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Multicriteria GIS Modelling of Terrain Susceptibility to Gully Erosion, using the Example of the Island of Pag

Fran Domazetović, Ante Šiljeg, Nina Lončar, Ivan Marić

Department of Geography, University of Zadar

Introduction

- Multicriteria GIS data analysis (GIS-MCDA) is process of transforming and combining various spatial data for the purpose of obtaining new information
- GIS-MCDA has application in numerous fields → urban planning, agriculture, forestry, mining, optimal site selection, natural hazards, etc.
- In geomorphological studies GIS-MCDA is used to determine the areas of different susceptibility for the appearance of certain morphological features and processes (e.g. gully erosion)
- Better understanding of spatial distribution of studied object or process

Gully erosion importance

- Gully erosion is **threatening** the valuable soil sediments
- Specific Mediterranean grassland eco-system

Examples of soil degradation and removal caused by gully erosion

Local sheep breeding depends on grassland areas

Study location – Pag Island, Croatia

- Largest island in Northern Dalmatia archipelago (**284 km²**)
- Specific karst landscape → scarce vegetation cover
- Many active gullies (Lončar, 2009)
- Gully erosion → one of the most prominent denudation processes

Location of the study area

Characteristics of study area

- **Mediterranean climate** - between Csa and Cfa climatic zones (Köppen)
- The annual average amount of **precipitation** on the island of Pag is between 1050 mm and 1106 mm
- Bare landscape shaped by the influence of **strong northern Bora wind**

Specific bare karstic landscape

Aims of the study

I. Modelling of gully erosion susceptibility of Pag Island

H1: Large parts of the Island are vulnerable to the gully erosion occurrence

II. Determine the correlation between high susceptibility areas and existing active gullies

H2: High and very high susceptibility areas coincide with existing gullies

III. Analyse the vulnerability of the settlements of Pag Island from gully erosion

H3: The immediate surroundings of many settlements is directly threatened by gully erosion

Data acquisition

I. DIGITAL ELEVATION MODEL (DEM)

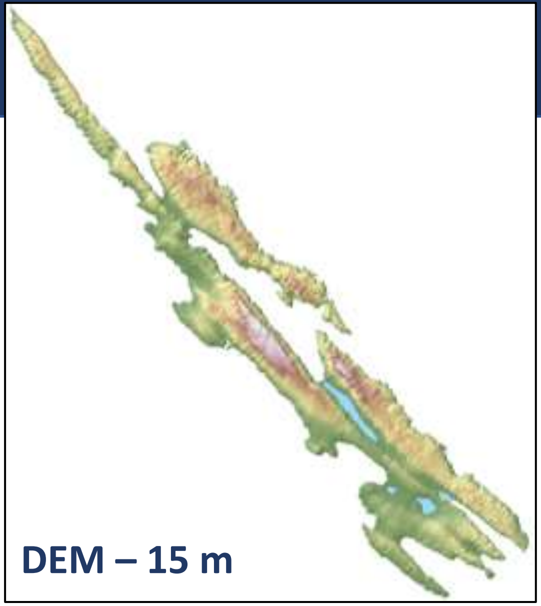
- DEM was made based on the height data collected by the **photogrammetric restitution** (DGU, 2017).
- Ordinary kriging (OK) interpolation of **148 518 height points** → 15 m spatial resolution of DEM (284 km²)
- Optimal interpolation method chosen by cross-validation results → **RMSE = 1,0279**

II. Medium resolution satellite image

- Sentinel 2 multispectral images → **supervised classification** (Erdas Imagine)

III. Soil maps (1:50 000)

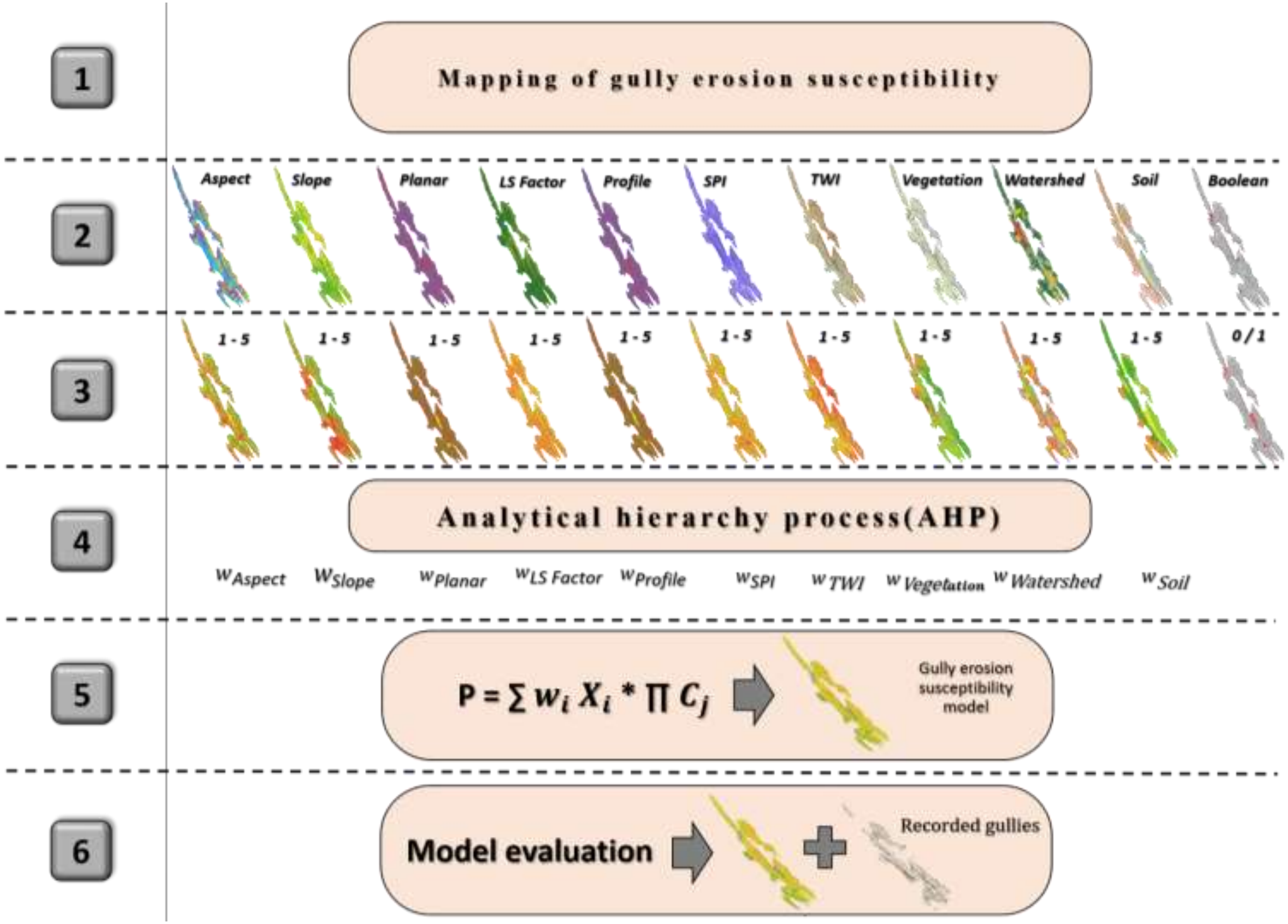
- Soil types are vectorized from basic soil maps at scale 1:50 000



Research methodology

GIS-MCDA WORKFLOW

1. Define the GIS-MCDA goal
2. Determination of criteria and constraints
3. Standardization of criteria
4. Calculation of the weight coefficients
5. Aggregating (*model creation*)
6. Model validation



I. Morphometric parameters

SLOPE (SLO)

- Main predisposing factor in the evolution of the slope relief
- Influences the intensity of the gully erosion
- Optimal slope for gully erosion is 12°-32°

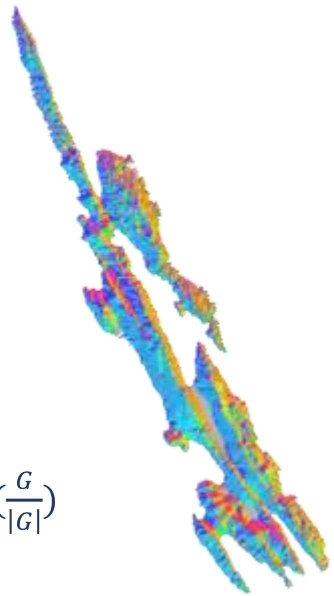
Data source:
15 m DEM

Horn method (1981.)

$$N\,(^{o}) = \sqrt{G^2 + H^2}\,\left(\frac{180}{\pi}\right)$$

ASPECT (ASP)

- Regulates the exposure of the terrain to various climatic factors
- Controls the vegetation cover development
- Northern and north-eastern slopes affected by Bora wind



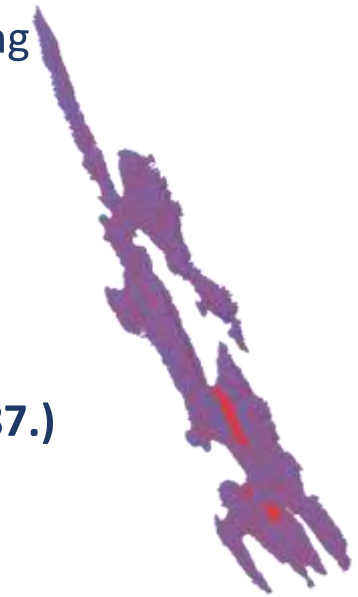
Data source:
15 m DEM

Horn method (1981.)

$$A = 180º - \arctan\left(\frac{H}{G}\right) + 90º\left(\frac{G}{|G|}\right)$$

PLANAR CURVATURE (PLAN)

- Affects the homogeneity of the surface runoff
- Concave slopes are causing the convergence of runoff → higher erosion potential (EP)
- Convex slopes are causing the divergence of runoff → lower EP



Data source:
15 m DEM

Zeverbergen & Thorne (1987.)

$$\omega = 2(\frac{DH^2 + EG^2 + FGH}{(G^2 + H^2)}$$

I. Morphometric parameters

PROFILE CURVATURE (PROF)

- Affects the speed of downslope surface runoff and occurrence of material removal
- Concave slopes are causing the

slowdown of surface runoff → lower EP

- Convex slopes are causing acceleration

Of runoff → higher EP

Data source:
15 m DEM

Zeverbergen & Thorne (1987.)

$$\emptyset = -2(\frac{DG^2+EH^2+FGH}{(G^2+H^2)})$$

LENGHT-SLOPE FACTOR (LSF)

- Measure of sediment transport capacity of surface runoff
- Applied in USLE and RUSLE

equations for calculation of soil erosion

- Higher LSF → Higher erosion EP

Data source:
15 m DEM

Zhang (2013.)

$$LSF = \left(\frac{A_S \times spatial\ resolution\ (DEM)}{22.13}\right)^{0.4} \times \left(\frac{\sin\beta}{0.0896}\right)^{1.3}$$

II. Hydrologic parameters

STREAM POWER INDEX (SPI)

- Represents the measure of the erosive power of surface runoff
- Influences the intensity of gully erosion
- Higher SPI → higher EP

Data source:
15 m DEM

Moore (1981.)

$$SPI = \ln(A_s \text{ x } \tan\beta)$$

TERRAIN WETNESS INDEX (TWI)

- Measure of the potential humidity of a given terrain
- Allows the separation and differentiation of the saturated areas from unsaturated areas
- Higher TWI

→ lower EP

Data source:
15 m DEM

Moore (1981.)

$$TWI = \ln(\frac{A_s}{\tan \beta})$$

Watershed (WAT)

- Erosion force of the surface runoff depends mostly on the surface of the catchment area
- Larger watershed → larger surface runoff → larger EP

Data source:
15 m DEM

III. Additional parameters

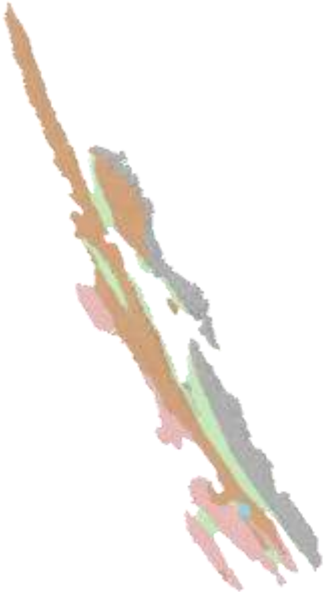
LAND COVER (LC)

- 9 land cover classes classified from satellite images
- Different vegetation and land-use types
- Bare rocks, grasslands, agriculture, forests, swamplands, etc.

Data source:
10 m Sentinel 2

PEDOLOGY (PEDOL)

- Different types of soil characterize different erosion resistance
- Soil characteristics are affecting the erosion intensity
- Connected with vegetation cover and land-use practice



Data source:
Soil map (1:50 000)

BOOLEAN (BLN)

- Areas that are not sutable for gully erosion
- Differenced from satellite images
- Water bodies and urban areas

Data source:
10 m Sentinel 2

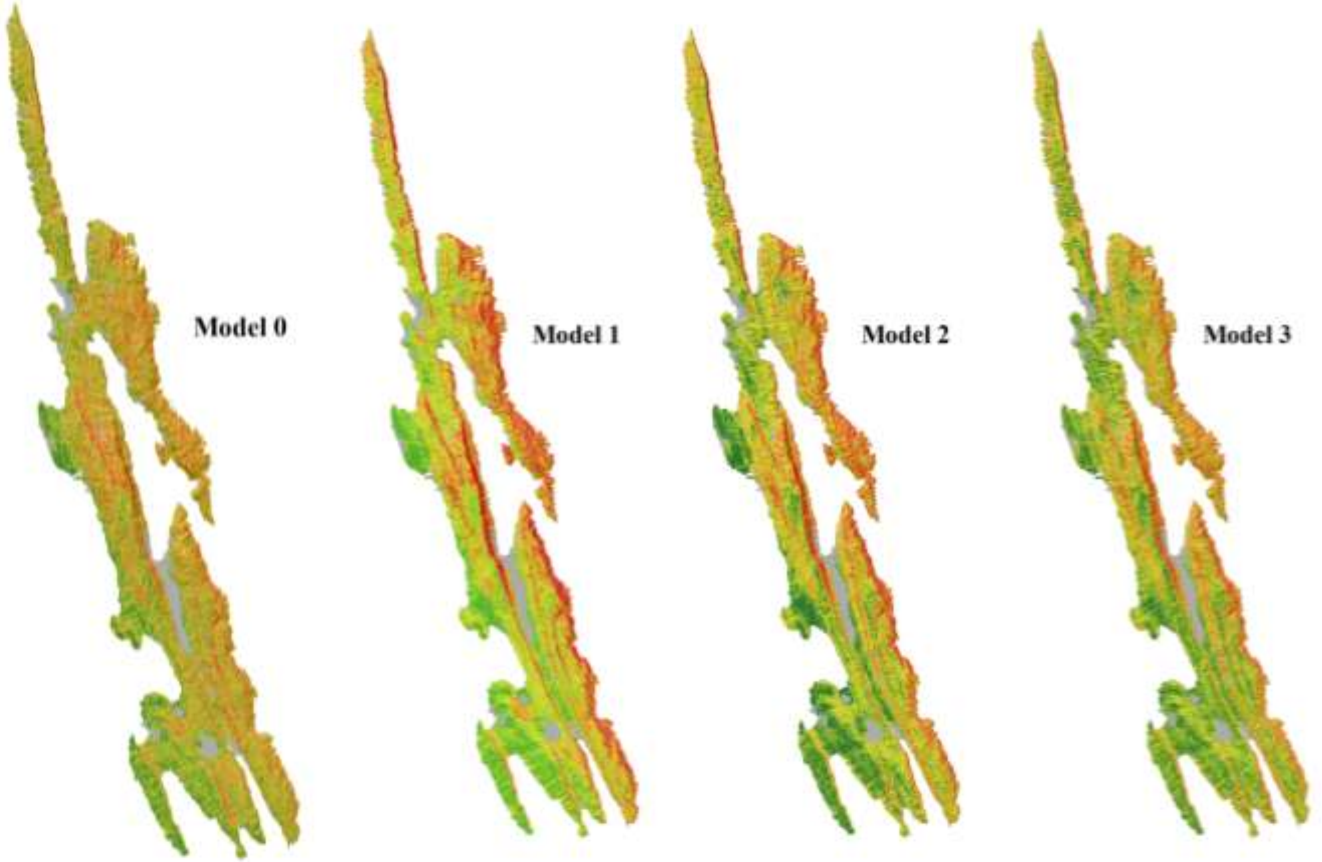
Standardization, weight calculation and aggregation of criteria

- **Standardization** of criteria is the basis for their mutual comparison (Malczewski, 2015)
- 10 predisposing criteria standardized to the scale (1 – 5), BLN criteria standardized to binary scale (0,1)
- Predisposing factors → lower values = lower importance

- **Weight coefficients** for each criteria were calculated by **analytical hierarchy process (AHP)**
- AHP allows the calculation and validation of weight coefficients for each criteria
- Validation is performed through the **consistency index (CI < 0,1)**

- Based on chosen criteria and their weight coefficients **four different models** were produced (Model 0, Model 1, Model 3, Model 4)

Output models of the GIS-MCDA



MODEL 0 → all criteria equally important

MODEL 1 → SLO, ASP, PEDOL, LC most important

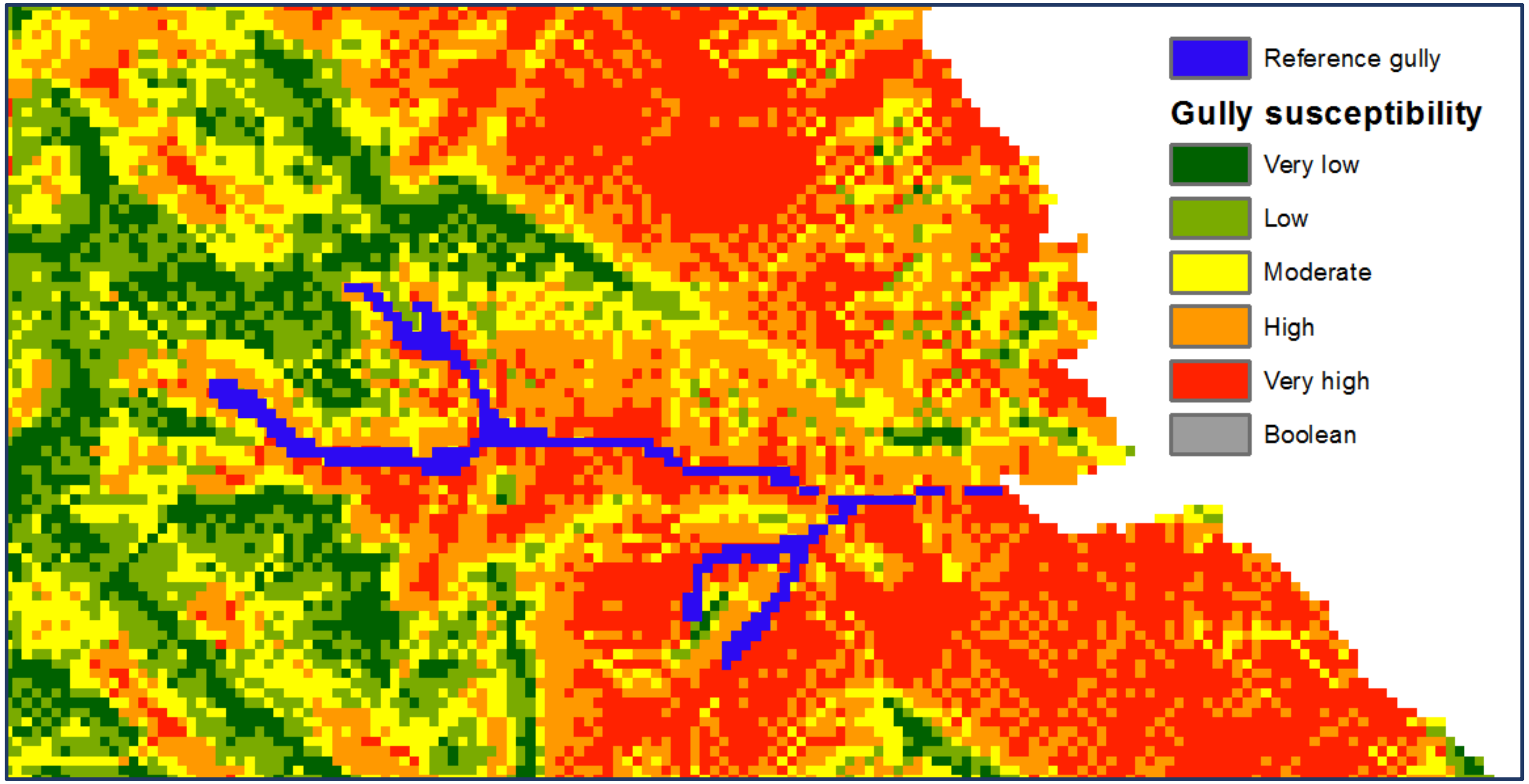
MODEL 2 → PEDOL less important (poor dana quality)

MODEL 3 →morphometric parameters most important

- Visual comparison of created models shows significant difference in distribution of susceptibility classes
- Models 0 and 1 are less good then other two models

Validation of created models

- Model validation performed through the creation of ROC curves



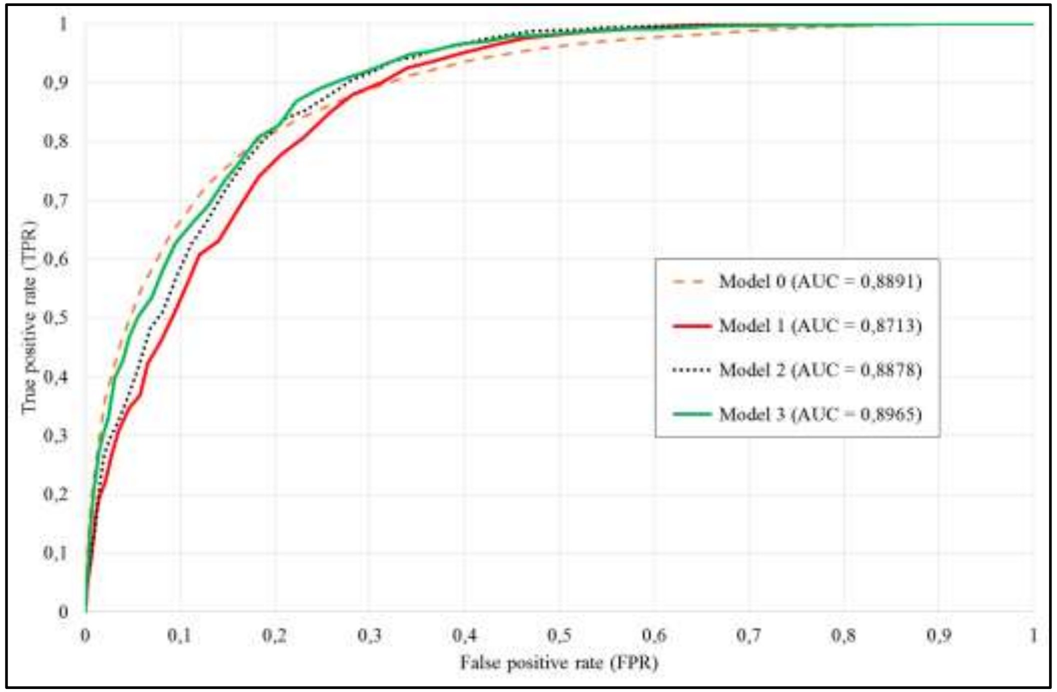
Validation of GIS-based MCDA model with gully reference data

REFERENCE DATA

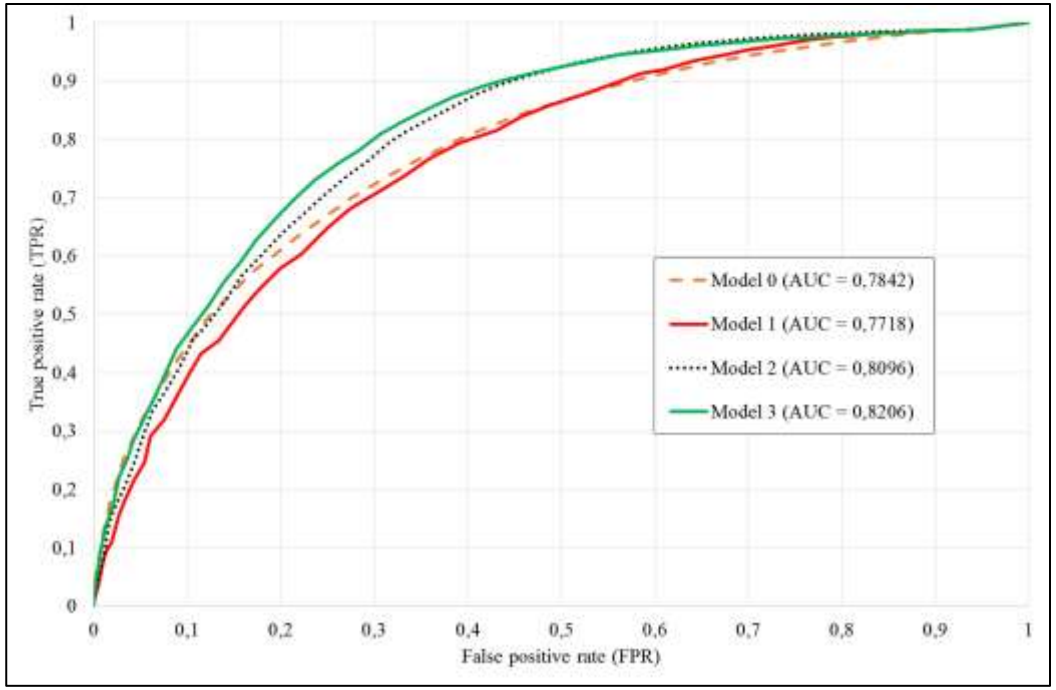
- Object-based Image Analysis (OBIA) → more then 100 gullies mapped
- Manual vectorization (DOF - 1:1000) → 10 reference gullies mapped

ROC curves validation

- **Model 3** is the most accurate model (**AUC > 0.8** → *very good quality model*)
- ROC curves have confirmed the **strong correlation** between existing gullies and high susceptibility areas



ROC curves for 10 reference gullies



ROC curves for 120 OBIA gullies

Final gully erosion susceptibility model

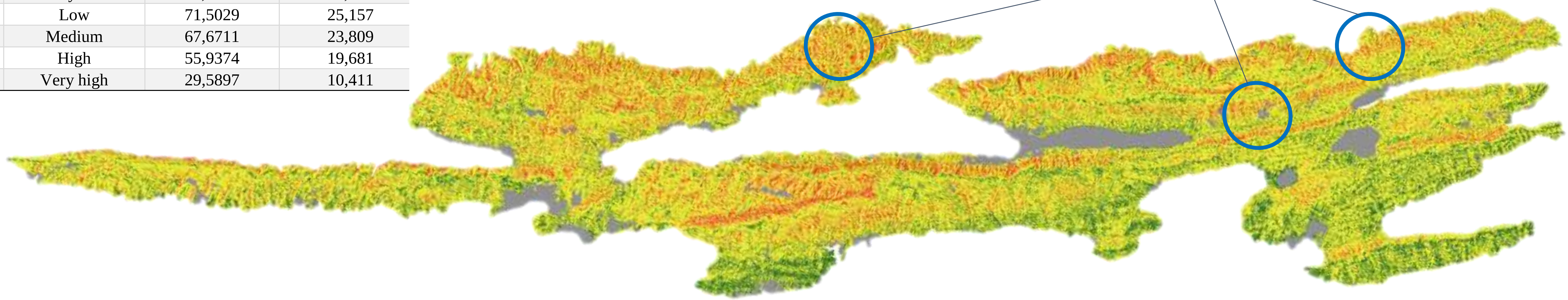
- High and very high susceptibility areas are covering around **30 %** of total island area
- **Low susceptibility areas** are mostly related to flat, inner parts of the island
- Baren NE and E slopes of karst hills are **most vulnerable** to gully erosion

Gully erosion susceptibility

- Very low
- Low
- Medium
- High
- Very high
- Boolean

#	Class	Area (km^2)	% of total area
1	Boolean	15,8796	5,587
2	Very low	43,6412	15,355
3	Low	71,5029	25,157
4	Medium	67,6711	23,809
5	High	55,9374	19,681
6	Very high	29,5897	10,411

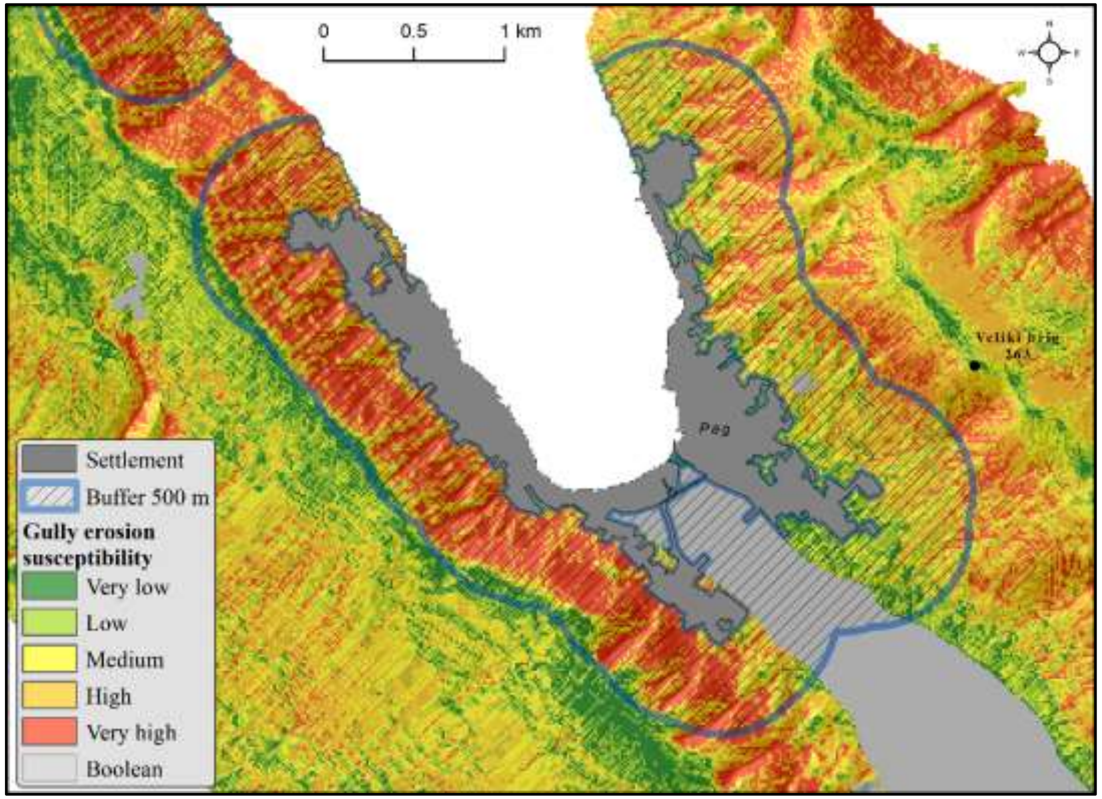
Field survey of high susceptibility areas



Field surveys have additionally validate the accuracy of created model

Settlement vulnerability analysis

- Buffer zone of 500 m around 25 settlemnts is analyzed
- The most endangered settlement is Pag town → recentaly built apartments are built in high gully erosion susceptibility areas
- Several other settlements are endangered (Kolan, Lun, Metajna, etc.)
- Gully erosion can negatively affect further development and expansion of the settlements



Gully erosion susceptibility within 500 m buffer **around Pag city**

Conclusion

- Created gully erosion susceptibility model shows that **large parts (30%)** of the Pag Island are directly endangered
- ROC curves have proven that high and very high susceptibility areas **coincide** with existing gullies
- The immediate surroundings of many settlements **is directly threatened** by gully erosion, while most vulnerable settlement is Pag city
- GIS-MCDA represents a **key basis** for planning and preparation for prevention of future negative effects of gully erosion

Thank you for your attention

Any questions ???