# Landslide Hazard Assessment of Bulgarian Black Sea Coast

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Engineering geological regions in Bulgaria

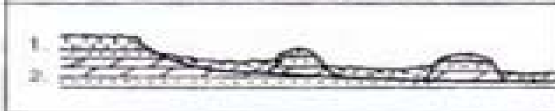
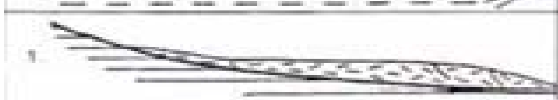

*largest LS areas*

Danube river Bank,

Northern Black sea coast,

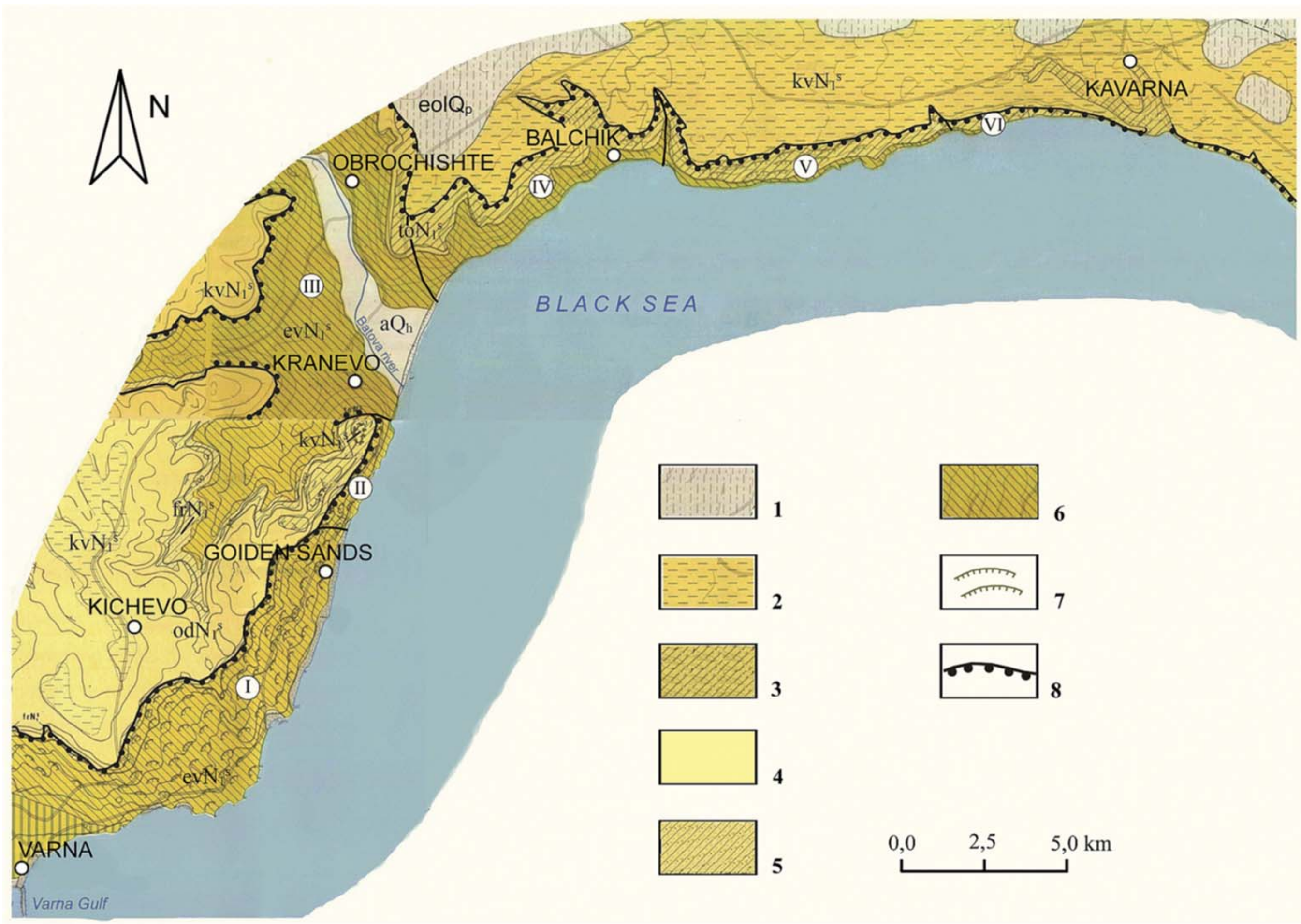
Rodopi mountain

# Representative profiles of landslides in the territory of Bulgaria

| Representative profile | Geological structure | Regions | |
|---|---|---|---|
|  | 1. Loess, Q<br>2. Clays, $N_2$ | West Danube River bank | |
|  | 1. Loess, Q<br>2. Sandstones and marls, K | Central Danube River bank | |
|  | 1. Limestones, $N_1$<br>2. Clays, $N_1$ | Black Sea Shore Line | Taukliman |
|  | 1. Limy marls, $N_2$<br>2. Clays, $N_1$ | | Balchik Town |
|  | 1. Limestones<br>2. Sands<br>3. Clays | | Varna City |
|  | 1. Flysch, $K_2$ | | Emine Cape |
|  | 1. Limestones, $K_2$<br>2. Marls, $K_1$ | Plateaus in NE Bulgaria and the Fore-Balkan | |
|  | 1. Clays, Pg or $N_2$ | Graben's border strips | |
|  | 1. Rhyolites, Pg<br>2. Clays, soft sandstones, Pg | Rhodope Mts. | |
|  | 1. Clays, $N_2$ | Maritza-Iztok open-pit coal mine | |
|  | 1. Clays, $N_2$ or Q | Slopes in the country | |

**Geological structure**

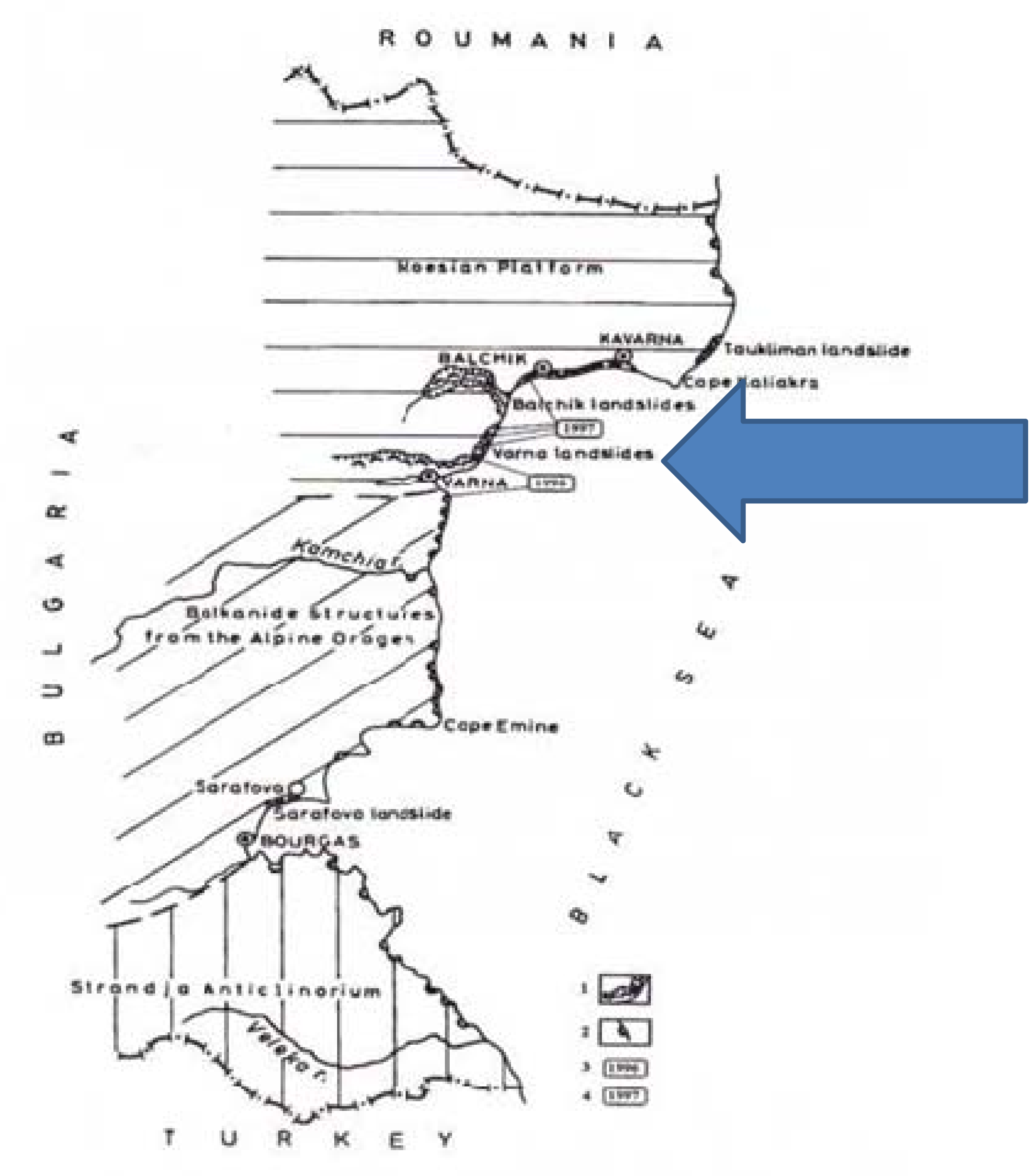
**1** – loess complex (eolQp); **2** – limestones of the Karvuna Formation (kvN1s); **3** – aragonite clays with limestone intercalations, Topola Formation (toN1s); **4** – limestones with sand intercalations, Odar Formation (odN1s); **5** – sands, Frangen Formation (frN1s); **6** – diatomaceous clays of the Euxinograd Formation (evN1kg-s); **7** – delapsium; **8** – oldest landslide scarp.



# Bulgarian Black Sea coast LS

- The territory of the Bulgarian Black Sea coast is highly hazardous in respect of LS
- In areas along the Black Sea coast more than 120 landslides are active
- Most are active landslides in the northern Black Sea coast of Varna to Kavarna (between the resorts of St. St. Constantine and Elena, Zlatni Pyasatsi, Albena, and the Balchik area).
- The depth of the main slip surface is usually up to 50-60 m or more (reaching 100 m at some places).

Landslide distribution on the Bulgarian Black Sea coast: 1 - landslide zone ; 2 - separate landslide; 3 - landslides triggered in 1996; 4 - landslides triggered in 1997



# South Black sea coast examples

Fig.1. Chernomorets area with mapped landslides

Fig.3. Tsarevo Town area with mapped landslides

Fig.9. Sarafovo landslides


Fig.10. Lahana landslides

# North Black sea coast

Fig.12. Landslides at Emine Cape area

Fig.13. Active landslide N from Irakli

# Mora & Vahrson Landslide Hazard Assessment

## Intrinsic Landslide Susceptibility (Susceptibility Indicator: SUSC)

**Slope Factor** **Sr :** Relative Relief representing the natural rugosity of the landscape within a grid unit (Table 1)

**Lithology Factor** **Sl :** based on lithological composition (Table 2)

**Soil Humidity Conditions** (**Sh**):

## Triggering Indicator TRIG

Derives from the combination of 2 factors

**Ts :** Seismic factor (100 years seismic event)

**Tp :** Precipitation factor (100 years rainfall intensity event)

$$H = SUSC * TRIG$$

$$= (Sr * Sl * Sh) * (Ts + Tp)$$

# Mora & Vahrson Landslide Hazard Assessment

## Susceptibility Indicator SUSC – Slope Factor Sr

Slope Factor is defined by the maximum difference in elevation per area **Rr = Relative Relief per grid unit (square km)  Rr = (Hmax-Hmin)/km2**

| Slope Value Rr (m/km2) | Classification | Slope Factor Sr |
|---|---|---|
| 0-75 | Very Low | 0 |
| 76-175 | Low | 1 |
| 176-300 | Moderate | 2 |
| 301-500 | Medium | 3 |
| 501-800 | High | 4 |
| >800 | Very High | 5 |

Table 1. Slope factor classification

# Implementation on Bulgarian Black Sea Coast

Table 2: Lithology factor criteria, classification and scores **(SI)**

| Lithology | Qualification | SI |
|---|---|---|
| All rocky formations: sedimentary, volcanic, (Neogene, Paleogene, Cretaceous, etc) | Moderate | 2 |
| Altered sediments (such as: flysch). Wheathered rocks and loess. Shallow water tables. | High | 4 |
| Diluvial, alluvial and clay formations of Quaternary and Neogene age | Very High | 5 |

# Mora & Vahrson Landslide Hazard Assessment

## Susceptibility Indicator SUSC – Lithology Factor (Sl)

The Lithology Factor (**Sl),** is assessed from the description of the geologic formations; ideally, geotechnical parameters should be taken into account.

**Parameters to be considered**: volumetric weight, shear strength, weathering, discontinuities and their spatial distribution and orientation.

***Lithology can be evaluated as***:

very low (0), low (1), moderate (2), medium (3), high (4) and very high (5) **susceptible** (the highest the number the highest the susceptibility)

# Mora & Vahrson Landslide Hazard Assessment

## Relative Soil Moisture Factor Sh

Takes into account he average conditions of soil moisture. Quantifies the influence of **accumulated humidity throughout the year.**

Best it's measured in situ; usually a simple methodology of soil-water balance can be used requiring only the average monthly precipitations.

**Steps to follow for implementation:**

1. Each monthly average precipitation is assigned an index value according to Table 3
2. The TOTAL of all 12 month assigned values are calculated for each analyzed rain gage station. These values range from 0 to 24.
3. The total is classified into 5 groups according to Table 4

# Relative Soil Moisture factor Sh

| Average Monthly Precipitation AMP (mm/month) | Assigned Value |
| --- | --- |
| <125* | 0 |
| 126-250 | 1 |
| >250 | 2 |

Table 3. Average monthly rainfall values classification

| Accumulated value of Precipitation Indices | Qualification | Factor Sh |
| --- | --- | --- |
| 0-4 | Very Low | 1 |
| 5-9 | Low | 2 |
| 10-14 | Medium | 3 |
| 15-19 | High | 4 |
| 20-24 | Very High | 5 |

Table 4. Moisture factor (Sh) from accumulated AMP values

# Mora & Vahrson Landslide HazardAssessment - The Triggering Indicator ***TRIG***

Represents the EXTERNAL driving forces which trigger the event.

Combines two factors: i) the 100 year earthquake and ii) maximum daily precipitation for a return period of 100 years

**Seismic intensity factor Ts** is determined by analyzing landslides triggered by earthquakes related to historical records.

| Intensities (MM) Tr=100yr | Qualification | Factor Ts |
|---|---|---|
| III | Slight | 1 |
| IV | Very Low | 2 |
| V | Low | 3 |
| VI | Moderate | 4 |
| VII | Medium | 5 |
| VIII | Considerable | 6 |
| IX | Important | 7 |
| X | Strong | 8 |
| XI | Very Strong | 9 |
| XII | Extremely Strong | 10 |

Table 5. Seismic Intensity factor **BASED ON OBSERVATIONS in Costa Rica and Central America**

# Mora & Vahrson Landslide HazardAssessment - The Triggering Indicator *TRIG*

Represents the EXTERNAL driving forces which trigger the event.

Combines two factors: i) the 100 year earthquake and ii) maximum daily precipitation for a return period of 100 years

**Rainfall intensity factor Tp** is determined by classification of maximum daily precipitations for a return period of 100 years.

| Max. rainfall Tr=100yr (n>10yr) | Qualification | Factor Tp |
|---|---|---|
| <100mm | Very Low | 1 |
| 101-200mm | Low | 2 |
| 201-300mm | Medium | 3 |
| 301-400mm | High | 4 |
| >400mm | Very high | 5 |

Table 4. Precipitation Intensity Factor resulting from the classification of maximum daily precipitations for a return period of 100 years.

# Implementation on Bulgarian Black Sea Coast

Assessment of landslide susceptibility along Bulgarian strip of Black Sea coast is based on M&V (1994) method.

The above method was chosen as the most appropriate, due to the complicated geological conditions of this area and lack of representative and reliable geotechnical data for the lithological units.

- Due to peculiarities of Bulgarian sea-side strip a new triggering factor has been added: **Te** (the abrasion and erosion activity) along the coast and rivers

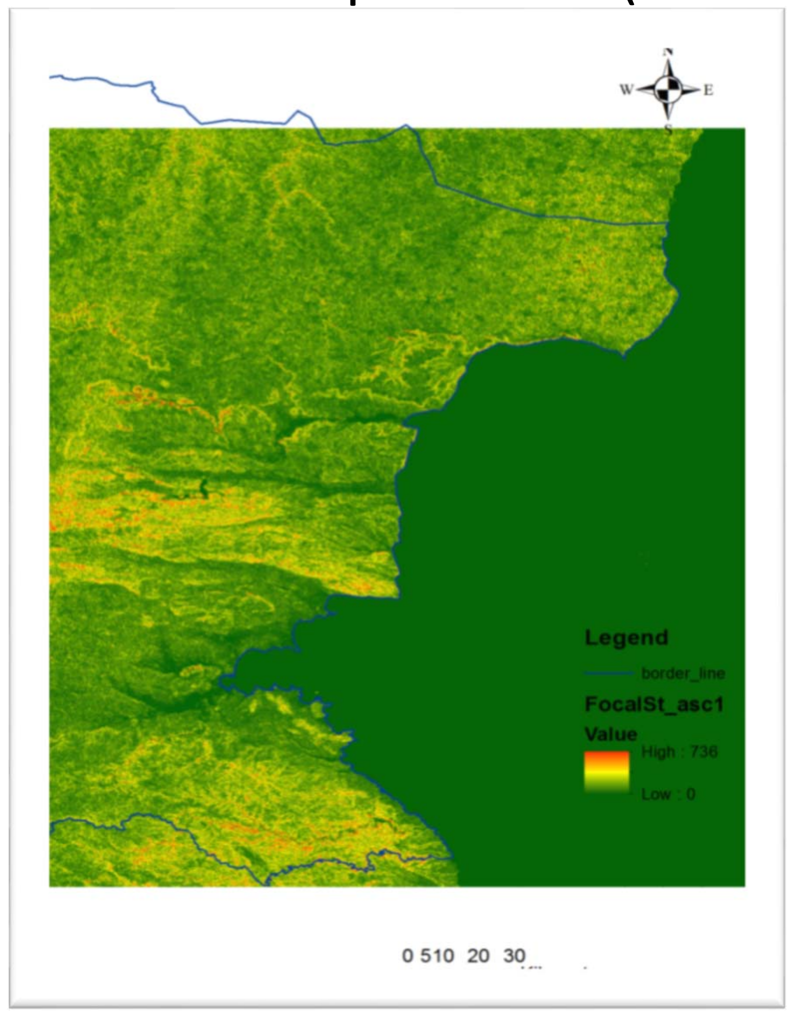
- So, the modified equation of M & V implemented herein is:

$$H = SUSC * TRIG = (Sr * Sl * Sh) * (Ts + Tp + Te)$$

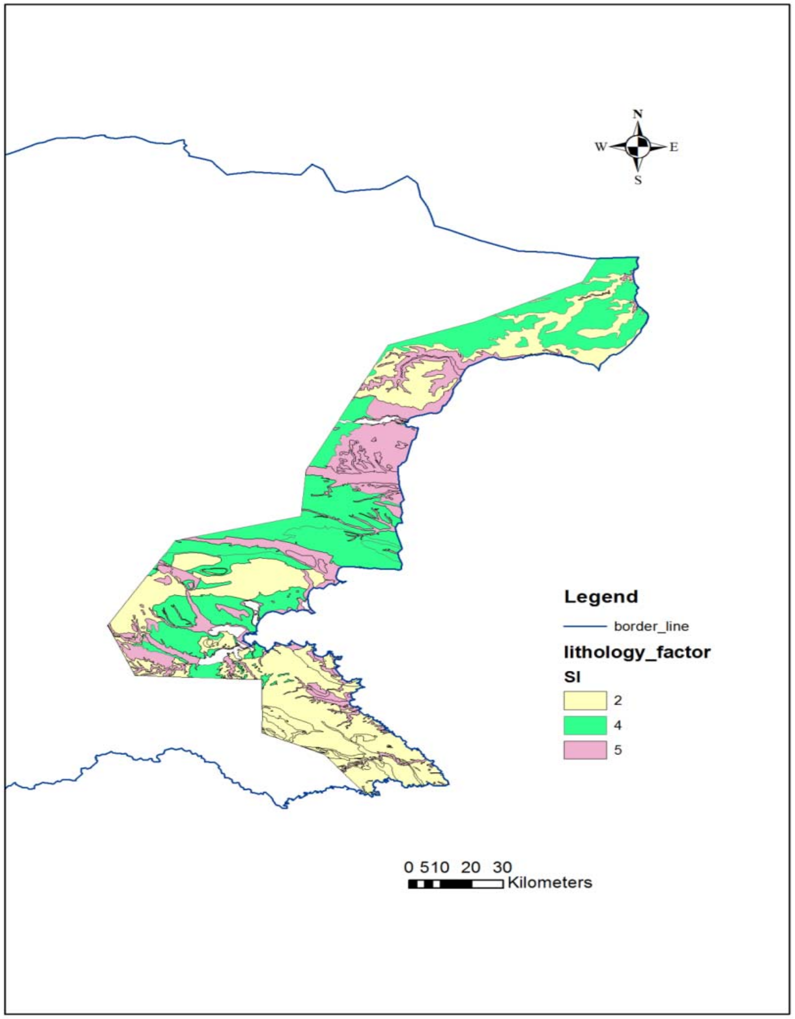
# Implementation on Bulgarian Black Sea Coast

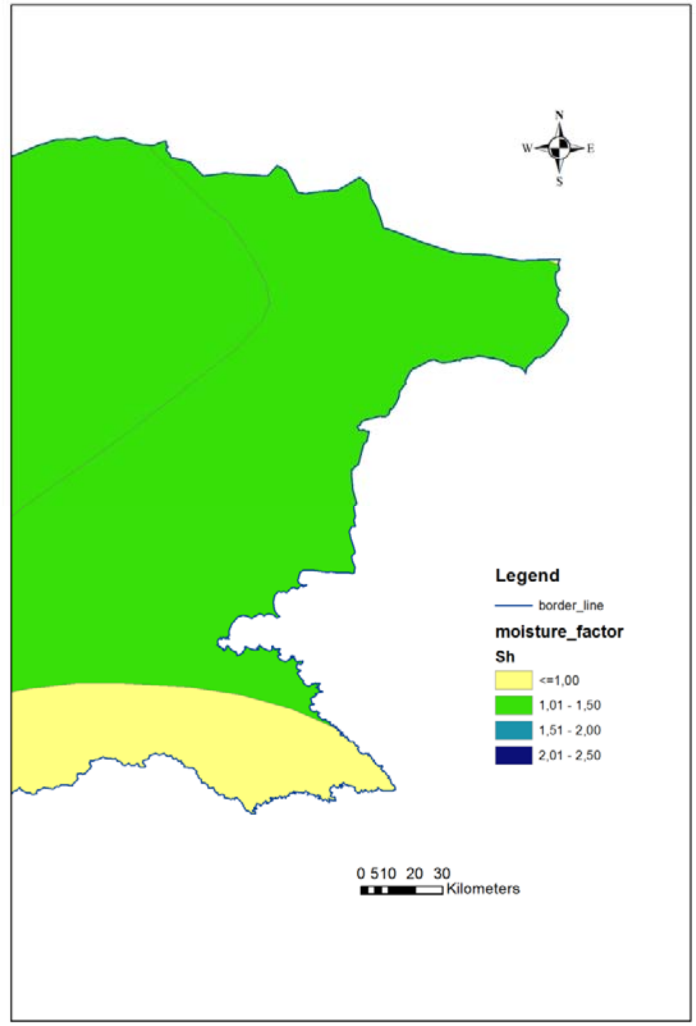
- The slope factor, Sr, is established by range of elevations according to Table 1 and based on NASA open data (30m DEM).

Map of Black Sea coast according to slope factor, **Sr**



# Implementation on Bulgarian Black Sea Coast

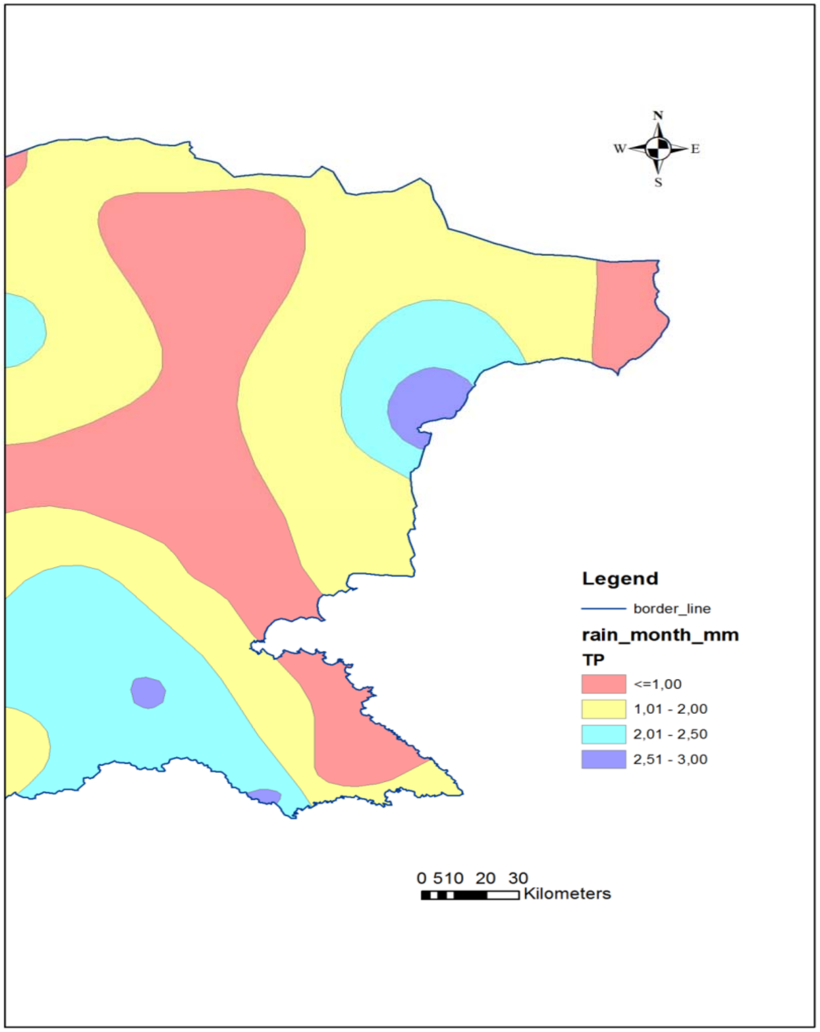


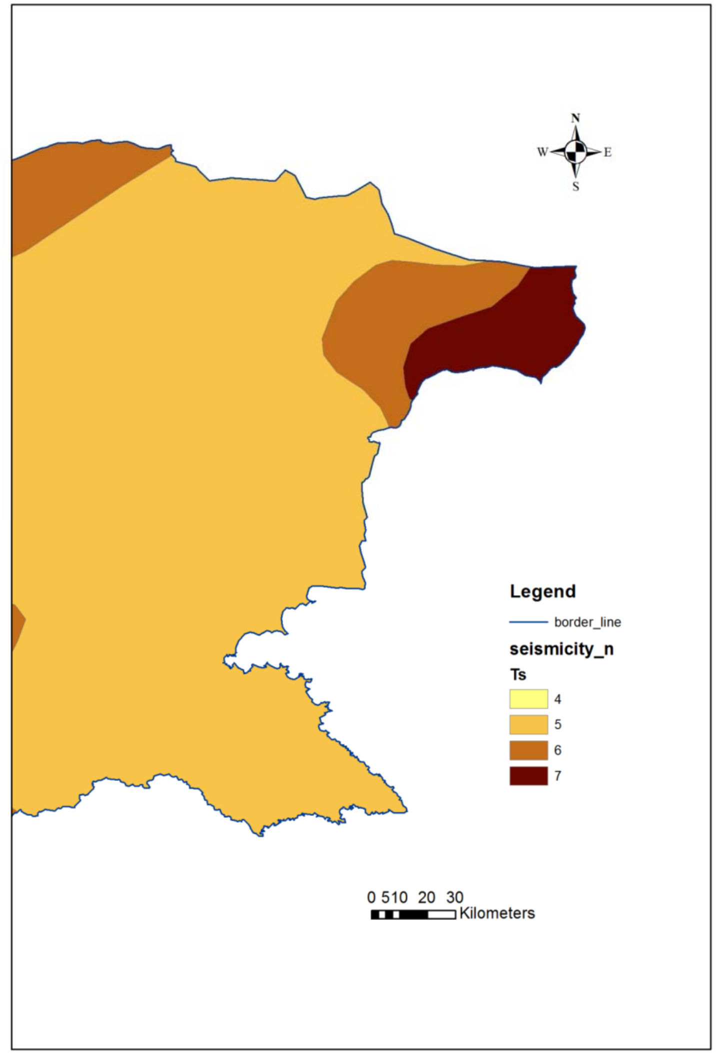

Map of Black Sea coast according to lithology factor, **Sl**

Map of Black Sea coast according to humidity factor, **Sh**

# Implementation on Bulgarian Black Sea Coast

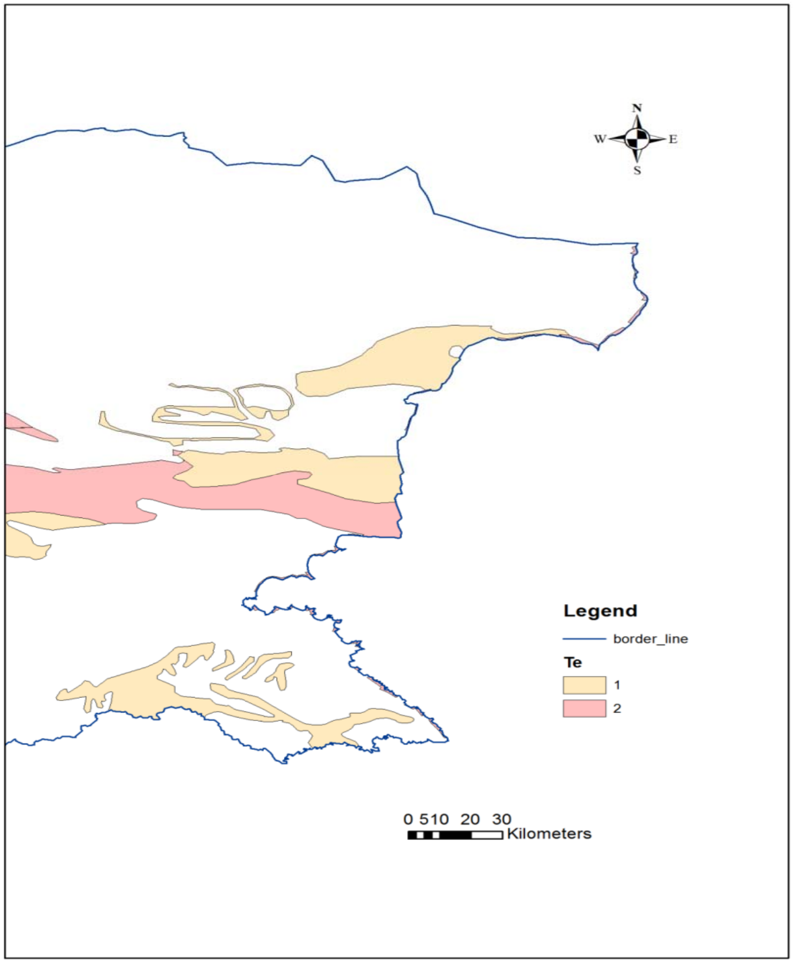



Map of Black Sea coast according to precipitation triggering factor, **Tp**




Map of Black Sea coast according to seismicity triggering factor, **Ts**

# Implementation on Bulgarian Black Sea Coast




Map of Black Sea coast according to erosion / abrasion triggering factor, **Te**

| Description of sea-side strip and cliff | Factor Te |
|---|---|
| Accumulation zone | 0 |
| Rocky cliff, with abrasion and erosion processes | 1 |
| Soft soils cliff, with abrasion and erosion processes | 2 |

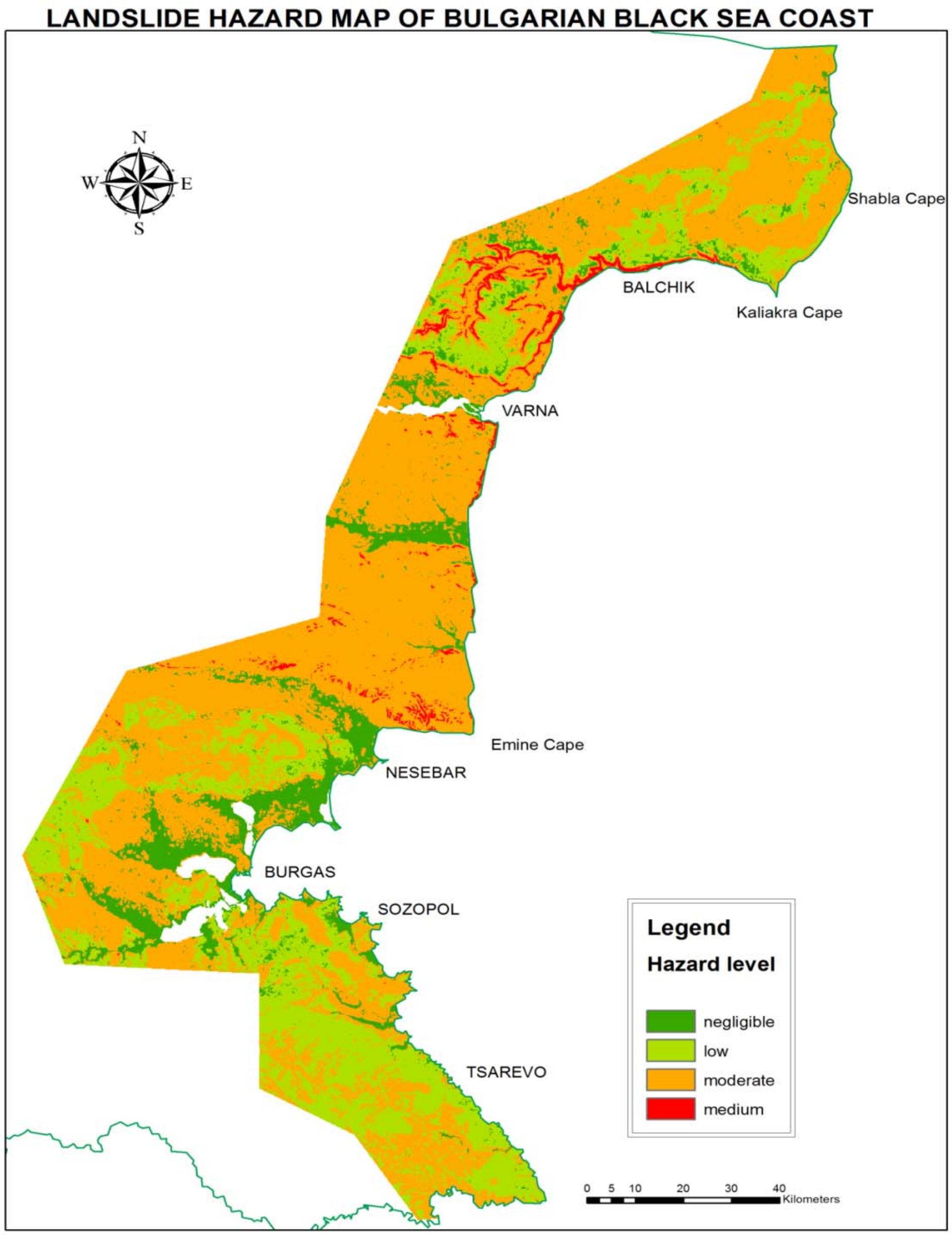
Table 3. Classification of landslide Te

# Implementation on Bulgarian Black Sea Coast – Susceptibility Mapping

Table 4: Classification of Landslide Hazard **(H)**

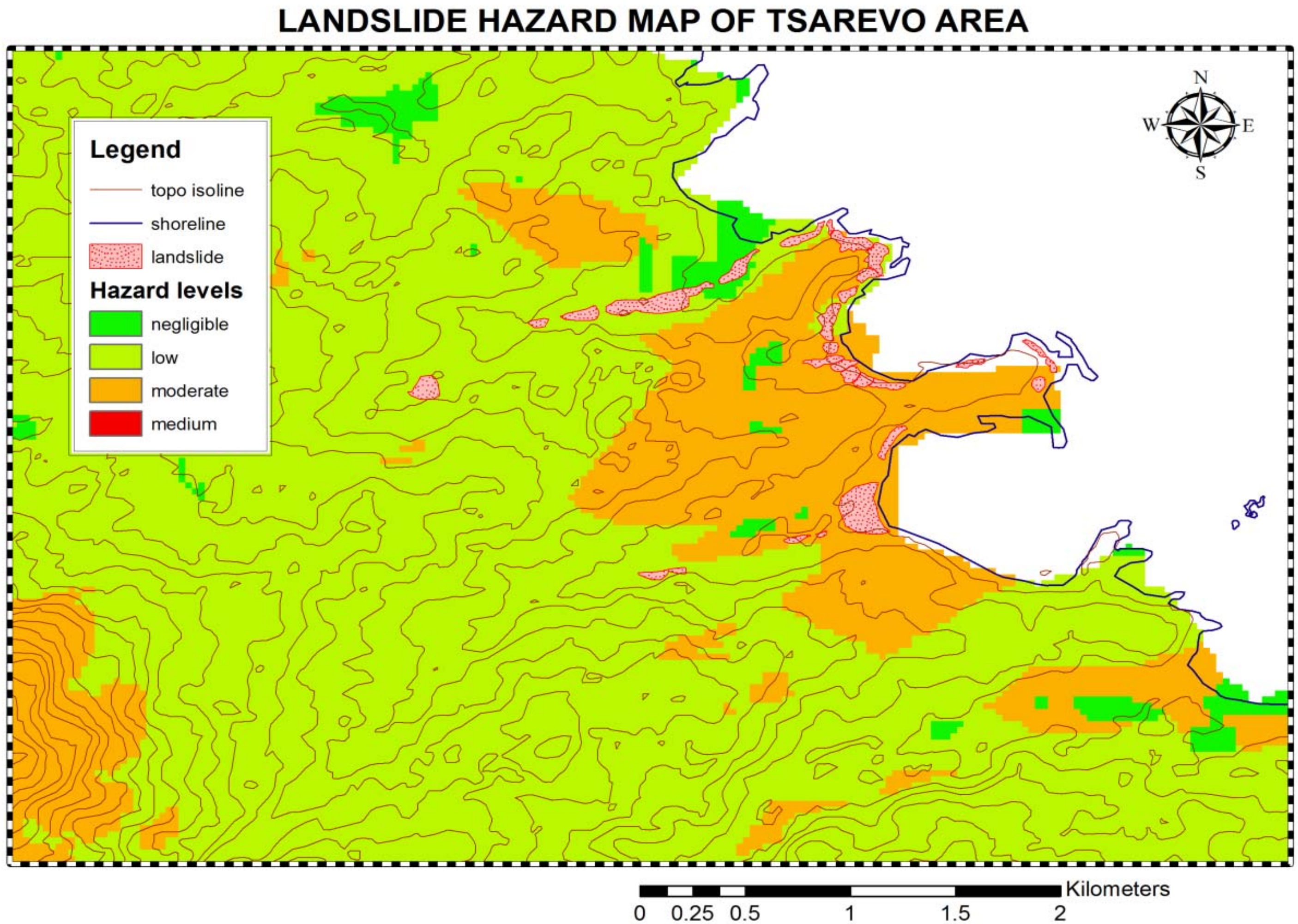
| H | Class | Classification of Hazard of Landslide Potential |
|---|---|---|
| <6 | I | Negligible |
| 7 – 32 | II | Low |
| 33 – 162 | III | Moderate |
| 163 – 512 | IV | Medium |
| 513 – 1250 | V | High |
| >1250 | VI | Very High |

# Landslide Hazard Map of Bulgarian Sea Coast




Landslide susceptibility map of the Bulgarian Black Sea coast according to the Mora and Vahrson (1994) method

# Implementation on Tsarevo Area & Black Sea coast




Landslide susceptibility map of Tsarevo area and Bulgarian Black Sea coast according to the Mora and Vahrson (1994) method

# Concluding Remark

- High Landslide susceptibility of Northern Black sea coast was assessed by Mora & Vahrson model with addition of erosion & abrasion triggering factor

Thank you for your attention