Integrated Soil Erosion Assessment: Concepts, Methods and Applications

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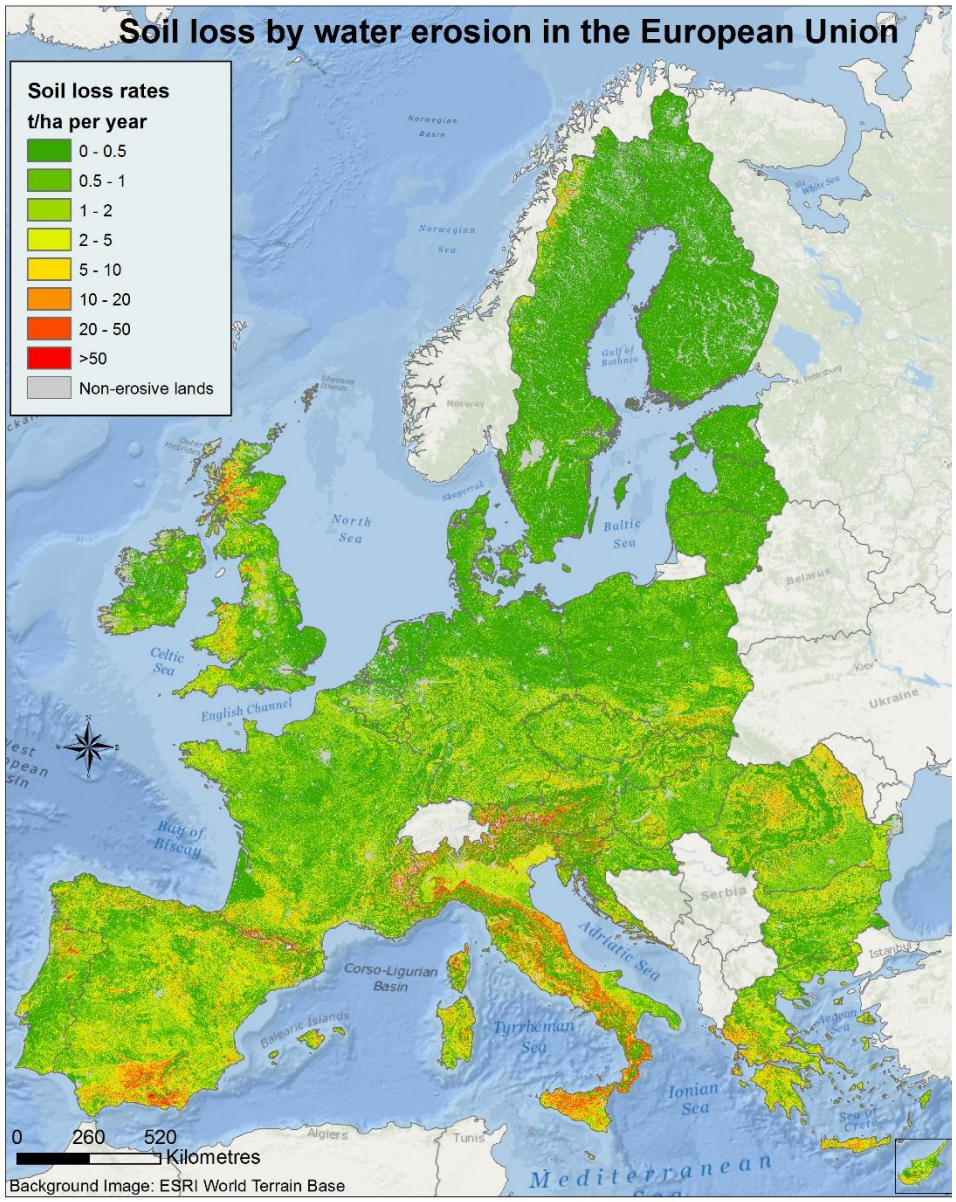
Soils are the basis for life and an important production resource

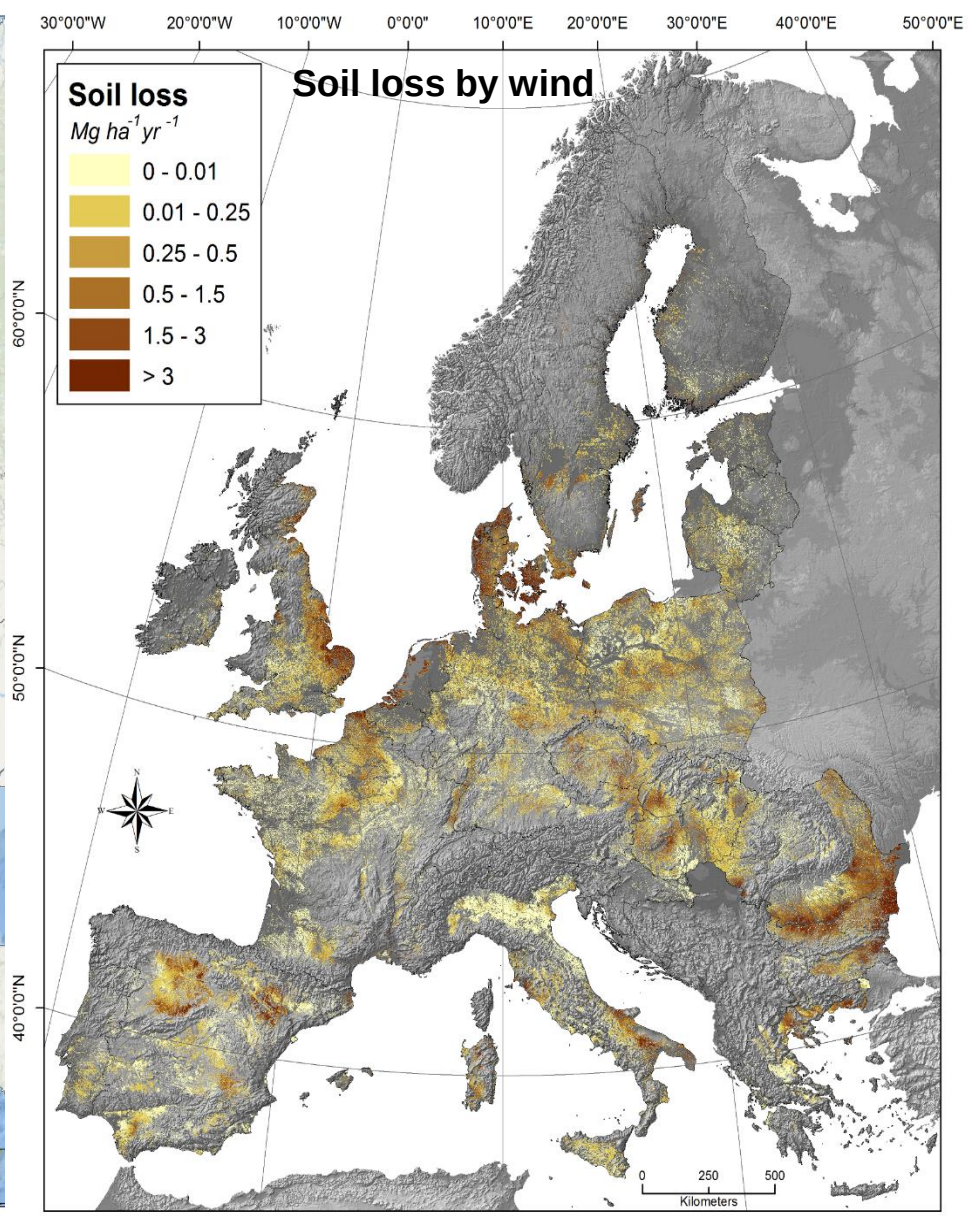
- Worldwide 95% of **food** is produced on soils,
- Soils play a key role in the **ecosystem** and for **ecosystem functioning**,
- Soils are habitats that are enormously rich in **biodiversity**,
- Soils are the third largest **carbon stock**.

PROBLEM → Soil degradation and soil loss

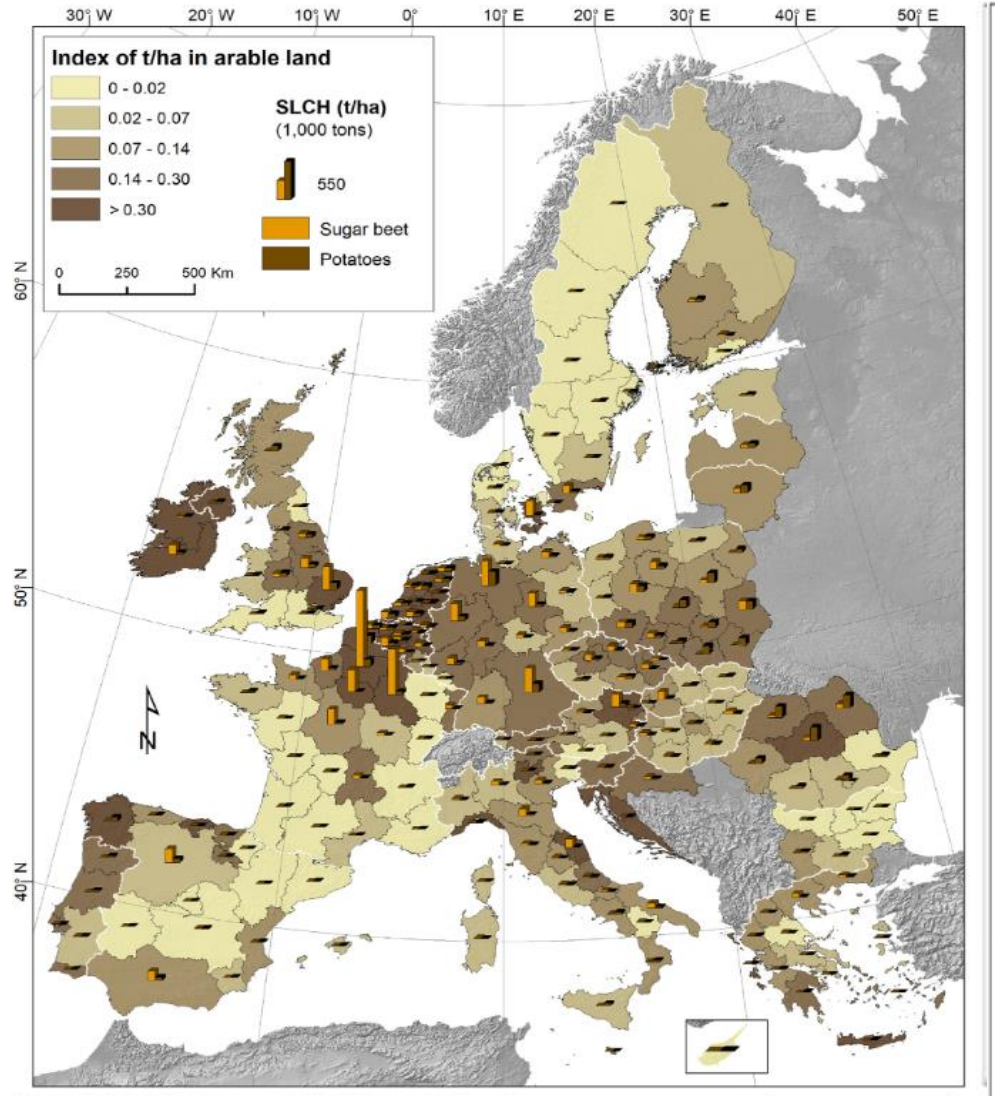
- Agriculture covers ~38% of the Earth's ice-free land*
- Accelerated water erosion represents a major socioeconomic and environmental threat through its several on-site and off-site effects

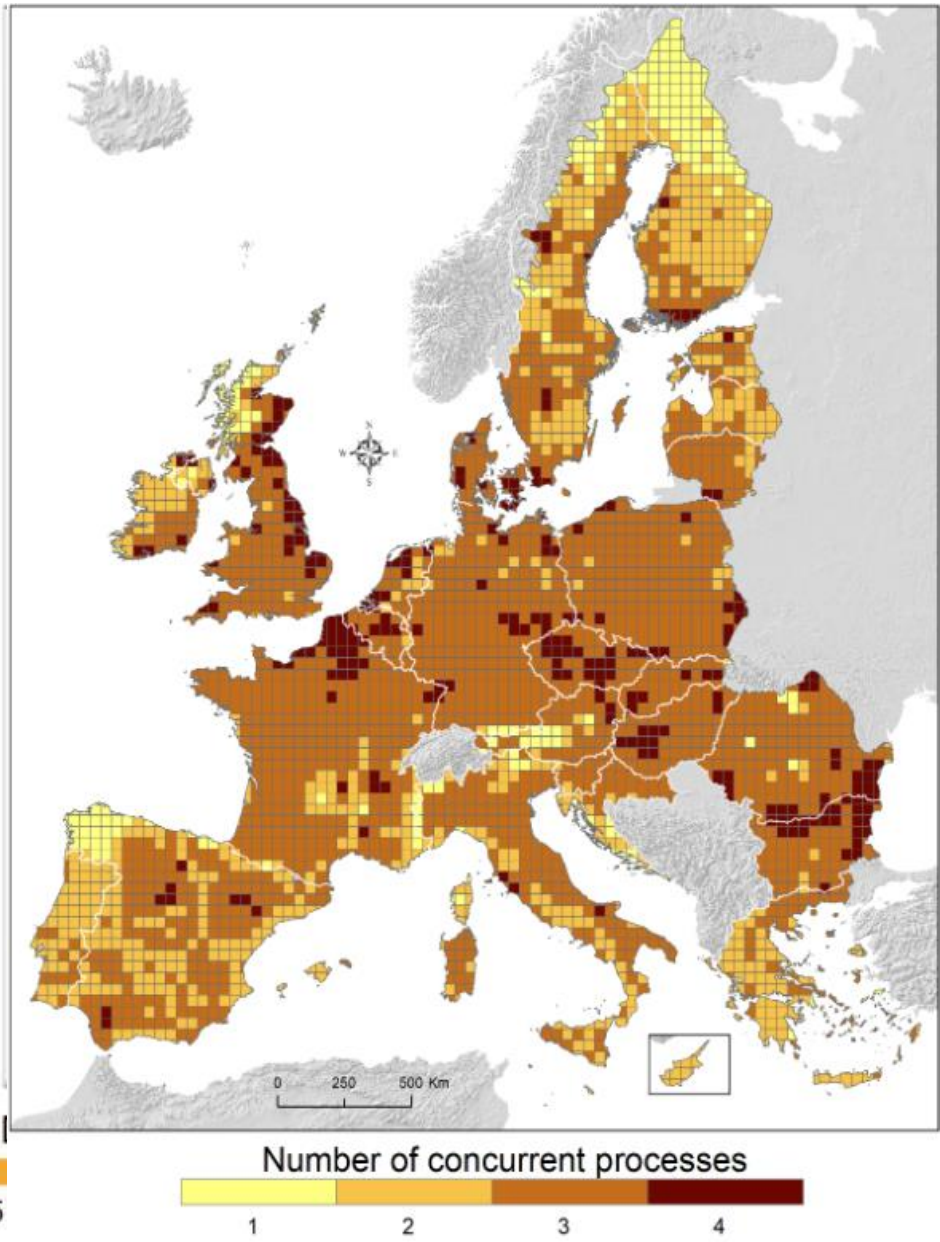
* Foley, J. A. *et al*. Solutions for a cultivated planet. *Nature* **478**, 337–342 (2011).

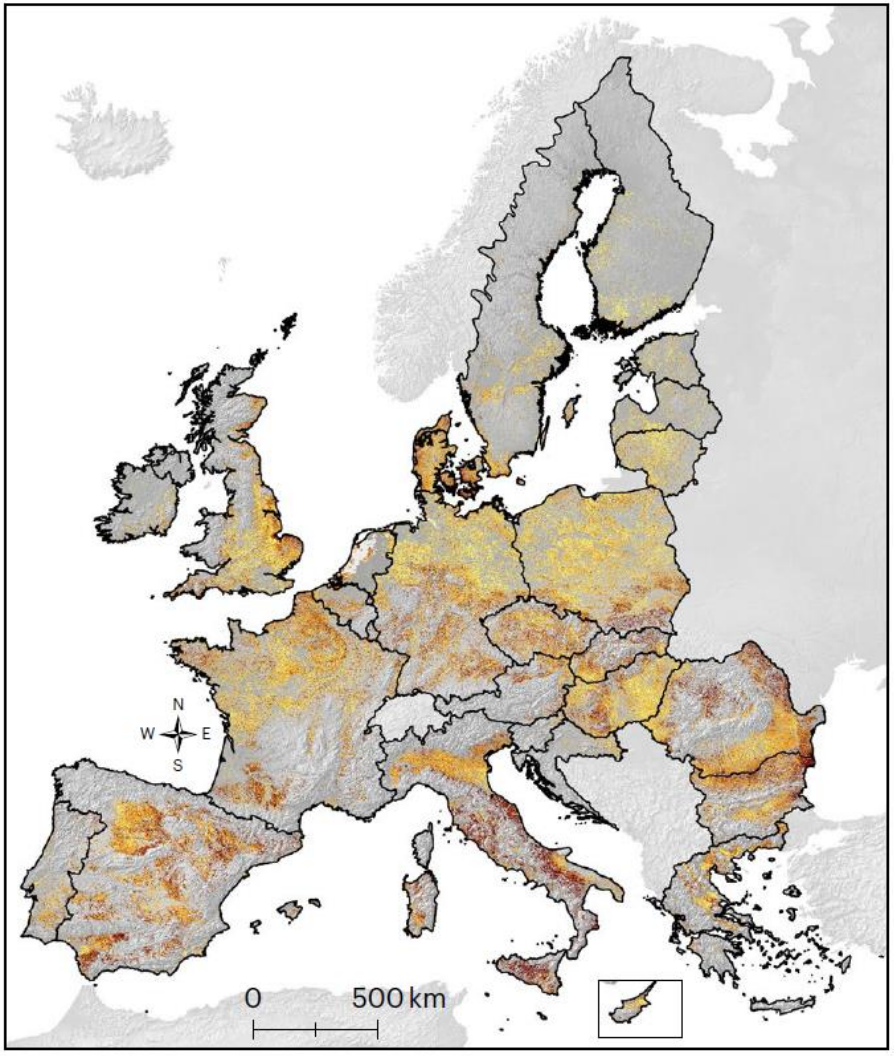


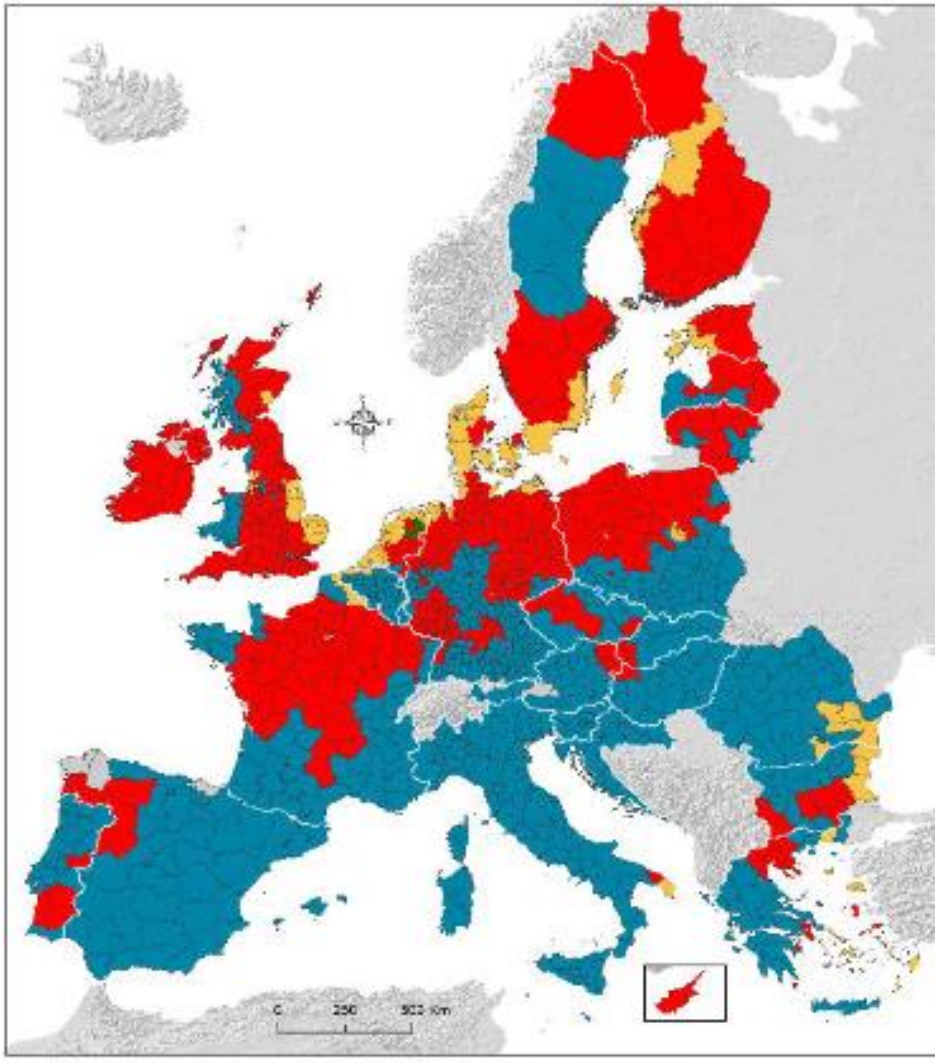


Borrelli, P., Panagos, P., Alewell, C. Maerker, M. *et al.* Policy implications of multiple concurrent soil erosion processes in European farmland. *Nat Sustain* (2022). https://doi.org/10.1038/s41893-022-00988-4


30° W
20° W
10° W
0°
10° E
20° E
30° E
40° E
50° E
60° N
50° N
40° N
Index of t/ha in arable land
0 - 0.02
0.02 - 0.07
0.07 - 0.14
0.14 - 0.30
> 0.30
SLCH (t/ha)
(1,000 tons)
550
Sugar beet
Potatoes
0
250
500 Km
Soil loss
0 - 1
1 - 2
2 - 5


0
250
500 Km
Number of concurrent processes
1
2
3
4





Soil loss (Mg ha^{-1} yr^{-1})

0–1 1–2 2–5 5–10 >10

Borrelli, P., Panagos, P., Alewell, C. Maerker, M. *et al.* Policy implications of multiple concurrent soil erosion processes in European farmland. *Nat Sustain* (2022). https://doi.org/10.1038/s41893-022-00988-4


Soil erosion by water

Monetary dimension of soil erosion

"Each year about **10 million ha of cropland are lost** due to soil erosion, thus reducing the cropland available for food production..... Overall **soil is being lost from land areas 10 to 40 times faster than the rate of soil renewal** imperilling future human food security and environmental quality." D.PIMENTEL (2006): Environment, Development and Sustainability

Damages due to soil erosion ("on site- & off site" damages) amounts to :

Globally ca. 450 Mrd. Euro per year

W. BLUM 2001 (Secretary General IUSS)

EU-wide ca. 20 Mrd. Euro per year

Panagos P. et al. (2015): *Nature* 526, 195.

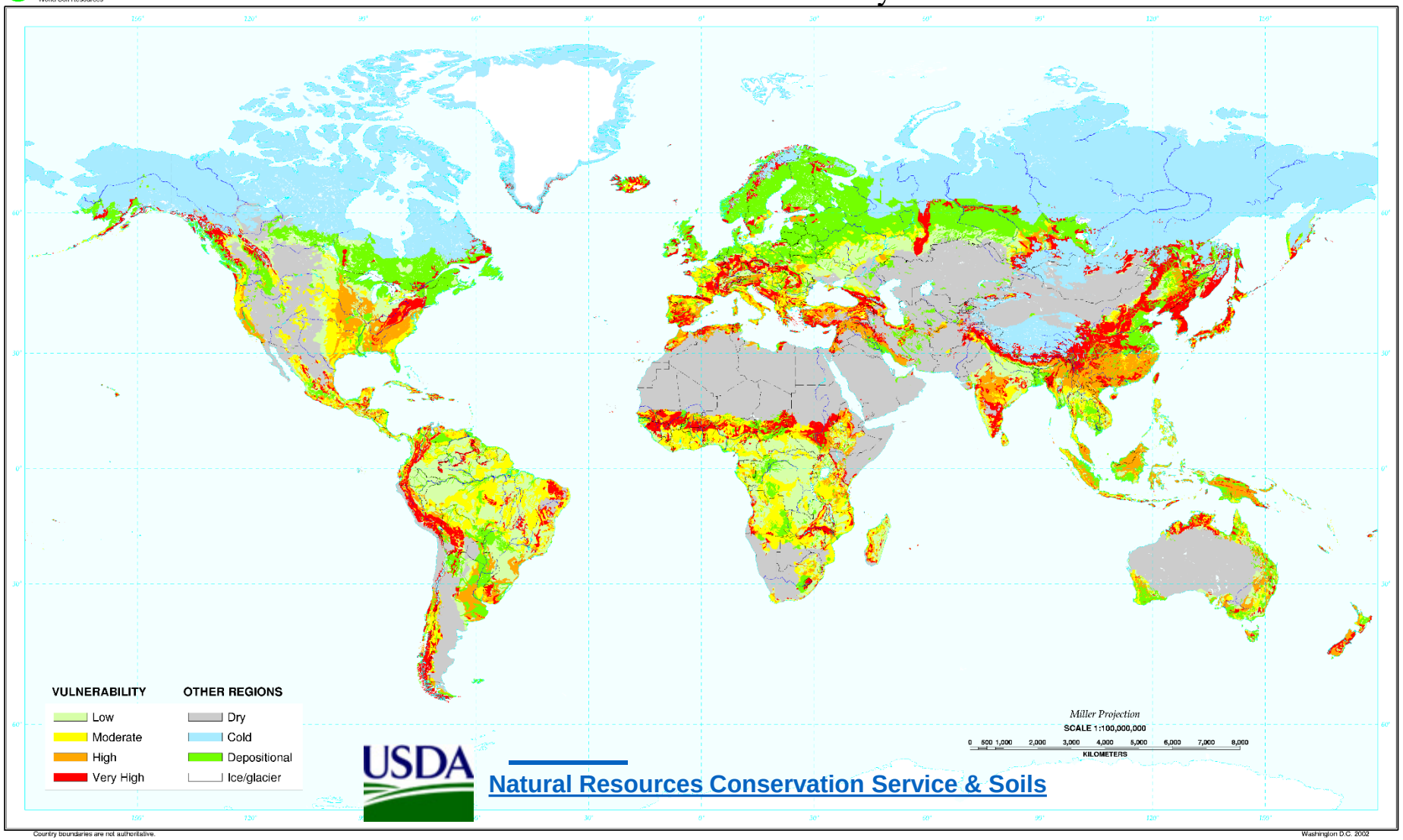
average world wide

ca. 60 Euro/year and person

Basilicata, Italy

U.S. Department of Agriculture
Natural Resources Conservation Service
Soil Survey Division
World Soil Resources

Water Erosion Vulnerability

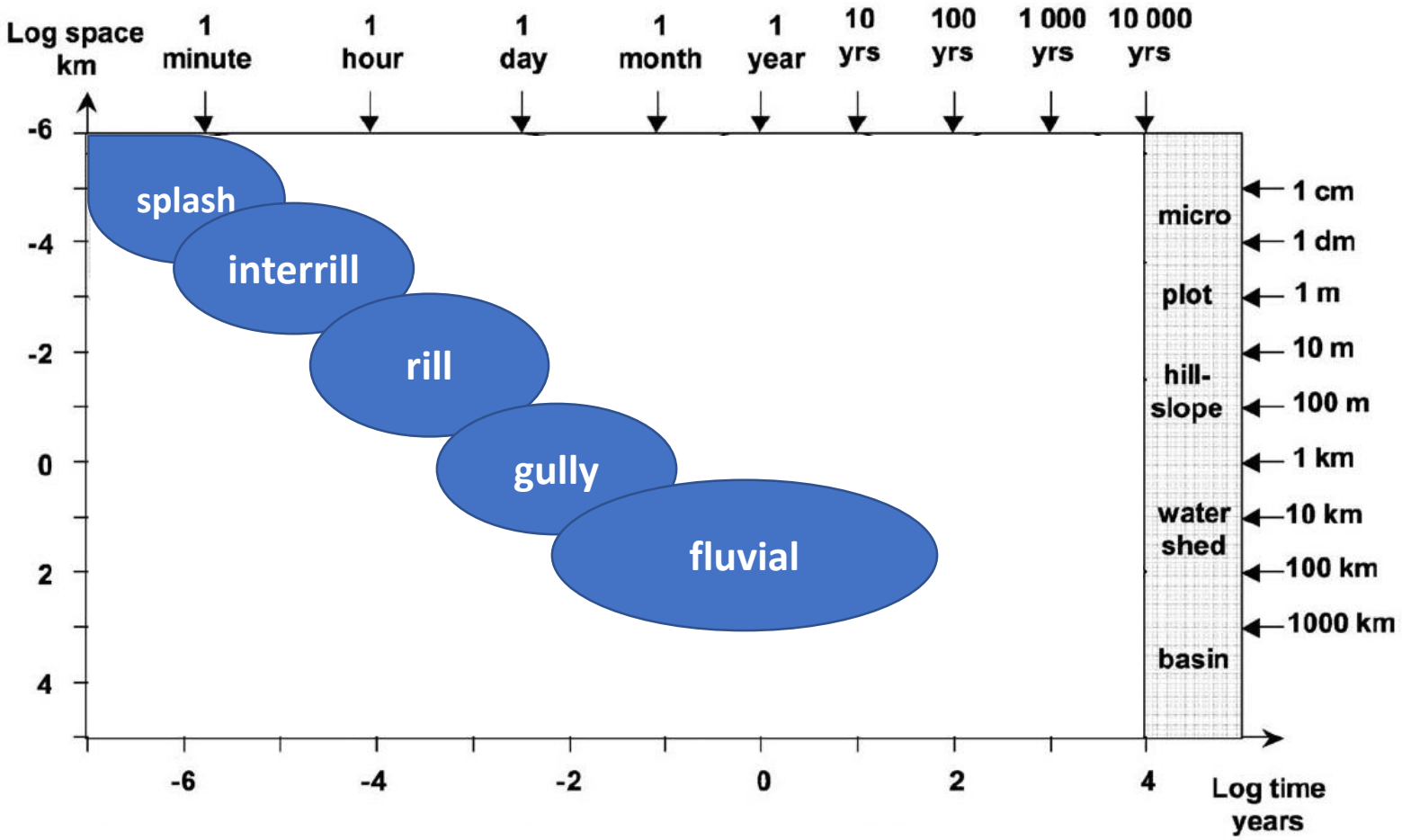


Research Questions:

- **Which processes can be differentiated?**
- **What spatio-temporal scales do these processes have?**
- **How do these processes interact?**
- **What concepts are available for an qualitative and quantitative assessment?**
- **How to integrated the different processes on catchment scale?**

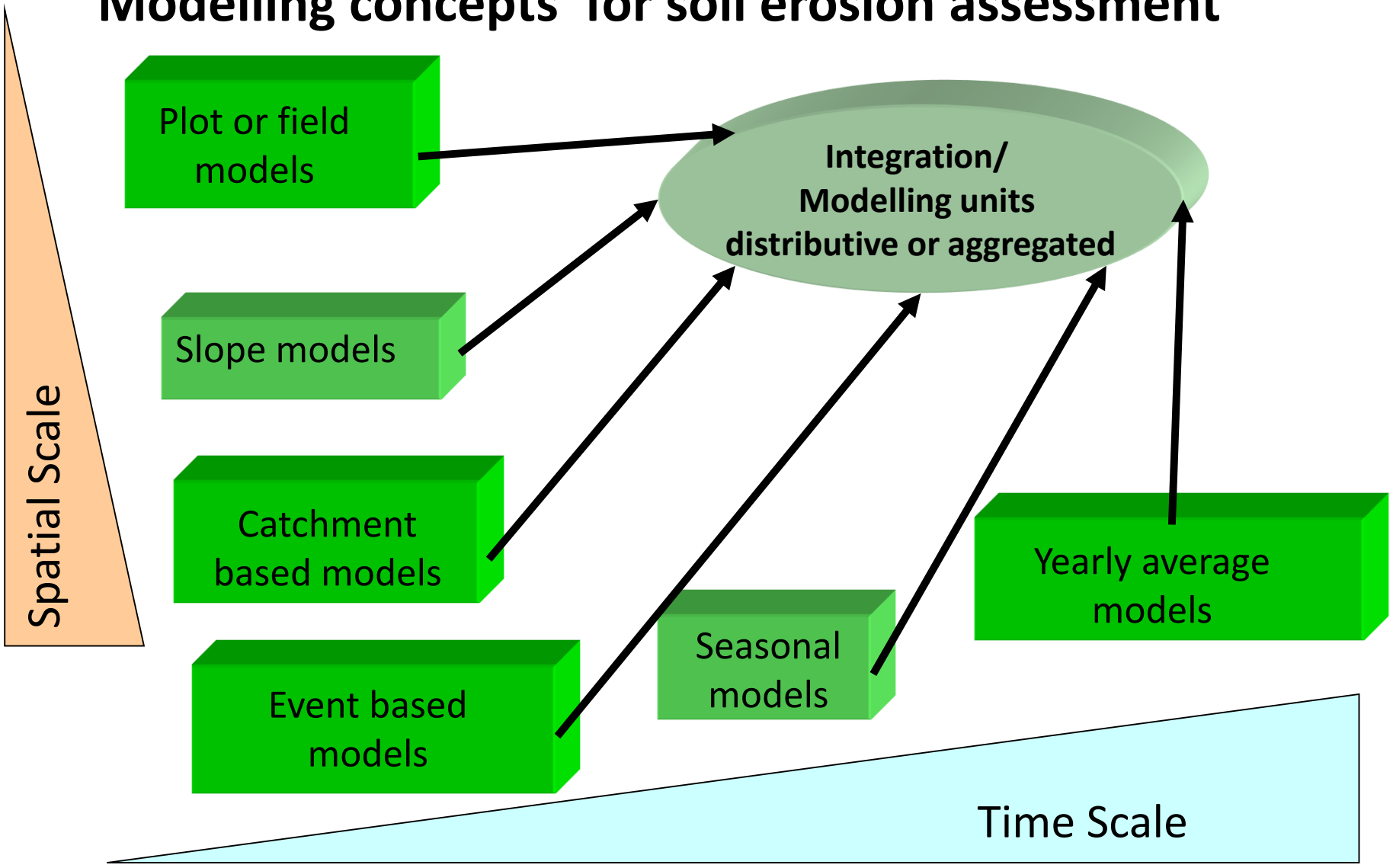
Ghiaia di Montalto basin; 25mm of rain in 2 hours

Spatio-temporal scales of soil erosion processes



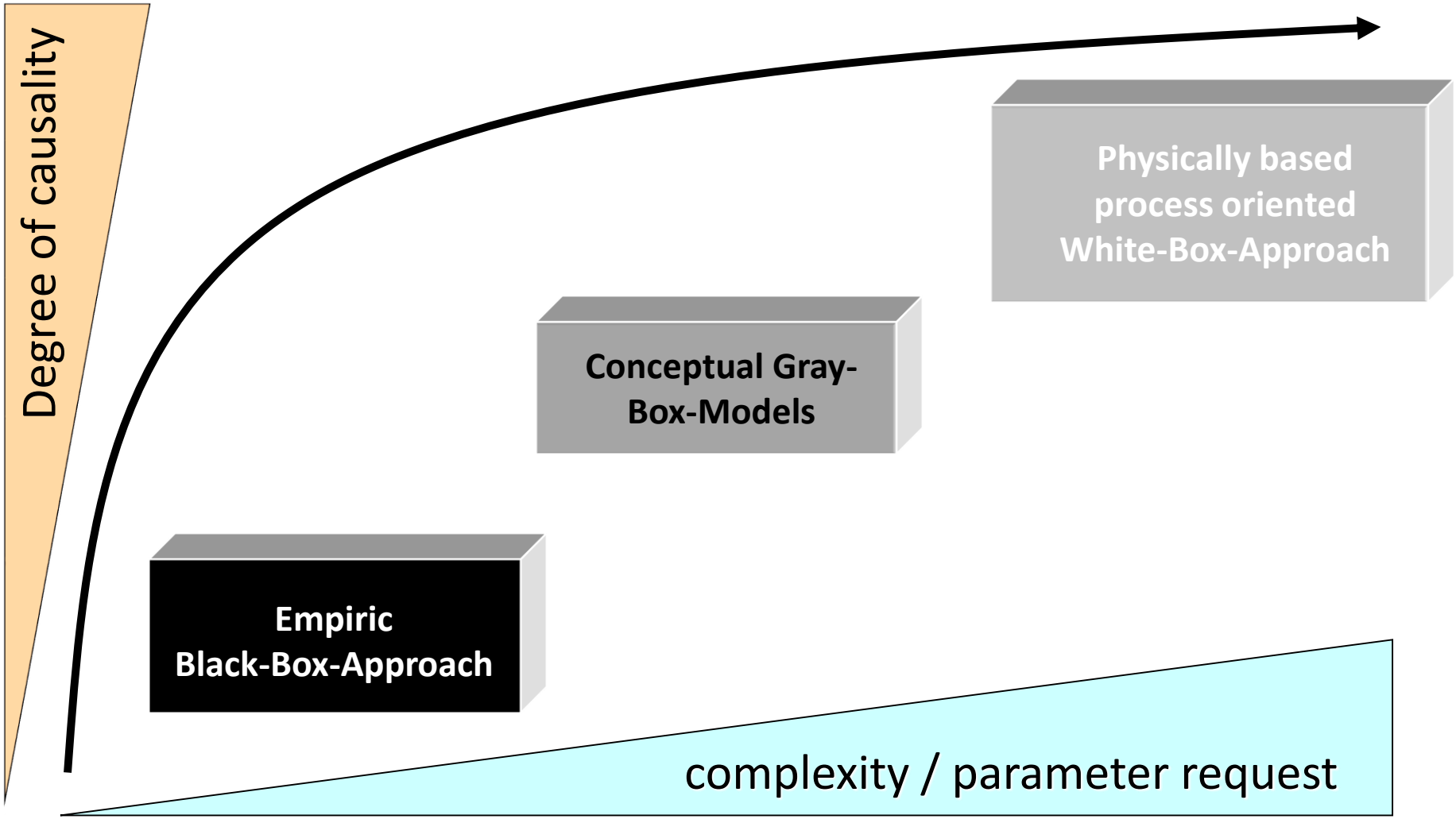
after Renschler & Harbor (2002): *Geomorphology* 47, 189-209.

Modelling concepts for soil erosion assessment



After Morgan & Nearing (2011): Handbook of Soil Erosion Modelling p 10. Wiley-Blackwell

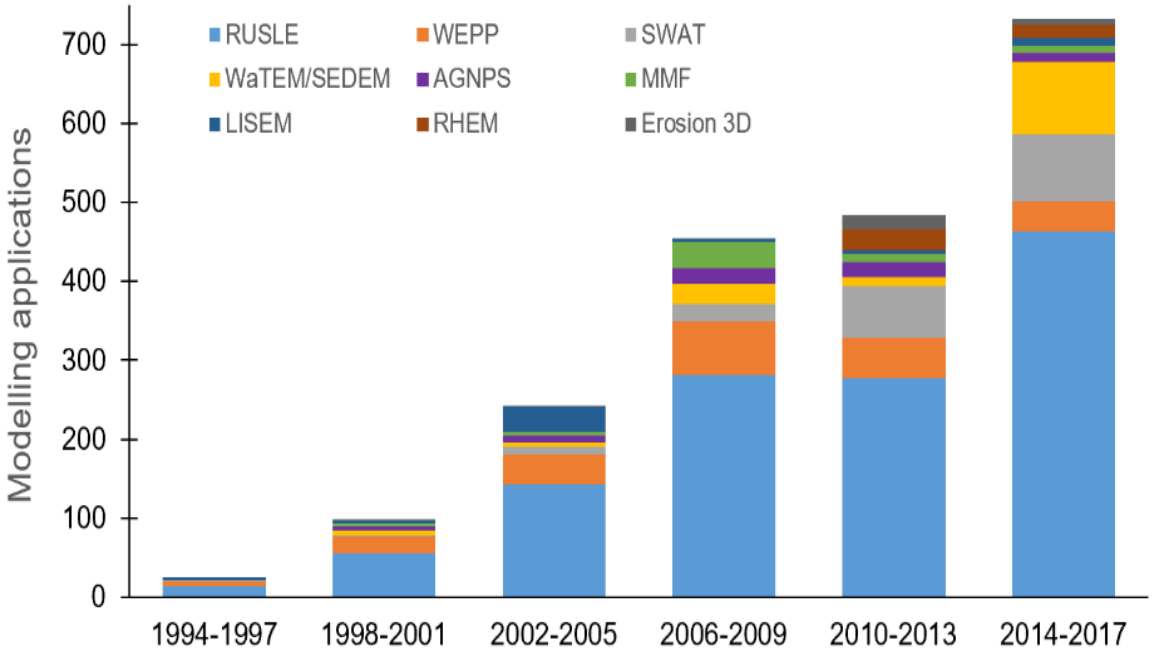
Modelling concepts for soil erosion assessment

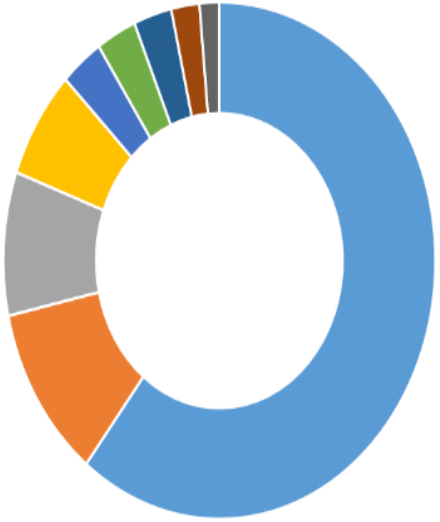


after Morgan & Nearing (2011): Handbook of Soil Erosion Modelling p 10. Wiley-Blackwell

Challenges for soil erosion modeling:

- Models often only address **single processes** and therefore are **scale dependent** (USLE, WEPP, Erosion 2D/3D, USPED)
- Models often are focussing only on **laminar soil erosion** (sheet/rill-interrill erosion)





Borrelli et al. (2020): Soil erosion modelling: A systematic review of metadata-analysis .

Challenges for soil erosion modeling:

- Models often only address **single processes** and therefore are **scale dependent** (USLE, WEPP, Erosion 2D/3D, USPED)
- Models often are focussing only on **laminar soil erosion** (sheet/rill-interrill erosion)
- **Integrated modelling is very complex**
  - Different soil erosion processes
  - Parameter request
  - Scale dependency (spatial/temporal)
  - Spatio-temporal distribution
  - Connectivity of process domains

Research Question: How to assess and quantitatively simulate different soil erosion processes?

Methodological Solution:

ERU as distributive, process based modelling entities

Erosion Response Units (ERU):

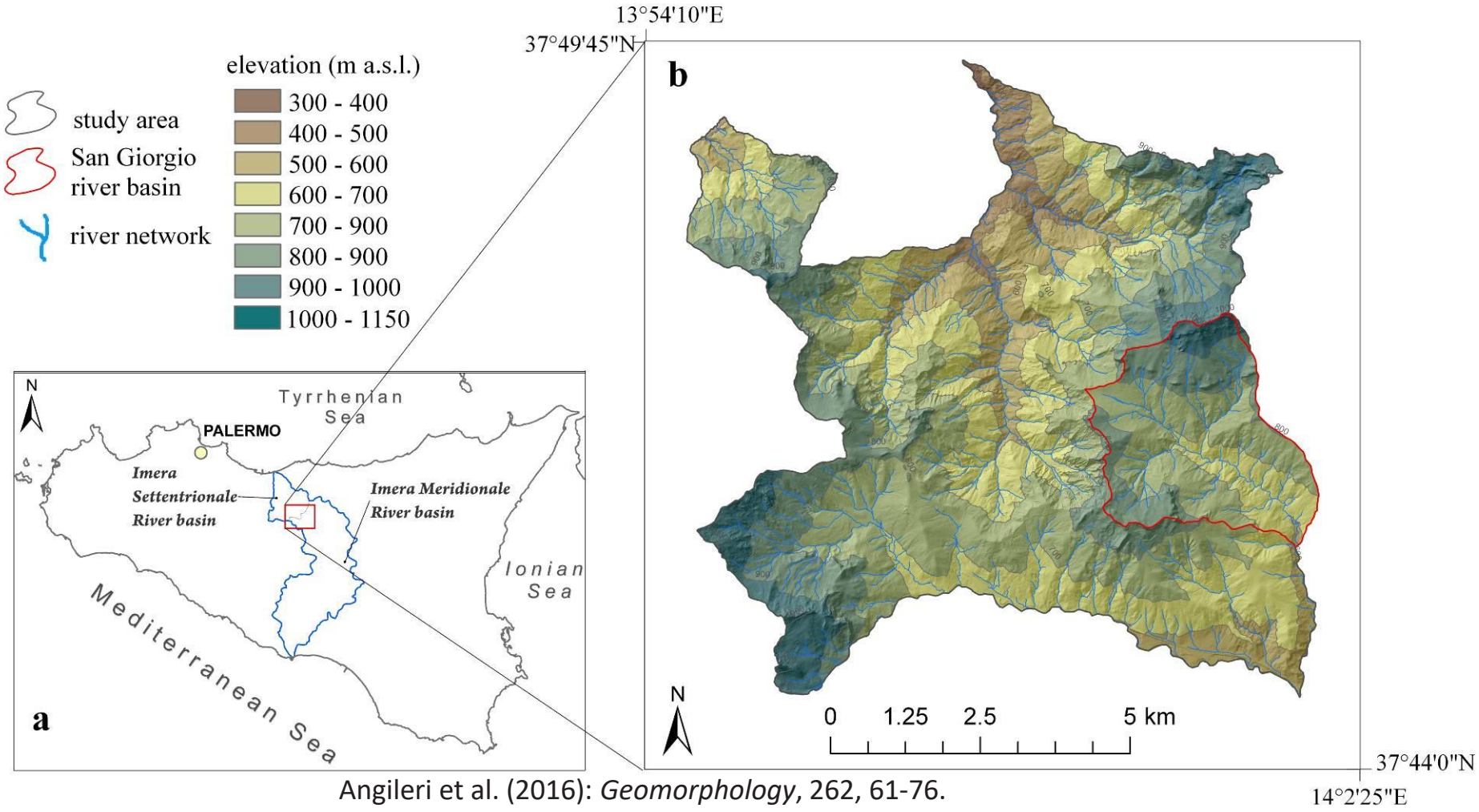
- are heterogeneously structured terrain units
- are having homogeneous erosion process dynamics that are controlled by the physiographic properties and the management of the human environment.
- allow for spatial scale transfer
- can be delineated by stochastic modelling and
- therefore can be spatially extrapolated

Märker et al. (2011): *Geomorphology*, 125(4), 530-540;
Sidorchuk et al. (2003): *Catena*, 50, 507-525.

Zakerinejad & Märker (2015): *Natural Hazards*, 79 (1), 25-50
Märker et al. (2001): *Geografia Fisica e Dinamica Quaternaria*, 24, 71-83

Case study from Italy:

San Giorgio Catchment, Imera River, Sicily



Angileri et al. (2016): *Geomorphology*, 262, 61-76.


Rill-interrill erosion


Ephemeral gully


Permanent gully

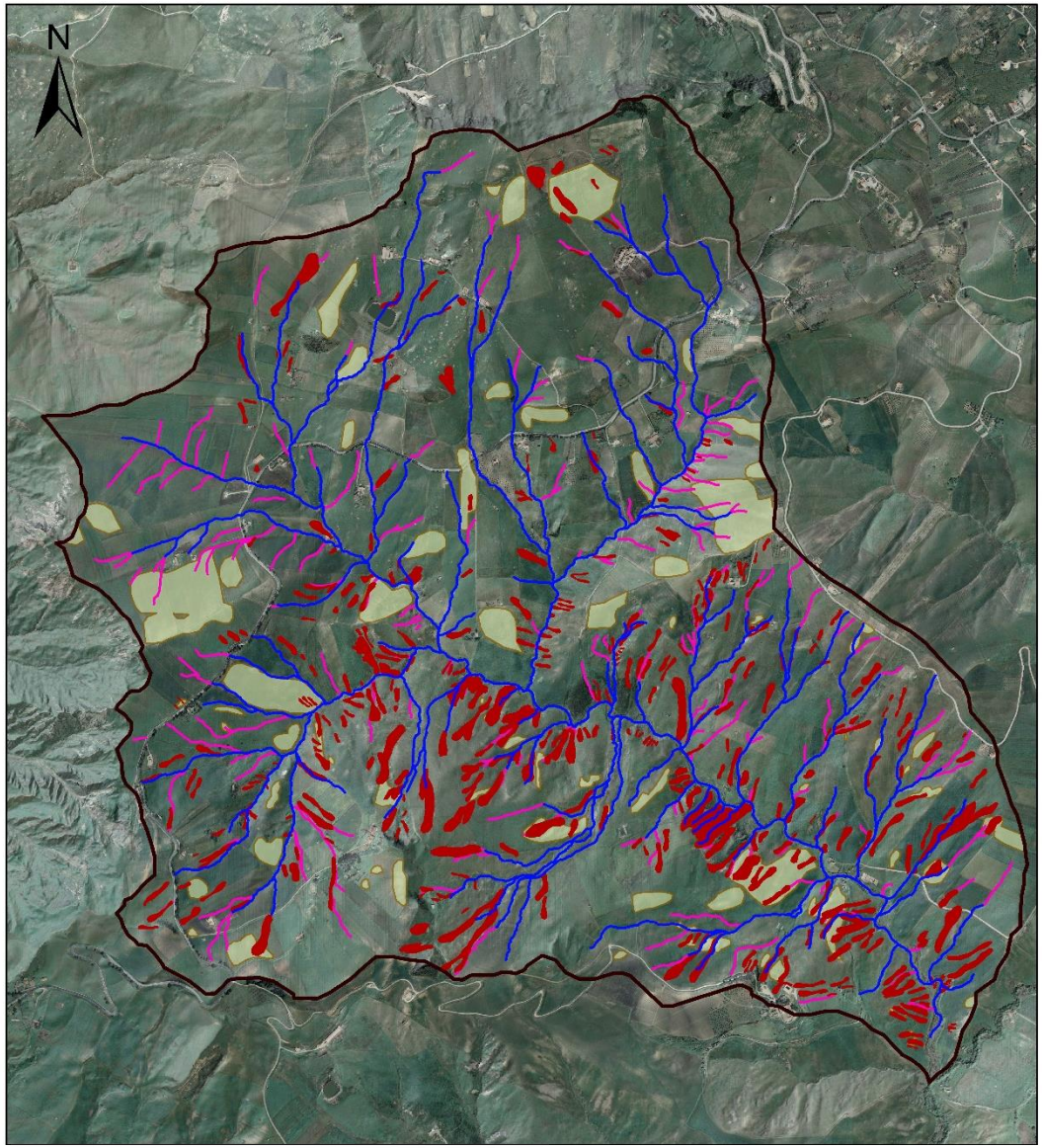

Permanent gully


Bank erosion


Gully head


Shallow landslide


Mudflow



bank erosion

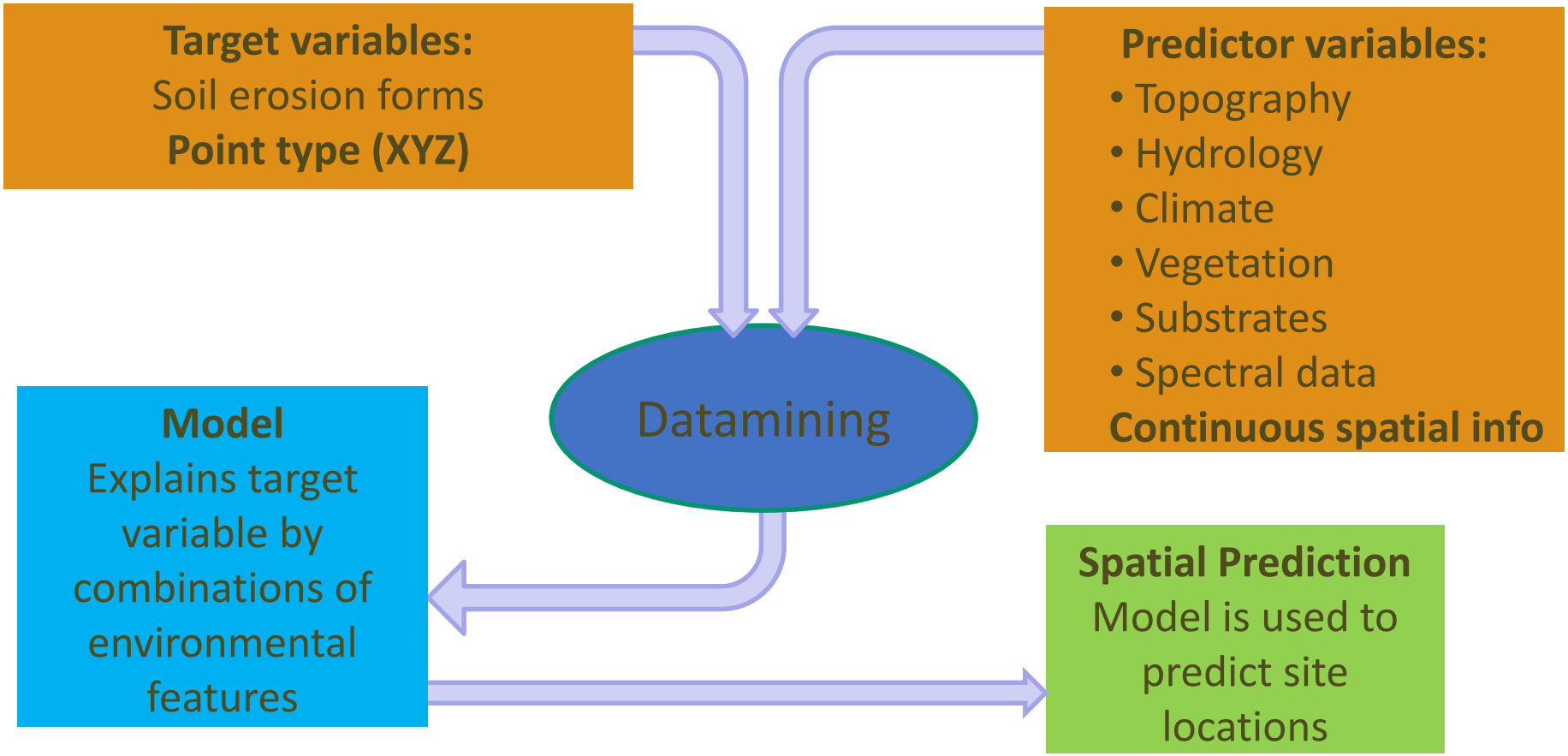
mass wasting

gully erosion

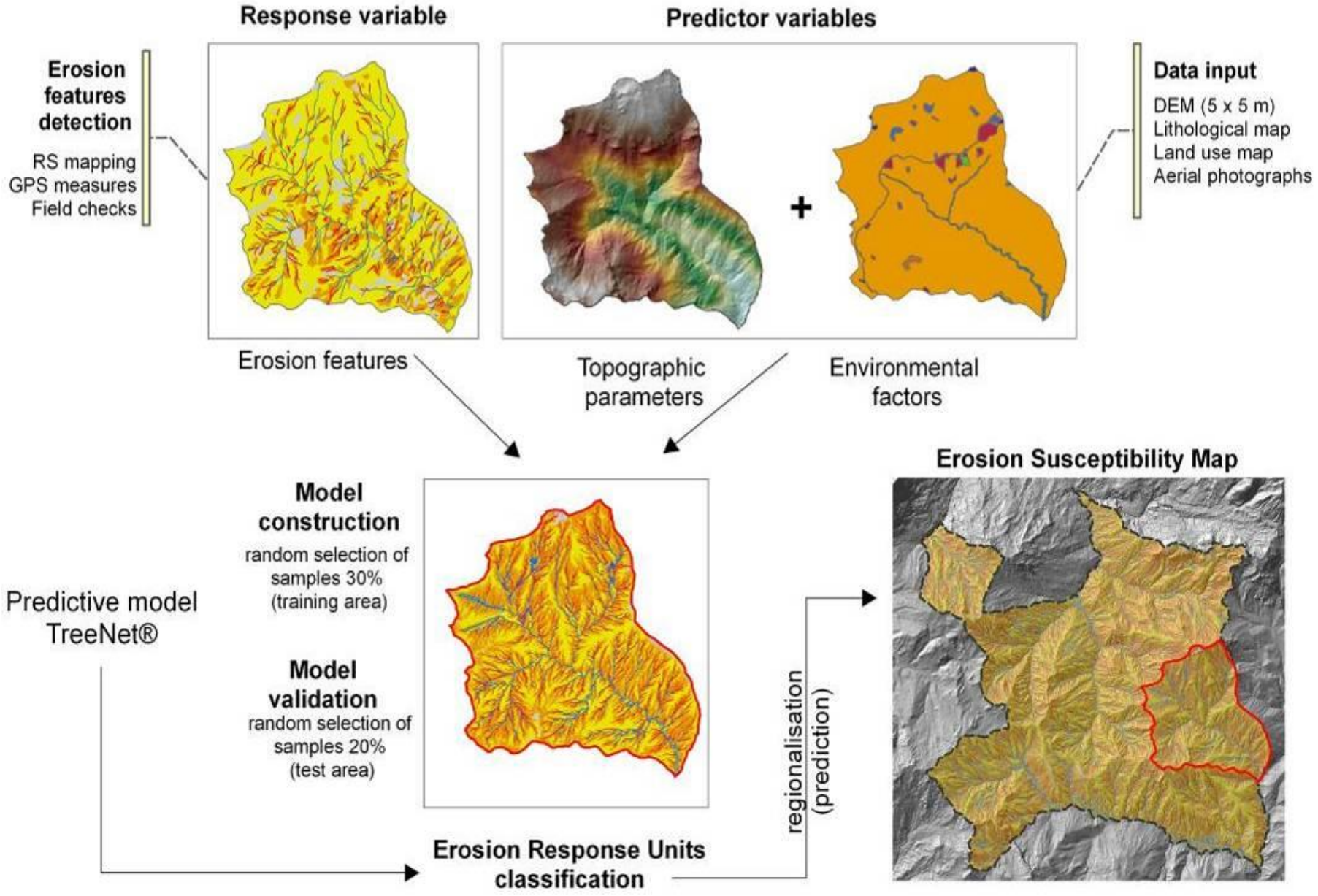
sheet-rill erosion

Landform	
Rill-interrill erosion	0.63 km^2
Gullies	260
Landslides	446
Bank erosion	0.3 km^2

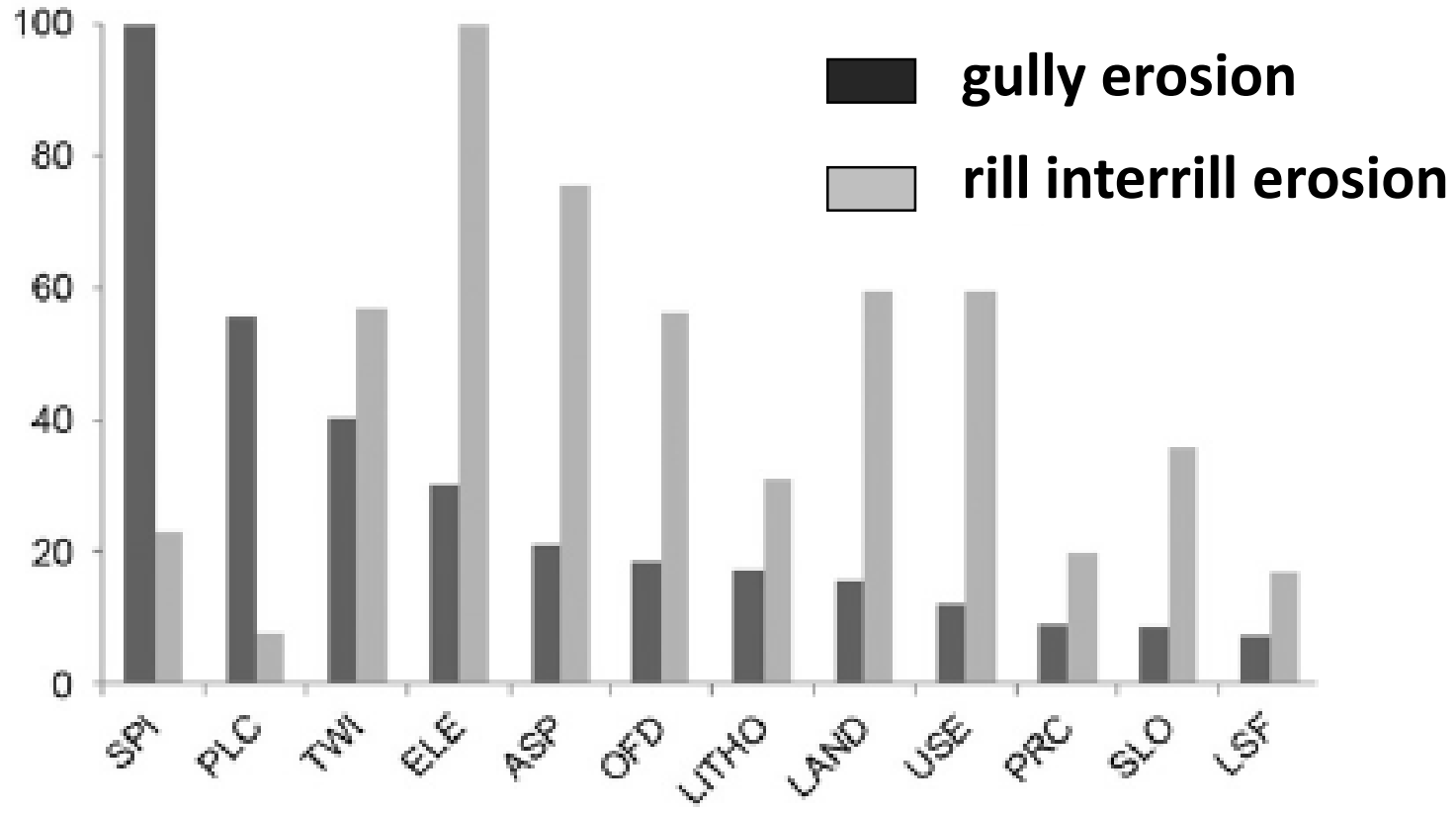
Stochastic Modelling Approach



Delineation of ERUs and spatial prediction (regionalization)



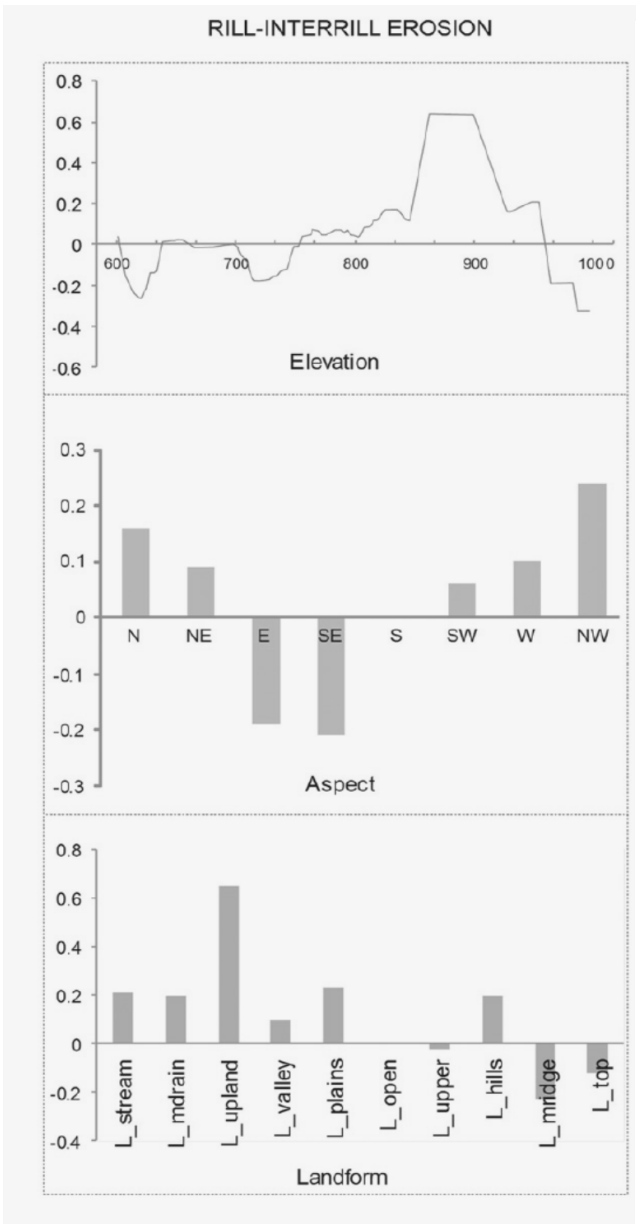
Which variables explain best the ERU-distribution pattern?



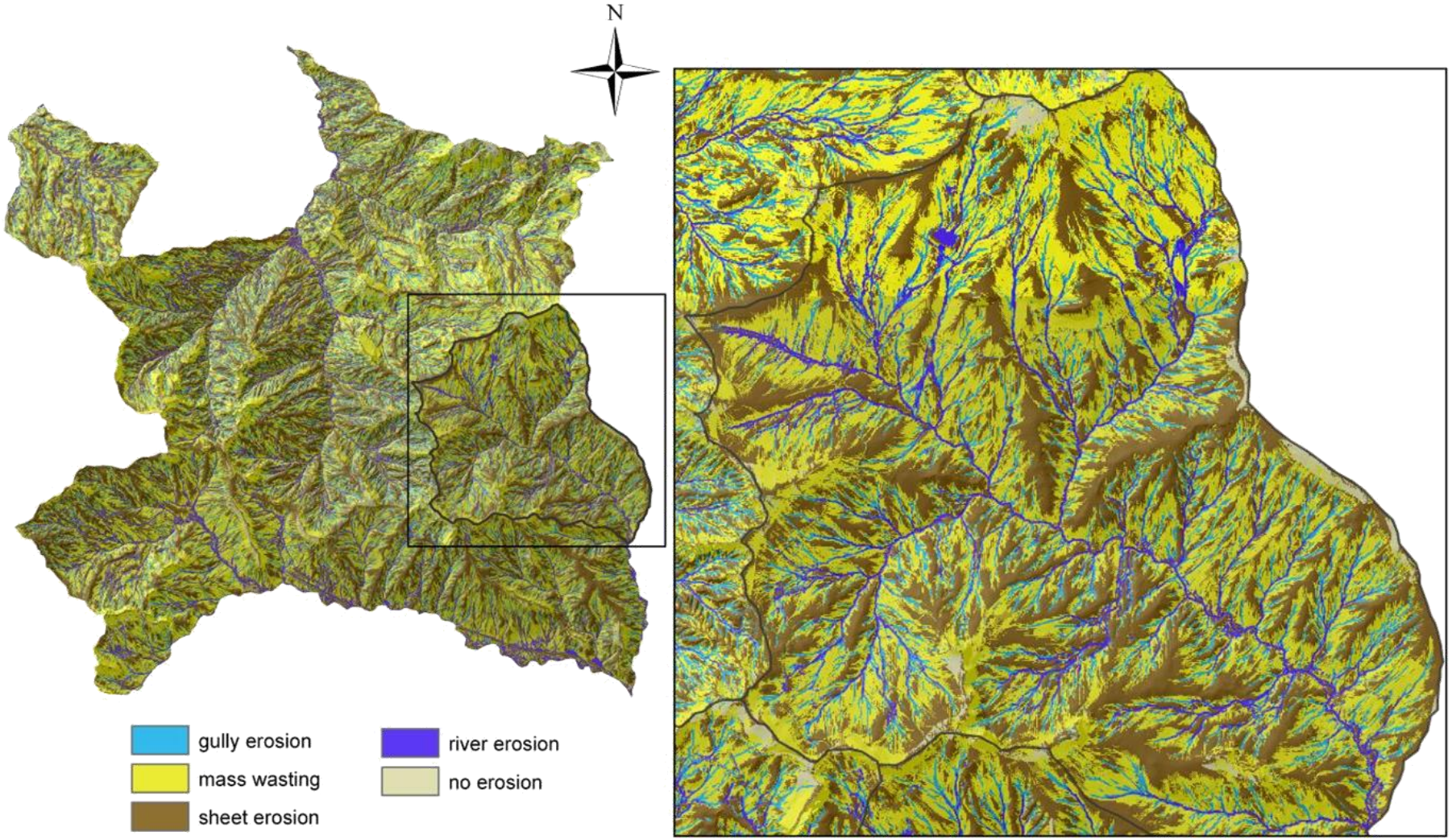
Angileri et al. (2016): *Geomorphology*, 262, 61-76.

Parameter analysis:

Which parameters and value ranges are relevant for specific ERU?



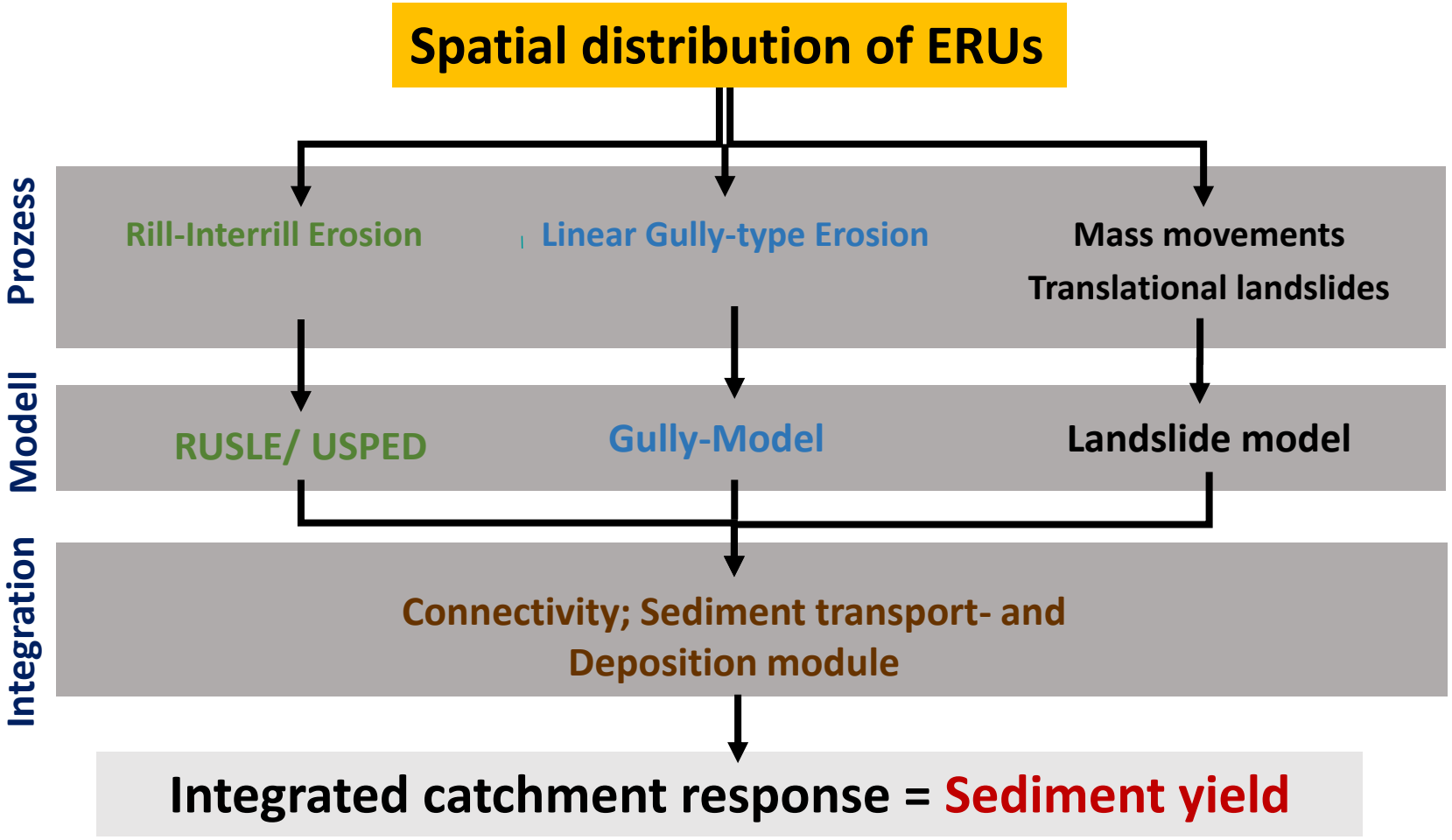
Regionalised ERU



Angileri et al. (2016): *Geomorphology*, 262, 61-76.

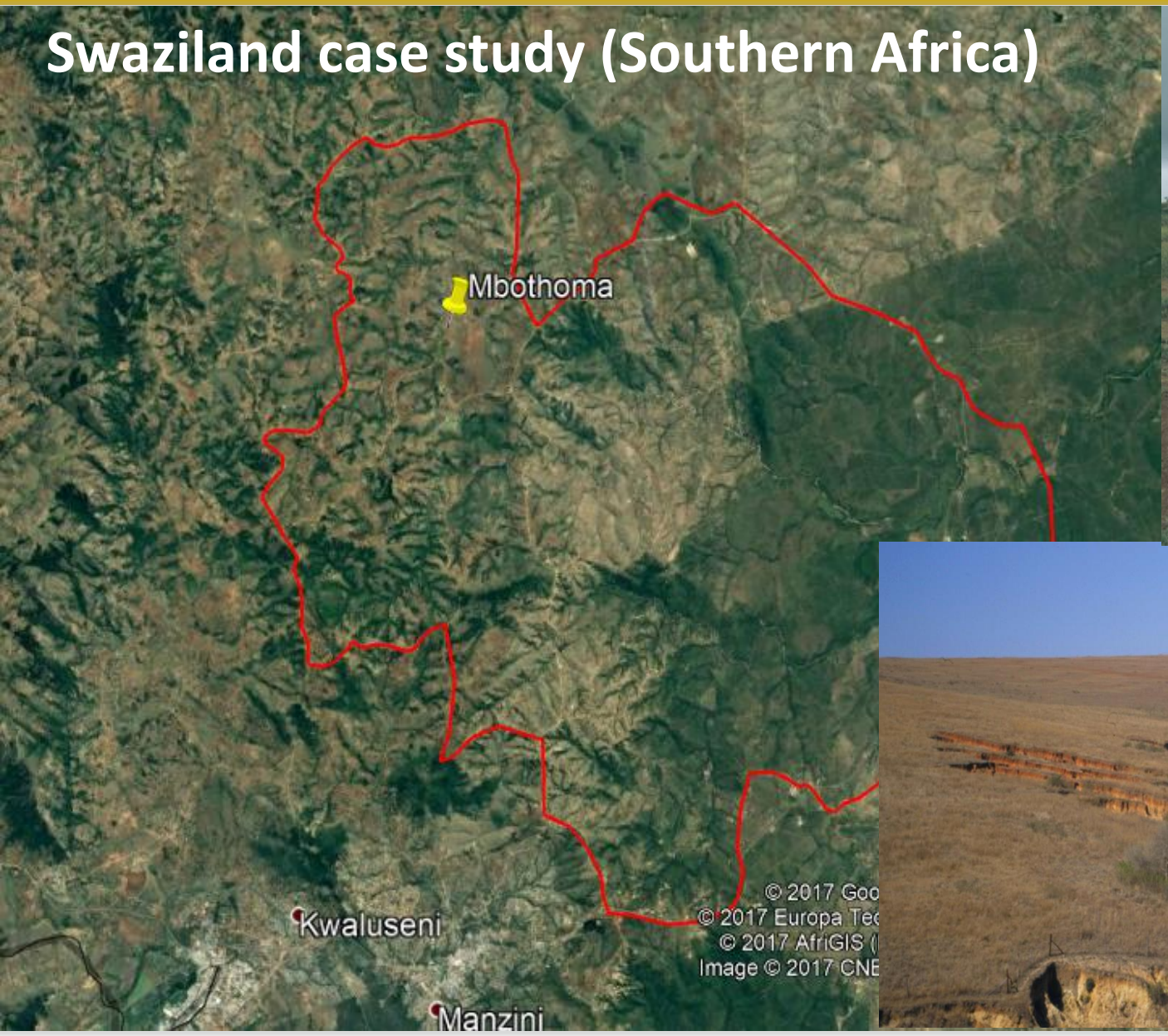
Integrated erosion modeling

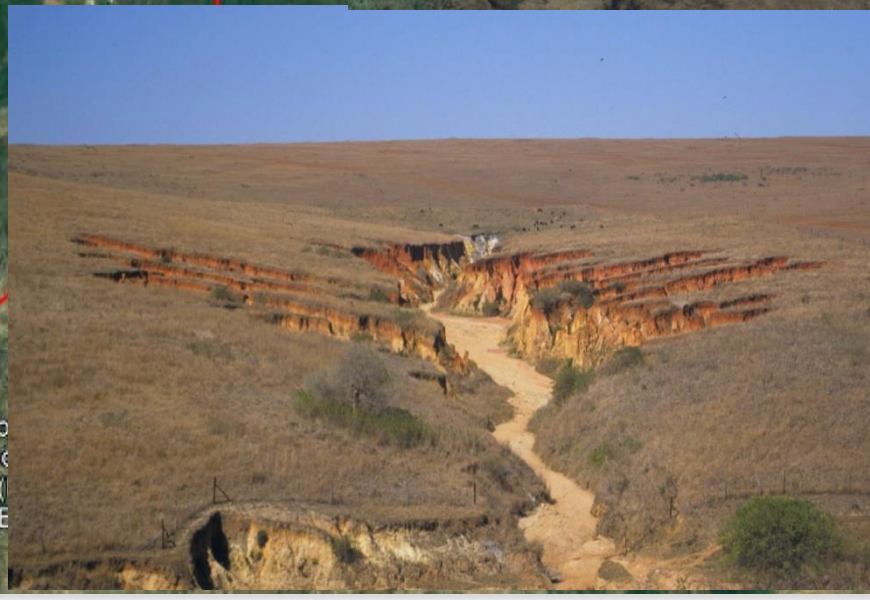
ERU-based quantification of soil erosion processes



Märker et al. (2008): *Geomorphology* 3, (1-2), 120-129. Märker et al. (2001): *GFDQ* Sidorchuk et al. (2003): *Catena*

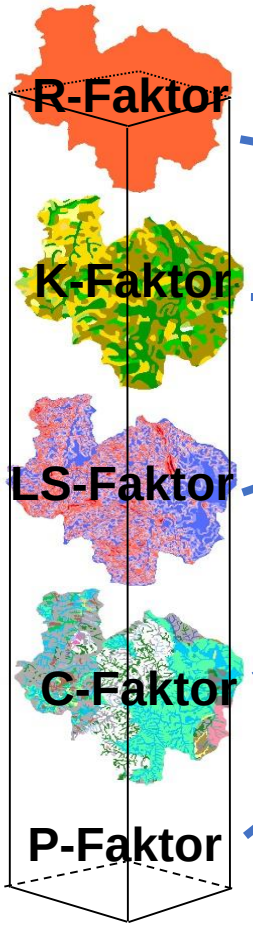
Swaziland case study (Southern Africa)





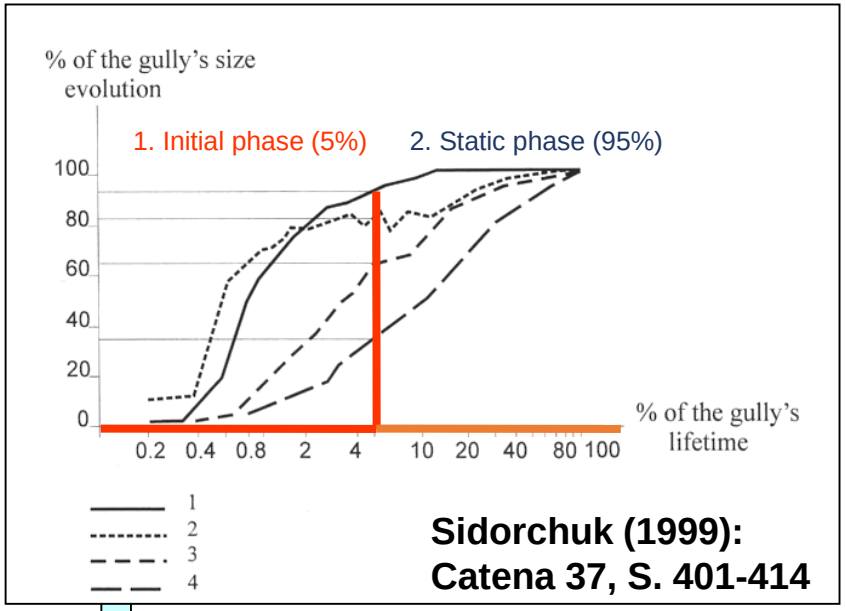
ERU model entity

interrill-rill erosion modeling



R * K * LS * C * P

gully erosion modeling

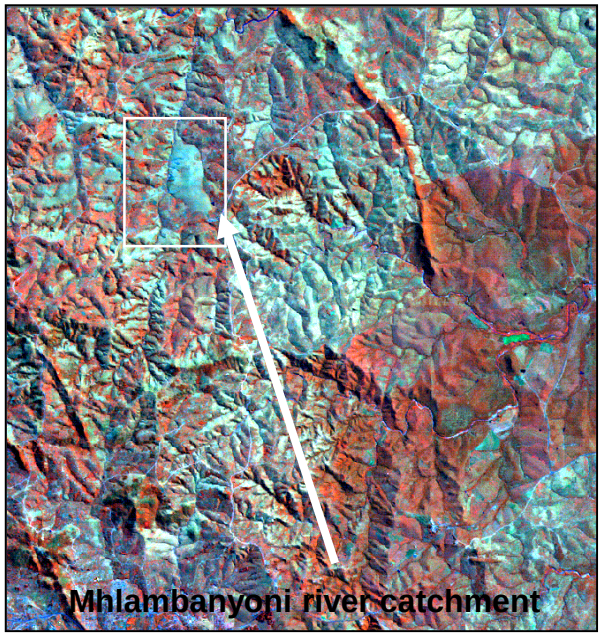


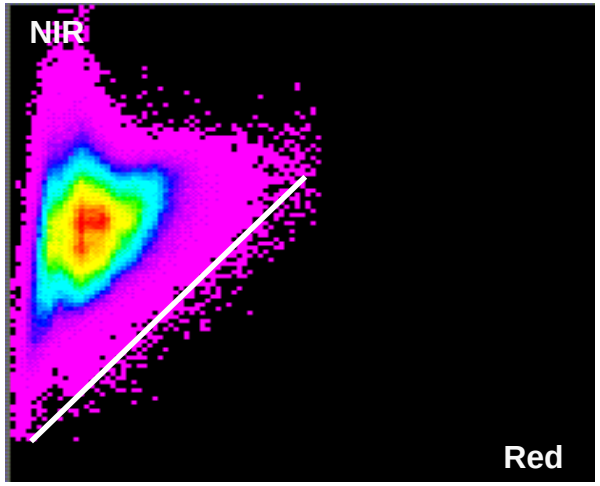
Sidorchuk (1999): Catena 37, S. 401-414

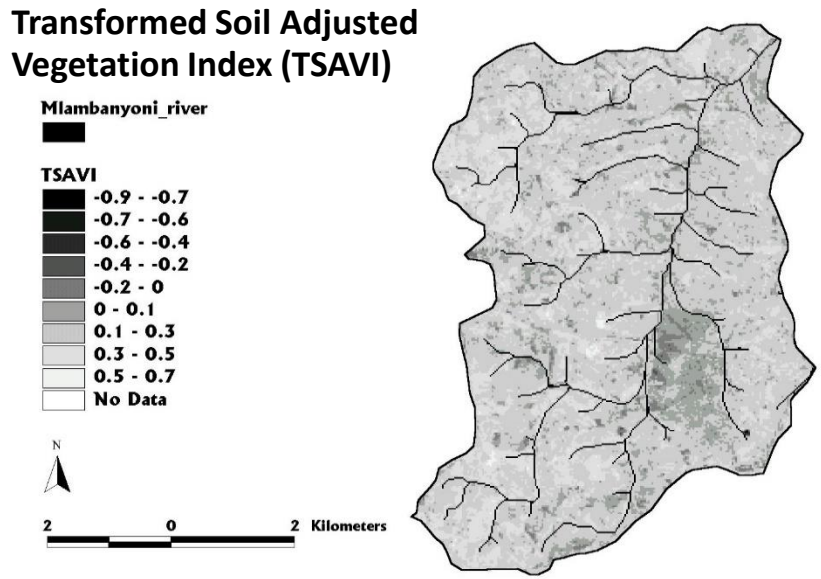
Soil erosion per ERU

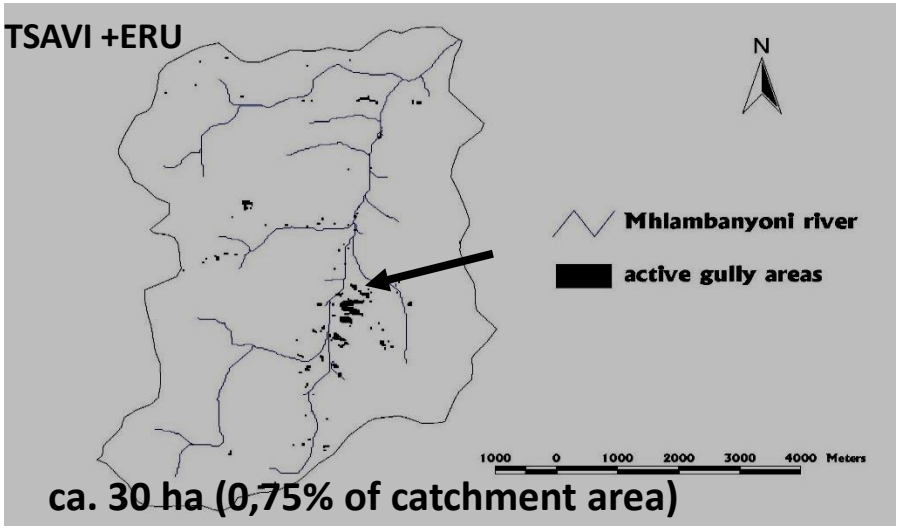
Märker et al. (2015): *Natural Hazards*, 79 (1), 235-253.

Regionalisation of gully erosion results using Landsat TM and GIS analysis



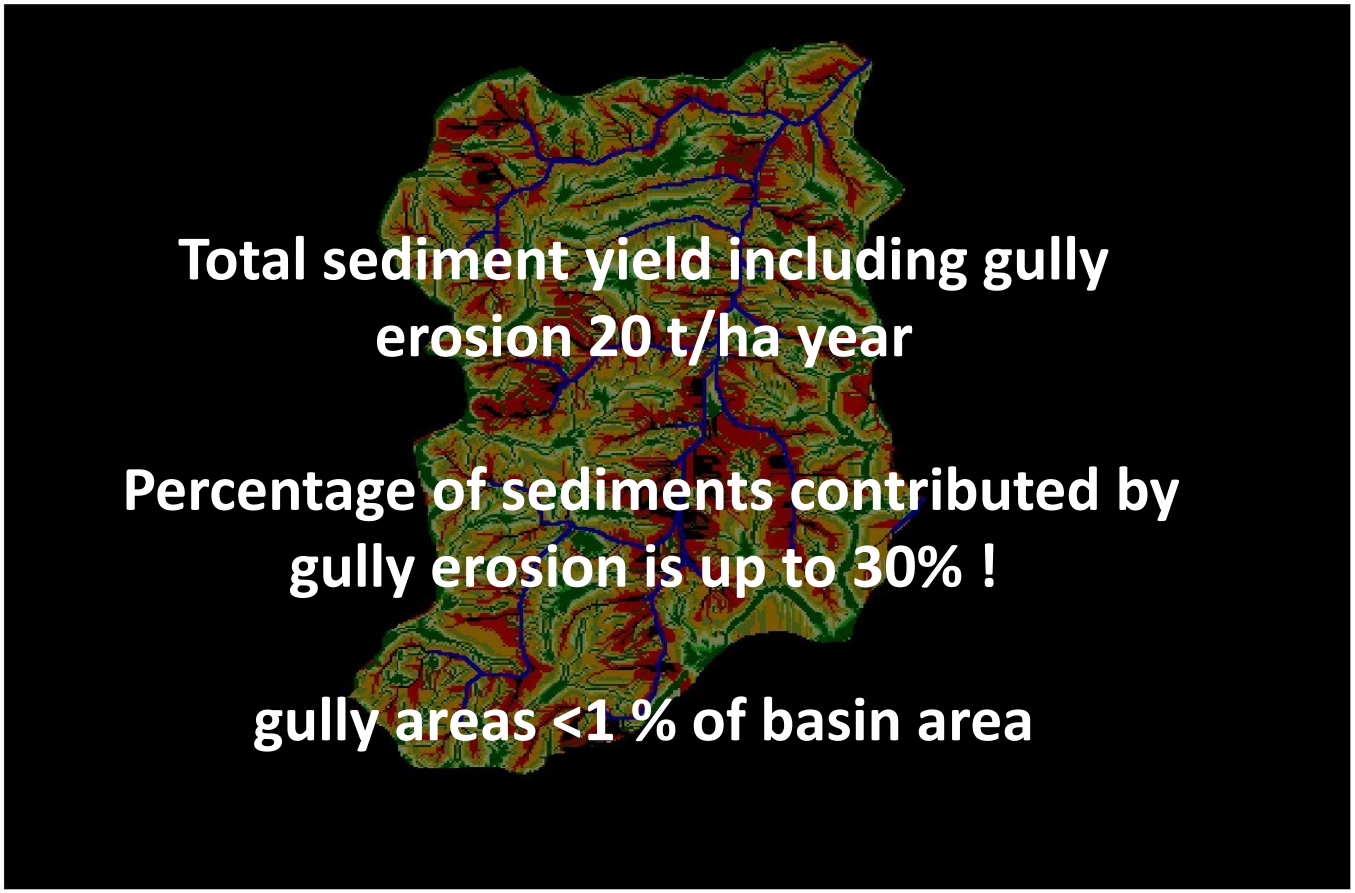






FLÜGEL, W.-A. & **M. MÄRKER** (2002) ASTM STP 1420, 163-177; **MÄRKER, M.** & A. SIDORCHUK (2003): IAHS Publication 279, 188-198.

Integrated soil erosion modeling: Example from Southern Africa



Rill-Interrill Erosion + Gullyerosion

Flügel et al. (2003): *Hydrological Processes* 17, 917-928. Sidorchuk et al. (2003): *Catena* 50, 507-525

Research deficits and future perspectives:

- **Integration of soil erosion models on landscape scale**
  -> Functional erosion units (ERU)
  -> Connectivity approaches
  -> Interaction of erosion processes
- **Regionalization** of soil characteristics and precipitation pattern
  -> Digital Soil Mapping, Stochastic approaches…

- **Real time modelling and early warning systems**

Which factors are influencing hydro-erosive processes? What kind of data we need?

Main Factors

- Climate/ precipitation
- Vegetation
- Soils
- Terrain management
- Topography

Data availability/quality

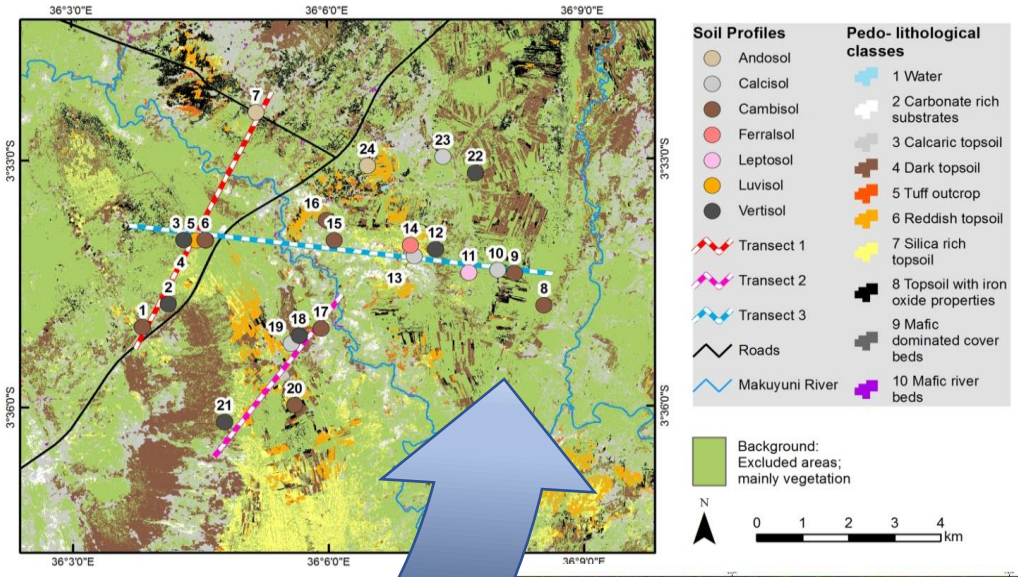
- Spatial distribution?
- ok e.g. Sentinel
- 3D medium 
- ok e.g. Sentinel
- Spatial Resolution?

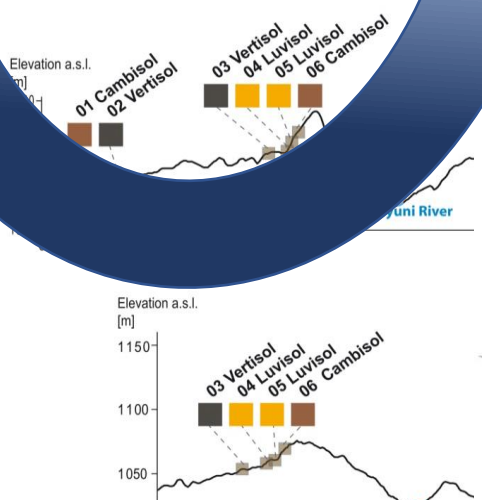
What kind of soil information do we need?

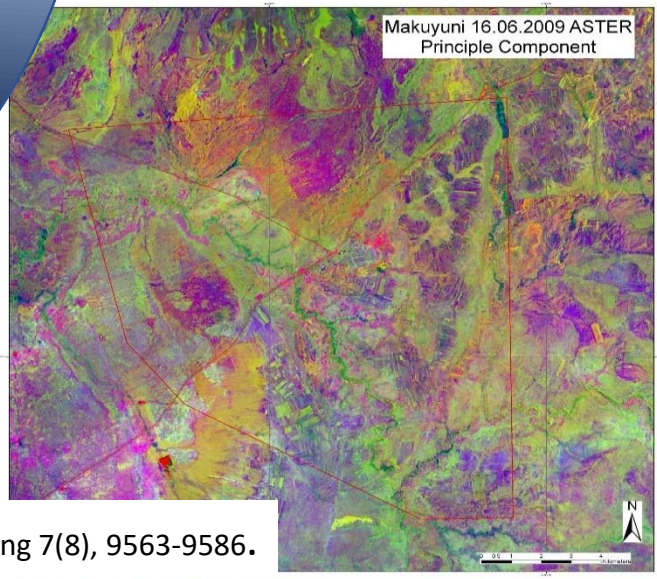
- Texture/skeleton
- Infiltration/hydraulic conductivity
- Density
- Porosity
- Roots
- Organic matter content
- Soil structure
- Soil depth
- ……..
-


S
KRANTZ
N

From point type information to continuose spatial data?

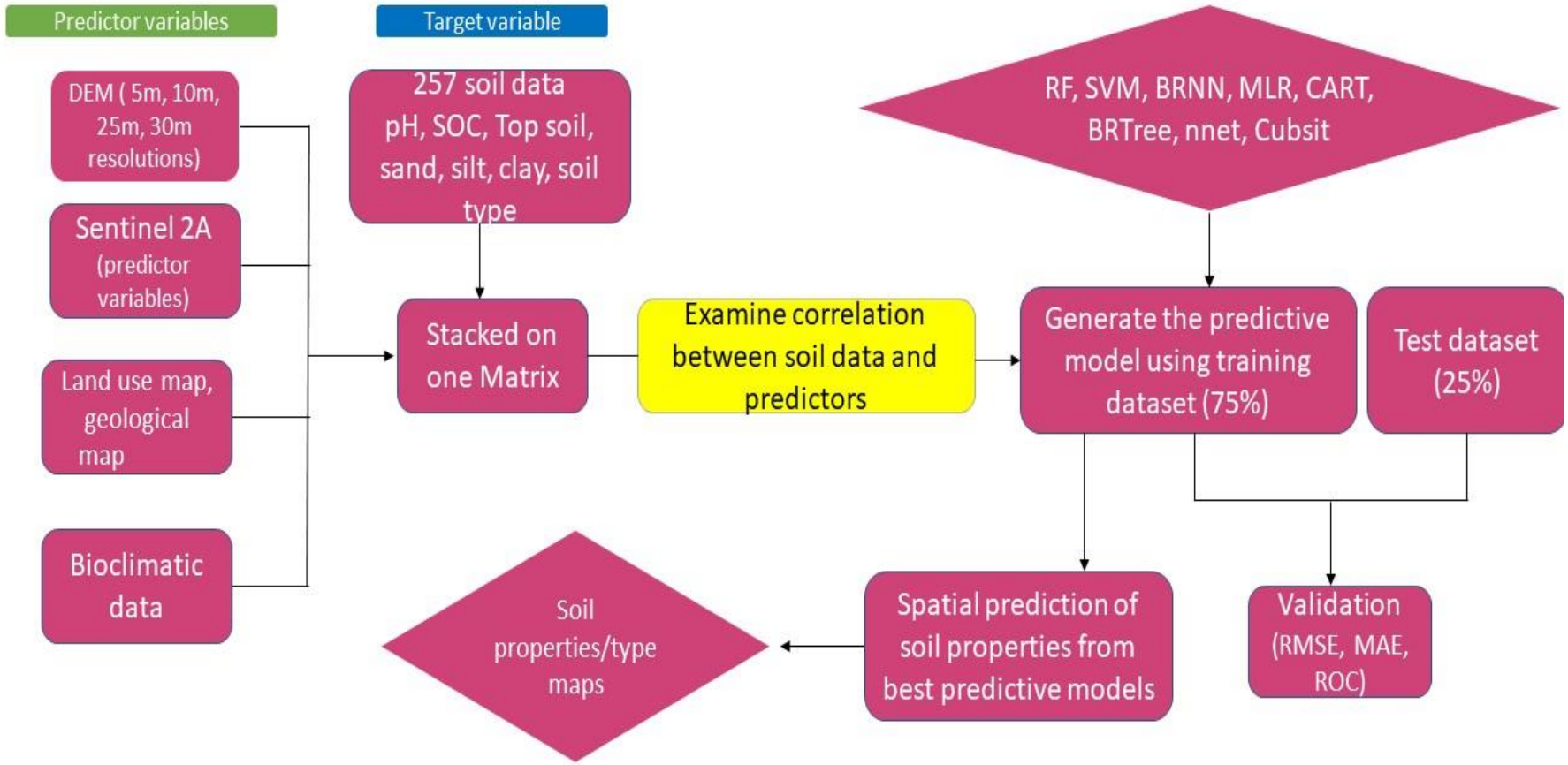






Bachofer et al. (2015): Remote Sensing 7(8), 9563-9586.

Digital Soil Mapping Procedure



GRIMM, R., BEHRENS, T., **MÄRKER, M.** ELSENBEER, H. (2008): soil organic carbon concentrations and stocks on Barro Colorado Island – Digital Soil Mapping using Random Forest analysis. GEODERMA, 146, (1-2), 102-113.

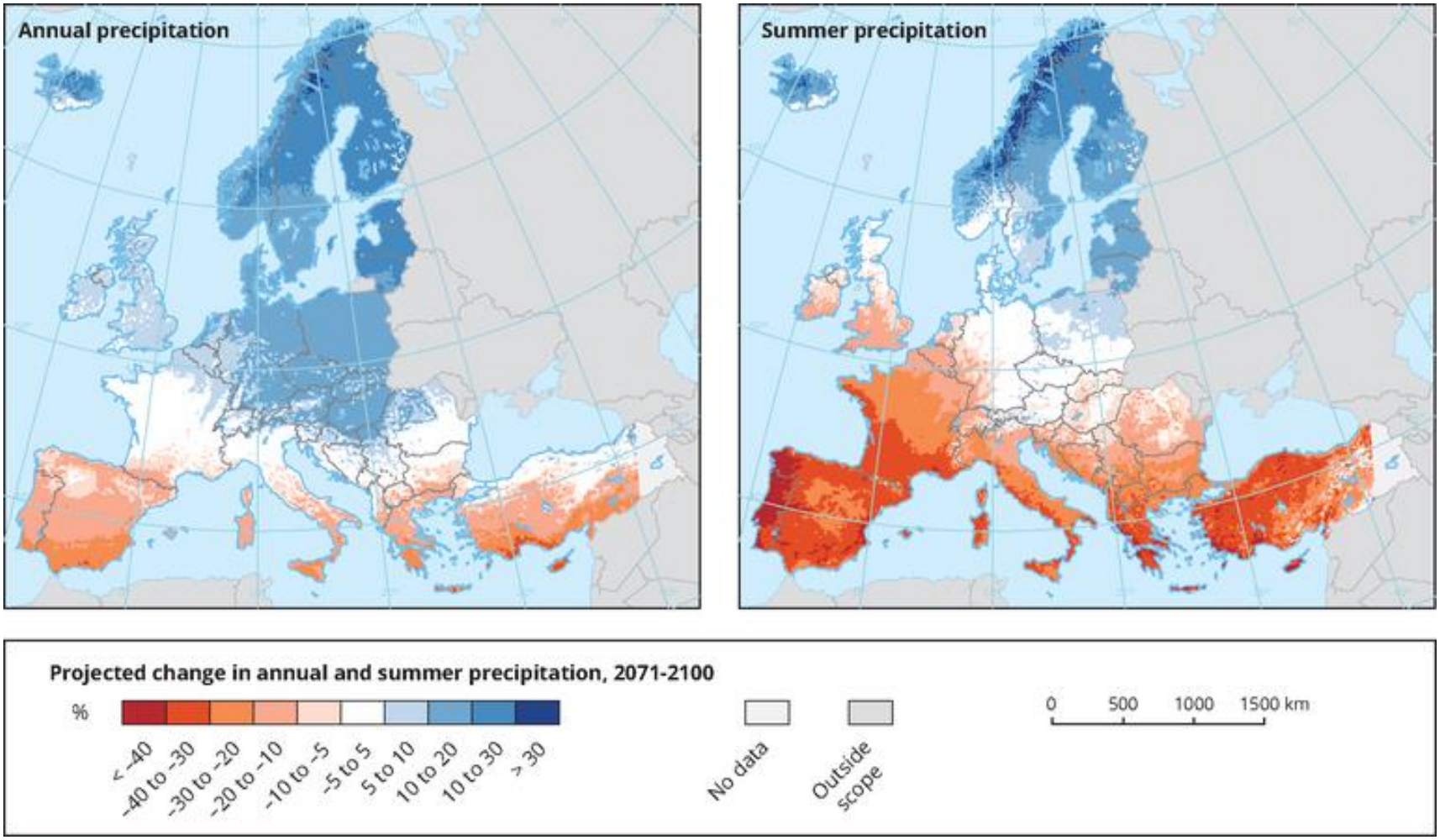
Bachofer F., Quénéhervé G., Hochschild V. & **M. Märker** (2015): Multisensoral Topsoil Mapping in the Semiarid Lake Manyara Region, Northern Tanzania. Remote Sensing 7(8), 9563-9586. **DOI:** 10.3390/rs70809563 **ISSN:** 20724292

FieldSpec Measurements

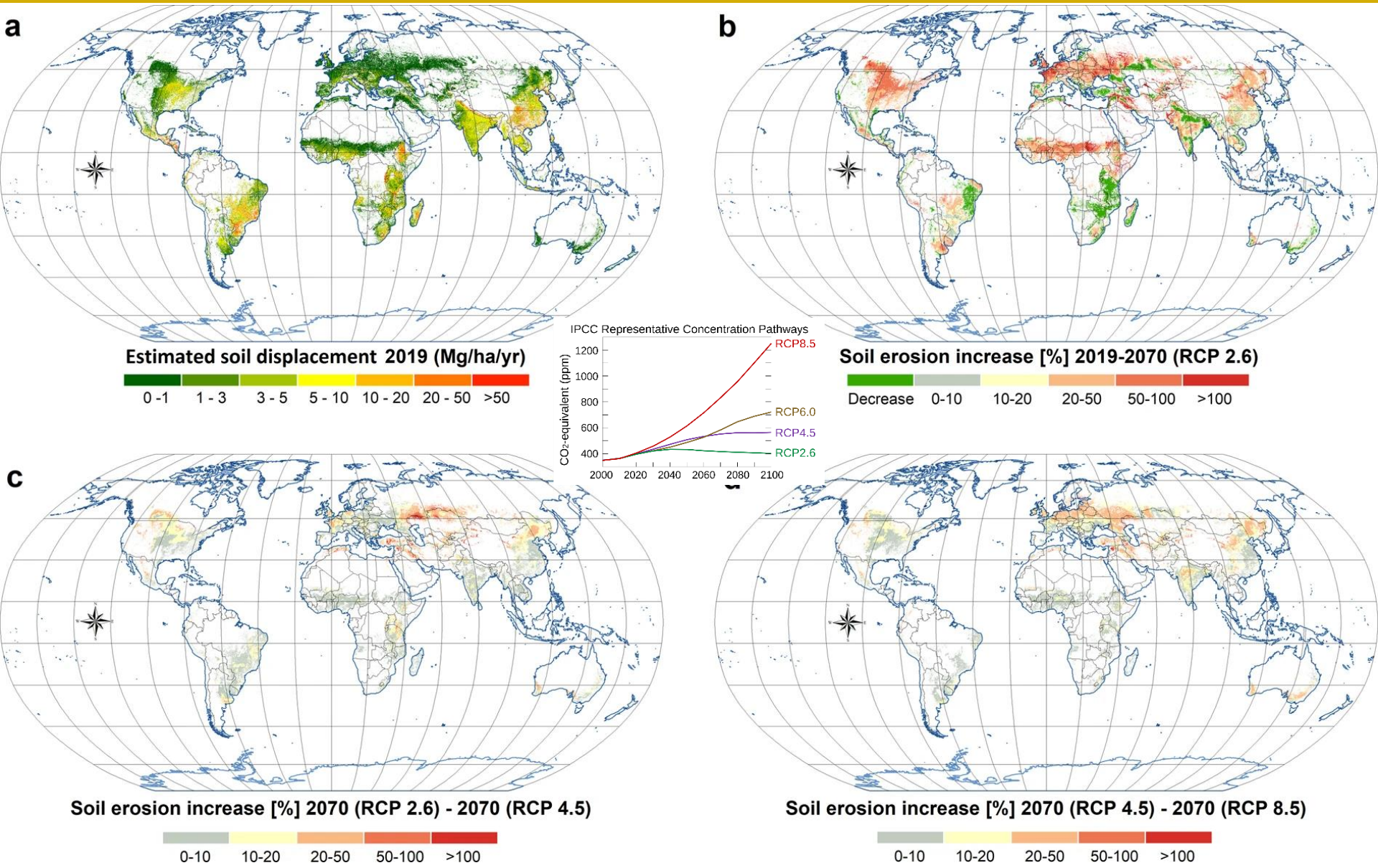
Proximal Sensing techniques: The instrument is able to detect the spectral signature of the organic and inorganic matter present in the soil.

Outlook

Climate change

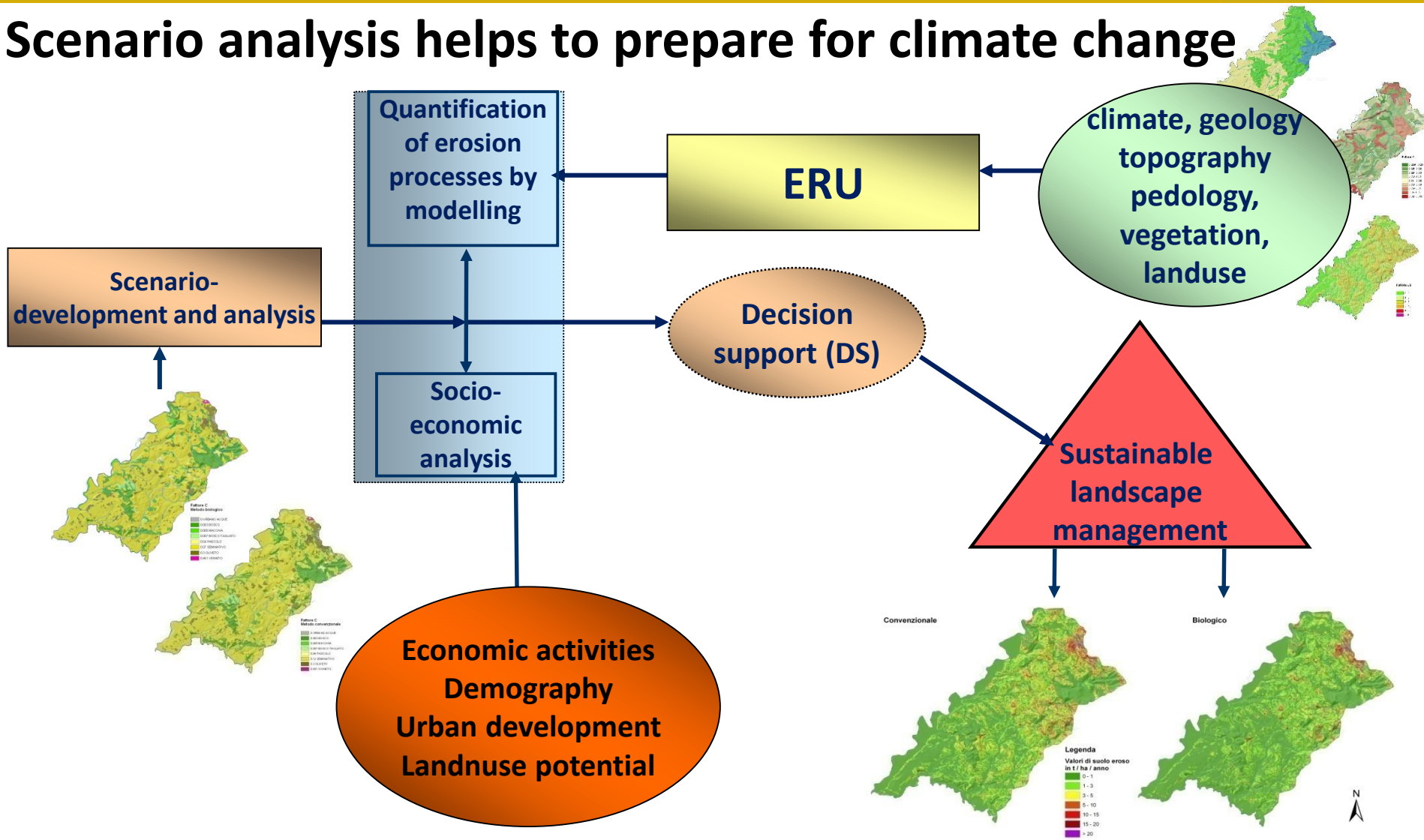


Projected changes in annual (left) and summer (right) precipitation (%) between 1971-2000 and 2071-2100 for the forcing scenario RCP 8.5. Jacob et al. 2013; http://dx.doi.org/10.1007/s10113-013-0499-2



Borrelli, P., Ballabio, C., Yang, J.E. *et al.* GloSEM: High-resolution global estimates of present and future soil displacement in croplands by water erosion. *Sci Data* **9**, 406 (2022). https://doi.org/10.1038/s41597-022-01489-x

Scenario analysis helps to prepare for climate change



Märker et al. (2008): Assessment of land degradation susceptibility by scenario analysis. A case study in Southern Tuscany, Italy. Geomorphology 3 (1-2), 120-129.

Summary

1. Soils play a key role for ESF and ESS. World wide 10 Mio. ha arable land/year destroyed (~ 450 Mrd. €).
2. **Problem:** Soil erosion processes and driving forces are scale dependent and therefore also the respective soil erosion models.
3. **Solutions:** Integrated soil erosion modelling based on ERUs as landscape related modelling entities.
4. **ERU**: Delineation via field work, geoinformatics and stochastic approaches/Data Mining including parameter and process analysis.
5. **Application of numerical process models**: be careful with resolution and quality of input information.
6. **Research deficit:** Regionalization, Routing between ERU, Scenario development and –analysis (climate change, socio-economic change, ESF and ESS).

OUTLOOK current foci of the work group

Soil erosion assessment

- ERU modelling framework
- Integration and interaction of erosion processes
- Gully erosion modelling (**DIMGUL4GIS**)

Integrated Digital Soil Mapping

- Non invasive field techniques
- Remote and proximal sensing

Global Change Assessment

- Scenario Analysis
- Sustainability Analysis

Thank you for your attention

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