MÓNICA PATRÍCIA PEREIRA RAPOSO FERREIRA

COASTAL RISK ASSESSMENT ASSOCIATED WITH CLIFF EVOLUTION AND MANAGEMENT PROPOSALS BETWEEN GALÉ AND ALBUFEIRA

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Declaração de autoria do trabalho

Declaro ser a autora deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

Mónica Patrícia Pereira Raposo Ferreira

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Resumo

As zonas costeiras são densamente ocupadas e habitadas, tornando-se suscetíveis aos impactos causados por determinados eventos (tempestades, aumento do nível do mar, etc.). Ao combinar a probabilidade de ameaça (evento) com o nível de exposição (tipo de ocupação existente na área exposta), determina-se o risco associado, que pode ser baixo, significativo, elevado e, em alguns casos, muito elevado. Por sua vez, este risco pode ter implicações sérias a vários níveis (social, económico e ambiental). A região do Algarve, em Portugal, é considerada habitualmente uma das regiões do país mais atrativas para o turismo, contribuindo para o aumento da pressão antrópica na sua zona costeira e, consequentemente, aumentando o risco costeiro. Este trabalho apresenta uma avaliação do risco costeiro associado à evolução (recuo) das arribas assim como a análise e proposta de medidas de gestão para o setor costeiro entre Galé e a marina de Albufeira.

No decurso desta dissertação, foram estudados e analisados os diferentes fatores de risco, isto é, fatores que colocam ou poderão colocar em risco a população e o edificado existente numa zona particular do litoral - parte adjacente ao topo da arriba - relativamente a uma ameaça específica – movimentos de massa em arribas. Para isto, foi utilizada uma metodologia, composta por duas análises complementares: *(i)* cálculo do Índice Costeiro, que resultou da combinação da ameaça com a exposição, sendo que para tal foram cartografadas a linha de topo da arriba, as áreas associadas a diferentes graus de ameaça com base no período de retorno dos movimentos de massa e o tipo de ocupação (uso do solo, população, transporte, atividade económica) aí existente e *(ii)* análise de propostas de gestão e minimização do risco costeiro, onde foram analisadas as zonas mais afetadas na área de estudo. Para complementar a análise, foi realizada uma avaliação das medidas de gestão já existentes, verificando a sua concordância com o risco presente e propuseram-se novas medidas com vista à sua diminuição.

Para a aplicação metodológica, recorreu-se ao programa ArcGIS, que permite criar e analisar mapas de forma objetiva e pormenorizada, tendo-se utilizado um conjunto alargado de dados, incluindo ortofotografia aérea, informação alfanumérica dos Census 2011 e cartografia temática da zona de estudo.

Os resultados obtidos indicam que a área de estudo apresenta, genericamente, um risco muito baixo e baixo. O grau de ameaça, para um período de retorno de 100 anos, estende-se ao longo de uma faixa de 67 m para interior do topo da arriba, mas o grau de exposição ao longo da área é genericamente baixo, nomeadamente nas componentes transportes e infraestruturas. Relativamente às áreas onde se identificou risco médio e elevado, dezoito diferentes propriedades/estruturas foram destacadas e consideradas zonas críticas, sendo por isso alvo de análise e de proposta de medidas de gestão. As medidas de gestão deverão ser ajustadas de acordo com a relevância de cada estrutura, tais como reposicionamento de hotéis, residências e restaurantes (com risco elevado) para uma zona fora dos 150 m da área de proteção costeira definida pelo Plano de Ordenamento da Orla Costeira, designados por POOC (o atual Plano da Orla Costeira – POC). Os restantes restaurantes, parques de estacionamento, estradas e os pequenos jardins deverão ser relocalizados para a faixa entre os 48 m e os 67 m. Sendo estas medidas de difícil aceitação social, poderão ser aplicadas de forma faseada, à medida que as licenças vão terminando, não permitindo a revenda de casas e propriedades, assim como a elaboração de uma política de desvalorização imobiliária da zona de risco e de incentivo à ocupação fora de zonas de risco. Em acréscimo, dever-se-ão implementar medidas como o aumento dos sinais informativos a alertar para o perigo de derrocadas no topo da arriba, assim como a adaptação da sinalização habitual a identificar e a caracterizar a praia de forma mais completa, com a identificação das faixas de ameaça na área para o interior, relativamente ao topo da arriba, resultantes deste trabalho.

Para futuros trabalhos e com o intuito de complementar o estudo até então desenvolvido, a análise do risco costeiro na área de estudo resultante da metodologia proposta neste trabalho, poderá ser melhorada e tornada mais próxima da realidade se uma das componentes inerentes à ocupação da zona costeira, isto é, o valor económico e vulnerabilidade associados às estruturas e população residente aí existente forem incluídas no cálculo do risco assim como a integração da exposição marítima e da litologia das arribas no índice de ameaça.

Palavras-chave: arribas, faixas de risco, risco, cartografia temática, SIG, gestão costeira

Abstract

Coastal areas are densely occupied and inhabited, being susceptible to suffer consequences of extreme events (storms, sea level rising, etc.). The combination of hazard (event) and exposure (occupancy) creates a significant, relevant and, in some cases, threatening potential risk. These events can cause serious implications at all levels (social, economic and environmental). The Algarve region, in Portugal, is often considered as one of the most appealing regions for tourism in the country, contributing to increase the pressure on coastal areas and, consequently, increasing the coastal risk. This dissertation presents an assessment of coastal risk associated with the evolution and development of rocky cliffs, as well as the analysis and definition of management procedures and proposals for the coastal sector between Galé and Albufeira. Throughout the dissertation, different risk factors were assessed, which may endanger the existing population and buildings in a particular area of the coast – cliff top section - in respect to a specific hazard – slope mass movements in cliffs. To accomplish this, the methods presented here combined two complementary analyzes: *(i)* Coastal Index calculation, based on the detailed mapping of the cliff top line, the areas associated to different hazard degrees according to mass movements return periods and existing variability in occupancy; *(ii)* analysis of coastal risk management procedures along with definition of mitigation proposals, based on the analysis of the hotspots present on the study area. In order to complement the analysis, an assessment of the existing management measures was carried out, evaluating its agreement with the present risk and new measures to reduced it were proposed.

The results obtained indicate that very low and low risk were dominant along the study area. The hazard index, for a return period of 100 years, until extends to 67 m landward of the cliff top, but the exposure index along the area is generally low, notably for the transport and infrastructure components. In the areas where the risk was medium and high, eighteen different properties/structures were highlighted and considered as hotspots and further subjected to detailed analysis and proposal of management measures. These measures should be adjusted according with the relevance of each structure, and include relocation of hotels, residences and the restaurants (under a high risk) to areas outside the protection area defined by *Planos de Ordenamento da Orla Costeira*, designed by *POOC* (the recent *Planos da Orla Costeira – POC*). The other restaurants, parking areas, roads and small gardens should be relocated to the area between the 48 and

67 m landward of the cliff top. Since relocation measures face difficult social acceptance, relocation and removal of properties from the protection area should be phased, as licenses are due to come to an end, not allowing residences and other properties to be resold. It is also essential the creation of a policy to promote a devaluation of property within the risk zone and incentive the removal out of protection area. Additionally, in order to improve the information to the public about the coastal risk, the number of signs that warn to the rockfall hazard should be increased alongside the adjustment of the existing information posters on the beach entrance to highlight the hazard zoning on the cliff top upper area.

In future research, in order to improve the proposed methodology for risk assessment, other components can be included on the coastal index calculation, such as the incorporation of the economic value and vulnerability associated to structures and residents on the coastal index, as well as the wave exposure and cliff lithology on the hazard index.

Keywords: cliffs, hazard lines, risk, thematic mapping, GIS, coastal management

Contents

Acknowledgements **i**

Resumo **ii**

Abstract **iv**

List of Figures **ix**

List of Tables **xi**

Abbreviations **xii**

1. Introduction **1**

1.1 Framework 1

1.2 Objectives 2

2. State of the art **3**

2.1 Characterization and evolution of rocky cliffs 3

2.2 Risk concepts 8

2.2.1 Definition 8

2.2.2 Hazard 11

2.2.3 Consequence (Impact) 12

2.2.3.1 Exposure 12

2.2.3.2 Vulnerability 13

2.2.4 Risk cartography 17

2.3 Coastal risk management 17

3. Study area **21**

3.1 Geomorphology 24

3.2 Wave exposure 25

3.3 Ciff evolution 25

3.4 Occupancy and tourism 27

3.5 Proposed measures 30

4. Methodology **33**

4.1 Cliff Top Line 38

4.2 Hazard Index 39

4.3 Exposure Index 42

4.4 Coastal Index 49

5. Results **50**

5.1 Hazard Index 50

5.2 Land Use 51

5.3 Population 52

5.4 Transport 53

5.5 Economic Activity 54

5.6 Exposure Index 55

5.7 Coastal Index 56

6. Discussion **59**

6.1 Data management 59

6.2 Risk assessment 59

6.3 Coastal risk management proposals 61

7 Conclusion **68**

8 References **70**

List of Figures

Figure 2.1 - Components of a cliff and location of cliff top upper area (Coelha beach, Albufeira)........ 3
Figure 2.2 - Shore platform development (Payo et al., 2015)........ 4
Figure 2.3 - Cliffs morphological variability: (a) São Rafael beach, Albufeira; (b) Castelo beach, Albufeira........ 4
Figure 2.4 – Cliff retreat........ 5
Figure 2.5 - Cliff profiles: (a) – Marine erosion >> Subaerial erosion; (b) – Marine erosion > Subaerial erosion; (c) – Marine erosion = Subaerial erosion; (d) – Marine erosion < Subaerial erosion; (A) – Homogeneous lithological composition; (B) – Heterogeneous lithological composition (resistant at top); (C) - Heterogeneous lithological composition (resistant at bottom) (Emery and Kuhn, 1982)........ 6
Figure 2.6 - Dimensional parameters of cliffs mass movements (Teixeira, 2006)........ 7
Figure 2.7 - Risk area for a particular hazard (adapted from Ribeiro, 2010)........ 8
Figure 2.8 – Source-Path-Receptor sequence (Manuel Lourenço’s beach, Albufeira).. 11
Figure 2.9 - Coastal vulnerability system (adapted from Balica et al., 2012)........ 14
Figure 2.10 - Coastal area covered by POOC (adapted from APA, 2015)........ 18
Figure 2.11 – Coastal Zone Management Plans: Plan 8 including the study area (adapted from Taveira-Pinto, 2004)........ 19
Figure 3.1 - Study area and main beaches view: (A) mainland Portugal; (B) Algarve region, with Albufeira municipality highlighted; (C) Study area with all the seven beaches on study (Figure 3.2)........ 22
Figure 3.2 - The seven beaches present on study area........ 23
Figure 3.3 - Morphological variability of rocky coast (São Rafael beach, Albufeira)... 24
Figure 3.4 - Cliffs dominant profile on the study area, according to the lithological composition and dominant erosion type (adapted from Nunes et al., 2009)........ 26
Figure 3.5 - Resident population growth (Census 2011)........ 28
Figure 3.6 - Anthropic occupation of the coast: (a) Beach facilities and tourist occupation in rocky coast (São Rafael beach, Albufeira); (b) Housing near cliff top (Arrifes beach, Albufeira)........ 30
Figure 3.7 - Coastal management measures: (a) Landslides warning nameplate (Arrifes beach, Albufeira); (b) Beach sand refill carried out in July 2015 (Coelha beach, Albufeira)........ 30

Figure 3.8 – Hazard mapping of Coelha beach, Albufeira 31
Figure 3.9 - The affected area by the sea stack collapse in Maria Luisa beach (August 2009): (a) Photo taken by Luís Forra and (b) Photo taken by João Xavier 32
Figure 4.1 - Rocky coast potencial dangerous zones: area of interest for dissertation marked in red (adapted from Teixeira, 2014) 33
Figure 4.2 - Different exposure components of study area: (a) Residential building (Arrifes beach); (b) Restaurant (Castelo beach); (c) Parking area (São Rafael beach); (d) Tourist building (Galé beach) 35
Figure 4.3 - Thesis methodolody 37
Figure 4.4 – Sample image of the 2008's orthophoto for the study area (between Castelo’s beach and São Rafael’s beach) 38
Figure 4.5 – Example of the cliff top line demarcation in detail in a morphologically complex zone of the study area 39
Figure 4.6 - Return period of mass movement maximum and mean inland extension (Teixeira, 2006) 40
Figure 4.7 - Layout of the proposed hazard index, according to the zoning by mass movement return period 42
Figure 4.8 - Layout of attributes to consider when setting the exposure index 43
Figure 4.9 - SVI steps 45
Figure 5.1 - Hazard Index along the study area 51
Figure 5.2 - Land use exposure along the study area 52
Figure 5.3 – Population exposure along the study area 53
Figure 5.4 – Transport exposure along the study area 54
Figure 5.5 - Economic activity exposure along the study area 55
Figure 5.6 - Exposure index along the study area 56
Figure 5.7 - Coastal index along the study area and hotspot areas (red circles) 57
Figure 6.1 – Examples of structures with a medium and high risk present on study area: (a) Building; (b) Restaurant 62
Figure 6.2 - Extreme relocation of the hotspots (discriminated on Table 6.2), from the protection area (red arrow – area from cliff top line till 48 m) to two different areas (blue arrow – area from 48 m till 150 m; yellow arrow – area from 150 m in the direction... 64
Figure 6.3 - Signs that warn the rockfall hazard 66
Figure 6.4 - Adaptation of the existing nameplates with hazard mapping on the cliff top upper area 67

List of Tables

Table 2.1 - List of studies/methods/programs developed by different authors concerning the vulnerability and risk assessment ... 9
Table 2.2 - Examples of exposure classes (Coelho, 2005) ... 13
Table 2.3 - Different types of coastal vulnerabilities (Satta et al., 2016) ... 15
Table 3.1 – References values of return period of the mass movement extension (adapted from Teixeira, 2006) ... 27
Table 3.2 Variations of the occupation per type for the Algarve and Albufeira between 2001 and 2011 and for tourism accomodation between 2009 and 2013 (source data: Census 2011 Portugal) ... 29
Table 4.1 - Reference return period values of the mass movement width ... 40
Table 4.2 - Reference return period values of the mass movement maximum width and the related hazard level ... 41
Table 4.3 - Description of the different exposure indexes ... 43
Table 4.4 - 2011 Census data and SVI variables calculation ... 45
Table 4.5 - Transformation of variables to Z scores ... 47
Table 4.6 - Range of SVI values and associated exposure degree ... 48
Table 5.1 - Wmax associated to a return period according to Teixeira (2006) and CPZ according to POOC ... 50
Table 5.2 – Description of the eighteen hotspots ... 57
Table 6.1 - Priority of the hotspots according to the occupation type and coastal index 60
Table 6.2 - Relocation of the study area hotspots ... 63

Abbreviations

A

APA – Agência Portuguesa do Ambiente (Portuguese Agency of Environment)

ArcGIS – Software of Geographic Information made available by ESRI Company, which comprises the applications “ArcMap” and “ArcCatalog”

C

CCFVI – Coastal City Flood Vulnerability Index

CI – Coastal Index

CMA – Câmara Municipal de Albufeira (Albufeira’s city council)

COS – Carta de Uso e Ocupação do Solo

CPS – Coastal Protection Structures

CPZ – Coastal Protection Zone

CRAF – Coastal Risk Assessment Framework

CVI – Coastal Vulnerability Index

CVI-SLR – Coastal Vulnerability Index – Sea-Level-Rise

CZMP – Coastal Zone Management Plans

D

DPH – Domínio Público Hídrico (Public Water Domain)

E

E – East

ESRI – Environmental Systems Research Institute

G

GIS – Geographic Information System

I

IGP – Instituto Geográfico Português (Portuguese Geographic Institute)

ISCED - International Standard Classification of Education

ISDR – International Strategy for Disaster Reduction

K

km – Kilometers

M

m – Meters

MHCRI – Multi Hazard Costal Risk Index

MS CRI – Multi-scale Coastal Risk Index

MS CVI – Multi-scale Costal Vulnerability Index

M.S.L – Mean Sea Level

N

NE – Northeast

O

OECD – Organisation for Economic Co-operation and Development

P

POC – Planos da Orla Costeira

POOC – Planos de Ordenamento da Orla Costeira (Coastal Management Plans)

R

RCM – Resolução do Concelho de Ministros (Resolution of the Ministers Council)

REN – Reserva Ecológica Nacional (National Ecological Reserve)

RISC-KIT – Resilience-Increasing Strategies for Coasts – toolKIT

S

SW – South-west

U

UN – United Nations

W

W – West

1. Introduction

1.1 Framework

The occupancy and development of coastal areas is increasing due to growing tourist demand for sun and beach, the main reasons why coastal areas have been transformed into urban areas, instead of small tourist clusters (Cearreta *et al*., 2013; Isla, 2013; Surjan *et al*., 2016). During summer, a large part of the Portuguese population and other tourists choose the Algarve coastline as holiday destination, taking advantage of resources and coastal landscape. According to Teixeira (2006), the Algarve coast is one of the most sought/demanded destinations by tourists in Portugal and, part of the western Algarve (between Lagos and Albufeira) receives about 60% of the total Algarve tourists, while approximately 50% of Algarve visitors occupy rocky beaches.

Cliffs are naturally unstable since they are erosional landforms continually exposed to costal erosion (Dickson *et al*., 2004; Naylor *et al*., 2010; Kennedy *et al*., 2013). Erosion occurs due to the exposure of the coast to factors such as wave action and subaerial erosion, mainly caused by intense precipitation events, which drives the evolution (retreat) of cliffed coastlines (Nunes *et al*., 2009; Bezerra *et al*., 2011; Kennedy *et al*., 2011).

The retreat of rocky coast reflects the balance between the mechanical strength of cliffs and the pressures that may exist in their own by gravity and the impact of wave kinetic energy on the cliff base (Sunamura, 1992 *in* Nunes, 2007). Cliff instability has implications for the economic, social and environmental development on the coast, and thus the risk is no longer negligible and becomes relevant (Helm, 1996). Concerning the area in question, a recent study by Teixeira (2014) shows that Algarve tourist occupancy pattern and natural geodynamics of rocky cliffs, reflected in discontinuous and intermittent occurrence of mass movements, determines the existence of risk for beach users. Similarly, the current occupancy at the cliff top is also subject to such irregular retreat. Since the anthropic pressure has been increasing, the risk is also accentuated.

Several studies concerning coastal zone hazards (e.g. Nunes, 2007; Nunes *et al*., 2009; Teixeira, 2009a), produced thematic maps to identify areas with greater hazard potential in the Algarve as conflicts between human uses and the inherent instability of cliffed coastlines has become a major problem (Moore and Griggs, 2002). Del Río and Gracia (2009) state that the potential negative consequences of cliffs retreat are a matter of great worldwide concern. Therefore, coastal risk assessment becomes essential to create and implement management measures in order to minimize the associated risk.

A study developed in the south coast of Spain indicated that, current protection policies reflect a strategy change, which began to emerge since the mid-80s, in response to high urbanization levels and susceptibility of the region (García *et al*., 2000). Portugal has undergone similar change of strategy in coastal management due precisely to increased human occupancy on the coast. Nowadays, there are Coastal Zone Management Plans in force, which aim to implement management, intervention and monitoring measures of the existing resources in Portuguese coastal areas (Marques, 2009). However, many of these plans are only partially implemented. Thus, it is essential to determine the coastal risk and structure management measures and strategies, in order to contribute to the reduction of impacts promoved by coastal hazards and consequent disaster possibility. In turn, the hazards analysis and assessment, exposed elements and coastal vulnerabilities are a very complex issue, because there are a large number of factors and variables, either natural or anthropogenic, influencing coastal behavior (Del Río and Gracia, 2009). A good example is the variety of the exposed elements – hotels, restaurants, residences, among others. Since the study area, as already mentioned, suffers an increase in building construction and expansion of economic activities, there is a permanent need to implement management measures and strategies.

1.2 Objectives

This thesis aims to assess the risk associated to cliff top retreat along the coastal zone from Galé and until Albufeira's marina, perform its characterization by mapping risk and, lastly, analyze management plans and propose improvements to prevent and reduce coastal risk. The main purpose of mapping and specifically characterize all risk factors is to allow a more accurate assessment, in order to detect the areas with major potential risk comparatively to other areas and to establish improvements on measures present in management plans for the study area and/or to propose new strategies. If implemented, the improvement of management measures will allow not only to decrease the risk on this coastal zone in particular, but also provide positive indications for management processes of other coastal areas.

2. State of the art

2.1 Characterization and evolution of rocky cliffs

Rocky coasts occupy three-quarters of total coastal areas (Bird, 2011), which largely correspond to coastal slopes subjected to direct or indirect sea action and its evolution proceeds by a discontinuous sequence of mass movements (Teixeira, 2006). Figure 2.1 shows the components of a cliff and location of cliff top upper area.

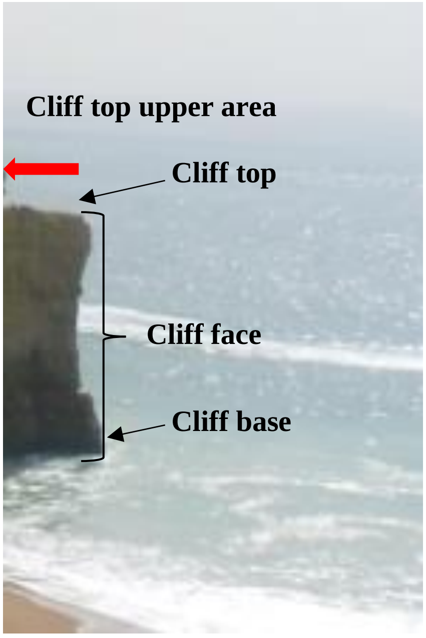

Figure 2.1 - Components of a cliff and location of cliff top upper area (Coelha beach, Albufeira)

There are other erosional landforms found on rocky shorelines, designated by shore platforms (Dana, 1849 in Kennedy, 2015). Shore platforms are the result of cliffs exposition to different erosional factors. This erosion can take the form of horizontal retreat, called backwearing, or occur by the vertical erosion, called downwearing (Payo et al., 2015). Figure 2.2 presents the shore platform components.

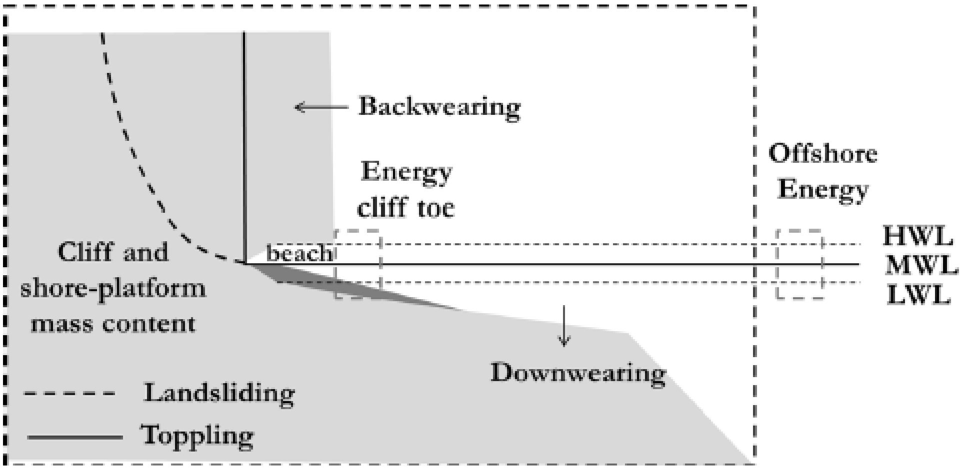

Figure 2.2 - Shore platform development (Payo *et al*., 2015)

As shown on Figure 2.2, cliff failure might be either induced by wave undercutting (toppling) or shear induced (landsliding).

Regarding downwearing rates, according to Moura *et al*. (2011), the rock porosity and mechanical stregth are important factors, which are, respectively, directly and inversely correlated with cliffs' retreat.

Figure 2.3 displays different morphologies resulting from cliffs erosion, such as stacks, caves, exposed sinkholes and blocks or debris resulting from mass movements.

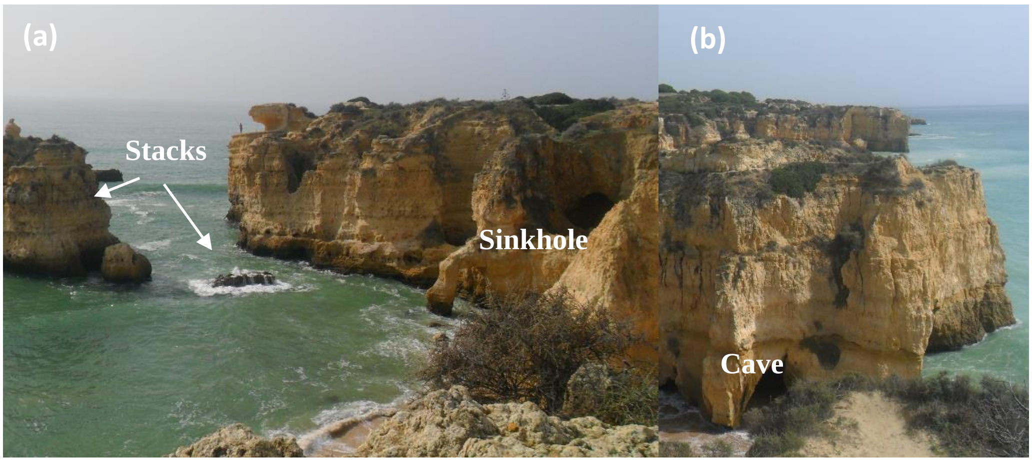

Figure 2.3 - Cliffs morphological variability: (a) São Rafael beach, Albufeira; (b) Castelo beach, Albufeira

These morphologies are associated with rocky coast erosion (Figure 2.4) and the main factors responsible for their evolution are wave energy, direction, length and height tidal regime, presence or absence of sediments, all of which may be responsible for major morphological changes (Moura *et al*., 2006). Sea level rise and storms can also contribute to cliffs evolution processes (Le Cozannet *et al*., 2014). The erosion of the rocky coast is intensified by situations of intense rainfall and storms (Trenhaile, 1987; Sunamura, 1992 in Nunes *et al*., 2009). Besides the factors mentioned above, granular disintegration, chemical or biological corrosion are also subaerial processes that contribute to cliffs retreat (Bird, 2011), though in a smaller, microscopic or crystalline dimensional scale (Trenhaile, 1987; Teixeira, 2006).

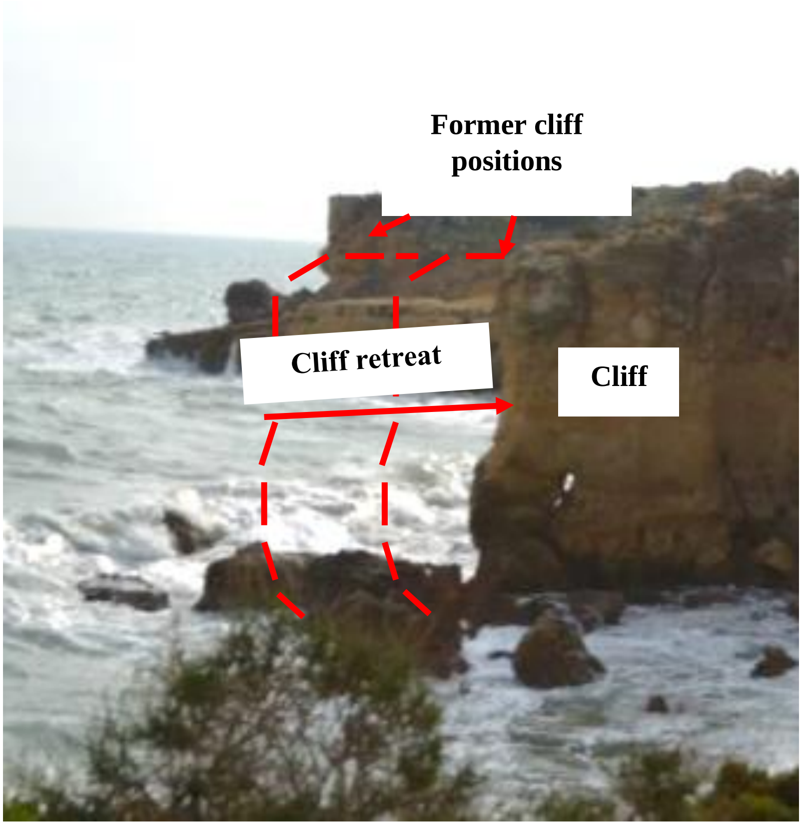

Figure 2.4 – Cliff retreat

Cliff profile morphology depends mainly on their exposure to marine and subaerial erosion, on the cliff lithology type as well as on their degree of heterogeneity. Emery and Kuhn (1982) defined twelve different profiles that relate to the characteristics mentioned above (Figure 2.5). Vertical cliffs reflect marine erosion, while the more rounded cliffs, and therefore less vertical, reflect the dominance of subaerial action.

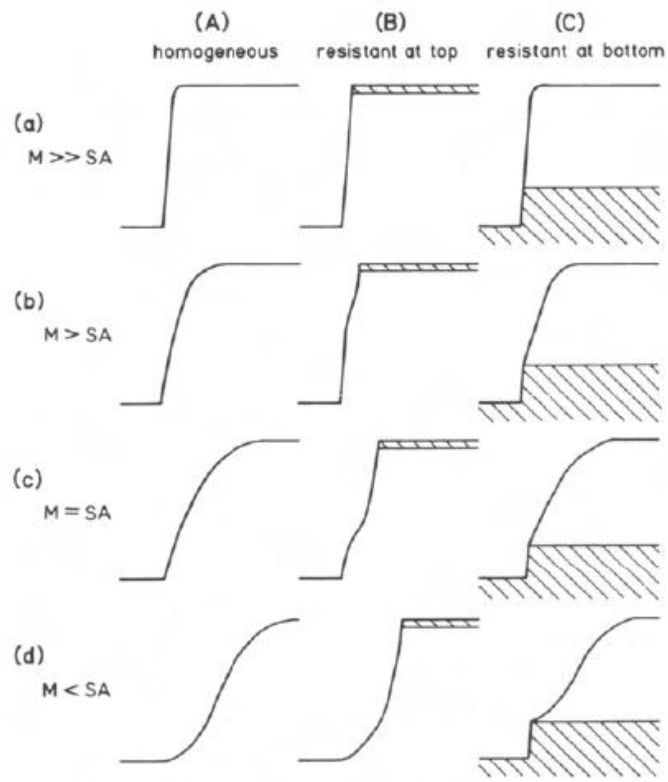

Figure 2.5 - Cliff profiles: (a) – Marine erosion >> Subaerial erosion; (b) – Marine erosion > Subaerial erosion; (c) – Marine erosion = Subaerial erosion; (d) – Marine erosion < Subaerial erosion; (A) – Homogeneous lithological composition; (B) – Heterogeneous lithological composition (resistant at top); (C) - Heterogeneous lithological composition (resistant at bottom) (Emery and Kuhn, 1982)

The complexity of cliffs retreat is mainly related to the fact that rocky coast often recede slowly, through low frequency but high magnitude events (Teixeira, 2006). Normally, cliffs retreat occurs in the form of different mass movement types and these events, in turn, are sporadic and unpredictable, thus making difficult its observation and measure (Del Río and Gracia, 2009).

Mass movements occur in three main types: rotational, translational and landslides (Violante, 2009). Figure 2.6 shows the dimensional parameters of cliff mass movements (width, length, area, volume) according to Teixeira (2006).

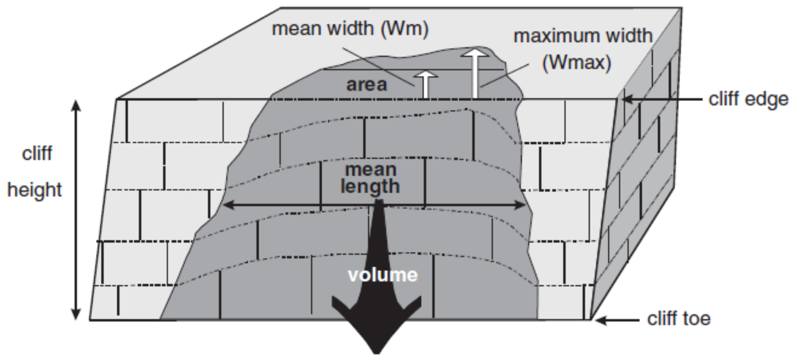

Figure 2.6 - Dimensional parameters of cliffs mass movements (Teixeira, 2006)

To fullfill the objectives of this work and determine the hazard at the cliff top and upper area it is particularly relevant the determination of the movement width (range) into the cliff top upper area.

The study of rocky cliffs, specifically the cliffs along the study area, has been investigated by several researchers. Dias (1988) carried out a study concerning a general geological characterization of Algarve rocky coastal area. Marques (1991) did a detailed study for the harder rocky cliffs of central Algarve, which quantified cliff evolution rates and their importance in geological risk assessment. Dias and Neal (1992) characterized the rocky coast of Algarve using Emery and Kuhn (1982) cliff profile evolution model, although they have focused on the soft cliffs of eastern Algarve. Marques (1997) assessed long-term cliff retreat rates in Miocene calcarenites through the identification and measurement of mass movements by comparative analysis of aerial photographs, between 1947 and 1992. The maximum local retreat measured in sea cliffs cut on the Miocene rocks was 45 m, in an arch collapse that occurred between 1974 and 1980.

More recently, Moura *et al*. (2006) did a research concerning the morphological features and processes in the central Algarve rocky coast. Moura *et al*. (2007) studied the Holocene sea level fluctuations and coastal evolution in the Central Algarve. Nunes et al. (2009) demonstrated that rock cliffs Galé and Olhos de Água are mostly subjected to high and very high hazard, probably related to the fact that 61.1% of the coastline is exposed to the most hazardous wave class. More recently, Bezerra *et al*. (2011) studied the influence of wave action and lithology on sea cliff mass movements in Central Algarve. Later, Chester (2012) investigated the Pleistocene and Holocene geomorphological development in Algarve. Recently, Teixeira (2014) analysed coastal hazards from slope mass movements on Algarve's Barlavento Coast (Western and Central Algarve).

2.2 Risk concepts

2.2.1 Definition

Risk corresponds to the exposure of population and economic activities to potential high hazard events, which may cause potential disasters involving large losses, at social, economic and environmental level (UN/ISDR, 2009).

In a general view, coastal risk can be translated by a quantitative index that takes into account not only the probability of the hazard, but also the consequences resulting from it. These are combined into two separate indexes (Figure 2.7), the hazard index and the impact index, which are related as a single numerical measure of risk for a given area (Del Río and Gracia, 2009; Salvadori *et al.*, 2015).

Figure 2.7 - Risk area for a particular hazard (adapted from Ribeiro, 2010)

In mathematical terms, according to Helm (1996):

$R = Hz \times C$ (Equation 1)

R = Risk

Hz = Hazard probability

C = Consequence

Danger variables (hazard) include cliff lithology and exposure to storms/wave action and the result is translated into the mass movements measurement, including the mass movement maximum extension into the cliff top upper area. To acess the impact of mass movements it is necessary to consider variables that represent the exposure and the consequence, which include the coastal zone land use type and/or population density, as well as social and economic factors. Table 2.1 shows a list of studies/methods developed by different authors concerning the coastal vulnerability and risk assessment, which could be applied to rocky shores.

Table 2.1 - List of studies/methods/programs developed by different authors concerning the vulnerability and risk assessment

Study/Method/Program	**Objectives**	**Author**
CVI (Coastal Vulnerability Index)	Assess vulnerability of physical system, socioeconomic and ecological systems (in the U.S. Southeast)	Gornitz *et al*., 1991 in Satta *et al*., 2015
CVI-SLR (Coastal Vulnerability Index to Sea Level Rise)	Assess vulnerability to sea level rise of physical system, socioeconomic (i.e. land use) and ecological systems (in Turkey)	Ozyurt, 2007
Multiscale CVI	Produce indexes (and maps) representing socioeconomic and ecological vulnerabilities (Northern Ireland)	Mclaughlin and Cooper, 2010
DESYCO (Software)	Assess socioeconomic and ecological vulnerability (in Italy)	Torresan *et al*., 2010 in Satta *et al*., 2016
SimCLIM (Software)	Assess climate change impacts and adaptation (both socioeconomic and ecological targets)	CLIMsystems Ltd. in Satta *et al*., 2016

CCFVI (Coastal City Flood Vulnerability Index)	Calculate flood vulnerability in certain areas	Balica *et al*., 2012
MHCRI (Multi-Hazard City Risk Index)	Assess which coastal assets are at risk to multiple hazards and to quantify that risk through different variables synthetized in a coastal risk index	Satta, 2014
MS-CRI (Multi Scale Coastal Risk Index)	Assess coastal risk through the combination of sub-indexes (hazard, vulnerability and exposure) synthetized in a coastal risk index	Satta *et al*., 2015
CRAF (Coastal Risk Assessment Framework)	Assess coastal risk at a regional scale (about 100 km of coastal length) through the combination of sub-indexes (hazard, vulnerability and exposure) synthetized in a coastal risk index.	RISK-KIT, 2015

According to Satta *et al.* (2016), just a few methods address coastal risk at an appropriate scale showing low flexibility to operate at various spatial scales.

Coastal risk assessment, in addition of being quite complex, requires a clear understanding of the driving factors and of their local environmental influence as well as potential receptors. Regarding previous studies, risk assessments related to the cliff bottom area (beach) is more frequent and have been developed in several coastal areas. The risk in the upper area of a cliff upper area is poorly studied, despite its extreme importance at various levels (environmental, economic and social).

2.2.2 Hazard

Hazard is considered as any "potentially damaging physical event, a natural phenomenon or human activity that may cause the loss of life, property damage, social and economic disruption and / or environmental degradation" (UN/ISDR, 2009). This, in turn, has an event source, which describes a sequence until it reaches the receptor, i.e., the entity that may be affected (Source-Pathway-Receptor-Consequence concept defined on Language of risk by Gouldby and Samuels, 2005). The event source may come form of sea waves and strong storms, two of the main factors causing cliff retreat (Moura *et al*., 2006; Le Cozannet *et al*., 2014); the path in the form of a cliff collapse, for example, and the receptor may be among others, the population, establishments/business, agricultural areas (Figure 2.8).

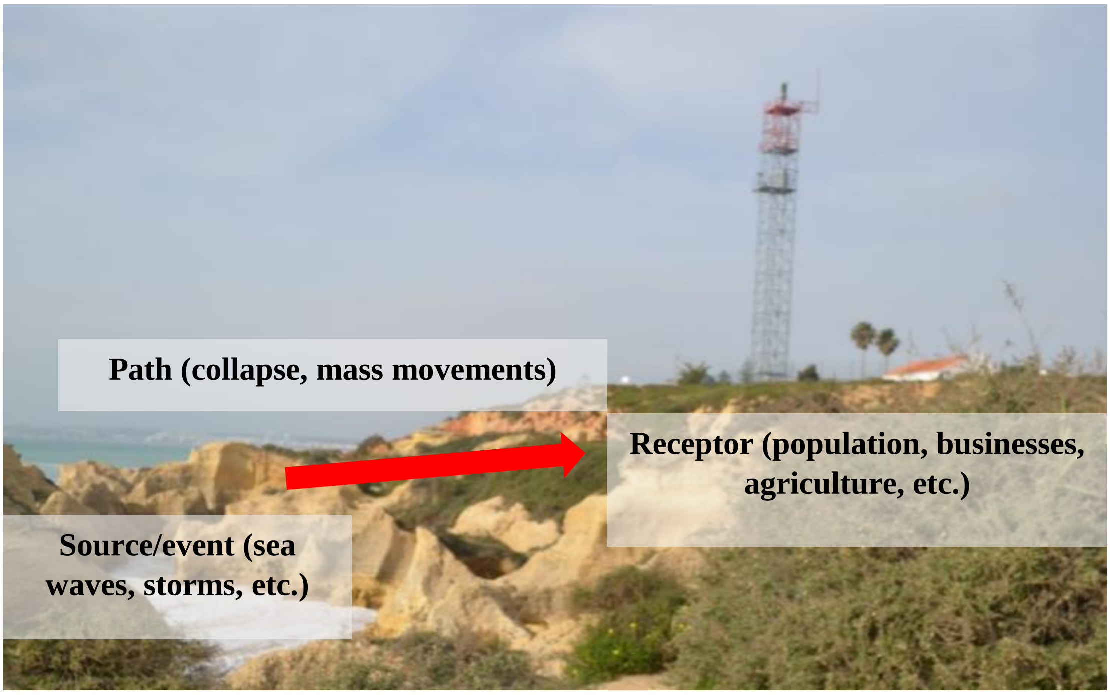

Figure 2.8 – Source-Path-Receptor sequence (Manuel Lourenço's beach, Albufeira)

In Portugal, the word hazard is often mistakenly understood as a synonym of risk, expressed in several official documents as risk assessment when actually is only a hazard analysis.

Research based on hazard evaluation is limited and this has became a relevant issue over the last decade.

2.2.3 Consequence (Impact)

Consequence is all the damage that resulted from a particular event/phenomenon, in a social, economic and environmental level (Gouldby and Samuels, 2005). Specifically in coastal areas, consequence is essentially related with damage to buildings, infra-structure and socio-economic activities, considering their vulnerability and exposure. On the other hand, a fundamental aspect inherent to hazards must be considered, when entities are affected, and that is resilience; this aspect depends on element exposure and vulnerability that will have a greater or lesser responsiveness after an event occurrence (Garrity *et al*., 2006).

In mathematical terms, according to Koppenjan and Klijn (2004):

$C = E \times V$ (Equation 2)

C = Consequence

E = Exposure

V = Vulnerability

2.2.3.1 Exposure

Exposure represents and quantifies people, goods and activities susceptible to being affected by an hazard (Green and Penning-Rowsell, 2004). It is considered a quantifiable variable when it comes to an approximation made by large areas and a qualifying variable in case of small areas; a large area integrates the exposure (or different types) by the area, whereas in a small area each exposed element is seen individually (or grouped by identical categories). Table 2.2, created by Coelho (2005), demonstrates the quantifiable variables, being just an application example.

Table 2.2 - Examples of exposure classes (Coelho, 2005)

Exposure factors	**Classes**				
	Very low	Low	Moderate	High	Very high
Population density (inhabitants/km^2)	<100	100 – 200	200 – 350	350 – 500	>500
Economic activities (number of enterprises/county)	<2000	2000 – 4000	4000 - 6000	6000 – 8000	>8000
Ecology	Areas without ecological relevance	National Agricultural Reserve	National Ecological Reserve	Ecological Protection Zones	Nature Reserves
Historical heritage (number of elements/parish)	<5	5 – 15	15 – 25	25 - 35	>35

As shown in Table 2.2, the population is a key factor in risk assessment and it can be both the risk inductor variable as the variable at risk.

2.2.3.2 Vulnerability

Vulnerability represents all the inherent characteristics in a system that create a potential harm, independently of any specific danger or extreme event probability (Sarewitz *et al*., 2003). The coastal areas vulnerability to environmental conditions (e.g. waves, tides, currents, floods, winds) can also be understood as the sensitivity of biophysical systems, manifested by hydromorphological changes (Nunes *et al*, 2009; Bezerra *et al*, 2011). On the other hand, there is a transversal concept of vulnerability that focuses on social, economic and ecological uses and values existing in a given area.

Balica *et al*. (2012) proposed a coastal vulnerability system, specifying all present components and their interconnections (Figure 2.9).

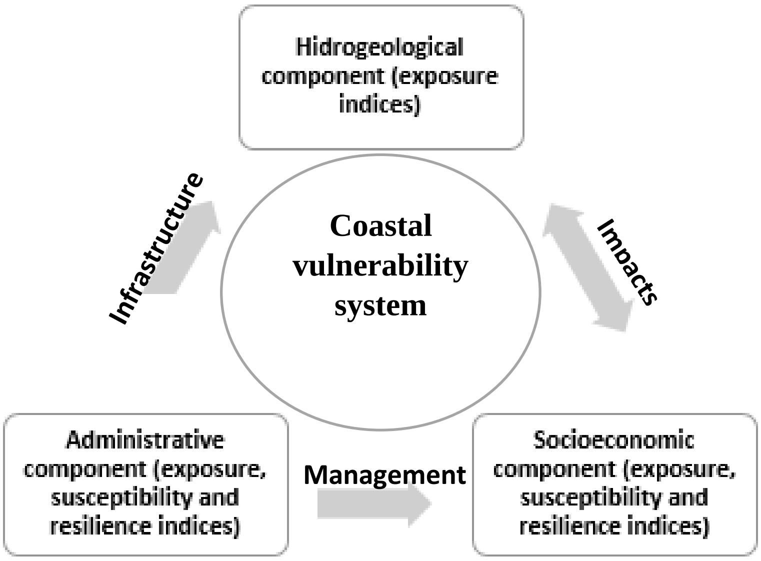

Figure 2.9 - Coastal vulnerability system (adapted from Balica *et al*., 2012)

In mathematical terms, according to Koppenjan and Klijn (2004):

$V = S \times Va$ (Equation 3)

V = Vulnerability

S = Sensibility

Va = Value

Sensibility describes the tendency of a receptor to be damaged and the value can be expressed either quantitatively, by category or descriptively. (Gouldby and Samuels, 2004). The sensibility can also be understood as the susceptibility of a particular good to the hazard and the value can take a monetary cost and/or be classified by importance degree.

Satta *et al*. (2016), in their research based on a Multi Scale Coastal Risk Index method, classified different important types of coastal vulnerability (Table 2.3).

Table 2.3 - Different types of coastal vulnerabilities (Satta *et al*., 2016)

Coastal vulnerability	Description	Score				
		1	2	3	4	5
Landform	Expresses the erodibility of the coastal zone. Scores are ranked according to the relative resistance of a given landform to erosion.	Hard Rock shores	Soft Rock Shores	River deltas, estuaries and cobble beaches	Sandy shores backed by bedrock or artificial frontage	Sandy shores and water plains
Coastal slope	Related to the relative risk of the shoreline retreat.	> 0,1	0,1 - 0,05	0,049 - 0,034	0,033 - 0,02	< 0,02
Land roughness	Represents the resistance to surface flow exerted by the land surface and is measured with the Manning's coefficient.	Urban Areas	Forest and Water bodies	Shrub land, grasslands, Sparse Vegetation	Agriculture	Bare areas
Historical Shoreline	Percentage of eroded coast / sediment budget.	> 30% in Accretion	30% - 10% - in accretion	9,9% - 9,9% Stable	10% - 30% erosion	> 30% erosion
Elevation	Represents the surface of selected coastal unit (pixel) within a specific class of elevation Xi (e.g. 0.15m_Xi _ 0.3 m).	8 - 5,26	5,25 - 3,6	3,59 - 2,76	2,75 - 1	< 1
Distance from the shoreline	Related to risk progression according to the inland penetration of the flooding.	> 4500	4500 - 2100	2099 – 900	899 - 300	< 300

River flow regulation	Represents the impact of dams on river flow regulation in terms of sediment supply.	No dams	/	Dams only in the minor tributaries	/	Dams in the largest tributary
Ecosystems health	Expresses the contribution of the ecosystem as a protection against storm surges, flooding and other coastal hazards.	No detectable change	Slight signs of disturbance	Moderate distortions with loss of 50% of Species	Major distortions	Severe distortions with loss of all species
Education level	Percentage of population whose level is equal at least to the level 3 of the ISCED.	> 60	60 - 44	43 – 28	27 - 10	< 10
Age of population (P65)	Percentage of population that is aged 65 years or older.	<3	3 - 8,5	8,6 – 15	16 - 20	> 20
Coastal protection	Percentage of the coastline with CPS (groynes, seawalls, revetments, etc.)	> 50	50 - 31	30 – 21	20 - 5	< 5

2.2.4 Risk cartography

Mapping becomes more and more an essential tool for a fast evaluation of the multiple hazards as well as supporting plan and management decisions (Solomon and Forbes, 1999). Considering the spatial dimension of the elements needed to determine the risk of a specific coastal area, these are usually mapped using a Geographic Information System (GIS), resulting in a risk mapping (UN/ISDR, 2004). A GIS's main functionality is spatial analysis, having the ability to integrate numerous data files, both physical (e.g. topography) and social (e.g. population), for hazard vulnerability and risk assessment (Seenath *et al*., 2016). The use of GIS also gives the opportunity to perform hot spot (the most affected areas) analysis (Torresan *et al*., 2012).

For a proper classification of coastal risk, ArcGIS software is very useful tool, which allows the mapping of coastal morphologies and different occupancy types present at or near the coast. Moreover, GIS applications and capabilities can be used to combine factors in order to produce hazard and risk maps (Nunes *et al*., 2009).

2.3 Coastal risk management

In general, risk management is known to be the systematic application of policies, procedures and management practices to identifying tasks, analyzing, evaluating, treating and monitoring risks. Involves a formal and quantitative assessment of the damage and/or potential losses over a given period (Helm, 1996).

Risk management approaches to coastal hazards have attracted significant attention for at least the past decade (Wainwright *et al*., 2015). To reach a sustainable and responsible coastal management, it is necessary to understand the coastal system, its physical processes (sediment transport patterns, sediment sources and sinks), forcing factors (wave energy, storms, tides currents), as well as their interconnections and effects.

Coastal management plans provide the basis for land use planning, beach management, sustainable tourism development, coastal water regulation and nature conservation (Taveira-Pinto, 2004). The ICZM – Integrated Coastal Zone Management - is a working and continuous process to promote a dynamic balance between economic growth, human use of natural resources and environmental protection of coastal systems (Cantasano and Pellicone, 2014). Ideally ICZM considers both shortterm and long-term impacts, therefore it is difficult to say for certain which activities, trends and processes will prevail in the future (Fabbri, 1998). ICZM protocols proposes the definition of a setback zone as an area to prevent natural hazards (Satta, 2014).

In Portugal, arguments and discussions about coastal management arrived quite late. The first decision happened in 1993, when it was decided that the entire Portuguese coast should be subjected to CZMP (Coastal Zone Management Plans), and these would be the next revolution in coastal areas (Gomes and Pinto, 2003). CZMP are widely referred in Portuguese by the acronym POOC, from *Plano de Ordenamento da Orla Costeira*, but recently changed to POC *(Plano da Orla Costeira)*. The POC keeps the scope of the preceding POOC, is an instrument to improve, valuate and manage the coastal resources, in order to protect and preserve the different coastal areas, specially critical areas (Ribeiro, 2010). Figure 2.10 illustrates the coastal area covered by POC (established by the old POOC), created by the Environmental Portuguese Agency (APA).

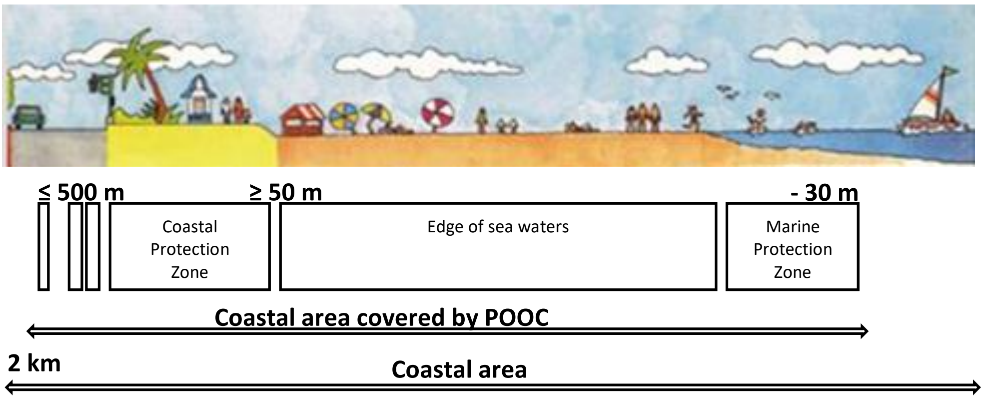

Figure 2.10 - Coastal area covered by POOC (adapted from APA, 2015)

The study area is integrated in the Odeceixe-Vilamoura POC (new Burgau-Vilamoura POOC) (Figure 2.11) and this, in turn, determines specific rules for the coast, by submitting proposals to integrate and articulate structural solutions to existing problems in coastal strip (Veloso-Gomes and Taveira-Pinto, 2003). The landward CPZ – Coastal Protection Zone - was defined according to the expected retreat of the coastline based on the magnitude of singular mass movements (Nunes, 2007).

The POOC includes a conditioning plan for the study area, where the main constraints are the prevention of certain activities and infrastructure by REN (National Ecological Reserve) and DPH (Hydric Public Domain).

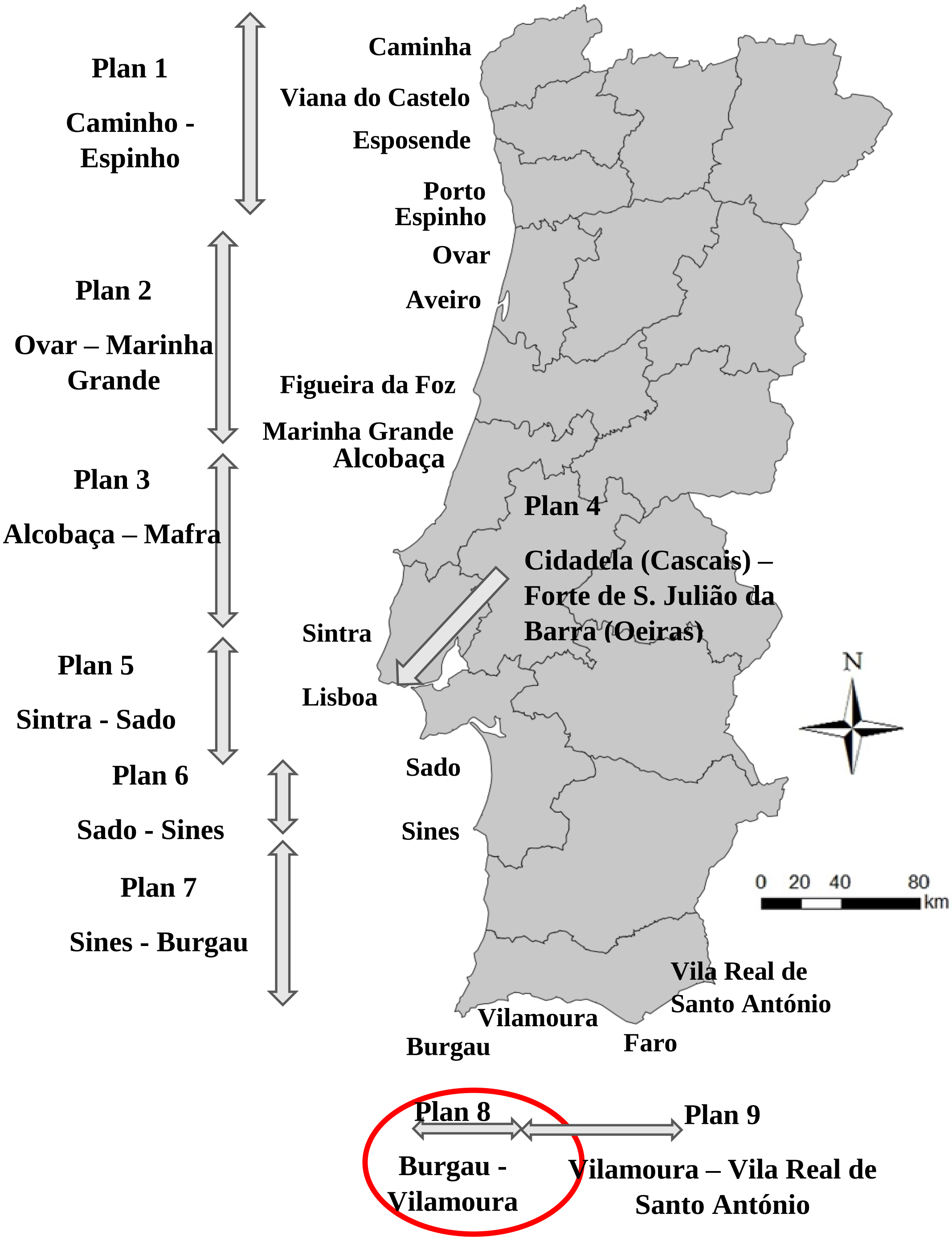

Figure 2.11 – Coastal Zone Management Plans: Plan 8 including the study area (adapted from Taveira-Pinto, 2004)

There is also a growing need for administrative and government support at various levels and in different sectors, such as the establishment of measures and strategies for coastal management; furthermore, it is crucial to improve significantly the flow of information, increasing the levels of communication and in terms of quality and quantity of information (Taveira Pinto, 2004).

While there is a major concern about the beach users regarding danger situations, there is still little interest in local communities in the different risks associated. In general, people just look for their own benefict, such as having a successful economic activity near the coastline, and there is still a certain level of unawareness in respect to coastal problems (Nunes, 2007).

In addition to CZMP, Regional and Municipal level plans have also coastal management proposals, such as (Taveira-Pinto, 2004):

- Implement measures that can lead to the reduction of intra regional development inequalities;
- Regulate territorial development;
- Establish regulatory planning tools;
- Establish the land use management by zoning, by proposing models of human occupancy, urban and transport organization, physical infrastructures location and parameters of land use and environmental quality;
- Define a model for regional territorial organization;
- Establish the carrying capacity of the territory;
- Support the social and economic development policies.

Although Regional and Municipal plans consider the problems of instability of rocky coast as a major concern there are still setting up areas for construction and defining urban perimeters.

3. Study area

The study area is the coastal area between Galé beach and Albufeira's marina, which is situated in the western Algarve, with a length of approximately 6 km (Figure 3.1). Geomorphologically, this area is dominated by rocky cliffs (Moura *et al*., 2006).

From Ponta da Baleeira, where Albufeira's marina was built, until Galé beach, the existing beaches have variable lenght, restrained by the configuration of the cliff coastline (Figure 3.2). Some of these beaches present only access by sea due to their small sizes and rough acessibility.

Over recent years, the central Algarve coast has been the subject of research, regarding the geomorphology (Moura *et al*., 2006) and its variability to sea level rise (Moura *et al*., 2007), the coastal exposure to the dominant waves and its relationship with cliffs lithology (Bezerra *et al*, 2011); the analysis of mass movements (Marques, 1997; Teixeira, 2006), cliffs evolution rate (Marques, 1997; Moura et al., 2011) and the associated hazards (Teixeira, 2014), as well as the determination and assessment of hazard indexes (Nunes, 2007; Nunes *et al*., 2009).

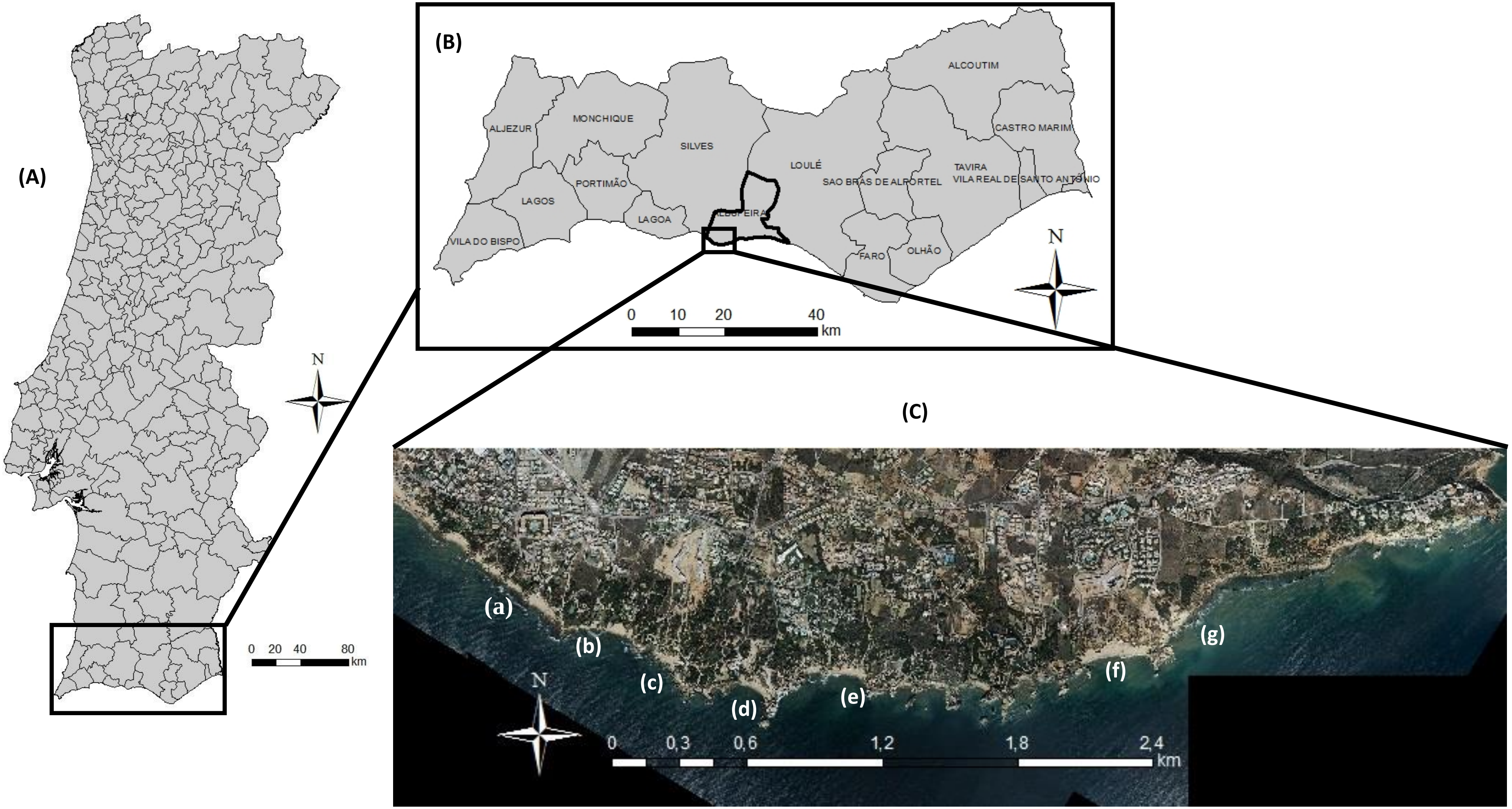

Figure 3.1 - Study area and main beaches view: (A) mainland Portugal; (B) Algarve region, with Albufeira municipality highlighted; (C) Study area with all the seven beaches on study (Figure 3.2)

Figure 3.2 - The seven beaches present on study area

3.1 Geomorphology

The rocky coast of the study area incorporates different morphological types, such as stacks, arches, caves, pinnacles, abrasion platforms and cliffs, mostly with a vertical profile (Figure 3.3).

Figure 3.3 - Morphological variability of rocky coast (São Rafael beach, Albufeira)

Cliff height in this area varies between 5 and 40 m (Teixeira, 2014). The predominant lithology of the cliffs in western and central sections of the study area is Miocene carbonate rocks and sandstones of the Plio-Pleistocene, while at the eastern sections cliffs are dominated by marly limestones of Cretaceous age (Teixeira, 2006; Terrinha *et al*, 2006; Bezerra *et al*., 2011). The Miocene rocky coast is moderately compact and, as such, considered more resistant to erosion, while Plio-Quaternary (lying on top of the Miocene rocky layer) consists of reddish clay-silty sands, and is softer and less resistant than the previous in relation to erosion processes (Bezerra *et al*., 2011).The area comprising São Rafael beach and Arrifes beach (until Albufeira's marina) includes a sequence of more resistant Jurassic limestone, vertical and horizontal marls from the Cretaceous and Miocene calcarenites and, still close to São Rafael beach, are marls and argillites (Moura *et al*., 2006, 2011). Also the coastline orientation is different along the study area, being the coastline that between Galé and Ponta do Castelo oriented NW-SE, between Ponta do Castelo and São Rafael W-E and between São Rafael and Albufeira's marina coastal orientation is SW-NE (Bezerra *et al*., 2011).

Shore platforms in the intertidal zone vary along the study area with respect to constituent lithology, roughness, topography, and slope (Moura *et al*., 2011). The resistant shore platforms provide protection to cliffs since they dissipate wave energy and force waves to break further offshore, thereby reducing the number and energy of waves that reach the cliff base (Lee EM & Clark A., 2002 in Nunes *et al*., 2009).

3.2 Wave exposure

Regarding the oceanographic characteristics of the Algarve coast, the significant height of waves has an annual average of 1 m and an average peak period of 8.2 seconds (Costa *et al*., 2001). About 85% of storms, where significant height reaches 2.5 m or more, occur during the winter (October to March) and arrive mainly from the SW. These events can persist for 2 – 5 days and reach maximum significant wave height greater than 6 m (Costa *et al*., 2001). The tide is considered semidiurnal and characterized by an average range of 2 m, although tidal range in this area may exceed 3 m.

The study area presents different exposure to the dominant waves: from Galé to Ponta do Castelo there is a high degree of exposure to SW waves (and a greater attenuation of SE waves), from Ponta do Castelo to São Rafael beach the coastline has higher exposure to the SW and SE (tends to be the most energetic) and from São Rafael beach to Marina de Albufeira is highly exposed to the SE incident waves (Bezerra *et al.*, 2011).

3.3 Ciff evolution

Cliff evolution is the result of interaction between the subaerial and marine erosion (Davies, 1972; Nunes *et al*., 2009). Specifically for the study area, cliff retreat is mainly caused by marine erosion (Dias and Neal, 1992) in the form of mass movements; the vertical profile, present in most of the study area denotes a dominant marine action (Figure 3.4), while it is heavily dependent on the position where the weakest layers occur and on the degree of karsification (Bezerra *et al.*, 2011).

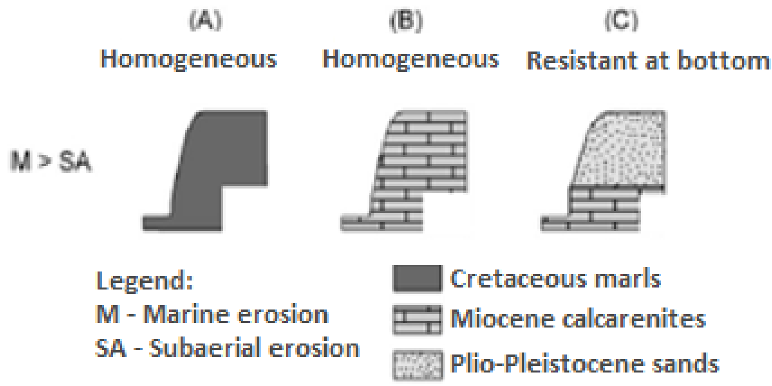

Figure 3.4 - Cliffs dominant profile on the study area, according to the lithological composition and dominant erosion type (adapted from Nunes *et al*., 2009)

The lithology determines different evolution processes (Dias and Neal, 1992), as is the case of the cliffs dominated by Miocene carbonate rocks. This cliffs evolve mostly during the stormy season, by wave weakening of the cliff base, which leads to cliff collapse and fall. On the other hand, the Plio Quaternary sandstones evolve mainly by landslide and small falls (Nunes, 2007).

The two different directions of the sea waves present on the study area – SW and SE - have different energetic conditions that when combined with morphological, lithological, and structural frames determine differential cliff hazard ratings and evolution due to mass movements (Bezerra *et al*., 2011; Nunes *et al*., 2009).

Teixeira (2006) shows that 80% of cliffs mass movements in the study area occur after the action of intense ocean storms or rainfall events. Despite variations in wave exposure and wave energy along the coast, rock lithology and structure play an important role on mass movement occurrence along the studied coastline (Bezerra *et al*., 2011).

Teixeira (2006) determined the inland extension, on the study area, on the basis of a return period, through the mass movements analysis in aerial photographs, between 1995 and 2004, that includes 140 recorded events. The Table 3.1 presents that the values of inland extension correspond to values for the hazard lines extension for defined periods. In turn, these values represent the extension of hazardous areas for a return period between 1 to 100 years.

Table 3.1 – References values of return period of the mass movement extension (adapted from Teixeira, 2006)

Return period (year)	**Hazard line**	**Mean extension (m)**	**Maximum extension (m)**
1	H_1	6	8
5	H_5	12	16
10	H_{10}	16	23
25	H_{25}	25	35
50	H_{50}	34	48
100	H_{100}	47	67

Teixeira (2006), presented above, conducted an analysis of slope mass movements on rocky sea cliffs on the Barlavento coast, in Algarve. This study enabled to define hazard lines and return period for mass movements through statistical analysis, based on inventories of mass movement in the Miocene calcarenites cliffs. Later, Nunes *et al*. (2009) carried out an important survey regarding the different hazard factors in rocky cliffs at Central Algarve demonstrating that the coastal area between Galé and Olhos de Água are mostly subjected to high and very high hazard, revealing a relation between the higher vulnerability areas and the larger mass movement average lengths, mainly due to the relationship between two factors: exposure to waves and the existence of Miocene biocalcarenites cliffs, with an indicative vertical profile of marine erosion. More recently, Teixeira (2014) reevaluated coastal hazards resulting from slope mass movements on Algarve's Barlavento Coast. This study showed that the continuous inventory of mass movements collected during nineteen years, presented on average 13 mass movements per year, mainly rock falls, concentrated during the winter and early spring. Also 78% of movements occurred in cliffs that are adjacent to beaches, in contrast to natural resistant headlands and promontories where only 22% of mass movements occurred.

3.4 Occupancy and tourism

The occupancy is an important factor in coastal risk assessments (Cearreta *et al*, 2013; Isla, 2013), particularly in the Algarve, as this increased significantly in the last decades (Dias and Neal, 1992; Teixeira, 2006).

Algarve has been the main destination for summer holidays tourism since the late 1960's (Almeida, 2012). In 2011, the Algarve had 451 006 inhabitants and Albufeira municipality had 40 351 inhabitants. From 2001 till 2011, there was a growth of around 30% on the resident population (Figure 3.5).

Albufeira is one of the oldest tourist destinations that has been successively growing as a touristic destination.

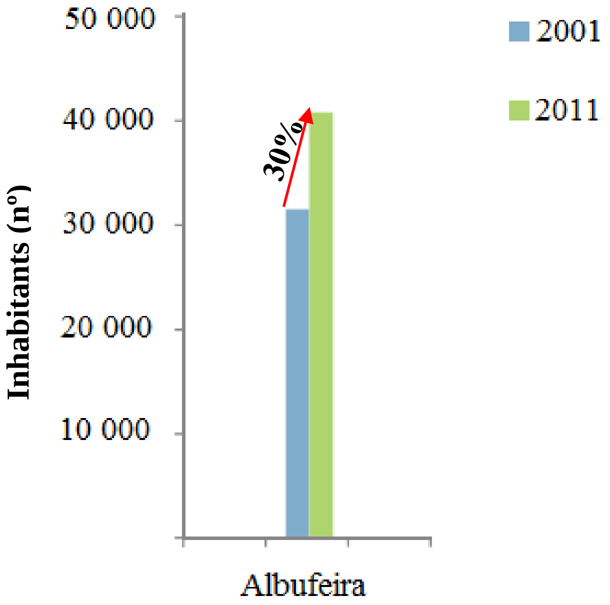

Figure 3.5 - Resident population growth (Census 2011)

Table 3.2 presents statistical data concerning the population, households, buildings and dwellings growth rate (from 2001 till 2011), and also proportion of seasonal dwellings (in 2011) and tourism accomodation growth (from 2009 till 2013) for the Algarve and Albufeira.

Table 3.2 Variations of the occupation per type for the Algarve and Albufeira between 2001 and 2011 and for tourism accomodation between 2009 and 2013 (source data: Census 2011 Portugal)

Variables		Algarve	Albufeira
Resident population growth (%), 01-11		14.1	29.4
Households growth (%), 01-11		22.5	>30
Buildings growth (%), 01-11		23.9	40.6
Dwellings growth (%), 01-11		36.5	47.1
Proportion of seasonal dwellings (%), 2011		39.5	>50
Tourism accomodation variation by type (%), 09-13	Hotels	31.9	43.5
	Apart-hotels	16.4	10.7
	Tourist resort	41.7	- 10
	Tourist apartments	13.1	5.9

As seen on Table 3.2, there is an increase of the occupation per type in Algarve and also in Albufeira, except for the tourist resorts. In Albufeira, the proportion of seasonal dwellings, in 2011, was more than 50% of the total dwellings, a quite significant portion. The existence of beaches and other leisure related to the sea and sun tourism allowed a remarkable growth in population and buildings, mainly in a context of tourism occupation type.

In respect to the tourism accomodation, tourist resort and also hotels assume great importance in the accomodation capacity increase, representing an increase of 41.7% and 31.9%, respectively, in the Algarve. In this context, in Albufeira, hotels show the most significant growth, indicating a notable rise (43.5%).

The constant increase of population, foreign and national visitors, as well as the tourist activities and seasonal dwellings growth has created different problems, mainly conflits between coastal urban development and coastal natural dynamic. In Albufeira this problem is visible, economic and seasonal activities and buildings are constantly growing near the coastline.

The study area presents a spatially differentiated exposure, i.e., the beach is usually occupied by the population, beach facilities and water activities (Figure 3.6a) while the cliff top upper area is occupied by houses, establishments (restaurants and hotels) and other exposure components, such as car parks, green areas, among others (Figure 3.6b).

Figure 3.6 - Anthropic occupation of the coast: (a) Beach facilities and tourist occupation in rocky coast (São Rafael beach, Albufeira); (b) Housing near cliff top (Arrifes beach, Albufeira)

3.5 Proposed measures

Regarding to the beach area, the nameplates/signs warning about the danger of landslides (Figure 3.7a) are more and more common nowadays, alongside with beach nourishment (Figure 3.7b), implemented and carried out by APA in order to reduce the associated risk.

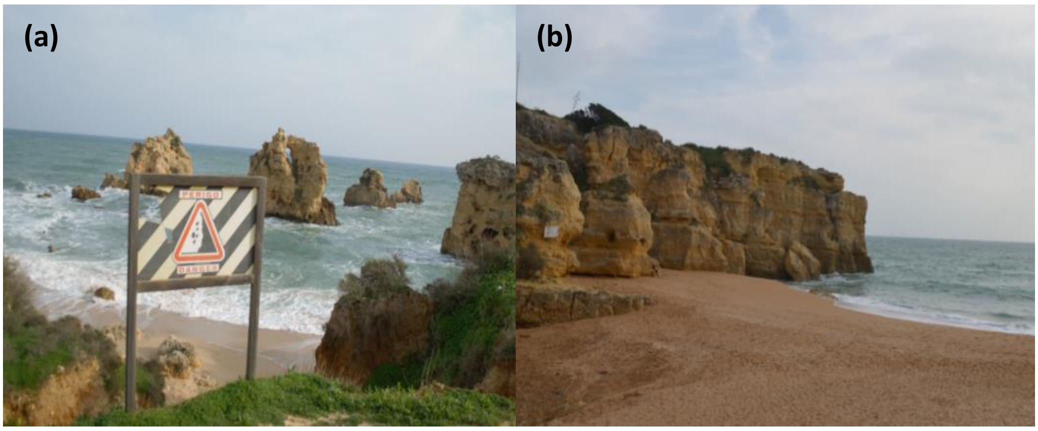

Figure 3.7 - Coastal management measures: (a) Landslides warning nameplate (Arrifes beach, Albufeira); (b) Beach sand refill carried out in July 2015 (Coelha beach, Albufeira)

The majority of beaches in the study area present danger zones associated with cliffs falls, which are mapped in order to inform and prevent use by beach users of the exact places where they are subject to phenomena and hazardous situations (Figure 3.8).

Figure 3.8 – Hazard mapping of Coelha beach, Albufeira

In addition, specifically to the area of interest for this study (cliff top upper area) and according to POC, the protection zone was aimed to guarantee the safe use of the coast. This was accomplished by defining a cliff-top landward strip with 150 m width between Galé and Arrifes beaches, based on the mass movements extension and the development of karstic depressions that could affect occupancy. For this 150 m wide protection zone, special measures were implemented, such as prohibit new buildings (swimming pools, terraces or other impermeable surfaces, even affecting residential buildings, hotels, tourist and sports equipment) in areas which, by their nature, have an increased associated risk (OECD, 2011); prohibit the opening or consolidation of access roads for vehicles or parking areas (except when intended for security services, emergency or support and maintenance of coastal areas); prohibit the construction of elevated water tanks for public supply; prohibit installation of billboards and golf courses or any other activity that involves intensive irrigation (RCM, 1999). Despite the limitations stated above, according with the beach plans, new parking areas were constructed or are still in construction in Manuel Lourenço, Arrifes, Evaristo, Castelo and Galé.

In August 2009, a sea stack collapse occured on the Maria Luisa beach, in Albufeira (Figure 3.9), with a failure in volume of approximately 100 m^3 (with a width of 2 m and a length of 6 m). This accident killed 5 people and injured 2, which were occupying the area near the base of the sea stack. All measures and strategies when applied will provide the needed prevention and minimize accidents like the one that occurred in Maria Luisa beach (in Algarve), in 2009 (Teixeira, 2009b). These measures are taken in order to alert the public about the occurrence of such events because, although low in frequency, they are high in magnitude (Teixeira, 2006). In the context of this thesis, this event will not be analysed and the management possibilities will not address this specific question, but instead are adjacent to the top of the cliff.

Figure 3.9 - The affected area by the sea stack collapse in Maria Luisa beach (August 2009): (a) Photo taken by Luís Forra and (b) Photo taken by João Xavier

4. Methodology

This main goal of the study as to determine the risk at the cliff top upper area (Figure 4.1). As such a specific methodology was needed to determine the risk nature and extent, which can be done by analysing potential hazards and evaluating existing vulnerability conditions including population, property, economic activity and the ecological and environmental systems exposed to possible dangerous situations (UN/ISDR, 2004).

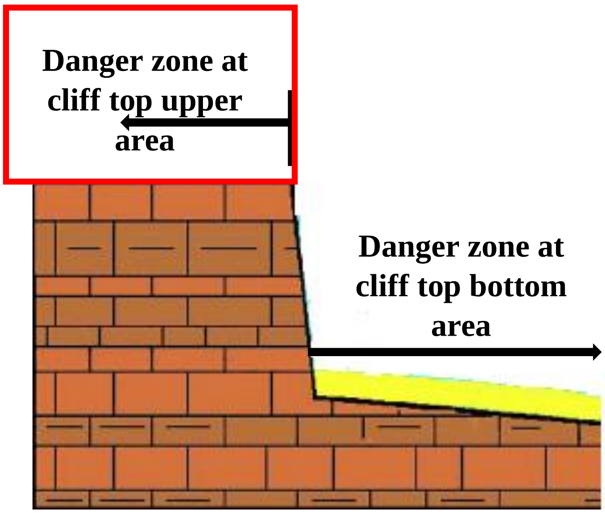

Figure 4.1 - Rocky coast potencial dangerous zones: area of interest for dissertation marked in red (adapted from Teixeira, 2014)

The methodology adopted in this study was based in a project, called RISC-KIT (http://www.risckit.eu/), that created the Coastal Risk Assessment Framework – CRAF - to assess the coastal risk based on a Coastal Index, very useful and essential for developing suitable coastal management plans. CRAF1 (Phase 1) integrates a hazard index and exposure indicators to create a final Coastal Index, in order to identify the most affected areas (Ferreira *et al.*, 2016).

The Coastal Index (CI) is calculated using the following equation:

$$CI = \left[\left(i_h \times i_{exp}\right)\right]^{\frac{1}{2}} \qquad \text{(Equation 4)}$$

CI = Coastal Index

I_h = Hazard Index

I_{exp} = Exposure Index

The hazard index is rated from 0 to 5 (nonexistent, very low, low, medium, high and very high). The overall exposure index is rated from 1 to 5 and is a combination of five exposure types, which are representative of potential direct and indirect impacts, such as (RISK-KIT, 2015):

- Land Use (iexp-LU) - measures the relative exposure of land uses (urban areas or rural areas) along the coast;
- Population (iexp-POP) – requires the adaption and/or creation of a Social Vulnerability Index (SVI);
- Transport systems (iexp-TS) – measures the relative exposure of different types of transport infrastructures, such as highways, local roads, etc;
- Critical Infrastructures (iexp-UT) – measures the relative exposure of different essential services, like water, electricity, communications, emergency, etc;
- Business (iexp-BS) – called also economic activity, measures the relative exposure of different kinds of business, such as hotels, restaurants, shops, etc.

As indicated above, each exposure component is rated from 1 to 5 given that it is a geometric mean and cannot take a null value. The overall exposure index is then calculated by:

$$i_{exp} = \left[\left(i_{exp-LU} \times i_{exp-POP} \times i_{exp-TS} \times i_{exp-UT} \times i_{exp-BS}\right)\right]^{1/5} \quad \text{(Equation 5)}$$

The exposure took a qualifying value, because the analyzed area is small, and each place was rated individually according to the different occupancy categories. Although this work consists mainly on Hazard x Exposure calculation, the vulnerability was introduced occasionally in some exposure items.

The methodology applied in this thesis includes two consecutive phases:

1) Coastal Index calculation – using the above-mentioned methodology, the Coastal Index was calculated considering specific factors of the study area and a sequence of actions, including:

I. A detailed mapping of the cliff top line; the cliff top line is essential for mapping, as precise as possible, the existing risk at the cliff top (section 4.1);

II. The determination of the areas associated with different hazard degrees based on the return period of mass movements (section 4.2);

III. The detailed mapping of different types of occupancy (land use, population, transport system and economic activity) (Figure 4.2) (section 4.3).

These methods allowed the rocky coasts zoning according to risk levels (hazard and impact) as also the recognition of critical areas where specific intervention strategies should be adopted.

Figure 4.2 - Different exposure components of study area: (a) Residential building (Arrifes beach); (b) Restaurant (Castelo beach); (c) Parking area (São Rafael beach); (d) Tourist building (Galé beach)

2) Coastal risk management proposals – an analysis of existing coastal management plans was performed and improvements proposed, including new measures and strategies that contribute to reduce the cliff top risk; these measures are based on the hotspots characteristics identified on the study area.

The risk maps represent the main outcome of the methodology developed and the values identified for each variable are associated to a coastal spatial unit through a GIS application. ArcGIS software (version 10.4.1) was used for the analysis of various spatial information types.

Figure 4.3 shows a very brief outline of the case study methodology.

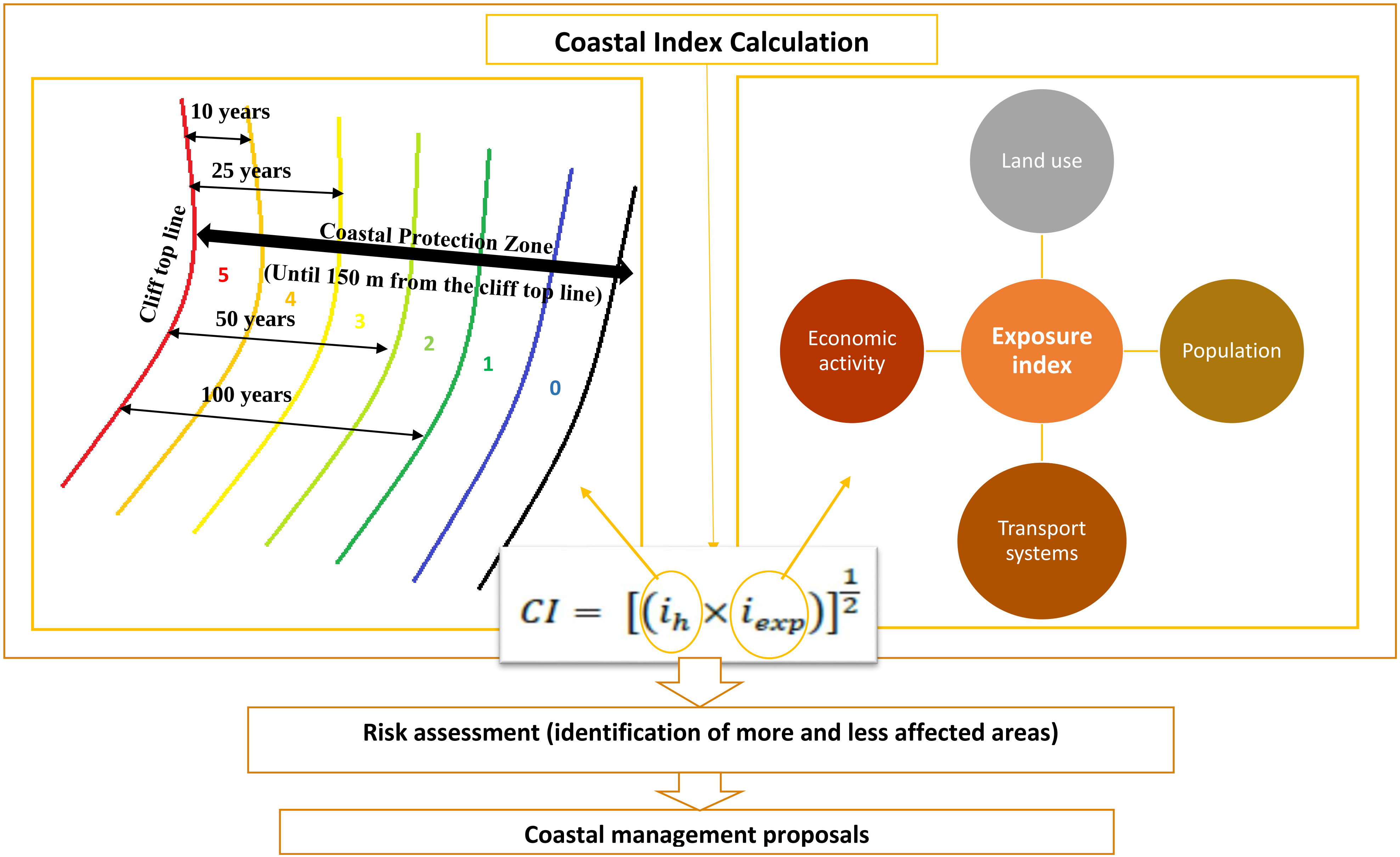

Figure 4.3 - Thesis methodolody

4.1Cliff Top Line

For the demarcation of the cliff top line, the 2008’s orthophotography (Figure 4.4) was used. This orthophotography shows advantage, since it is a realistic representation of the coast surface (Haberling and Hurni, 2002) and presents a resolution of 10 cm (Silva *et al*., 2012), allowing for detailed and precise analysis.

Figure 4.4 – Sample image of the 2008's orthophoto for the study area (between Castelo’s beach and São Rafael’s beach)

In the demarcation of the cliff top through the visual analysis, some criteria were followed, such as the existence/absence of vegetation that allows, in most cases, the active and exposed cliffs areas to be distinguished from not affected cliffs. In many cases, it was possible to infer that the limit of the natural vegetation occurring on the cliffs corresponds to its top. In several places, this demarcation is simplified by geomorphological criteria, such as the presence of mass movements scars, colouration and textures differences, indicators of different morphology/surfaces and also the contrast of smooth and irregular surfaces. In addition, the preliminary procedure (field visits) on the study area was also important to connect the aerial photographs to different lithologies and morphological features. On the other hand, in some areas lack of vegetation and areas covered by Plio-Quaternary sandstones, the presence of ravines or shadows, make the location of the cliff top a complex task. Figure 4.5 shows an example of the detailed cliff top line demarcation in the study area, for a morphologically complexity section.

Figure 4.5 – Example of the cliff top line demarcation in detail in a morphologically complex zone of the study area

4.2Hazard Index

The Hazard Index calculation was estimated and mapped by knowing the return period of mass movement maximum extension defined by Teixeira (2006), which performed a statistical analysis to compute return period-size distribution and determine the maximum inland extension (maximum width according to Teixeira, 2006) of a mass movement with a return period associated (Figure 4.6).

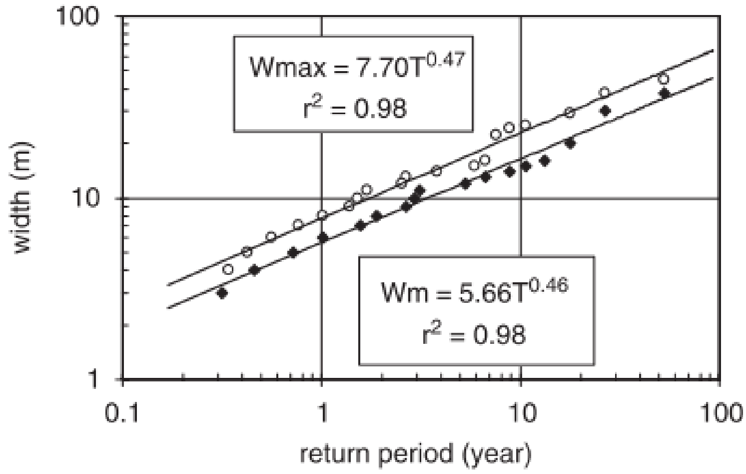

Figure 4.6 - Return period of mass movement maximum and mean inland extension (Teixeira, 2006)

Teixeira (2006) determined the return period of a mass movement maximum inland extension based on the combination of two available inventories for mass movement width (mean and maximum). The mean inland extension series includes 167 events with a mean inland extension equal or larger than 3 m and the maximum inland extension series has 155 events with a maximum inland extension equal or larger than 4 m.

By observing Figure 4.6, the mean and maximum inland extension of a mass movement are 6 and 8 m, respectively, for a return period of 1 year. Table 4.1 shows the reference values of return period of the mass movement extension.

Table 4.1 - Reference return period values of the mass movement width

Return period (year)	Mean width (m)	Maximum width (m)
1	6	8
5	12	16
10	16	23
25	25	35
50	34	48
100	47	67

To achieve the objectives of this thesis, the return period of a mass movement maximum width is a fundamental and essential indicator. Table 4.2 and Figure 4.7 show the reference return period values of the mass movement maximum inland extension and the related hazard level.

Table 4.2 - Reference return period values of the mass movement maximum width and the related hazard level

Return period (year) range	**Maximum width (m) range**	**Hazard level**
<10	<23	5
[10 – 25[	[23 – 35[	4
[25 – 50[	[35 – 48[	3
[50 – 100[	[48 – 67[	2
Coastal Protection Zone (m)	[67 – 150]	1

The hazard level 1 corresponds to the Coastal Protection Zone (CPZ), that was defined and implemented by Burgau – Vilamoura POOC, according to the expected retreat of the coastline based on the magnitude of singular mass movements (Nunes, 2007). Although the protection zone, according with the plan, covers the whole are between the cliff top line (0 m) to 150 m, for calculated questions only the area between 67 m and 150 m was considered.

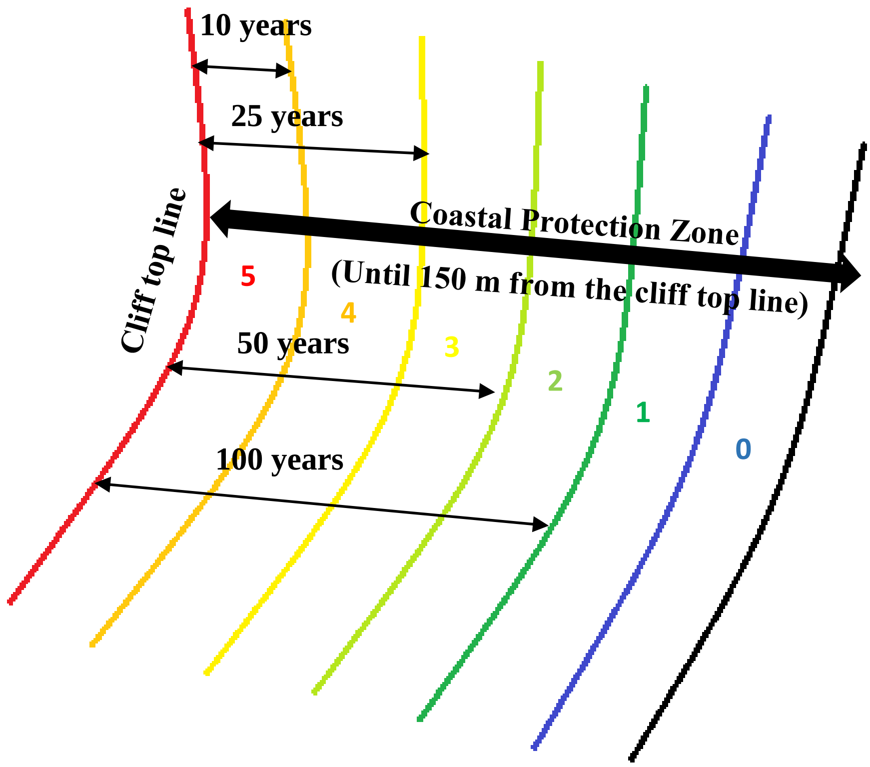

Figure 4.7 - Layout of the proposed hazard index, according to the zoning by mass movement return period

4.3Exposure Index

In relation to the variables of the exposure index – land use, population, transport system, business and critical infrastructure - they are representative for the study area, except the critical infrastructure, since there are no significant essential services and therefore it was not considered for this study. In turn, each variable has different exposure components present in the study area (Figure 4.8). In previous investigations, the exposure variables were not specified, i.e., there is no differentiation between them (e.g. residences, hotels, parking areas, among others). The current dissertation enabled a particular classification of the exposure to a specific hazard, therefore would become an asset to the progress of the coastal dynamics and management.

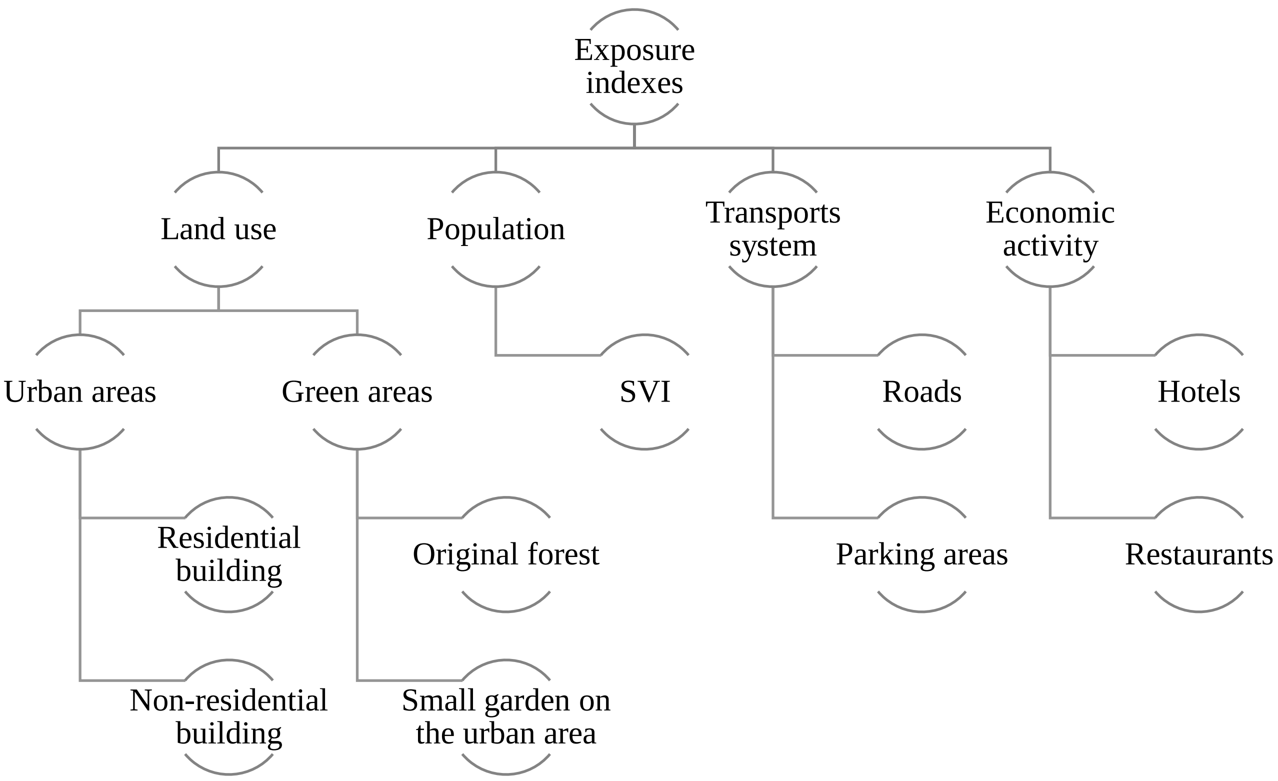

Figure 4.8 - Layout of attributes to consider when setting the exposure index

Table 4.3 presents in detail the different exposure factors that were included in the GIS analysis. The different types and definition of the exposure indexes were created based on exposure indicators created by the project RISC-KIT, as well as the characteristics of the study area, based on expert judgment.

Table 4.3 - Description of the different exposure indexes

Exposure index	**Typology**	**Description**	**Exposure degree**
Land use	Urban areas	Residential building	5
		Non-residential building	4
	Green areas	Original forest	1
		Small garden on the urban area	2
Transport	Roads	Nonexistent or very low	1

		Small road or path	2
		Local importance road	3
		Regional importance road	4
		National importance road	5
	Parking areas	Nonexistent	1
		Informal (unpaved roads until 5 cars)	2
		Small dimensions (1 – 10 cars)	3
		Medium dimensions (15 – 20 cars)	4
		Big dimensions (> 20 cars)	5
Economic activity	Hotels	Nonexistent	1
		Small dimensions hotel/hostel	2
		Local hotel	3
		Regional importance hotel	4
		National/international importance hotel	5
	Restaurants	Nonexistent	1
		Small local restaurant	2
		Big local restaurant	3
		Regional importance restaurant	4
		National/international importance restaurant	5
Exposure Index	**Typology**	**Description**	**Weight**
Population (SVI)	Demography	Unemployment	1
		Low education level	
		Elderly	
	Housing	Small residences	0.25
		Non-home ownership	

The land use was based on the Land Use and Land Cover Map of Continental Portugal for 2007, designed by COS2007, which presents different levels of land use and specific rules to define each area (IGP, 2010). Table 4.3 shows the relevant land use typologies adapted from COS2007 to the study area. The indicators transport and economic activity were mostly based, as mentioned above, on the indexes created by the project RISC-KIT and also the characteristics of the study area (Table 4.3). In some cases, it was difficult to recognize the characteristics of each place to define correctly the exposure degree and, therefore, it was necessary to do fieldwork on the respective area.

The variable related to population exposure was based on a specific index, the Social Vulnerability Index (SVI). The SVI measures the relative vulnerability of different areas to long-term health and financial recovery from an event (Viavattene *et al.*, 2015). In Portugal, there is no SVI widely used and accepted, therefore a SVI was developed for this study. The Figure 4.9 presents all the steps needed to calculate, categorize and map the SVI, according with RISC-KIT methodology.

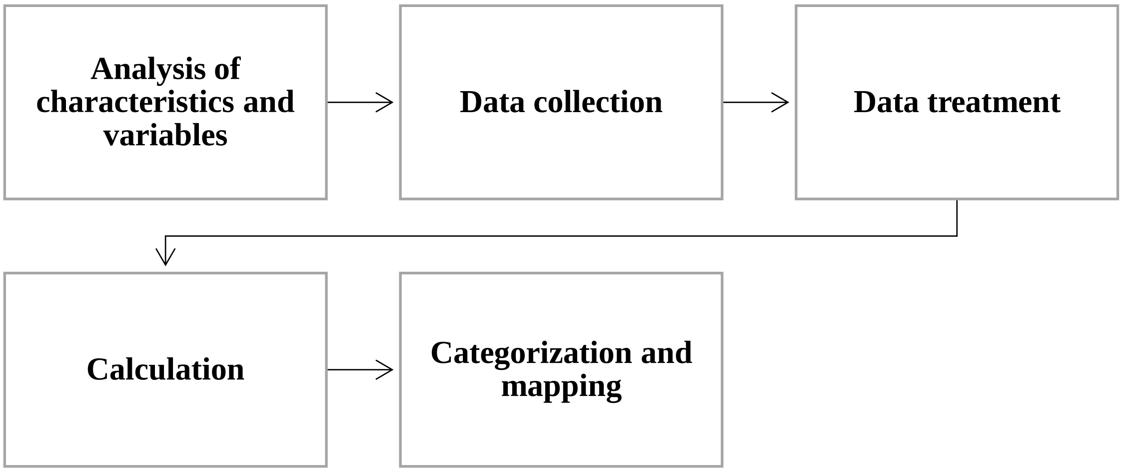

Figure 4.9 - SVI steps

The data used for the SVI were collected by the 2011 Census of Algarve, available in the statistical database on the INE website, and the study area was analysed based on the 2011 Census sub-sections. The Table 4.4 presents the variables chosen significant for this work, which were transformed into percentages of the total population of each sub-sections of the study area.

Table 4.4 - 2011 Census data and SVI variables calculation

2011 Census data	SVI variables
Number of unemployed residents searching for their first job (N_{UFJ})	$Unemployment\ rate = \frac{(N_{U_{FJ}} + N_{U_J})}{N_E} \times 100$
Number of unemployed residents searching for a job (N_{UJ})	
Number of employed residents (N_E)	

Number of residents that does not know how to read or write (N_{DNKRW})	
Number of residents who attends the first stage of the basic education (N_{A1BE})	
Number of residents who attends the second stage of basic education (N_{A2BE})	
Number of residents who attends the third stage of basic education (N_{A3BE})	$Low\ education\ level\ rate = \frac{(N_{DNLRW} + N_{A1BE} + N_{A2BE} + N_{A3BE} + N_{1BEC} + N_{2BEC})}{N_R} \times 100$
Number of residents with the first stage of the basic education complete (N_{1BEC})	
Number of residents with the second stage of the basic education complete (N_{2BEC})	
Number of residents (N_R)	
Conventional dwellings of usual residence with owner-occupier (CD_{URO})	$Non-home\ ownership\ rate = \frac{CD_{RUR}}{(CD_{URO} + CD_{RUR})} \times 100$
Conventional dwellings of rented usual residence (CD_{RUR})	
Number of residents aged over 65 ($N_{>65}$)	$Eldery\ rate = \frac{N_{>65}}{N_R} \times 100$
Number of residents (N_R)	
Conventional dwellings of usual residence with an	

area lower than 50 m2 ($CD_{UR<50M2}$)	$Small\ residences\ rate = \frac{CD_{UR<50M2}}{CD_{US}} \times 100$
Conventional dwellings of usual residence (CD_{US})	

After these calculations, it was necessary to standardise the previous variables as Z scores (Table 4.5), based on log-naturals (ln) and square root transformation.

Table 4.5 - Transformation of variables to Z scores

Variables	Transformation method
Unemployment	$\ln(x+1)$
Low education level	$\ln(x+1)$
Non-home ownership	$\sqrt{x}$
Elderly	$\ln(x+1)$
Small residences	$\ln(x+1)$

The SVI of each sub-section, subsequently, is calculated using the following Equation:

$$SVI = \sum_{i=0}^{n} [W_i \times C_i] \quad \text{(Equation 6)}$$

W = Weight of each category

n = Number of characteristics

C = Characteristics (average of the variables).

Adapted to the case study, the SVI is calculated using the following Equation:

$$\mathrm{SVI} = \mathrm{U} + \mathrm{LE} + \mathrm{E} + ((\mathrm{SR} + \mathrm{NHO}) \times 0.25) \quad \text{(Equation 7)}$$

U = Unemployment

LE = Low education

E = Elderly

SR = Small residences

NHO = Non-home ownership

The variables small residences and non-home ownership present a weight of 0.25, while unemployment, low education and elderly present a weight of 1. This weight difference was created to distinguish the variables related to the housing and to the demography, the latter having a greater importance to the SVI. Lastly, the resultant SVI was categorised into different bands. Given the size of the study area and the sub-division into so few sub--sections, the SVI was not categorised into five bands like the other indicators, but into three bands. Relatively to the exposure degree, these were defined as 1,3 and 5 in order to reduce the concentration in the median values and highlight areas from the others. The Table 4.6 shows the range of SVI values and respective exposure degree.

Table 4.6 - Range of SVI values and associated exposure degree

Range of SVI values	Exposure degree
[-3.28, -0.56[	1
[-0.56, 1.61[	3
[1.61, 4.14[	5

In ArcGIS, for each shapefile, it was added a new field on the attribute table and, this way, the different exposure degrees (1,2,3,4,5) were defined on the respective polygon. After defining the exposure degrees for each exposure indexes, it was necessary to merge the four shapefiles through the union tool. For the final calculation of exposure index, it was necessary to add a field in the attribute table and calculate the exposure index by field calculator option, using the equation for the respective calculation.

$$i_{exp} = \left[\left(i_{exp-LU} \times i_{exp-POP} \times i_{exp-TS} \times i_{exp-EA}\right)\right]^{1/4} \qquad \text{(Equation 8)}$$

4.4 Coastal Index

As for the exposure index, to calculate the coastal index it was also necessary to add a field in the attribute table and calculate the risk by field calculator option, according to the equation for the respective calculation. In ArcGIS, each of the variables and categories defined to risk assessment were represented by polygons.

$$CI = \left[\left(i_h \times i_{exp}\right)\right]^{\frac{1}{2}} \qquad \text{(Equation 9)}$$

CI = Coastal Index

I_h = Hazard Index

I_{exp} = Exposure Index

5. Results

The application of the methods described to the coastal area between Galé and Albufeira's Marina has resulted in the characterization of:

- The hazard index, based on return periods of mass movements (section 4.2);
- Four types of exposure components - land use, population, transport, economic activity - as the principal contributors for assessing exposure in the top of sea cliffs. The aggregation of such factors enabled the definition of an exposure index (section 4.3);
- The coastal index, determined by the aggregation of the hazard index and the exposure index (section 4.4).

5.1 Hazard Index

According to the statistical analysis of past mass movements in this area (Teixeira, 2006), the mass movement maximum landward extension was determined for each given return period (Table 5.1).

Table 5.1 - Wmax associated to a return period according to Teixeira (2006) and CPZ according to POOC

Return period (years)	Wmax (m)	Hazard level
<10	<23	5
[10 – 25[	[23 – 35[	4
[25 – 50[	[35 – 48[	3
[50 – 100[	[48 – 67[	2
CPZ (m)	[67 – 150[	1

As shown on Figure 5.1, there are different hazard degrees – 5, 4, 3, 2 – corresponding, respectively, to a return period of 10, 25, 50 and 100 years. In addition, there is a wider zone – hazard level 1 - known as terrestrial protection strip or coastal protection zone and defined according to the maximum landward limit of the CPZ defined by the POOC for the study area, 150 meters landward from the cliff top line (Figure 5.1)

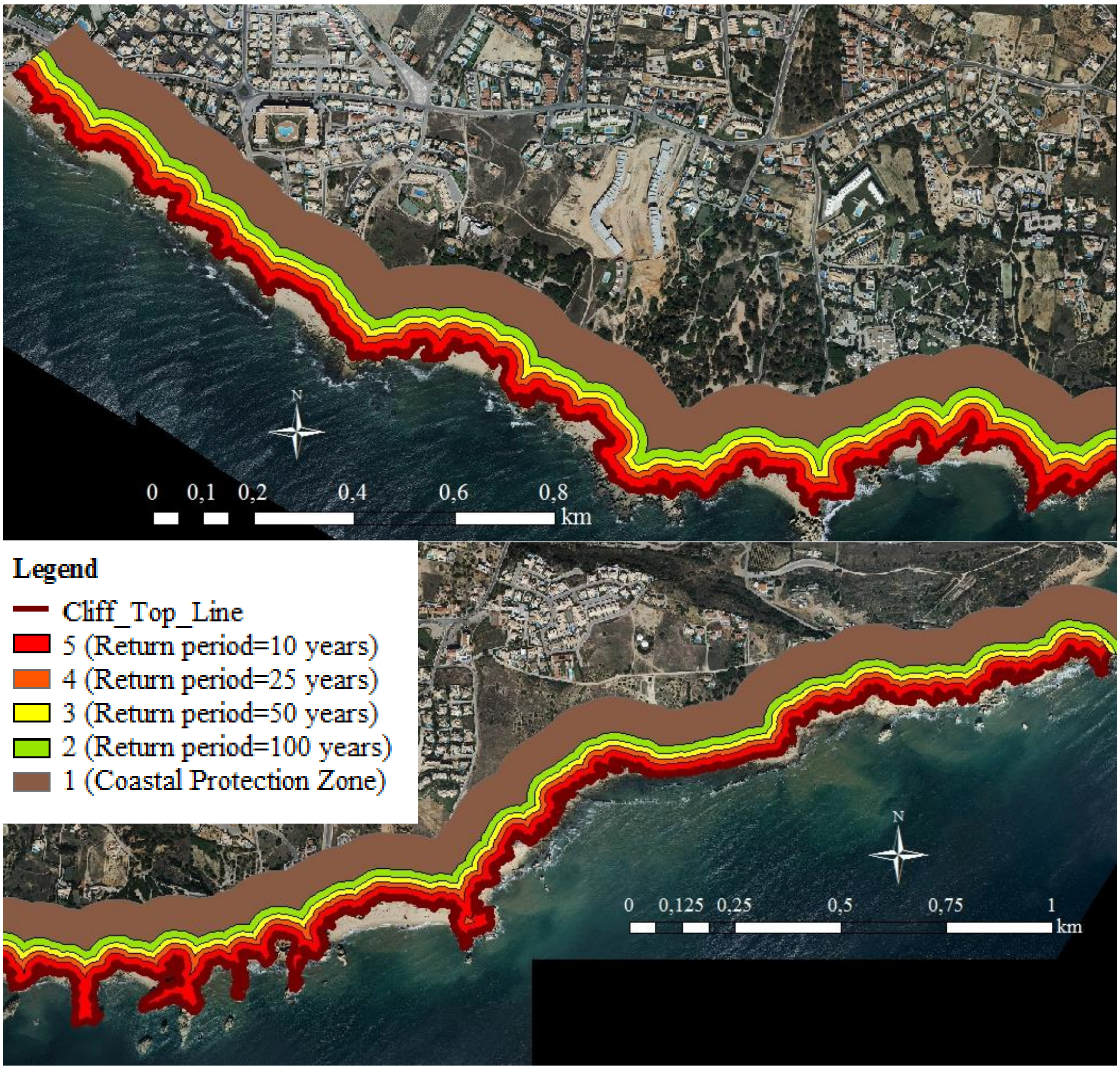

Figure 5.1 - Hazard Index along the study area

5.2 Land Use

Land use is the exposure component that combines natural with anthropogenic occupancy (section 4.3, Table 4.3). The study area presents largely original forest (1) and the small gardens (2) are concentrated specially in east and west side. On the other hand, there are few non-residential buildings (4) and the residential buildings (5), similarly to small gardens, are concentrated in east and west side of the study area (Figure 5.2).

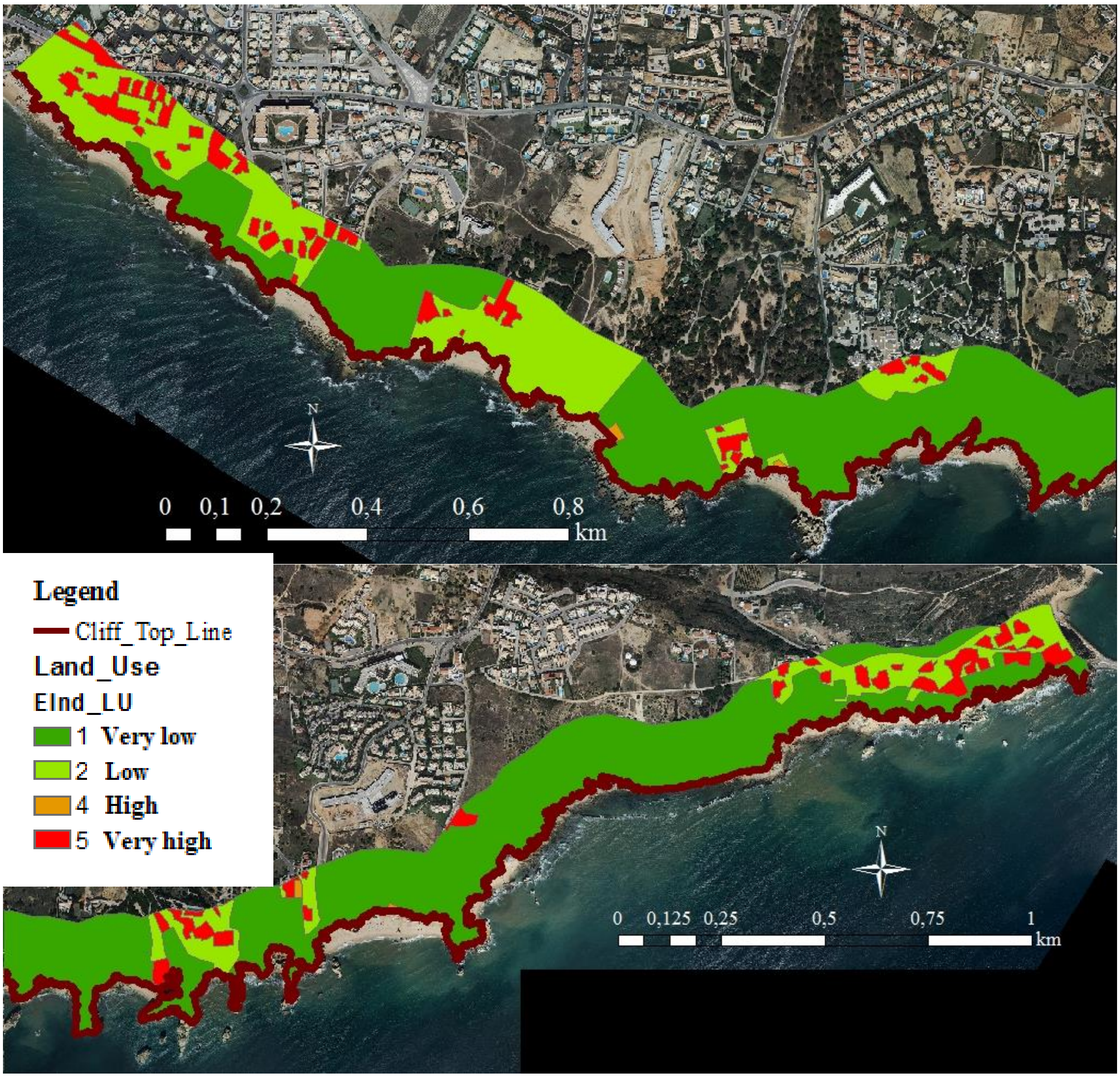

Figure 5.2 - Land use exposure along the study area

5.3 Population

The analysis of the aspects related to the population and its exposure was based in the SVI, which encompassed five variables (section 4.3: Table 4.3, 4.4, 4.5 and 4.6): unemployment, elderly, low education level, small residences and non-home ownership; these last two items present lower weight in relation to other variables. As visible on Figure 5.3, in the west and central part of the study area, the majority of the population is under a very high vulnerability. On the contrary, the majority of the population is under a very low and medium vulnerability in the east side of the study area.

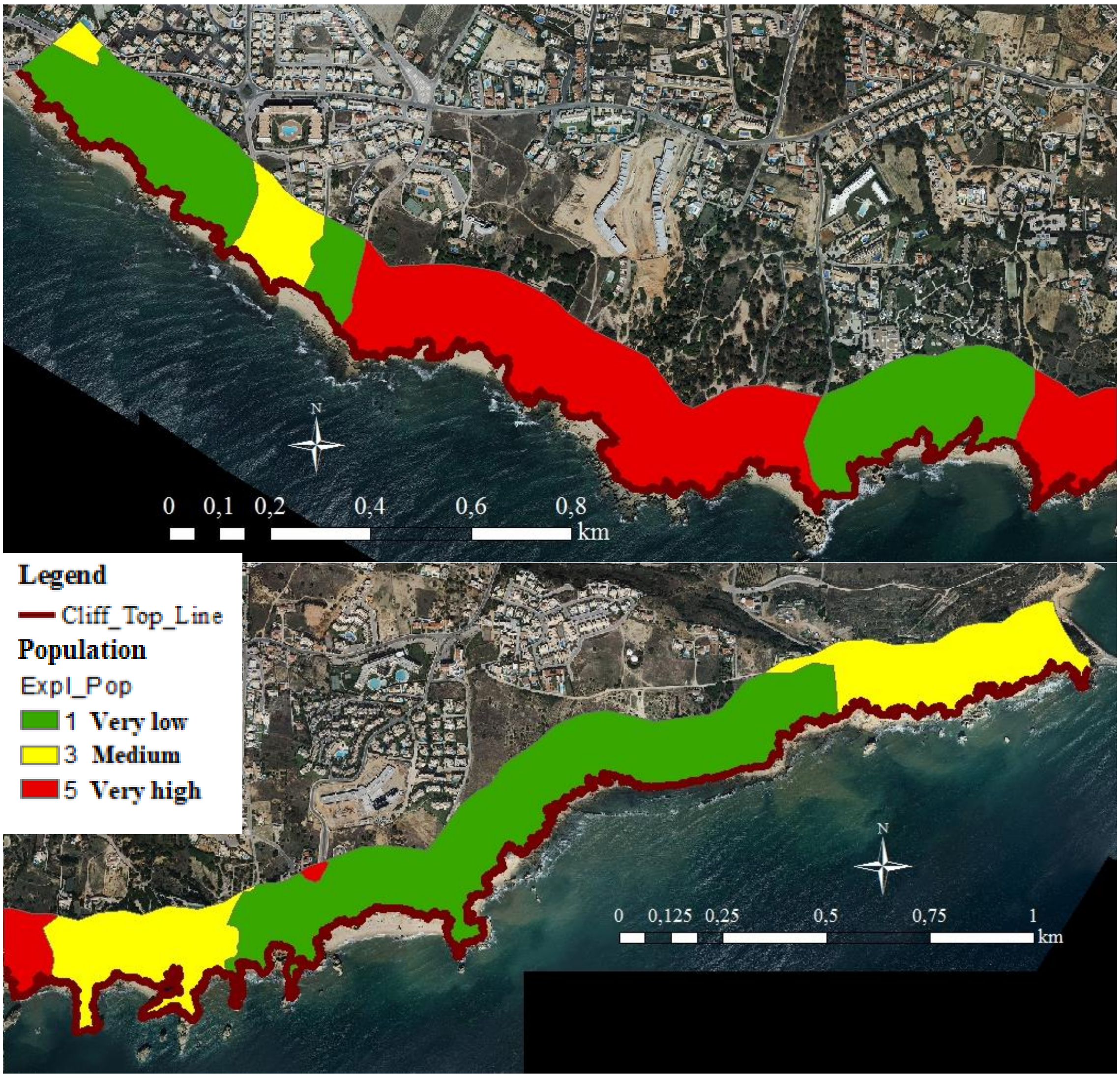

Figure 5.3 – Population exposure along the study area

5.4 Transport

Transport includes roads and parking areas (section 4.3, Table 4.3). The majority of the roads are local (3) and a few correspond to small roads (2). Big (5) and medium (4) dimensions parking areas are dominant, while small (3) dimensions parking areas are few (Figure 5.4).

Figure 5.4 – Transport exposure along the study area

5.5 Economic Activity

The economic activity along the study area includes the mapping and characterization of all existing hotels and restaurants (section 4.3, Table 4.3). The majority of the economic activity is found on the west side of the study area, with some being extremely close to the cliff top line. As visible on Figure 5.5, national/international importance hotel (5) are dominant and the majority of the restaurants are big and local importance (3).

Figure 5.5 - Economic activity exposure along the study area

5.6 Exposure Index

The aggregation of the four different types of occupancy present on study area allowed the definition of a final exposure index. The study area does not present a very high (5) exposure. Very low exposure (1) is dominant, few places are under low (2) and medium (3) exposure and very few places are under high (4) exposure (Figure 5.6).

Figure 5.6 - Exposure index along the study area

5.7 Coastal Index

The hazard index (section 4.2, Table 4.2) combined with the exposure index (section 4.3, Equation 7 and 8), results on the coastal index (section 4.4, Equation 9). Figure 5.7 shows a final result of the risk assessment. The majority of the study area presents a very low risk (1), followed by low risk (2) and a few medium (3) and high (4) risk areas. In turn, the places under a moderate (3) and high (4) risk can be considered as the most affected areas, designated by hotspot areas (Figure 5.7).

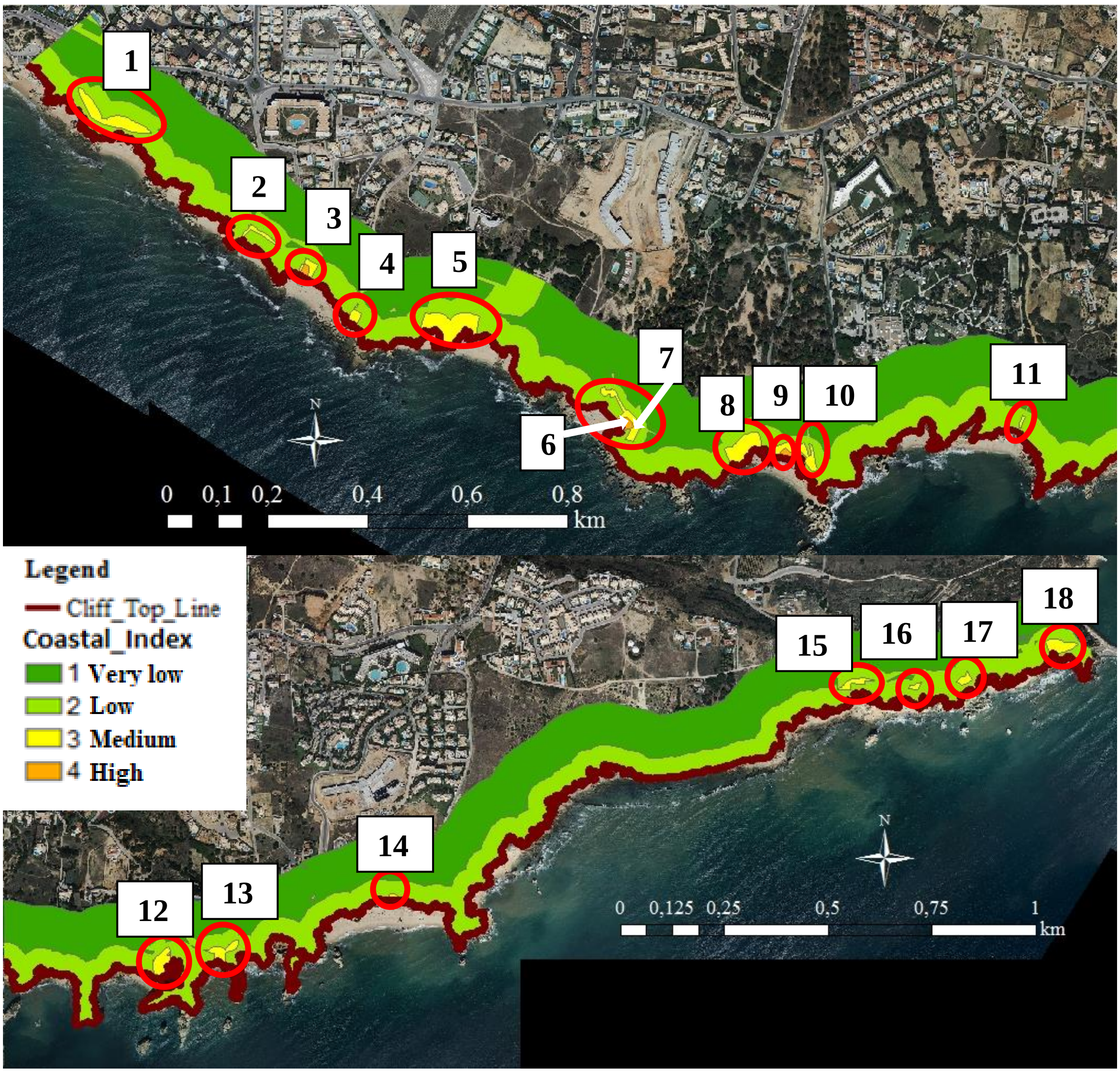

Figure 5.7 - Coastal index along the study area and hotspot areas (red circles)

In order to proceed with the coastal risk management proposals, it is necessary to differentiate the eighteen most affected areas (Table 5.2).

Table 5.2 – Description of the eighteen hotspots

Number of the affected area	Coastal Index	Occupancy type
1	3	International/national importance Hotel
2	3	Medium dimensions parking area
3	3 and 4	Residential area
4	3	Small local restaurant under high vulnerability

5	3	Residential and small garden under high vulnerability
6	4	Big local restaurant under high vulnerability
7	3	Small dimensions parking area under high vulnerability
8	3	Residential area under high vulnerability
9	4	Big local restaurant under high vulnerability
10	3	Big dimension parking area under high vulnerability
11	3	Local importance road under high vulnerability
12	3	Residential area
13	3	Small garden in urban area
14	3	Big local restaurant
15	3	Small garden in urban area
16	3	Small garden in urban area
17	3	Residential area
18	3	Residential area

As shown on Table 5.2, the most exposed areas are five residences, four restaurants, four small gardens, three parking areas, one road and one hotel. Thus far, these were considered as priority areas of intervention.

6. Discussion

6.1 Data management

The 2008's orthophoto, as previously mentioned, has a good resolution (1:10 000) and is suitable to identify the exact cliff top line and the various elements exposed to hazard. However, in relation to the determination of the cliff top line and the other areas, issues of subjectivity and uncertainty will always be a constant, partly depending on the user experience. This is noticeable in difficulties in identifying the right position of a feature, given similar colours of distinct features, reason why a field research on some places of the study area was needed. To solve this problem, in future projects, a non-visual method can be used to define the cliff top line, in order to avoid the problems described above.

In some cases, to correctly define the different exposure degrees is difficult due to the limitations in available information (e.g. land use, SVI). One example of this was the lack of information (e.g. SVI) in COS 2007 (1:100 000) and definition of relevant categories for analysing coastal risk along the study area, especially regarding residential and non-residential areas. Additionally, COS 2007 presents lower resolution than the 2008's orthos. To overcome these difficulties, an extensive research, including field evaluation and analysis of Census 2011 data of the various sub-sections of the study area, was performed to define the different exposure components and its characteristics.

6.2 Risk assessment

Risk assessments require the definition and calculation of a hazard index and an exposure index. The hazard index was based on the return period of mass movement maximum extension (Teixeira, 2006), while the exposure index considered four different factors, corresponding to the main elements at risk from a hazard event, according to the CRAF (RISK-KIT, 2015).

The results obtained demonstrate that the study area does not experience very high risk, presenting a few places with a medium and high risk. Although some of the four exposed elements (land use, population, transport, economic activity) separately present a very high exposure, when combined the overall exposure index becomes lower. This happens because there are a limited number of areas with more than one high exposure factor at the same time. On the other hand, the outcome is not absolute and what matters for this study is the risk variation within the study area, which allows the definition of hotspot areas, in order to prioritize the management options. In this case, it was possible to define eighteen hotspots and depending on their characteristics and coastal index, there are distinct priorities among them (Table 6.1).

Table 6.1 - Priority of the hotspots according to the occupation type and coastal index

Occupancy type	**Coastal Index**	**Number of the hotspot**	**Priority**
Residence	3	3, 5, 8, 12,17, 18	Medium
	4	3	High
Small garden	3	5, 13, 15, 16	Low
Hotel	3	1	Medium
Restaurant	3	4, 14	Low
	4	6, 9	Medium
Parking area	3	2, 7, 10	Low
Road	3	11	Low

Legend:
- Low (green)
- Medium (yellow)
- High (red)

The priorities were defined according to expert judgment, higher in structures where there may be more people and also a higher economic value. For example, a hotel, which has higher economic and social value, is more relevant than a parking area. In addition, the same exposure component with different coastal index values will result in different priorities (the higher the coastal index, the higher the priority), as is the case of the residence (hotspot number 3) and the restaurants (hotspots number 6 and 9) present on the study area (Table 6.1). After the identification of the hotspots, a way to improve the priority ranking is to have it defined by expert judgment together with the stakeholders (managers, population, local authority)

Hazard presents a clear zonation on the study area, however it would not be possible to use only this component to establish management priorities and determine hotspots. Comparing with previous studies, Nunes *et al*. (2009) determined a hazard index and showed that the study area is mostly under high and very high hazard, presenting the different hazard levels along the cliff top line, whereas the present study, where the hazard index was based on the return period of a mass movement maximum extension (Teixeira, 2006), presents a maximum hazard (5) along all the cliff top line. In turn, applying Teixeira (2006) method, results in a map with homogeneous strips with the different hazard levels, from the cliff top line till the 150 m, while Nunes *et al*. (2009) does not provide any approach or zonation for the inland areas.

In order to improve this work, it would be interesting to combine this study with Nunes *et al*. (2009) and Bezerra *et al*. (2011), since there would then be the combination of important factors: cliff lithology, cliff profile, cliff morphology and wave exposure. According to Bezerra *et al*. (2011), wave exposure has an important role on cliff erosion and evolution and, consequently, in the hazard index. On the other hand, the calculation of the coastal index is only possible if there is a combination of the hazard index with the occupancy (exposure index). It is therefore necessary to incorporate all the important hazard and exposure components towards the inland area and not only for the cliff top line.

6.3 Coastal risk management proposals

Coastal policies and management plans are indispensable to avoid and/or reduce risk situations in coastal areas. In Portugal, the measures and plans already proposed and imposed the relevant agencies are only partly implemented, even though there are some exceptions. Although CZMP for the study area were discussed, a variety of buildings and infrastructures were not removed, before or even after the existence of CPZ. There is a lack of commitment regarding coastal plans, including the Burgau-Vilamoura POOC, since the proposed management strategy was only partly implemented (Nunes, 2007). As mentioned previously, according to the beach plans, new parking areas were constructed or are still in construction in Manuel Lourenço, Arrifes, Evaristo, Castelo and Galé., increasing the coastal risk.

The pressure induced by urban development and economic activities on coastal area is increasing (Taveira-Pinto, 2004). As previously mentioned, the places with a medium and high risk (Figure 6.1) were considered as hotspots and therefore focus of attention. The majority of the polygons that present a moderate and high risk are near or even under the cliff top line, reason why measures such as the removal or relocation of these structures should be implemented.

Figure 6.1 – Examples of structures with a medium and high risk present on study area: (a) Building; (b) Restaurant

The construction of buildings and development of economic activities (restaurants, hotels, shops) must respect the natural cliff evolution/recession and also the terrestrial protection zone, defined by the POOC. According to the risk map, there is a zone under a very low risk and some of the problematic structures could be relocated to this area. The protection/management measures are dynamic and depend on the occupancy type (residences, hotels, roads, etc). Regarding the context of this work, the management priorities are higher in structures where there may be large number of people and also a higher economic value. The hotel and all the residences on the study area that are under medium or high risk should be relocated and moved out from the protection area defined by POOC (more than 150 m); also the restaurants under a high risk should be relocated from this area. On the other hand, the small gardens, the restaurants, the parking areas and the local importance road do not require an extreme relocation and could be relocated to areas within the very low risk zone (Table 6.2).

Table 6.2 - Relocation of the study area hotspots

		Area		
		Cliff top line – 48m	48m – 150m	>150 m
Hotspot	1	-	-	X
	2	-	X	X
	3	-	-	X
	4	-	X	X
	5	-	-	X
	6	-	-	X
	7	-	X	X
	8	-	-	X
	9	-	-	X
	10	-	X	X
	11	-	X	X
	12	-	-	X
	13	-	X	X
	14	-	X	X
	15	-	X	X
	16	-	X	X
	17	-	-	X
	18	-	-	X

Legend:

- Not possible to relocate

X Possible to relocate

If a structure/building located between the cliff top line and the 48 m is removed, the exposure will be reduced and, therefore, the risk will decrease. This measure might be difficult to implement, especially because it causes losses to the owners of economic activities and to the population that lives all year on these buildings. On the other hand, for each hotspot, with its hazard and exposure values, it is possible to undertake simulations to determine if the relocation maintains achieves a low risk or if changes in the occupancy considerably increases the risk. When relocating activities and buildings located on a hotspot, the risk decreases in this zone, but is enhanced in the new area. This may be acceptable as the objective is to improve situations of critical risk, even if that implies a slightly increase the risk in the new area.

Table 6.2 and Figure 6.2 represent relocation measures likely to be of difficult social acceptance and an idealistic vision in order to reduce the risk associated to the study area.

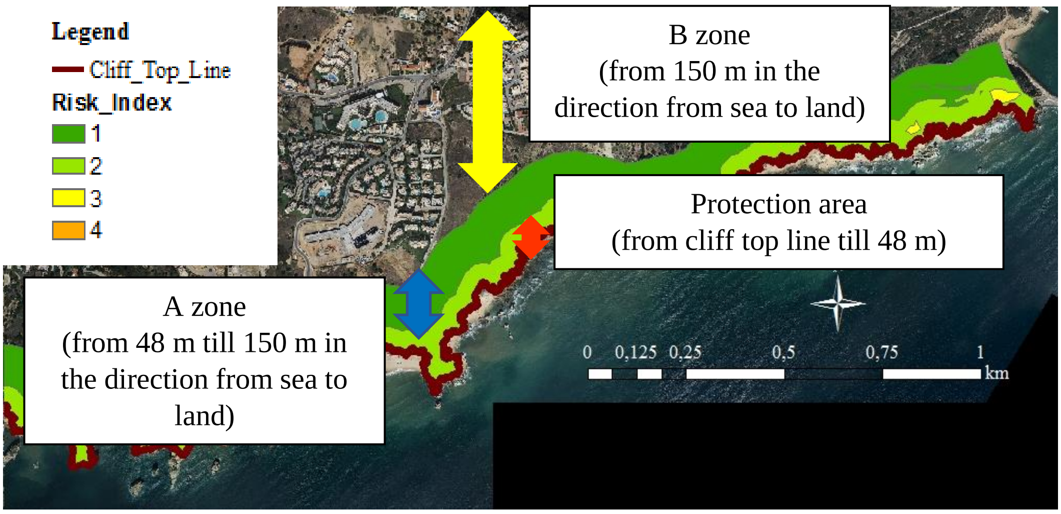

Figure 6.2 - Extreme relocation of the hotspots (discriminated on Table 6.2), from the protection area (red arrow – area from cliff top line till 48 m) to two different areas (blue arrow – area from 48 m till 150 m; yellow arrow – area from 150 m in the direction

However, there are economic and social aspects that might jeopardise the application of this idealized relocation, specially regarding the residences and hotel. The hotel has, in this case, an international relevance due to its location and characteristics, so if there is an extreme relocation, it will probably lose regular and new customers and decrease its international appeal. Also the residences on the study area are strategically located close to the cliff top line in order to take advantage of the ocean view and the tranquility of the setting. The restaurants, with the intention of a better economic value, are located quite close to the cliff top line to provide the sea view to the customers.

Regarding the difficulties of implementing the relocation of the residences, hotel and restaurants, these should be relocated and removed from the protection area in a progressive, phased out process, as licenses are due to come to an end, not allowing residences and other properties to be resold. Addictionally, it is essential to create a policy that promotes a lower valuation of property in the risk zone and incentive the occupancy outside of the protection area defined by POOC.

Another aspect that makes difficult the implementation of the measures referred, is the level of knowledge of the population concerning the coastal risk (Costas *et al*., 2015).

This article raises important issues regarding the different points of view of the population to coastal risk. It indicates that the opinion of local residents about measures to mitigate risk largely contrasts with the vision of coastal experts. Local residents, even with knowledge about coastal hazards and risks, choose to remain under high risk situations and they usually do not support or accept management plans for the area, including the relocation of the local population. They often consider that measures and plans are submitted with no proper community participation. For local residents the privilege of the surrounding and the placeattachment overcomes the existence of risk (Michel-Guillou *et al*., 2015).

Based on previous studies, the best way to tackle coastal problems in this specific case will comprise, initially, a good and transparent communication between the managers and the community, aiming to let the population know and contribute with solutions/measures, retaining the responsability to make decisions together with the experts, including actions like cliffs cementation, structures demolition and relocation of local residentes, among others. It is also essential to explain to the community how natural cliff retreat works and the main coastal hazards that the communities may be subjected if they are on the exposure area.

Another way to transmit information to the public, concerning coastal hazard and risk, is to improve the information about the cliff top upper area. This information can be provided in three forms:

- Assure the occurrence of dissemination events targeted at the population and other stakeholders;
- Increase the number of signs that warn to the rockfall hazard (Figure 6.3);
- Adaptation of the existing posters on the beach entrance (Figure 3.10) with hazard mapping on the cliff top area (Figure 6.4).

Providing information to local population, residents, hotels, holiday-makers and other stakeholders must also be continuous over time.

Figure 6.3 - Signs that warn the rockfall hazard

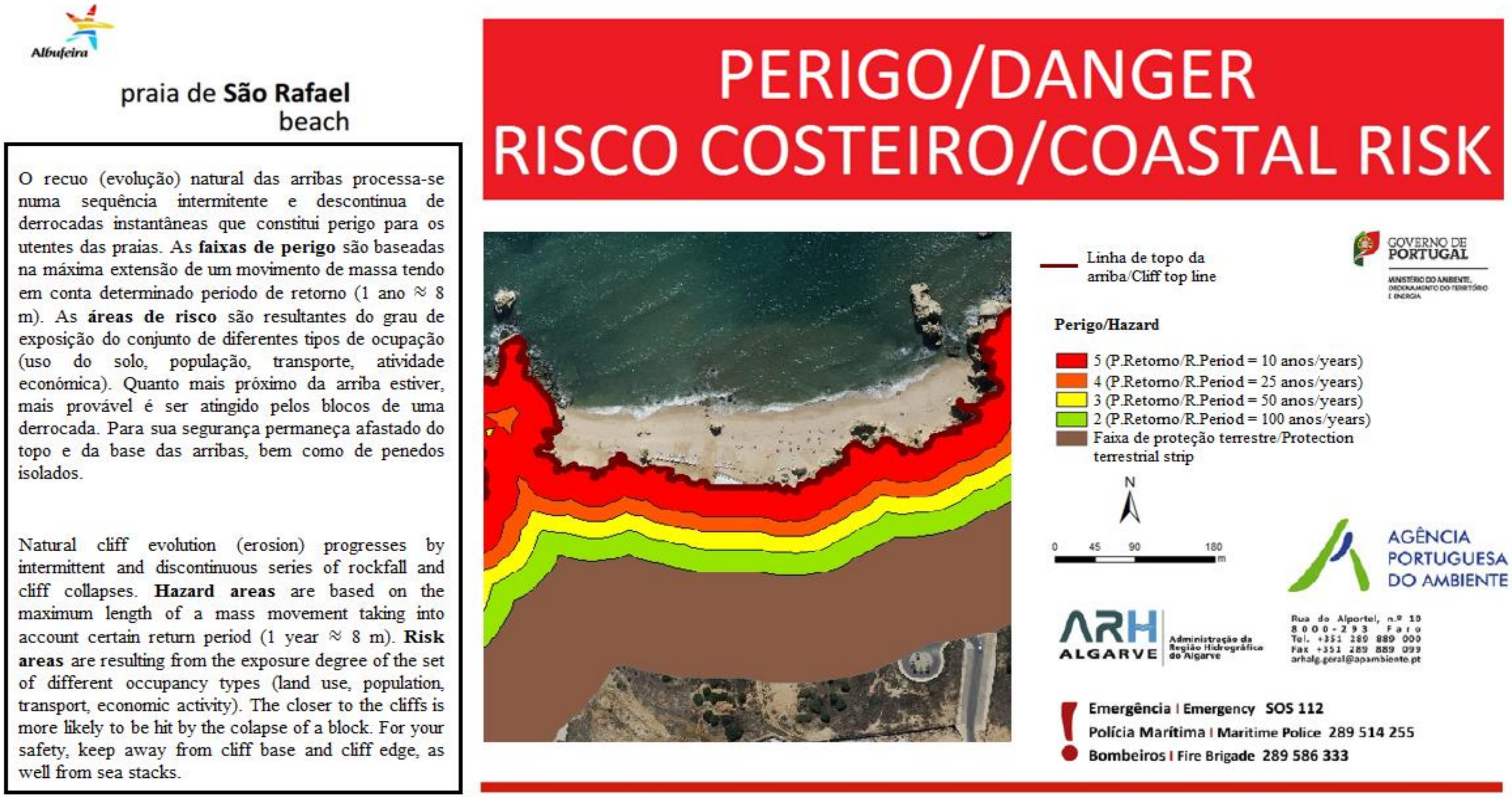

Figure 6.4 - Adaptation of the existing nameplates with hazard mapping on the cliff top upper area

7 Conclusion

Coastal erosion is one of the main geologic hazards leading to risks in occupied areas (Teixeira, 2006). The study area, part of the Barlavento Coast in Algarve, is dominated by rocky sea-cliffs, cut on Miocene calcarenites, which evolves through intermitent and discontinuous slope mass movements events (Teixeira, 2014). The Algarve region is an area of intense urban occupancy and fast growing tourism, increasing the coastal risk (Vaz *et al.*, 2012).

With the aim of assessing risk in sea cliffs, this study uses a pre-existent statistical analysis by Teixeira (2006) to create an hazard map based on the maximum extension of a mass movement for specific return periods and combines it with an exposure map, based on four different exposure components. These were defined considering the characteristics of the area and, partially, based on the indexes created by the project RISC-KIT. The analysis was supported by the integration of digital orthophotomaps and GIS techniques and allows to assess risk, further enabling management proposals in the most affected areas. The application of the method indicates that occupancy in the cliff top upper area is mainly exposed to very low and low risk, with only a few areas exposed to moderate and high risk, the latter were considered as hotspots. The results might have been influenced by some subjectivity, especially in the creation of maps, through GIS comands and tools.

Coastal management proposals for the hotspot areas include the relocation of the hotel, residences and the restaurants under a high risk present on the study area on the B zone and the other restaurants, parking area, road and small gardens on the A or B zone (section 6.3, Figure 6.2). These relocation measures were suggested in order to avoid high risk situations and it is essential to have a good relationship between the managers and residents, to make fair decisions. On the other hand, since these relocation measures are difficult to implement, the properties should be relocated and removed from the protection area in a progressive way, as licenses are due to come to an end, not allowing residences and other properties to be resold. It is also essential to develop a policy that promotes a lower valuation of buildings in the risk zone and incentive the occupation outside of protection area defined by the POOC. In case of future construction, it is important to keep the area from the cliff top line till the 48 m free of structures. At the same time, in order to reduce the coastal erosion, measures like the beach nourishment are also considered important.

Furthermore, a good way to improve the information to the public about the coastal risk is to assure the occurrence of dissemination events targeted at the population and other stakeholders, increase the signs that warn to the rockfall hazard and the adjustment of the existing posters on the beach entrance to also include the hazard mapping on the cliff top upper area.

In future research, in order to improve the proposed methodology for risk assessment, other components can be included on the coastal index calculation, such as the incorporation of the economic value and vulnerability associated to structures and residents on the coastal index, as well as the wave exposure and cliff lithology on the hazard index.

Human occupation has grown significantly over the years and, as seen in this work, has an essential role on risk assessment. Although the study area is not overcrowded, since the anthropic occupation is growing, it can become, depending on the success or failure of the management measures. Therefore, this dissertation was based on this area to contribute to the development of new coastal indexes with respect to this zone and other similar areas, in order to identify hotspots and take necessary management measures. In addition, new research is always necessary to create and improve coastal management measures and to reduce coastal risk.

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