were carried out in Mar del Sur in General Alvarado Municipality (Fig. 1). In this resort, the increasing vulnerability to coastal erosion risk was considered to result from sticking to the market logics that permits the occupation of fragile natural areas to ensure greater economic benefits (Hernández 2008). Whereas, in Mar Chiquita Municipality (Fig. 1), in view of the very high coastal erosion risk in some urban centers due to coastal retreat (Merlotto and Bértola 2007), the authorities suspended constructions on lands adjacent to the coast as a way of reducing damages to the exposed elements (Mantecón 2013). This kind of actions diminishes vulnerability.

In the study area, real estate development denotes the lack of planning policies and the absence of legal measures to address long-term sustainable coastal management. Nevertheless, some actions have been taken in Necochea. Beach resorts are being remodeled on the basis of a sustainable environmental approach and car use has been prohibited in beaches and dunes. These measures can help diminish the hazard of coastal erosion. Risk management should be part of coastal management programs whose preparation and application require a great effort from the community. Indeed it should be a central objective for any coastal municipality wishing to exploit its environmental resources as economic and tourist assets.

Conclusion

A useful method to coastal erosion risk assessment in urban centers has been presented. Assessment is based on the selection of natural and socioeconomic indicators to compose the hazard and vulnerability indices, both essential components of risk. The results obtained have shown differences in hazard and vulnerability spatial distribution in the study area. Both component interactions, along with their spatial variability, have defined risk setting.

The selected indicators and derived indices have allowed identifying areas of different risk levels. The risk map obtained could help model management actions and develop and implement different prevention and mitigation measures in respect of each sector needs, thereby favoring coastal erosion risk reduction. The indices constructed could be enriched in future works with the incorporation of new indicators. To enhance hazard assessment, oceanographic variables measured at both sides of the port it could be include. This would particularly increase the number of indicators and, therefore, build on knowledge on the coastal erosion phenomenon. As far as vulnerability is concerned, factors such as social and institutional networks and connections, beliefs and customs, social capital, development of assistance networks, could also be included. Needless to say, generating all this information requires a great economic effort from the government authorities. Moreover the availability of such data for risk assessment constitutes a significant difficulty. This explains why these factors are rarely found in the literature. The risk assessment developed herein constitutes a practical and adequate tool that can be utilized with other elements and tasks in the elaboration of a coastal management program based on improved decisions.

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