* Landslide susceptibility assessment of Bulgarian Black Sea coast with using of Mora and Vahrson method

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Introduction

* Black Sea coast is one of the regions of the country with a distribution of an essential part of Bulgarian landslides. More than 200 landslides affect only urban areas, resorts and villa zones. The main triggering factors are: impact of surface and ground water, abrasion, erosion and earthquakes.
* In this study, we applied the Mora and Vahrson (1994) method with aim to estimate the landslide susceptibility along the Bulgarian Black Sea coast, which is strongly affected by landslides. This method is based on evaluation of various local factors for slope instability.

* The Mora and Vahrson estimations are applied by formulas:
* $H = SUSC * TRIG$ *Equation 1*
* $H = (S_r * S_l * S_h) * (T_s + T_p)$ *Equation 2*
* where *H* is relative hazard level and it is multiplying between susceptibility factor *SUSC* and triggering factor *TRIG*. Susceptibility factor is multiplying of slope factor S_r, slope factor S_l and soil humidity factor S_h.
* T_s – seismic triggering factor
* T_p – precipitation triggering factor
* Due to specific peculiarities of Bulgarian sea-side strip, we have add additional triggering factor concerning the abrasion and erosion activity along the coast and rivers that has to be taken into consideration and we propose to be marked it as T_e. It is expressed in Equation 3:
* $H = (S_r * S_l * S_h) * (T_s + T_p + T_e)$ *Equation 3*

The soil humidity factor is taken from data published by Koleva and Peneva (1990) for 15 sites in Bulgaria. The range of raining time per 24 hours varies between 1 and 3 hours for territory of Bulgaria. For Black sea coast area the range is 1 and 1.5 hours as the lowest values are measured in southern part of Burgas region (Strandja Mts area).

The triggering seismic factor T_s varies in Bulgaria from 4 (VI degree in MSK-64) to 7 (IX grade). For example, the Burgas region has he T_s = 5, but in a seismically active area in Shabla-Kaliakra the value is T_s = 7 (M7.2 on 31 March 1901). The data is from Seismic zoning of Bulgaria.

The precipitation factor T_p has been taken from few data published by National Institute of Hydrology and Meteorology, Sofia.

Table 2. Lithology factor criteria, classification and scores

Lithology	Qualification	S_l
All rocky formations: sedimentary, volcanic, etc. (Neogene, Palaeogene, Cretaceous ets.)	Moderate	2
Altered sediments, as flysch of Palaeogene and Cretaceous age. Weathered rocks and loess. Availability of shallow water tables	High	4
Deluvial, alluvial and clay formations of Quaternary and Neogene age	Very high	5

We propose to add the following scores for erosion and abrasion triggering factor (Table 3):

Table 3. Classification of landslide hazard H

Description of sea-side strip and cliff	Erosion and abrasion factor T_e
Accumulation zone	0
Rocky cliff, with abrasion and erosion processes	1
Soft soils cliff, with abrasion and erosion processes	2

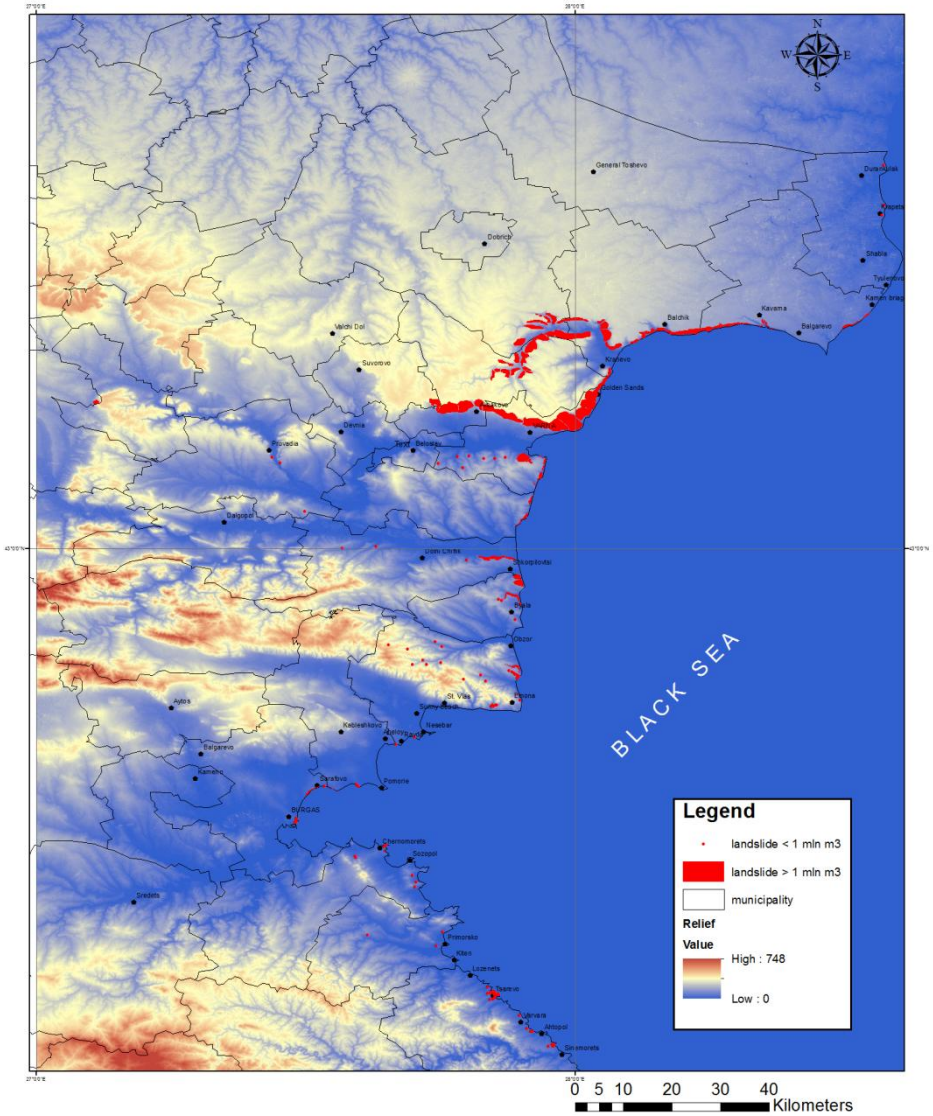
Table 4. Classification of landslide hazard H

H	Class	Classification of hazard of landslide potential
<6	I	Negligible
7-32	II	Low
33-162	III	Moderate
163-512	IV	Medium
513-1250	V	High
>1250	VI	Very high

LANDLSIDE INVENTORY MAP

Bulgarian Black Sea Coast

scale 1:500,000



Kabakum Landslide (1996) – North Black Sea coast

Asparuhovo flood (19.06.2014) – mud deposits

Taukliman-Rusalka Landlside (lateral-spread type)

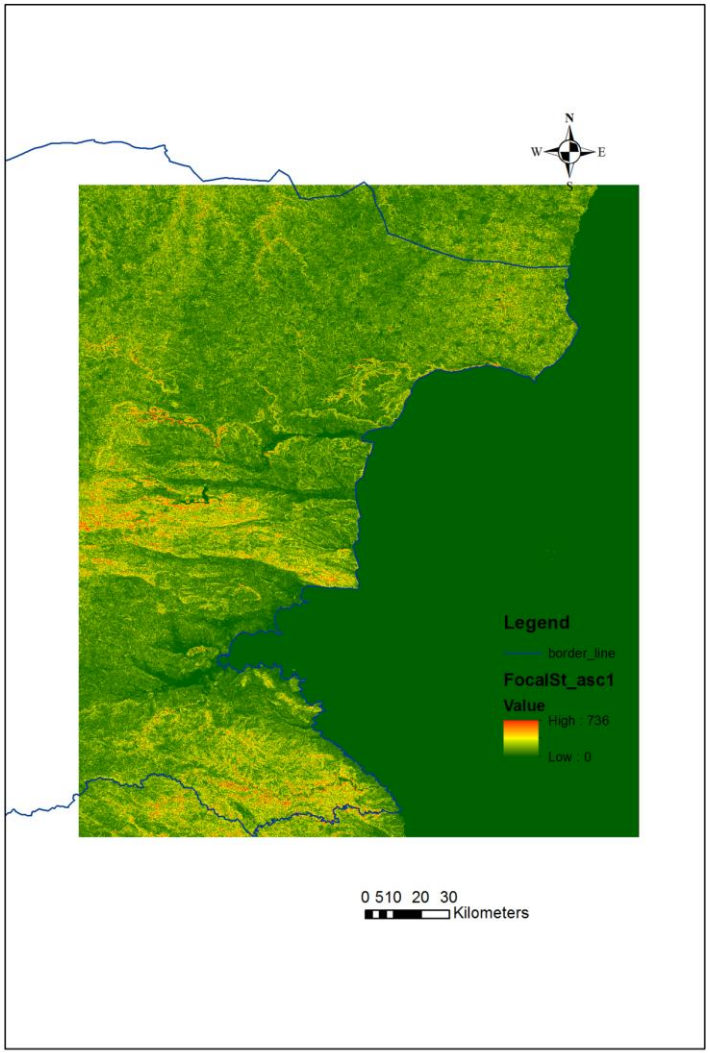


Fig. 1. Map of Black sea coast according to slope factor S_r

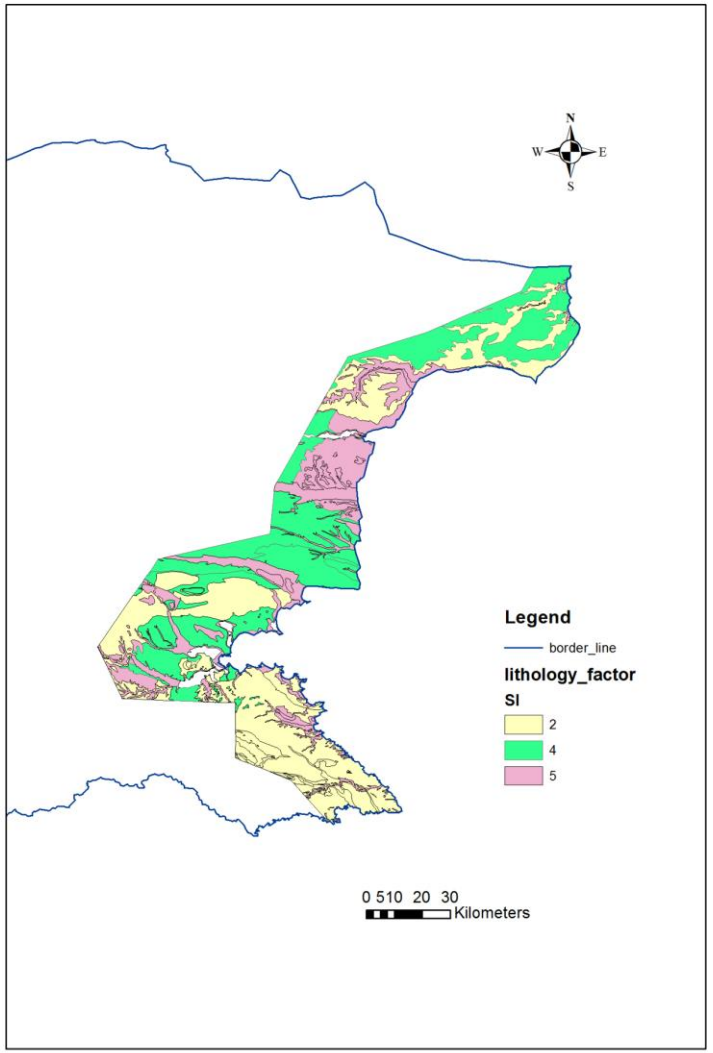


Fig. 2. Map of Black sea coast according to lithological factor S_l

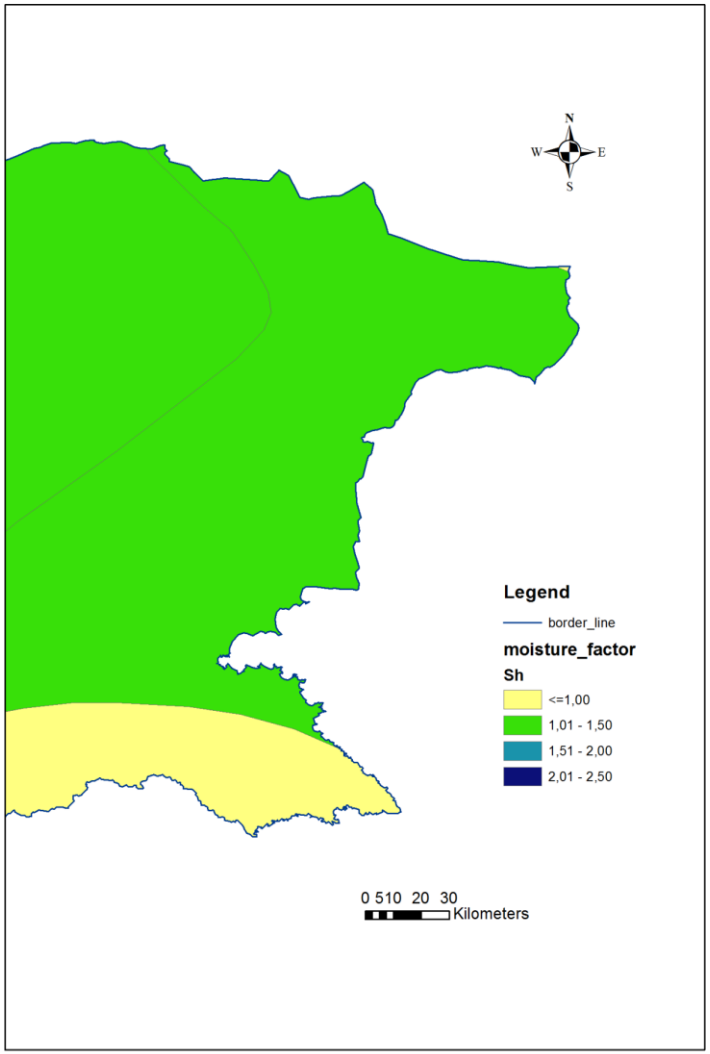


Fig. 3. Map of Black sea coast according to moisture (humidity) factor S_h

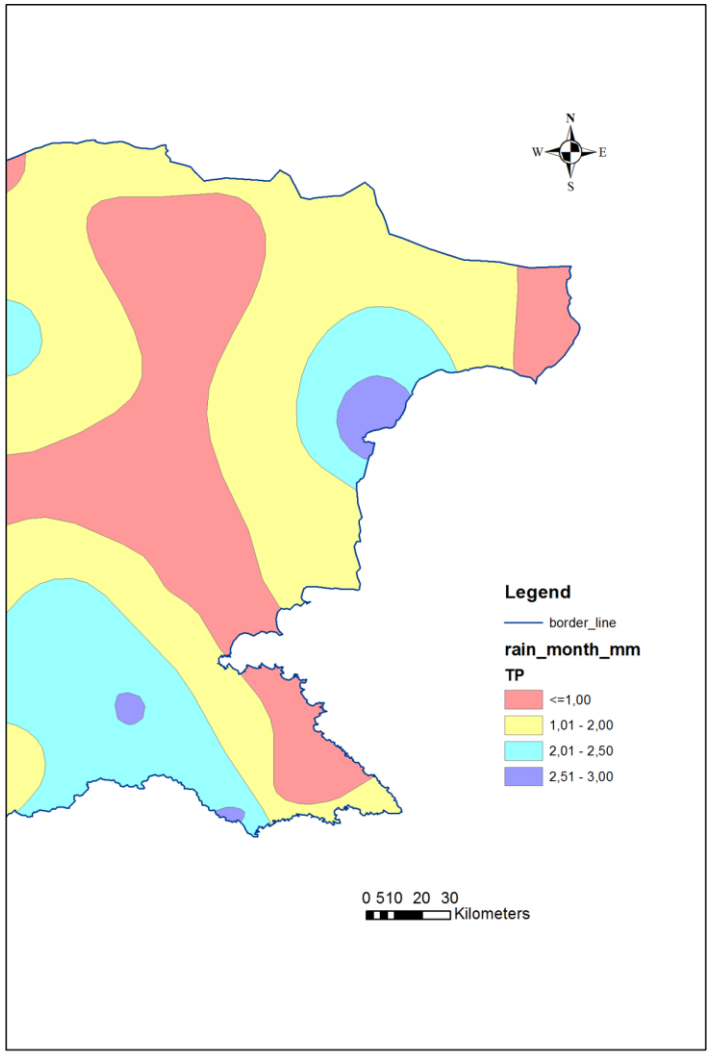


Fig. 4. Map of Black sea coast according to precipitation triggering factor T_p

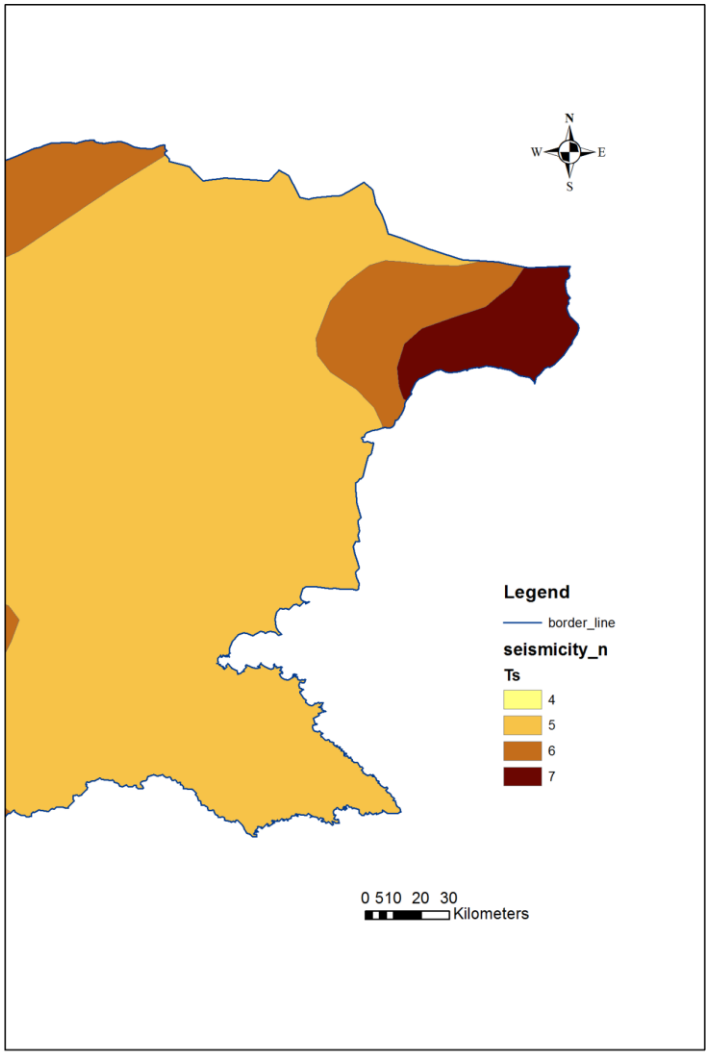


Fig. 5. Map of Black sea coast according to seismicity triggering factor T_s

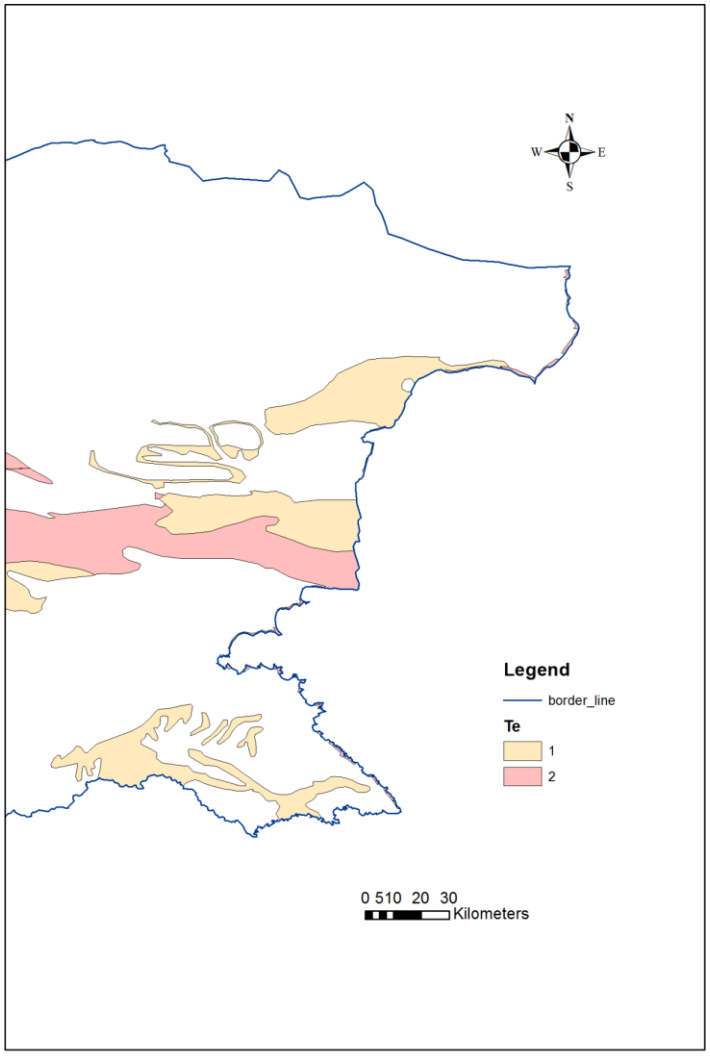


Fig. 6. Map of Black sea coast according to erosion/abrasion triggering factor T_e

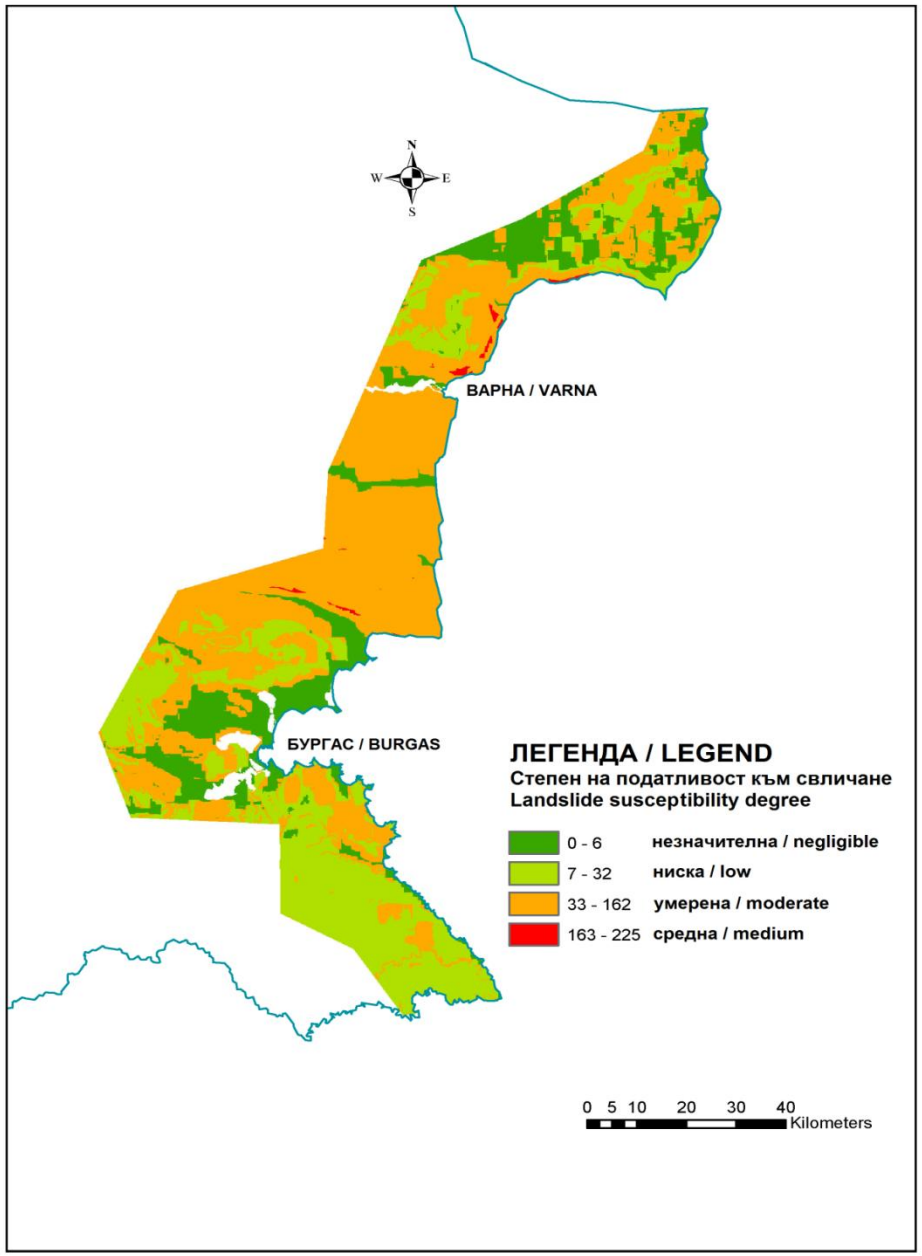


Fig.7. Landslide susceptibility map of the Bulgarian Black Sea coast acc. to the method of Mora and Vahrson

Pilot site study: Tsarevo area

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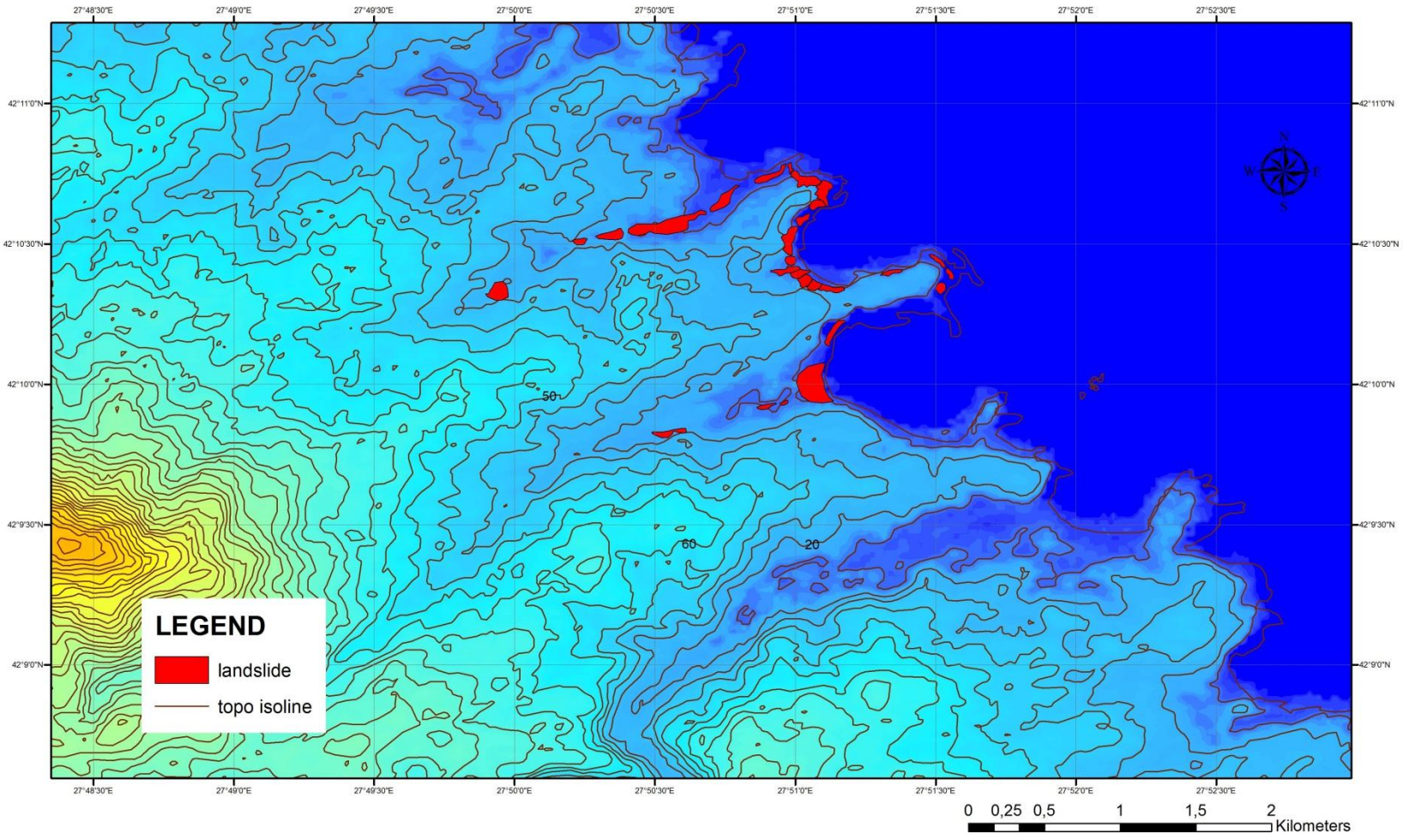
* Burgas sea-side park landsldies

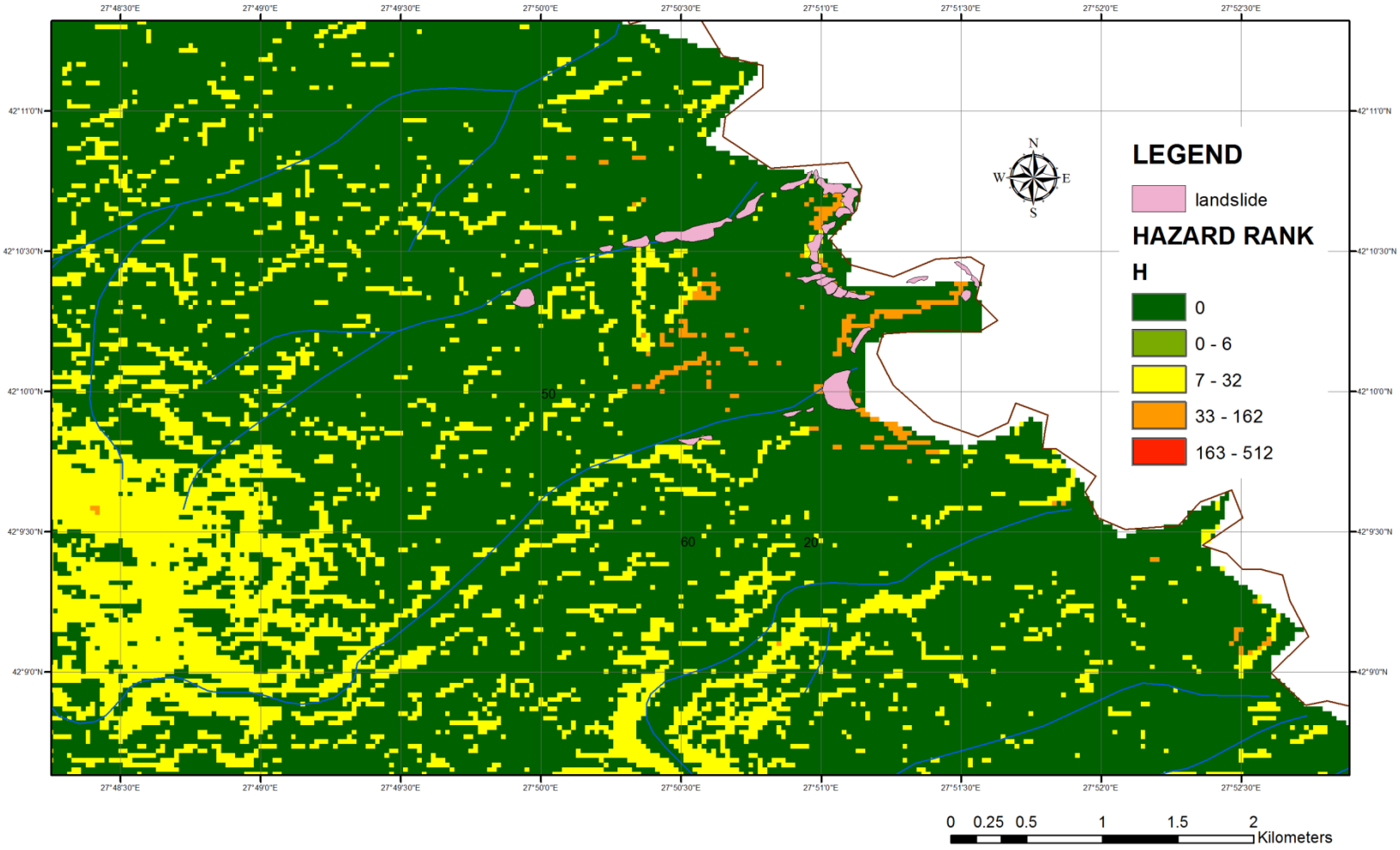
LANDSLIDE INVENTORY MAP

Tsarevo area, scale 1: 25,000



LANDSLIDE SUSCEPTIBILITY MAP

Tsarevo area, scale 1: 25,000



*Discussion

- As seen from the results expressed in the Landslide susceptibility Map (Fig. 7), the maximum number of scores obtained in the calculations for the Black Sea coast is 225. This corresponds to an MEDIUM level of susceptibility in accordance to the accepted methodology. Most prone to landslides are slopes in the Balchik and Varna coast (mailny deep landslides and frequent activation of parts of them) and parts of Eastern Balkan Mts - mostly southern slopes (shallow landslides formed in flysch sediments; presence of proluvial deposits). The majority of the region of investigation is characterized by MODERATE level.
- The disadvantage of this method is that a moderate degree of risk covered some parts of the flat terrain, such as the Dobrudja plateau, but this is due to local variations in terrain and high seismicity (from Shabla-Kaliakra seismic zone), presence of weak soils (in this case loess, which has the highest number of scores of the factor S_l).
- The relatively low values indicator of soil moisture S_h are due to weak precipitation, which, compared to tropical countries (from where origins this method) is several times smaller. Therefore, it would be better to add some additional criteria for Mora and Varson classification for countries with temperate climate.

THANK YOU FOR ATTENTION!