

## Landslide susceptibility assessment in the coastal area of Essaouira – Morocco

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**Abstract.** Landslide susceptibility mapping is an important tool for landslide risk management and urban planning. The main aim of this study is to assess coastal slope landslide susceptibility in Essaouira city (Morocco) using a deterministic approach. The primary data needed for analyzing the risk of landslides include a record of landslides factors that contribute to their occurrence factors that trigger them and elements in the area at risk. Among these the inventory of landslides holds significance. It provides information, about where landslides have happened in the past the types of landslides how they failed, the causes, behind their occurrence and the extent of damage they caused.

Historical archives, field data and image interpretation are sources, for creating landslide inventories. However it is unfortunate that these sources are often incomplete making it challenging to conduct a risk assessment. A total of 588 landslides were recognized and mapped in the study area, the terrain units of the study area were divided according to morphometric and operational criteria. A total of 2975 terrain units with 50 m wide were classified in coastal system type, based on information from satellite imagery, aerial photographs, digital elevation model, geological maps, and data and field surveys.

Afterward, the landslide susceptibility assessment model was carried out by classifying the terrain units into stable and unstable units. The classification process is based on the quantification of the percentage of the unstable area of each terrain unit. This initial method, for assessing the likelihood of landslides, which involves analyzing land forms using photos, satellite images and fieldwork along, with GIS analyses helped us identify 931 areas of land that are considered unstable. This accounts for 61% of the study area (known as the Rocky subsystem). Additionally, more information was added to a Geodatabase of various independent variables such as morphology (height, slope, curvature, and aspect), geology (structure, lithology, tectonics, soil, and bedrock geotechnical properties), hydrogeology, and climatology. A statistical model that uses information values is employed to analyze instances of landslides and identify the conditions in which they have occurred. This helps determine the combinations of factors that contribute to the likelihood of landslides.

To guarantee meaningful validation process, the inventory dataset was subdivided into a test and a validation group. The model building process utilized a test group comprising 40% of the inventory while the validation group was employed to perform cross validation on the results of the model. Finally, the susceptibility map was validated to define the sensitivity analysis for independent variables and combinations of variables.

54 **Keywords:** Inventory, Cliff instability, triggering factors, Landslide  
55 susceptibility, Essaouira, Morocco.

## 56 **1 Introduction**

57 One of the most damaging and destructive natural hazards is landslides, particularly  
58 menace cliff coastal areas. It threatens the local communities and human activities  
59 exposed to cliff retreat. Furthermore there is a growing impact, in cliff regions, which  
60 can be observed along 80% of the worlds ocean coasts [1]. The rapid growth and  
61 development in these areas have consequences especially since approximately 1.2  
62 billion individuals worldwide reside within 100 km of the shoreline and less than 100  
63 m above mean sea level. These areas are particularly vulnerable, to changing sea levels  
64 [2]. Additionally it is important to recognize that rising sea levels and climate change  
65 may further exacerbate processes that contribute to degradation.

66 A variety of processes both, in continental environments contribute to the erosion of  
67 rocky coastlines as discussed in studies [3] and [4]. Several factors play a role in  
68 triggering this erosion, such as how rocks respond to wave impacts the type of rock  
69 composition freshwater effects, vegetation coverage, soil depth, width of beaches,  
70 exposure of cliffs to prevailing winds and waves human activities like footpath  
71 placement or increased artificial areas and rising sea levels [5]. In protected regions  
72 specifically retreat of cliff tops is primarily influenced by weathering processes that  
73 occur on land [6] [7].

74 The African coast faces vulnerability to climate change impacts and coastal erosion. At  
75 a scale flooding and erosion pose risks as more than half the coastline is classified with  
76 a very high level of susceptibility [8]. Due to its location at the north corner of Africa  
77 within moderate latitudes and along the northern border of the African plate Morocco  
78 experiences various meteorological hazards [9] [10] including sea level rise connected  
79 to climate changes [11] well, as marine storms [12] [13]. Indeed these facts play a role,  
80 in triggering and causing landslides well as rockfalls [9] [14].

## 81 **2 Study area and Methods**

82 The study site in this research is the Essaouira coast area, and it is located along the  
83 central section of Atlantic Morocco, composed of a complex of sandy and rocky coast  
84 over 134 km. This morphological subsystem is locally interrupted by heavily anthropic  
85 coastal areas especially at the Essaouira city. The rocky coastal sectors are  
86 characterized by the presence of many debris flows, rock falls, rock topples and rock  
87 slides, which are being the dominant natural hazards responsible for no safe land use  
88 and huge constraint for human activities [15].

89 The purpose of landslide susceptibility assessments is to determine the likelihood of  
90 landslides occurring in an area [16]. To assess this it is important to analyze the factors  
91 that contribute to instability. This involves identifying landslide occurrences and  
92 determining the combinations of triggering factors that could lead to landslides.  
93 Additionally having an representative inventory of landslides is crucial, for assessing  
94 their susceptibility, risk and potential hazards [17] [18] [19]. Furthermore predictive  
95 models and statistical methods are essential for forecasting landslides based on  
96 conditions, which was the approach used in this study. Alongside a landslide inventory  
97 susceptibility maps can provide information about the likelihood of landslides  
98 occurring. These maps should be considered during stages of land use planning [20].  
99 Various methods exist for conducting assessments in areas with different approaches,  
100 to managing hillslope instability factors [21] [22].

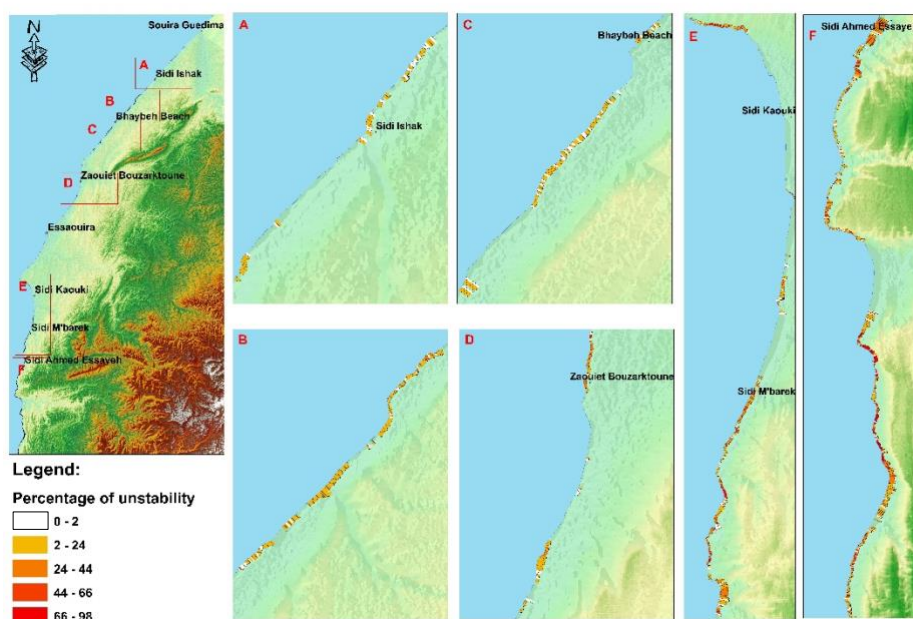
### 101 3 Results and Discussion

102 The aim of this study is to identify and map areas at risk of landslides and determine  
 103 the zones, along the Essaouira coast that're most susceptible, to instability. This will be  
 104 accomplished by considering factors that contribute to the instability of the sea cliff.  
 105 Landslides inventory was done according to Varnes classification system [23]; it was  
 106 supported by medium to high-resolution satellite imagery and aerial photographs  
 107 interpretation, previous bibliographic data, field surveys, and different scales of Digital  
 108 Elevation Models (DEMs), all this allows to mapping 588 landslides.

109 As a result once the coastal systems are categorized into rocky sub systems we can  
 110 define terrain units based on an operational criterion. This methodology was proposed  
 111 by [24]. The upper and lower ends of the terrain units are determined by the top and  
 112 bottom of the cliff respectively. The lateral boundaries are drawn perpendicular to the  
 113 lines of the landscape. Defined by dividing the ridgeline into 50 meter wide sections.  
 114 Overall we had a total of 2975 terrain units consisting of 1441 units and 1534 tailed  
 115 units.

116 Along, with triggering factors we assess the susceptibility of the terrain units by  
 117 classifying them into stabilized and stabilized categories (refer to Fig. 1). This  
 118 classification process involves quantifying the percentage of area in each terrain unit.  
 119 It is carried out individually for each type of landslide under study due, to their varying  
 120 sizes. The average unstable area is predominantly found towards the region of our study  
 121 area (refer to Fig. 1).

122 As we already expect in the objectives, deterministic statistical modeling based on the  
 123 information value model was done to identify the conditions under which landslides  
 124 have occurred in the past and to delineate the possible occurrence of further landslides,  
 125 then a validation was done to guarantee the efficacy of the model, by dividing the  
 126 inventory dataset into a test and a validation group. Around 40% of the inventory was  
 127 utilized for model building as a test group while the validation group was employed to  
 128 conduct a validation process on the initial outcomes of the model. At last, the  
 129 susceptibility map was validated to define the sensitivity analysis for independent  
 130 variables and combinations of variables.



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 132

Fig. 1. Categorizing terrain units based on their susceptibility to instability

## 133 4 Conclusions

134 This exploratory approach to landslide susceptibility in the 134 km of the coastal area  
 135 of Essaouira, especially in the rocky subsystem, based on morphological analysis  
 136 (interpretation of aerial photos, satellite images, and field survey), statistical analyses,  
 137 and GIS analyses allowed to identify 931 terrain units as unstable, which means that  
 138 about 61% of the study area (rocky subsystem) has high problems with cliff stability,  
 139 mostly the anthropic areas, which needs a real intervention to minimize their effects  
 140 and ensure sustainable development.

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