AN APPROACH TO ASSESS CLIMATE-INDUCED CHANGES OF LANDSLIDE HAZARD AND RISK IN ROMANIA.

Results from FP7 ECLISE project

(http://www.eclise-project.eu/content/mm_files/do_857/D5.2_RSV_final_report.pdf)

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E3S Extreme Events and Environments: from Climate to Society
cross community workshop
Berlin (February 14-16, 2016)

CONTEXT: EXTREME EVENTS IN ROMANIA

• Romania is highly exposed to **natural disasters (earthquakes, floods, landslides)** (WHO, 2013; Romanian Catastrophe Insurance Scheme - PRAC).

• **2005-2010:** 62,000 affected houses, 15,600 destroyed houses, total loss >3 bill. €, 233 mil. € of assistance (Natural Disaster Insurance Poll - PAID, www.paidromania.ro)

• Insurance of dwelling became mandatory since 2008 (Law no. 260/2008, republished and augmented through Law no. 243/2013).

Chendeş et al. 2015

National profile on natural disasters (1990-2014)

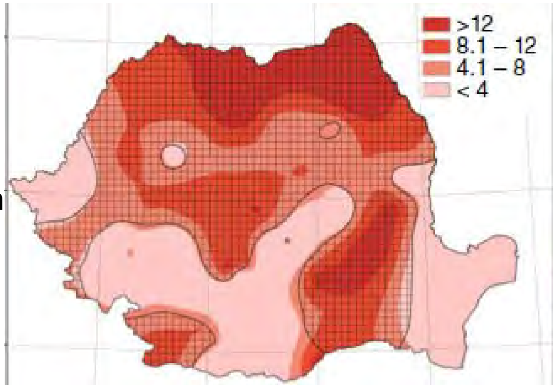
Global Risk Index (UNU-ESH):

Romania holds the 89th position of 173 in the ranking of countries with highest natural disaster risk (medium rank) and 4th position in Europe (high rank).

Climate change effects become increasingly evident causing extreme events like **severe drought**, **floods**, **vegetation fires and landslides** (WRR, 2012).

Increasing frequency of precipitation extremes (e.g. days without precipitation days with abundent precipitation, heavy rainfall) after 1981 (Busuioc et al. 2015)

Frequency of heavy rainfall days



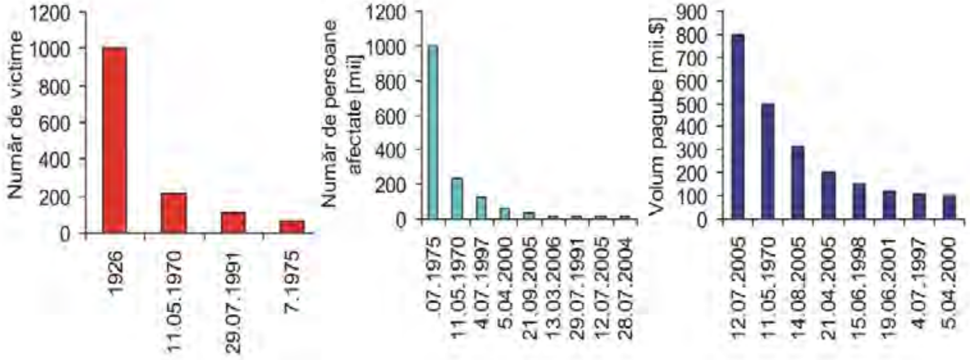
METEO ROMÂNIA

Source: National Meteorological Administration (Meteo Romania)

CONTEXT: EXTREME EVENTS IN ROMANIA

Major flood ranking in Romania

Data source: http://www.emdat.be/



-**Floods of June 2010** in Romania = the costliest from all past flood events, total economic damage = >1 million US$x1,000 US$ at national scale (Chendeş et al. 2015)
-**Floods of June 2005** (800,000 US$x1,000)

- **2005-2012**
- **39 events at national level** (without the Danube) => 237 fatalities (6.6 fatalities / event)

(*National Institute of Hydrology and Water Management; National Administration of “Romanian Waters”*)

SOUTH EAST EUROPE Transnational Cooperation Programme

Danube FLOODRISK

Programme co-funded by the EUROPEAN UNION

www.danube-floodrisk.eu

➢ **Most important floods along the Danube:** May 1930, April 1940, July 1942, May 1955, June 1970, June 1988, April 2004, April 2005, **2006**, 2010 (Gabor & Şerban, 2004, updated).

➢ **April 2006:** 15.834 evacuated people, 154 affected settlements, 1,774 flooded houses (443 destroyed), 4,700 annexes, 64,350 ha arable land, 6.8 km national roads and 593 km county and communal roads (*National Institute of Hydrology and Water Management; National Administration of “Romanian Waters”*)

CONTEXT: LANDSLIDES AS EXTREME EVENTS

• **Landslides** → significant disasters every year in many parts of the world
→Landslides = complex-disaster phenomenon, can be caused by earthquakes, volcanic eruptions, heavy rainfall, sustained rainfall, heavy snowmelt, unregulated anthropogenic development, mining etc. or only due to natural weathering

→ impact residents living on and around slopes

• **International Consortium on Landslides (ICL)** → global cross-cutting and cooperative platform on *Strengthening Research and Learning on Earth System Risk Analysis and Sustainable Disaster Management within the UN/ISDR as regards Landslides* - towards a dynamic global network of the **International Programme on Landslides (IPL)**
→ cooperation and identification of focus areas to reduce landslide risk worldwide

→ the **2006 Tokyo Action Plan**. Global Cooperating Fields of the IPL: *Technology Development* → *Hazard Mapping, Vulnerability and Risk Assessment (local and global scales*)

• **Risk reduction of landslides** – **Hyogo Framework for Action 2005 – 2015** "Building the Resilience of Nations and Communities to Disasters" (adopted at the WCDR on Kobe 2005)
Priority Action 2: Identify, assess and monitor disaster risks and enhance early warning.
The starting point for reducing disaster **risk** and for promoting a culture of disaster resilience lies in the knowledge of the **hazards** and the physical, social, economic and environmental **vulnerabilities** to disasters that most societies face, and of the ways in which hazards and vulnerabilities are **changing in the short and long term**, followed by action taken on the basis of that knowledge.

RESEARCH QUESTIONS & AIMS

Hazard

Hazard I refers to an actual **physical entity (process or situation) that has the potential to cause damage** (Crozier & Glade 2005)

A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. (UNISDR)

Hazard II (techn.) threatening condition resulting from the behavior of that potentially damaging process or situation, expressed as the **probability of occurrence** of a damaging landslide (Crozier & Glade 2005)

In technical settings, hazards are described quantitatively by the likely frequency of occurrence of different intensities for different areas (UNISDR)

Elements at risk: Population, buildings and engineering works, infrastructure, environmental features and economic activities in the area affected by a hazard (ISSMGE)

Vulnerability

The **characteristics and circumstances of a community, system or asset** that make it susceptible to the damaging effects of a hazard. There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors.(UNISDR).

The degree of loss to a given element or set of elements within the area affected by a hazard. It is expressed in a scale of 0 (no loss) to 1 (total loss) (ISSMGE)

Risk analysis

The use of available information to estimate the risk to individuals or populations, property or the environment, from hazards. Steps: definition of scope, danger (threat) identification, estimation of probability of occurrence to estimate hazard, evaluation of the vulnerability of the elements at risk, consequence identification, and risk estimation (ISSMGE).

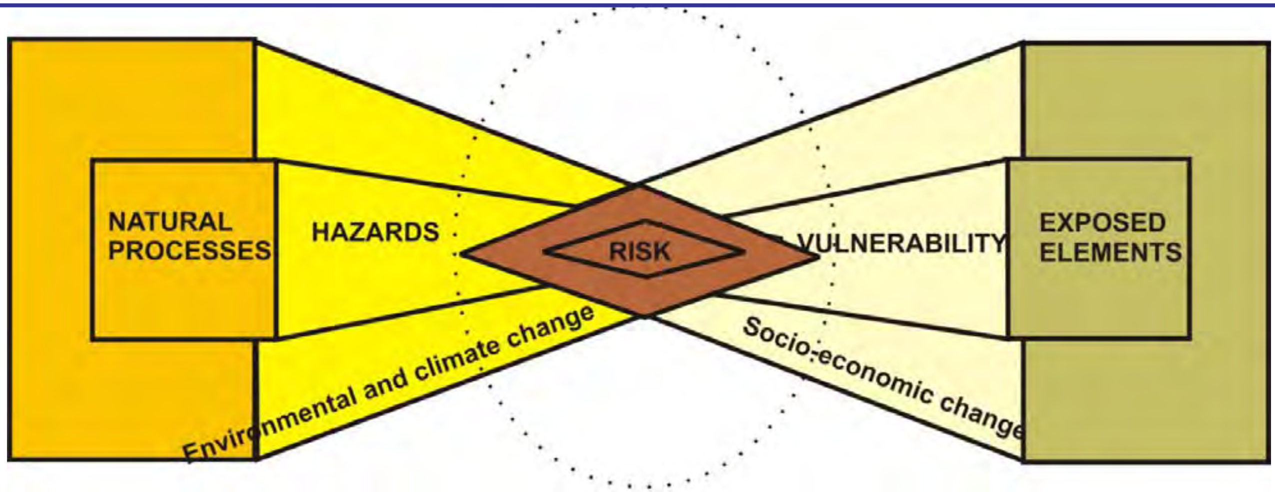
Qualitative risk analysis

An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur (ISSMGE).

Quantitative risk analysis

An analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of risk (ISSMGE).

RESEARCH QUESTIONS & AIMS



after Malet et al, 2012; Alexander 2002

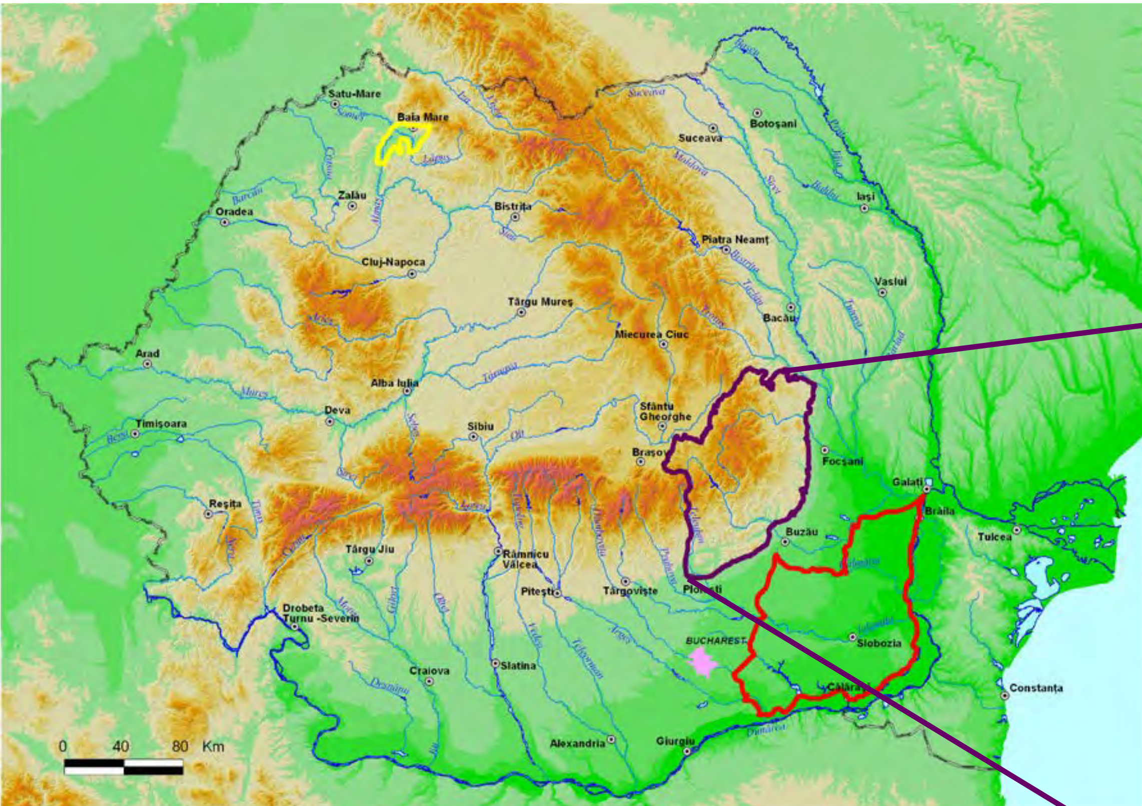
- Hazard and risk analyses = **predictions**
- Important in predictions: → **changes**
- What will be these changes: several **scenarios** are used
- Changed time series of input data
- Here: only climate change scenarios, other factors = assumed constant
- **Approach** to identify changes in landslide hazard (susceptibility, frequency, intensity) and landslide risk (elements at risk, vulnerability) induced to climate change scenarios
- Results: actual and changed landslide hazard maps,

  actual and changed landslide risk maps

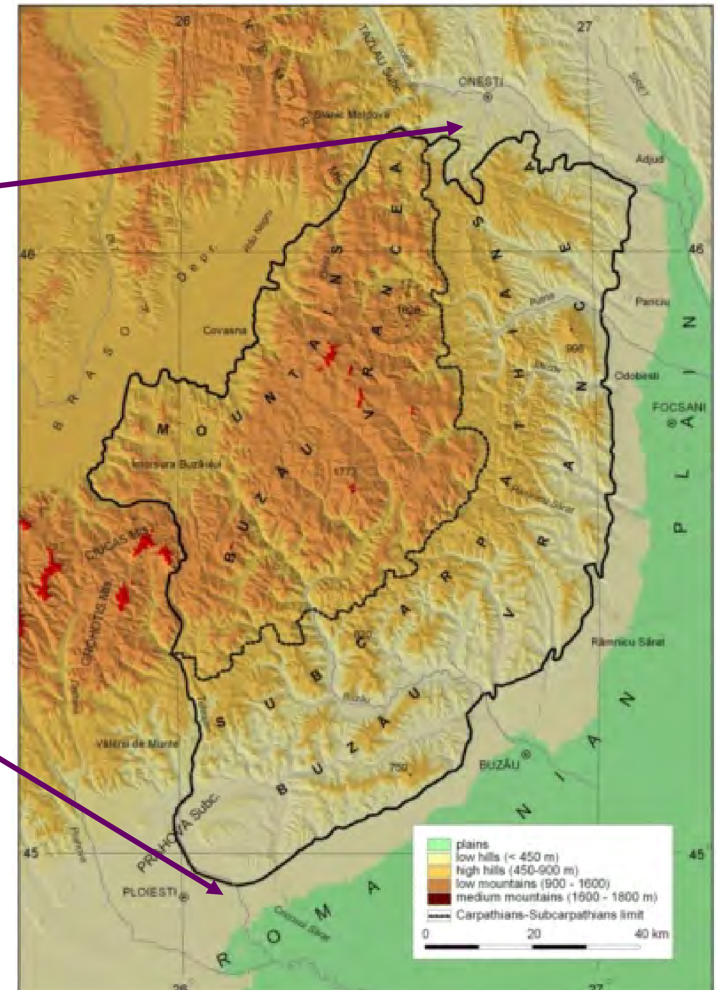
CONTENTS

- Study area
- Methodology for landslide hazard and risk analysis under climate change scenarios
- Role of the climatic factors
- Results: Actual and future landslide triggering factor maps, hazard and risk maps under climate change conditions
- Expressing changes in landslide triggering factor, hazard and risk
- Conclusions

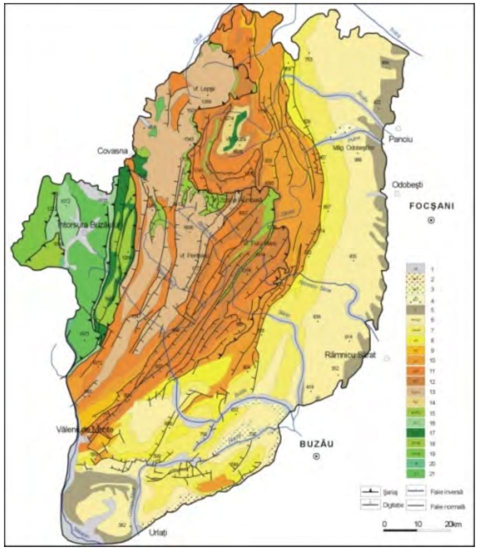
STUDY AREA: VRANCEA SESIMIC REGION



Vrancea seismic region:
landslides and floods



STUDY AREA: VRANCEA SESIMIC REGION



IGR, 1966

Relief: great structural and petrographical complexity, a young and very dynamic relief of mountains (1400-1500 m, up to 1800 m), hills (400-800 m) and depressions;

Precipitation regime: 500-1000 mm yearly amount, torrential heavy summer rainfalls (80–100 mm in 24 h), spring showers overlapping snow melt; monthly values peak at 70–150 mm in June

Human activity and land use/land cover: long history of intensely populated (90-150 pers./sq.km.) and used areas; large deforestations;

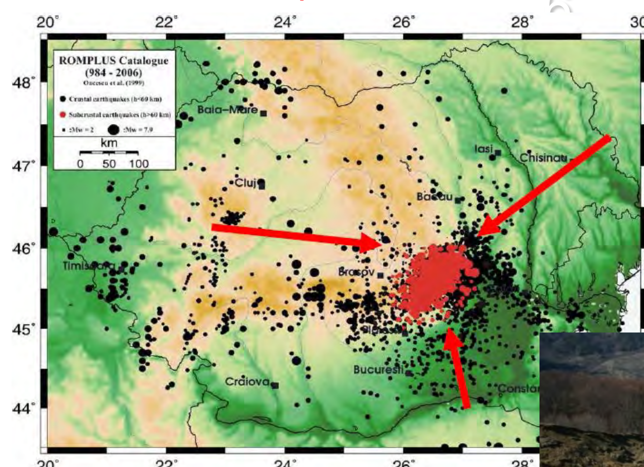
Geology:

-the most active seismic region of Europe with subcrustal earthquakes (depths of 80-160 km)

-folded and faulted Cretaceous and Paleogene flysch – Mio-Pliocene molasse – Quaternary deposits (great lythological heterogeneity; *clays, marls, sands*)

-neotectonics: uplift rates of 5 mm/year in the mountain sector and 3–4 mm/ year in the Subcarpathian hills

Natural hazards: shallow and deep-seated landslides; floods and flash floods, earthquakes.



Oncescu et al, 1999

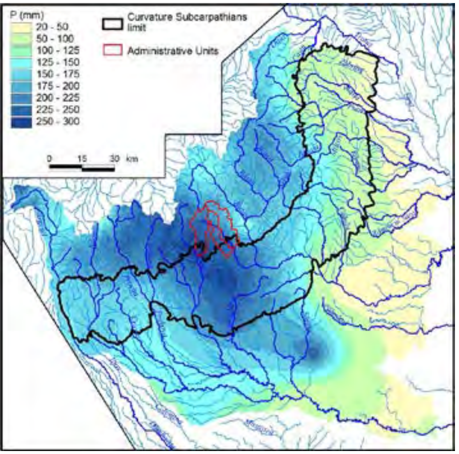
Photos: M. Micu

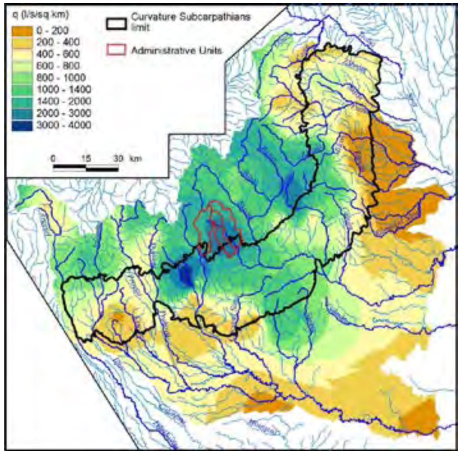
Photo: M. Micu

Floods/flash flood events in the Bend Subcarpathians region

o Affected by flash-floods are in general small rural settlements with a high socio-economic vulnerability (high exposure and sensitivity).

o **Exceptional local events were recorded in 1975, 1991, 2005 (<2,000 l/s/sqkm)** and **2010**.





1975

>170-200 mm in 3 days (Jul1-3) over extensive areas within the Bend Subcarpathians

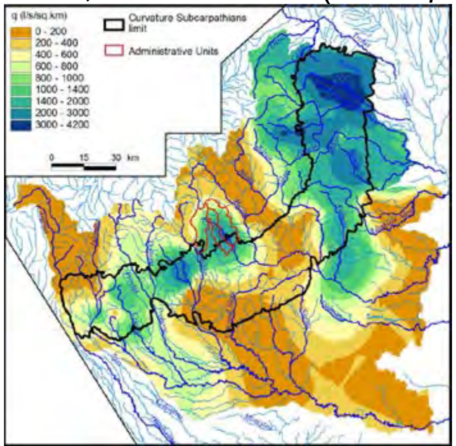
<u>Consequences:</u>

- several small catchments registered flash-floods lasting 1-2 consecutive days.
- numerous shallow landslide failures and deep-seated landslide reactivations

Chendeş, 2011

o **2005** is a historical record year in Romania (total precipitation and greatest 1-day precipitation for most weather stations)

o The above-normal precipitation triggered 7 flooding episodes covering the April-September interval: 76 casualties, 1,734 affected settlements, 94,000 destroyed houses and households, and a total economic loss of about 1,5 billion Euro (*Masterplan for Flood Management - Romanian Waters, 2009*).



Rmax1day >90-130 mm (Jul11-13) in the middle drainage area of the Siret and Buzău Basins.

<u>Consequences in the Bend Subcarpathians:</u>

- severe flash-floods on tributaries .
- numerous shallow landslide failures and deep-seated landslide and mudflow reactivations.

Chendeş, 2011

STUDY AREA: VRANCEA SESIMIC REGION

Natural hazards: shallow and deep-seated landslides; floods and flash floods, earthquakes.

July 28, 2005 (NehoiuV.):
6 settlements (300 dwellings)
200 m railroad,
16 bridges destroyed.

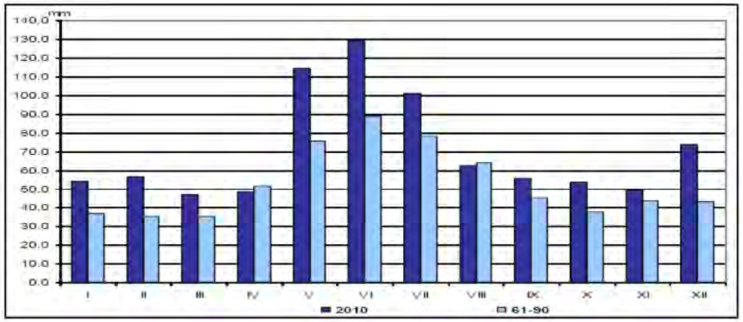
May 4-8 2005 (NehoiuV.):
4 000 people isolated,
destruction of roads and bridges (20 areas)

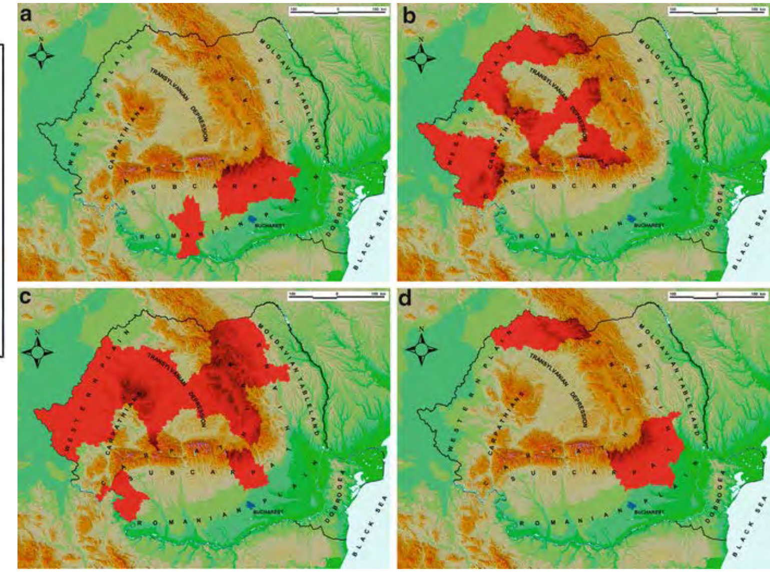
Photos by M.Micu

STUDY AREA: VRANCEA SESIMIC REGION

2010: hydro-meteorological hazards (Micu et al. 2013)

2010 vs. multiannual mean precipitation
Min. of Environment 2010





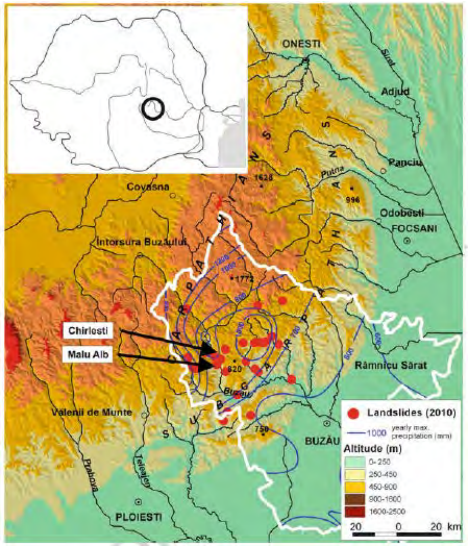
Riverine floods, flash-floods and landslides
a. Feb-Mar, **b**. May-Jun, **c**. Jul, **d**. Nov-Dec
(Annual Environmental Report, 2010)

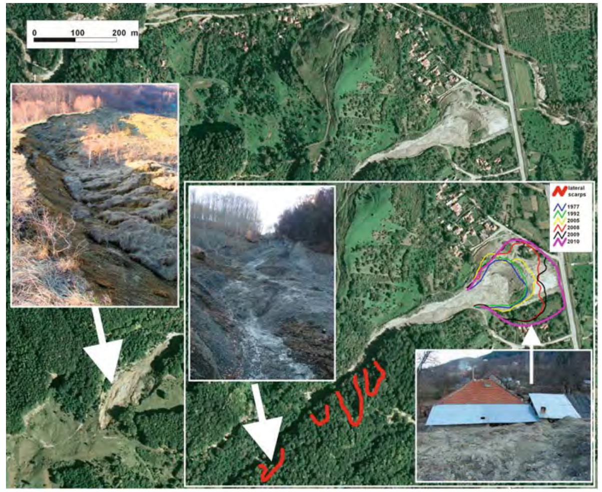
May 16 2010: flash-flood on the Bâsca Chiojdului catchment. (*Photos by R. Zarea)*

Flash-flood of July 2010, Drajna catchment (*Photos by M. Micu*).

STUDY AREA: VRANCEA SESIMIC REGION

2010: hydro-meteorological hazards (Micu et al. 2013)





Chirleşti Mudflow. Accumulation fan expansion on 5,000 m2. One house destroyed, one communal and one national road blocked.

Landslides: in Feb (temperature rise), Mar (showers + snowmelt). Jun-Jul (torrential rainfall), Nov-Dec (showers)

Cost of damage (landslides and floods) = € 20 million in Buzău county

Damage June-July 2010: 7.1 km dikes; 6.8 km bank protection; 6 km dams; 11.1 km ntional road; 72.2 km communal road; 51.1 km streets; 25 km forestry road; 43 bridges; 3 km water networks, 107 ha agricultural land; 1 damaged house, 1 destroyed house; 16 damaged annexes.

METODOLOGY: HAZARD

- **Landslide hazard** :
- probability of occurrence of a given magnitude of event (Crozier & Glade, 2005)
- frequency of a particular type of landslide of a certain magnitude (i.e. volume or velocity or intensity etc.) (Cascini, 2008).

-Three components: spatial probability, temporal probability (or frequency) and magnitude

→ **Spatial probability (susceptibility)**

METODOLOGY: SUSCEPTIBILITY

- **Medium scale (1:25 000) / 20m resolution**

- **Inventory**: type (shallow and medium-seated landslides), various sources

- **Susceptibility**: Multivariate statistical method

The **logistic regression** describes the relation among a dichotomous response variable and a series of landslide predisposing factors (i.e. slope angle, material, vegetation cover etc.)

$$P = 1 / (1 + e^{-z})$$

$$z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n,$$

i) Preprocessing of the variables before their introduction in the logistic regression.

→ classification of variables and normalization of classes by simple bivariate analysis

ii) Design of the sampling procedure: random and representative.

iii) The analysis through logistic regression on the selected database.

- Stepwise forward logistic regression, Likelihood ratio to test significance of each variable
- model evaluation – training dataset
- model validation - two validation datasets (Buzău and Vrancea counties)
- ROC (*relative operating characteristic*) curve – to test accuracy of the model

iv) Construction of the final susceptibility map.

- probability values (0-1)
- OR five susceptibility classes, using the Natural Breaks classification

Softwares: ArcGIS v.10.x, SPSS v.17.0

METODOLOGY: HAZARD

• **Landslide hazard**:

- probability of occurrence of a given magnitude of event (Crozier & Glade, 2005)
- frequency of a particular type of landslide of a certain magnitude (i.e. volume or velocity or intensity etc.) (Cascini, 2008).

-Three components: spatial probability, temporal probability (or frequency) and magnitude

→ **temporal probability (or frequency) and magnitude**

-usually:

- direct estimations of landslides frequency (based on series of landslide events)
- correlation of landslide events to **triggering factors** (rainfall event, snow melting, earthquake …) (change the state of stresses of slopes in a very short time)

→ critical values → return period of landslides = return period of the critical trigger

- Difficulty: scarcity or incompleteness of historical landslide databases (van Westen et al, 2006),

- **impossible** to make *direct* estimations of landslides frequency.
- **impossible** to make *indirect* frequency estimations by correlating historical landslide records to triggering factors

➢ Solution here: **Indirect & expert knowledge approach** to define the triggering factor based on **climate data series only**

➢ Under reference (1971-2000) climatic conditions

➢ Under future (near: 2021-2050, far: 2071-2100) climatic conditions

METODOLOGY: TRIGGERING FACTOR ANALYSIS:

The temporal behavior of the triggering factor: here rainfall

- ***Magnitude***: *couple amount/duration*

  - high-intensity rainstorms (ID = well-known rainfall threshold, Caine 1980)
  - moderate-intensity storms of long-duration (weeks or months)
  - high seasonal rainfall (Corominas, 2000; Remaître & Malet, 2012).

  - duration ↔ permeability of the slope material:
    - in permeable soils - high rainfall intensity and short episode duration (convective storms) commonly trigger shallow slides and debris flows (Corominas & Moya 2008; Remaître & Malet, 2012) *(rapid build-up and dissipation of positive pore pressures)*
    - in low-permeability soils - ***antecedent rainfall***. Long rainfall periods (weeks - months) usually trigger/reactivate debris flows, shallow and deep-seated slides (*reduces soil suctions and increases the positive pore-watre pressures*). But what time period is significant?

- ***Frequency***

  - Cannon and Ellen (1988): extraordinary events → extreme events generate geomorphic responses
  - Sandersen et al (1996): since the last glaciation, topography adapted to normal climatic conditions with respect to failures
  - Common conditions = normal = mean annual precipitation (MAP) or rainy-day normal (RDN)
  - The higher the MAP of a region → the higher precipitation amounts that slopes tolerate → the higher the rainfall threshold.
  - For spatial comparison between rainfall values: **normalization of rainfall values between regions**: Guidicini and Iwasa (1977): total rainfall of the event / MAP of the site; Wilson (1997): excess from avg daily precip.

- **Time scales**: annual, seasonal, monthly, periods of consecutive days, daily , hourly

CLIMATE MODEL DATA

- Output of three regional models available from the CORDEX project (Coordinated Regional Climate Downscaling Experiment) carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the **World Climate Research Programme (WCRP)**
- The CORDEX regional simulations downscaled the new CMIP5 global climate projections (Taylor et al. 2012) and the new Representative Concentration Pathways (RCPs, former climate scenarios)
- Grid data, spatial resolution: 25 km, temporal resolution: 1 day
- **Radiative emmission scenarios:** RCP2.6, RCP4.5, RCP8.5
- **Periods**: reference (1971-2000) and two future horizons (2021-2050 and 2071-2100).

Simulations	**Short name**	Spatial resolution	Scenarios	Time horizons	Climatic variables
CNRM-CERFACS-CM5	**CNRM-CM5**	25 km	RCP4.5, 8.5	1971-2000, 2021-2050, 2071-2100	precipitation
ICHER-EC-EARTH	**ECE**	25 km	RCP2.6, 4.5, 8.5		
MOHC-HadGEN2-ES	**HC**	25 km	RCP4.5, 8.5	1971-2000, 2021-2050, 2071-2095	

Data provided by the project partner Swedish Meteorological and Hydrological Institute (SMHI).

CLIMATE MODEL DATA

- Van Vuuren et al. (2011):

overview on the **new representative concentration pathways**

- one mitigation scenario leading to *a very low forcing level* (RCP2.6)
- one *medium stabilization scenario* (RCP4.5/RCP6)
- one *very high baseline emission scenario* (RCP8.5).

RCPs	Description	Mean characteristics by scenario components
RCP8.5	Rising radiative forcing pathway leading to a **8.5 W/m^2** (~1,370 ppm CO_2 eq) by 2100	GHG: High baseline Agricultural area: Medium for both cropland and pasture Air pollution: Medium-high
RCP4.5	Stabilization without overshoot pathway to **4.5 W/m^2** (~650 ppm CO_2 eq) at stabilization after 2100	GHG: Medium-low mitigation, very low baseline Agricultural area: very low for both cropland and pasture Air pollution: Medium
RCP2.6	Peak in radiative forcing at ~3.0 W/m^2 (~490 ppm CO_2 eq) before 2100 and then decline (the selected pathway declines to **2.6 W/m^2** by 2100)	GHG: Very low Agricultural area: Medium for cropland and pasture Air pollution: Medium-low

METODOLOGY: TRIGGERING FACTOR ANALYSIS

- Only **precipitation** was analyzed

- Antecedent precipitation
  → **seasonal precipitation (seasonal timescale)**

- Extraordinary events: high amounts, reduced frequency
  → extreme seasonal precipitation events: **30-year return levels of maximum seasonal precipitation** were calculated for each of the three time periods from 1971 to 2100, for each grid cell of 25 x 25 km.
  → *extRemes– Weather and Climate Applications of Extreme Value Analysis (EVA)* package (Gilleland, 2012) of the R software, (maximum likelihood method, assumption of a GEV distribution).

- Regionalization and classification of triggering values:
  -normalization with average reference climatic conditions (MAP of the reference period) → incorporates potential changes in avg. climatic conditions between REF and FUT period

- **Relative** ↔ absolute values: eliminates problem due to underestimation of simulated extreme values

- Reclassification of the values → proxy for the triggering event in the landslide hazard model

- **30-year return maximum seasonal precipitation amounts, as fraction of MAP_{ref}**

METODOLOGY: HAZARD ANALYSIS

Original spatial resolution of triggering factor (25 x 25 km),
- -no observation data available for additional bias correction,
- -no interpolation,
- -no regression with altitude,
- -intended: further downscaling of the climate simulations

small spatial scale dictated by input data

Recommended zoning levels and methods at different scales
(after Cascini, 2008, Fell et al. – JTC-1, 2008, modified)

Scale description	Indicative range of scales	Zoning levels			Zoning methods		
		Preliminary	Intermediate	Advanced	Basic	Intermediate	Sophisticated
Small	< 1:100 000	x			x		
Medium	1: 100 000 – 1:25 000	x	(x)		x	(x)	
Large	1:25 000 – 1:5 000	x	x	x	x	x	x
Detailed	>1:5 000	(x)	(x)	x	(x)	(x)	x

METODOLOGY: HAZARD ANALYSIS

after Cascini, 2008

Method	Procedure
Basic	Heuristic
Intermediate	Statistical analysis
Sophisticated	Statistical or deterministic

•**Hazard**:

Heuristic method = overlay of susceptibility zoning and the distribution of the triggering factor.

- The triggering factor varies in terms of magnitude (intensity), frequency = constant (1/30y).

- An event of major intensity will affect the susceptibility classes in a different manner than an event of moderate or minor intensity, leading to landslides originating also in less susceptible areas

→ Expert-based matrix

Susceptibility x Trigger (frequency, magnitude)

METODOLOGY: HAZARD ANALYSIS

Expert-based hazard matrix

Zones of equal susceptibility are expected to respond in a similar way to a same value of the trigger

HAZARD MATRIX

Triggering factor (frequency, magnitude)	Intensity (frequency constant: 1/30)	Class	very low	low	medium	high	very high	
		extremely strong	2	3	5	6	6	
	Major event	very strong	2	3	5	5	6	Prioritizing triggering event
		strong	2	3	4	5	6	
	Moderate event	medium	1	2	4	4	5	Prioritizing susceptibility
		medium-weak	1	2	3	4	5	

Susceptibility

Hazard classes (indexes)

1	very low
2	low
3	medium
4	high
5	very high
6	extremely high

- Different prioritization depending on the intensity of the rainfall event:
  - -for medium intensities, susceptibility dictates hazard levels
  - -for major intensities, susceptibility levels are translated into higher ranks of hazard.
  - -for high susceptibility, possible important increments
  - -for low susceptibilities: possible increment is reduced

Replaces the usual overlay with fixed weights for the two components (susceptibility and triggering factor)

METODOLOGY: HAZARD ANALYSIS

•General recommendation in spatial analysis when combining different scale/resolution maps:

the coarser scale/resolution imposes

•Still, to give a general idea about the possible spatial pattern of hazard within each 25x25 km cell → vizualization at a medium resolution

→ (the matrix never decreases the value of S, only increases are possible)

→ to use the intensity of the triggering event as a background, against which the detailed distribution of hazard classes is dictated by the spatial pattern of susceptibility

Caution for map use → comparison among cells rather than inside cells

METODOLOGY RISK

• **Vulnerability:** limited historical damage data worldwide (for diff. types, volumes, elements at risk) → loss estimation models do not exist for landslide hazard; damage due to landslides is isolated (in “points”) than for other hazards (“in polygons”: floods) (van Westen et al. 2006)

→ qualitative index at regional scales = representation of amounts of elements at risk

- social (population density at NUTS5 level)
- physical (households – density of built-up areas and communication networks – density km/km^2)
- economic (lack of econom. data)
- environmental (protected areas, IUCN and Natura 2000 classification)

• Standardized rating

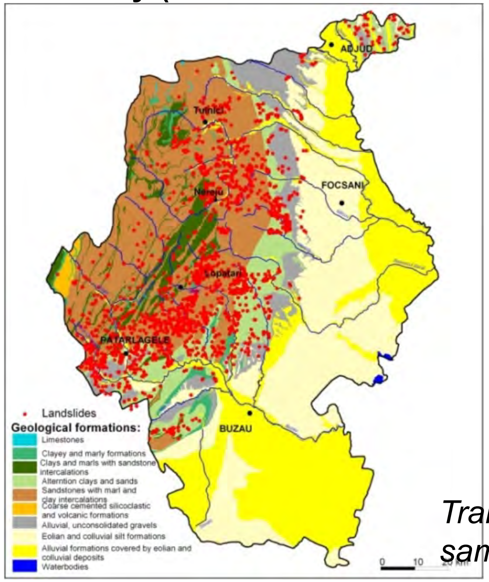
• Composite vulnerability index (Castellanos Abella & van Westen 2007)

• **Risk**: weighted overlay of qualitative maps → qualitative (probability and losses expressed in qualitative terms) risk index

- applied at regional scales
- scarcity of vulnerability information

RESULTS : SUSCEPTIBILITY

Landslide inventory (*shallow and medium-seated*)



Landslide predictors

-geology,

hydrological soil groups,

-land use

-altitude,

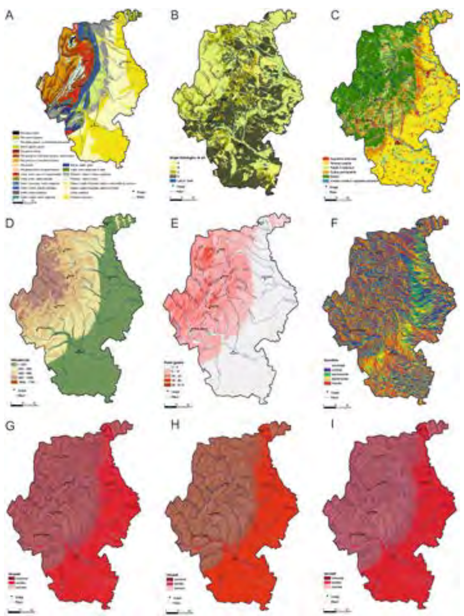
-slope angle

-slope aspect

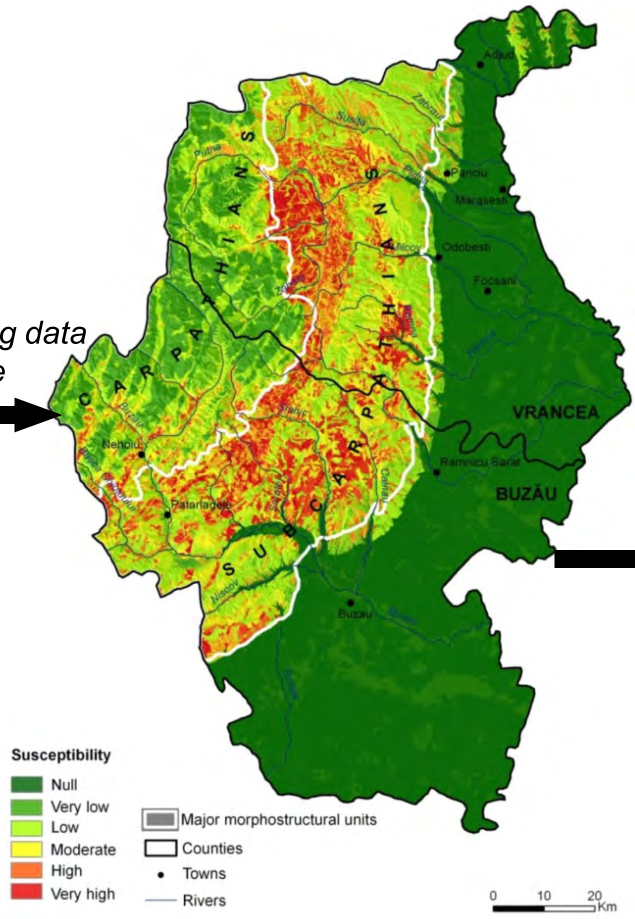
-total slope curvature

-plan curvature

-profile curvature



Training data sample



Map validation using a validation data sample

Confusion Matrices

		Reality	
		1	0
Logistic Model	1	TP	FP
	0	FN	TN

% correctly classified pixels=(TP+TN)/N*100

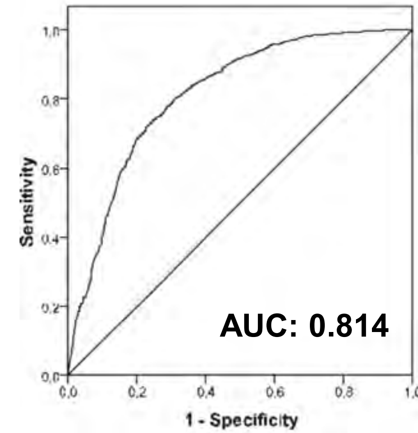
		Calibration dataset	
		Reality	
		1	0
Logistic Model	1	750	292
	0	244	790

% correctly classified pixels=74.2

		Validation dataset	
		Reality	
		1	0
Logistic Model	1	324	114
	0	111	333

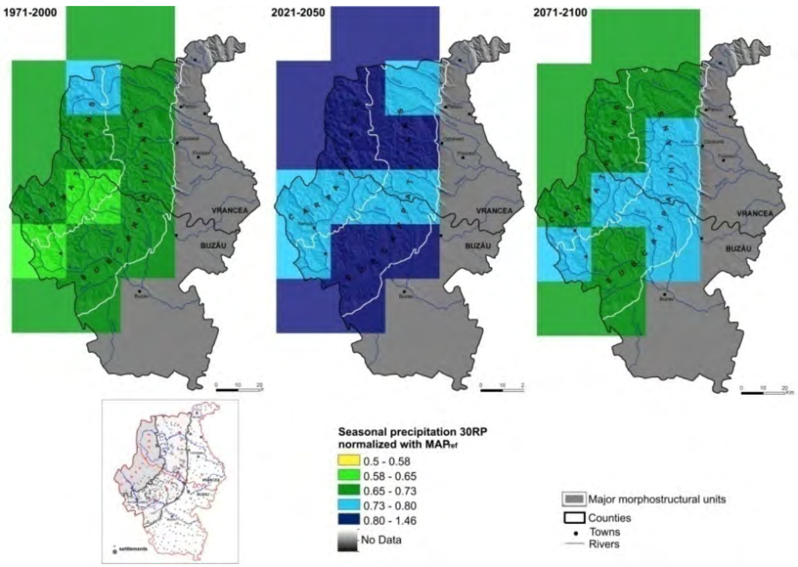
% correctly classified pixels=74.5

ROC curve

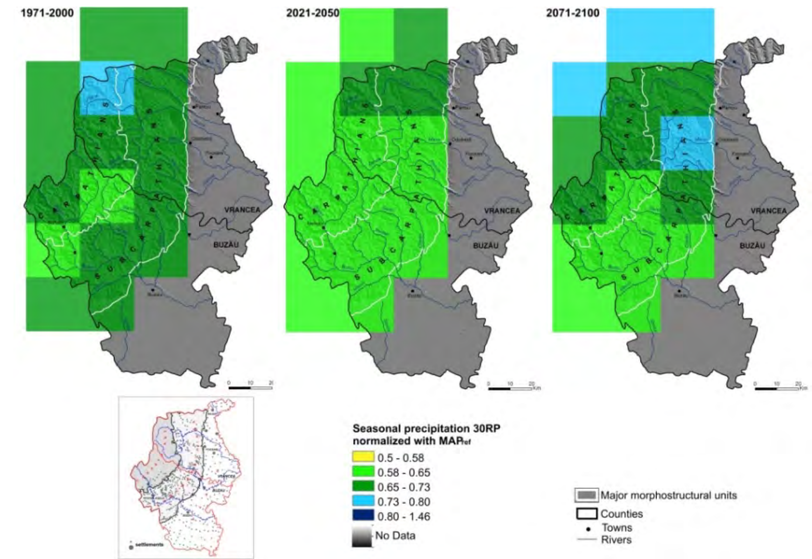


RESULTS: TRIGGERING FACTOR

ECE RCP4.5

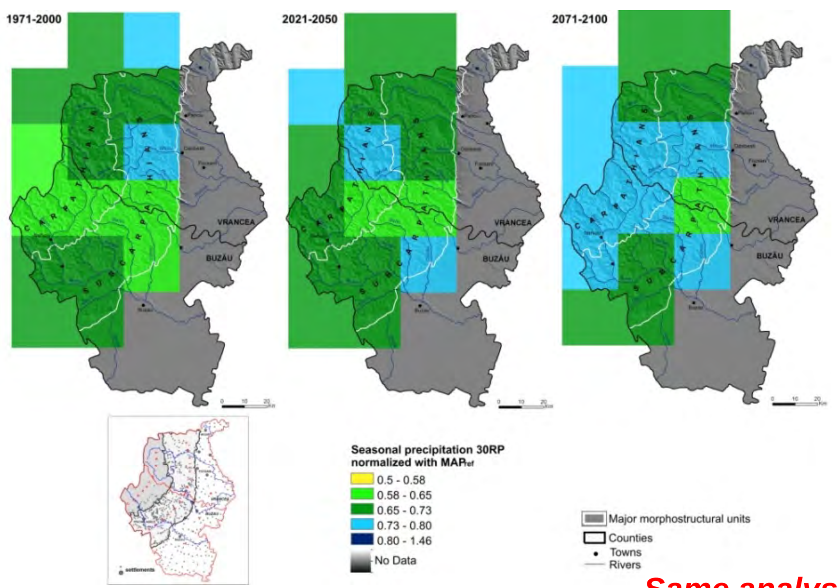


ECE RCP8.5

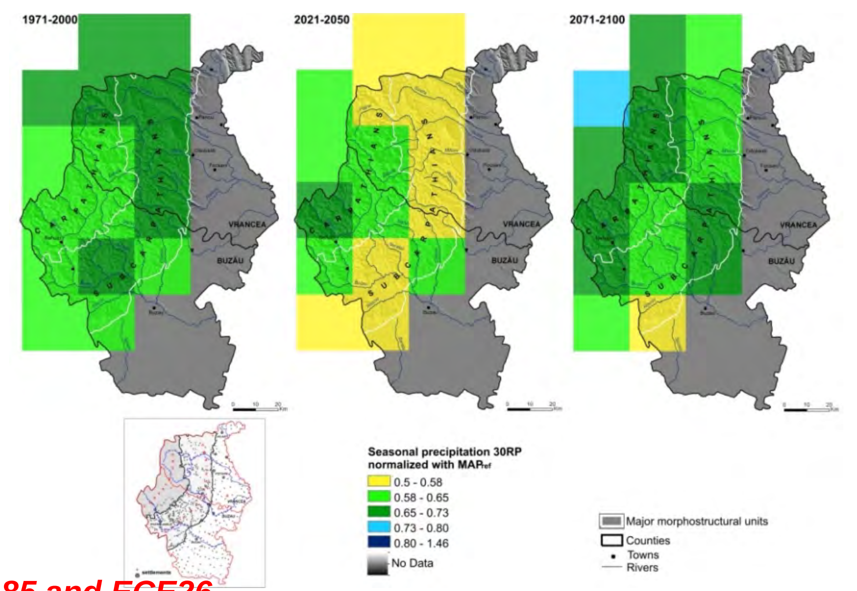


30-year return levels in seasonal precipitation → normalized with MAPref (mean annual precipitation of reference period) → to allow for spatial comparison

CNRM RCP4.5



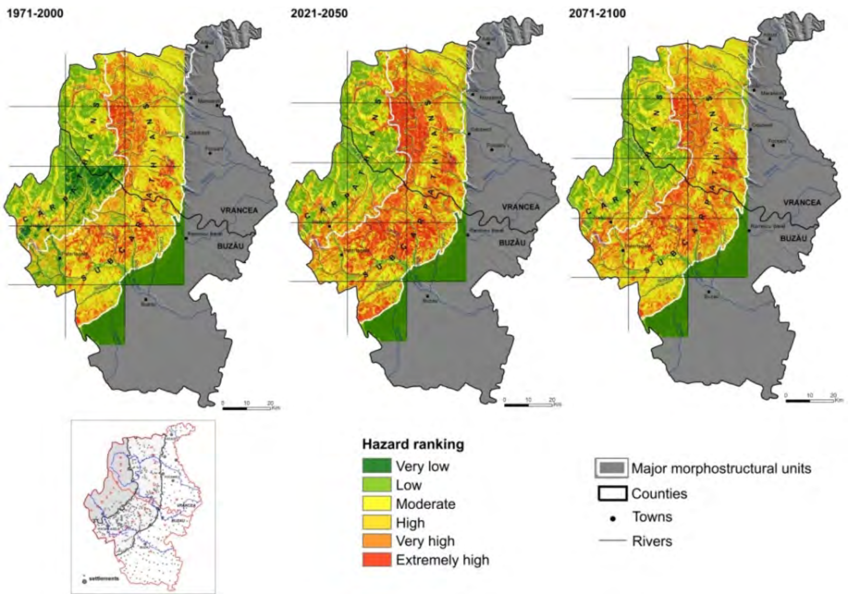
CNRM RCP8.5



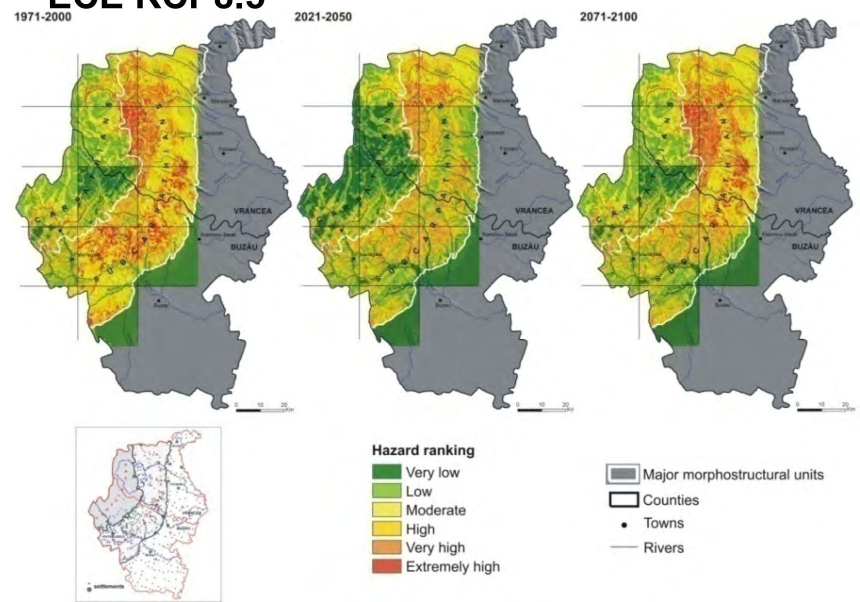
Same analysis for HAD 45,85 and ECE26

RESULTS: LANDSLIDE HAZARD ANALYSIS

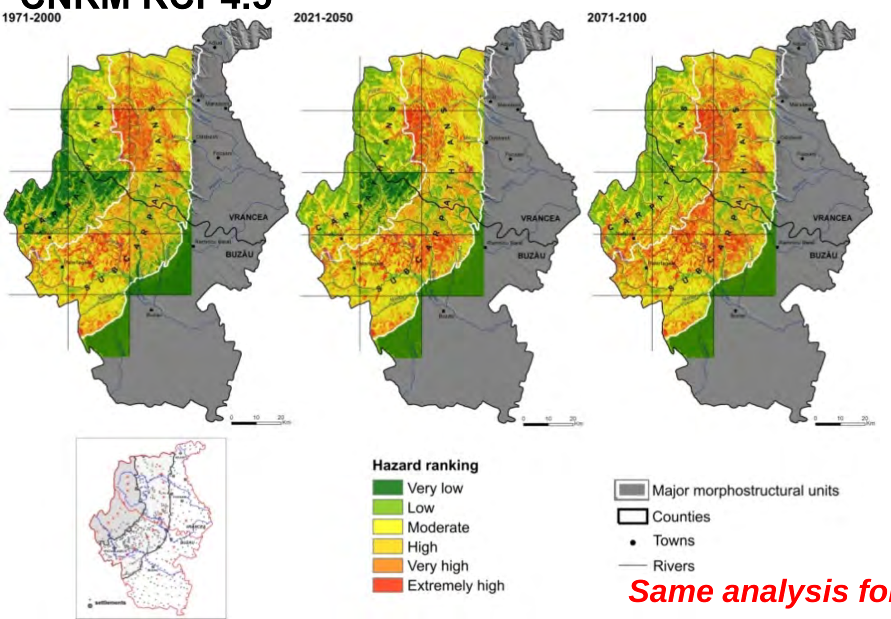
ECE RCP4.5



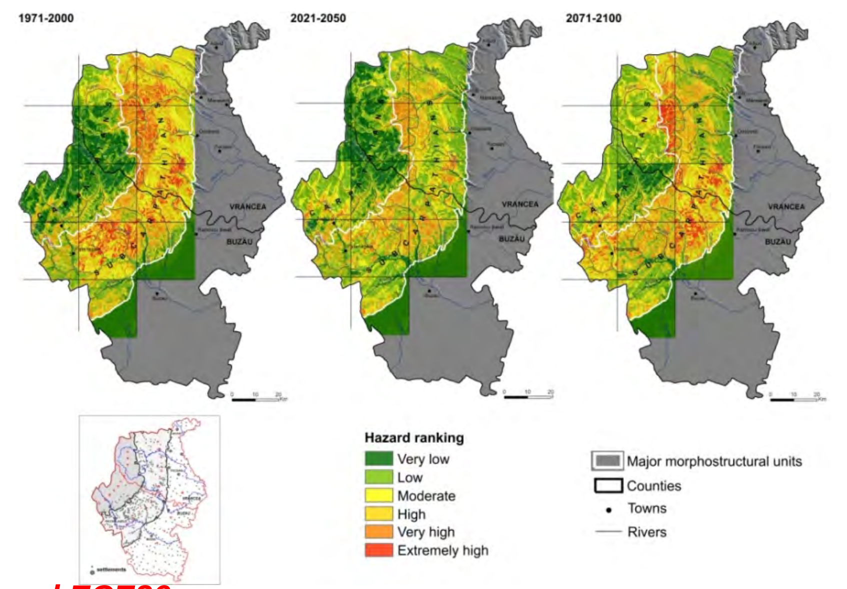
ECE RCP8.5



CNRM RCP4.5



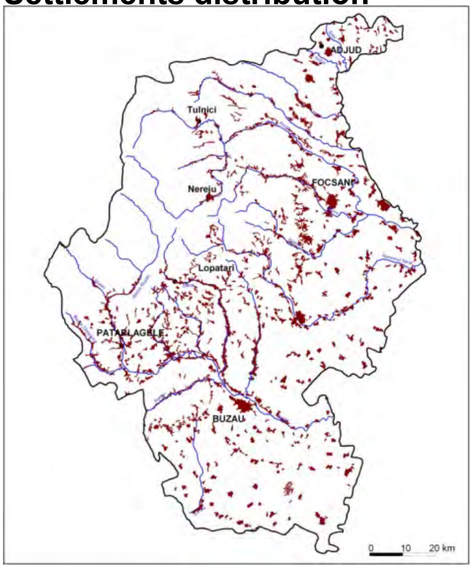
CNRM RCP8.5



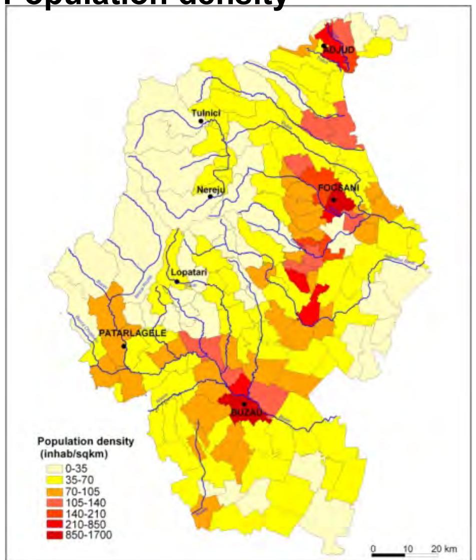
Same analysis for HAD 45,85 and ECE26

RESULTS: VULNERABILITY

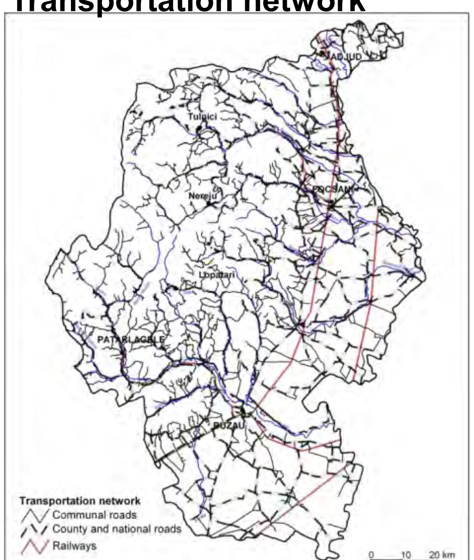
Settlements distribution



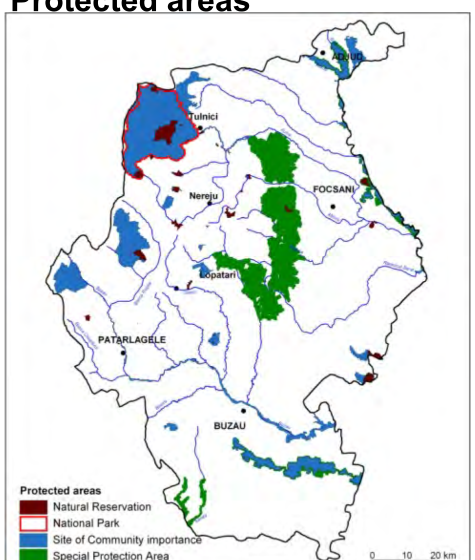
Population density



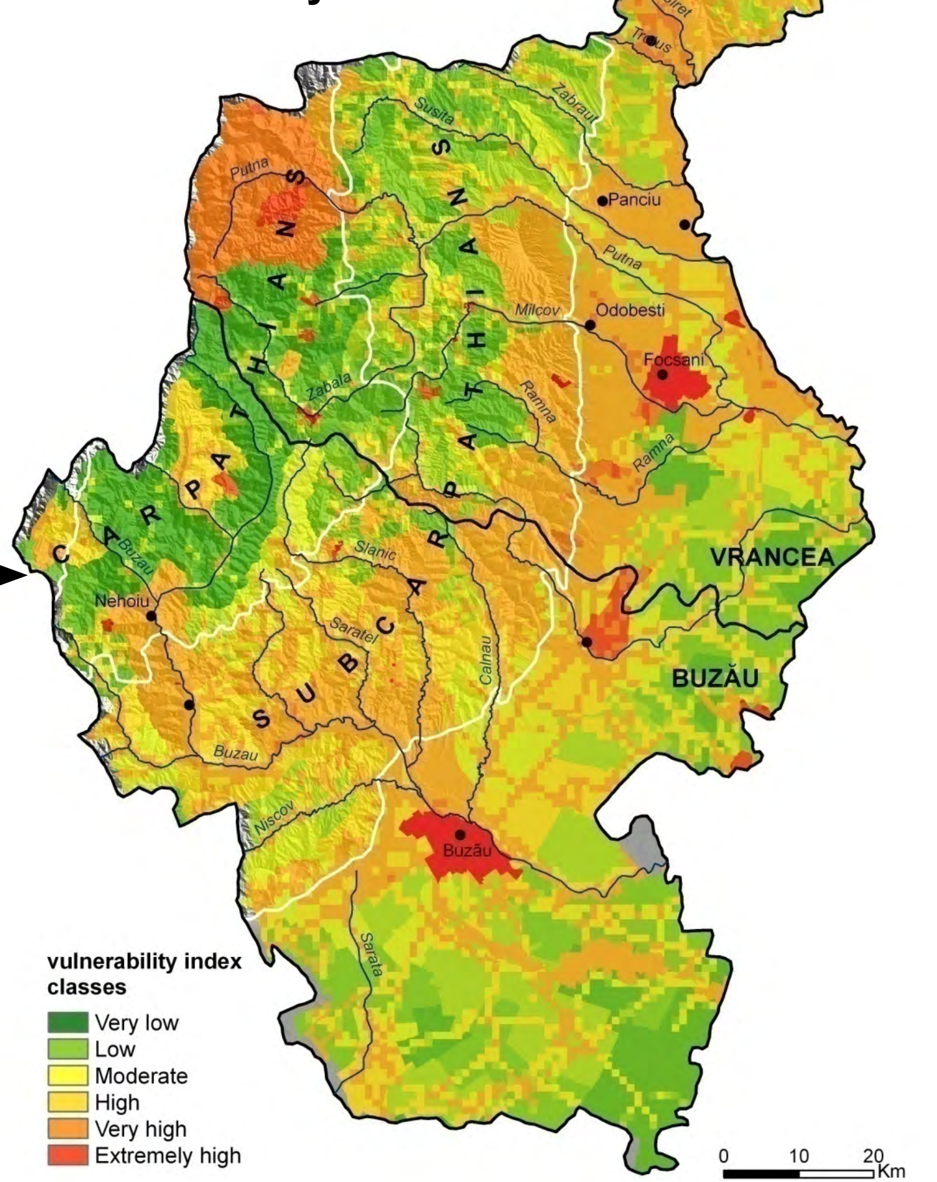
Transportation network



Protected areas

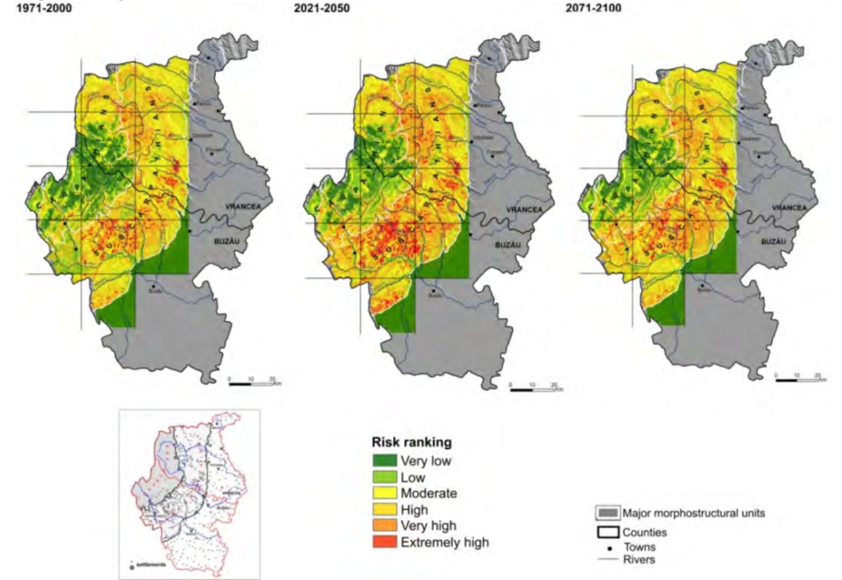


Vulnerability index

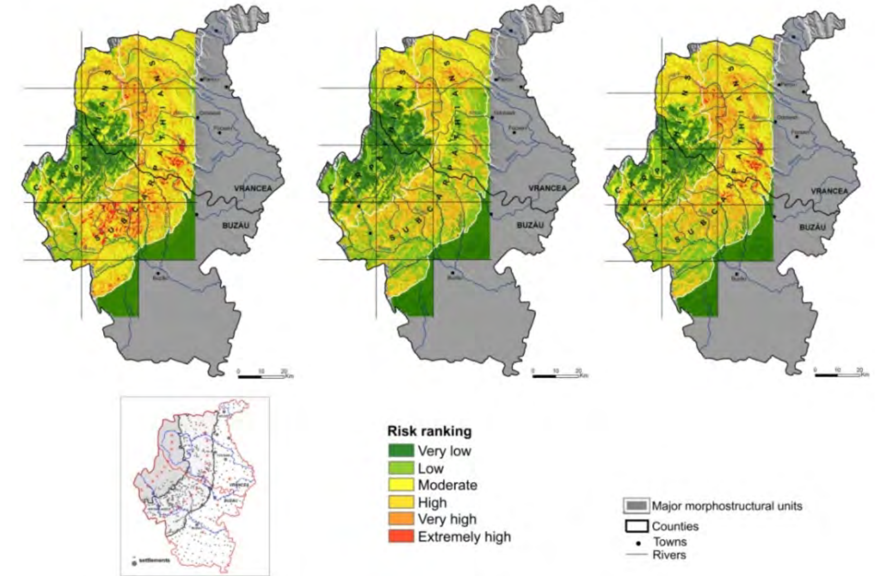


RESULTS: LANDSLIDE RISK

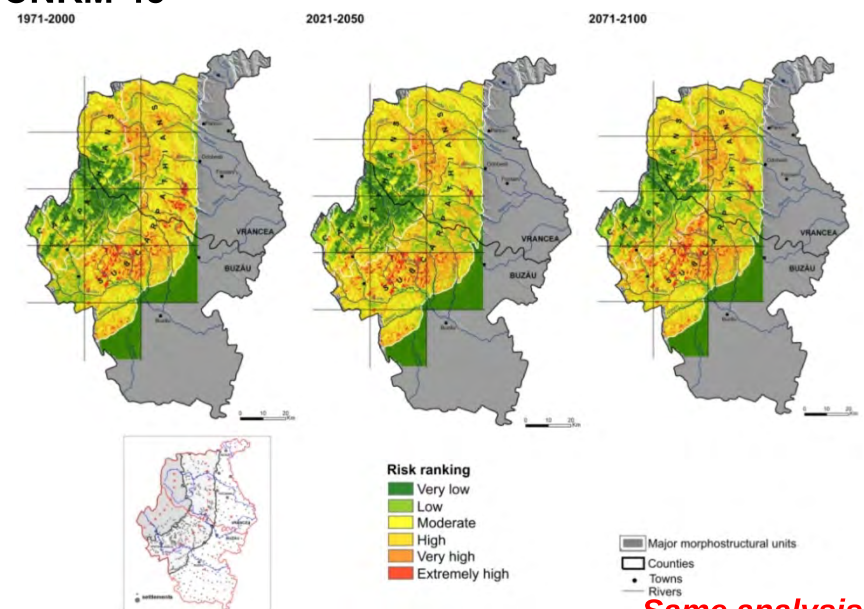
ECE 45



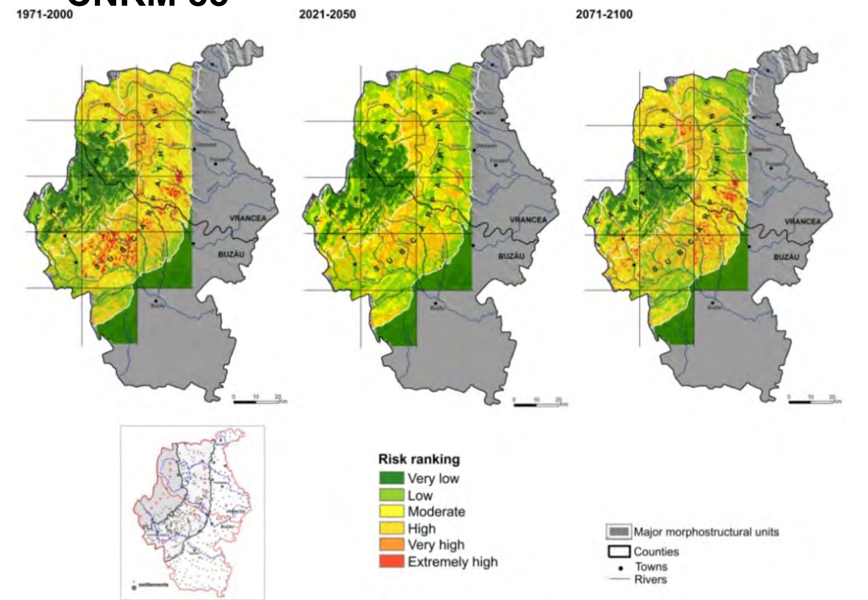
ECE 85



CNRM 45



CNRM 85



Same analysis for HAD 45,85 and ECE26

HOW TO EXPRESS CHANGES

Triggering factor

Climatic triggering factor t_0

Climatic triggering factor t_1

Climatic triggering factor t_2

→ Ratio t_1/ t_0

→ Ratio t_2/ t_0

Hazard

Hazard t_0

Hazard t_1

Hazard t_2

→ Hazard t_1 – Hazard t_0

→ Hazard t_2 – Hazard t_0

Risk

Risk t_0

Risk t_1

Risk t_2

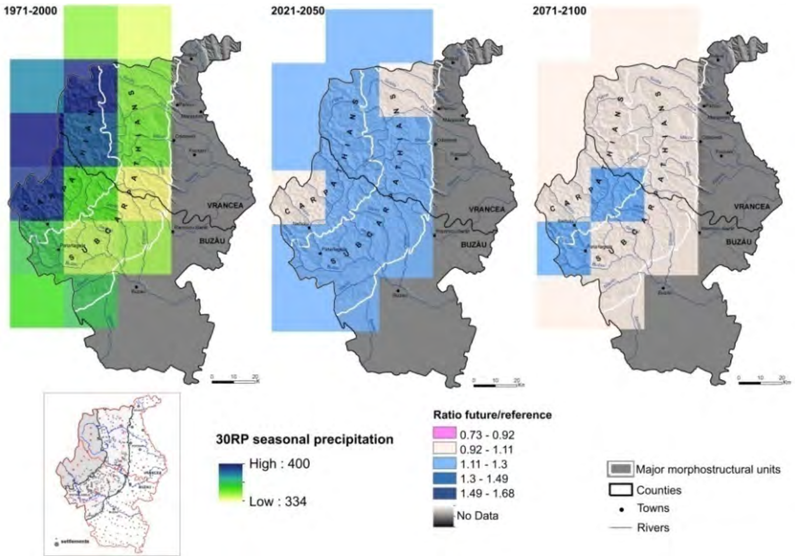
→ Risk t_1 – Risk t_0

→ Risk t_2 – Risk t_0

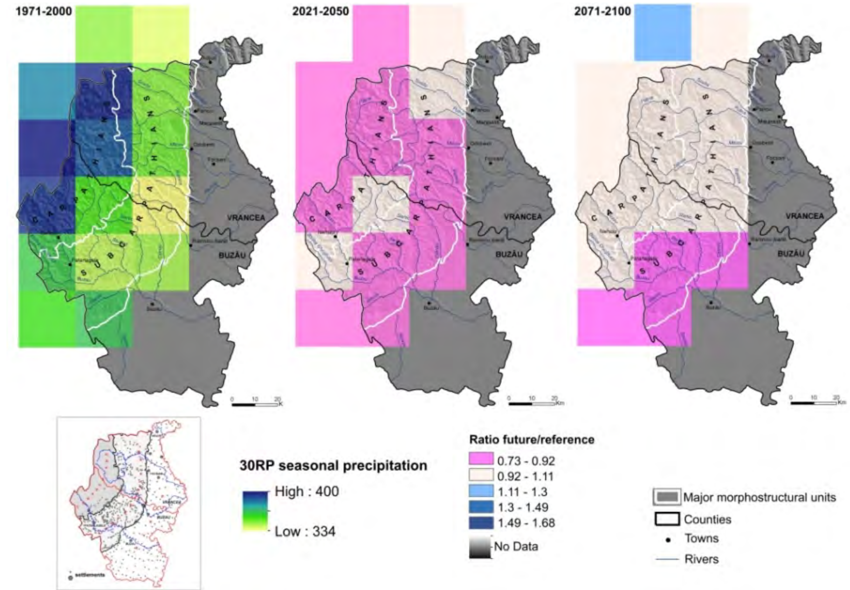
ECLISE

RESULTS: CHANGES IN THE TRIGGERING FACTOR

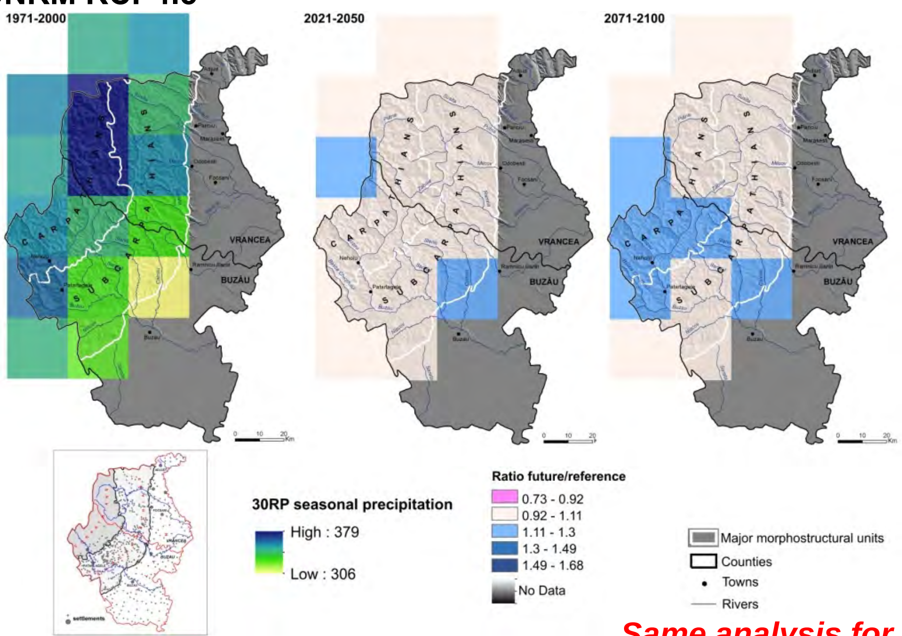
ECE RCP4.5



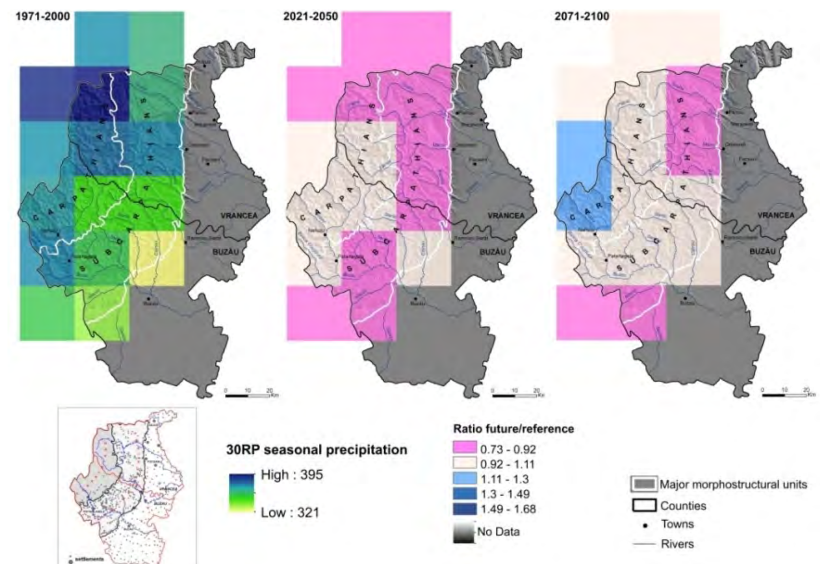
ECE RCP8.5



CNRM RCP4.5



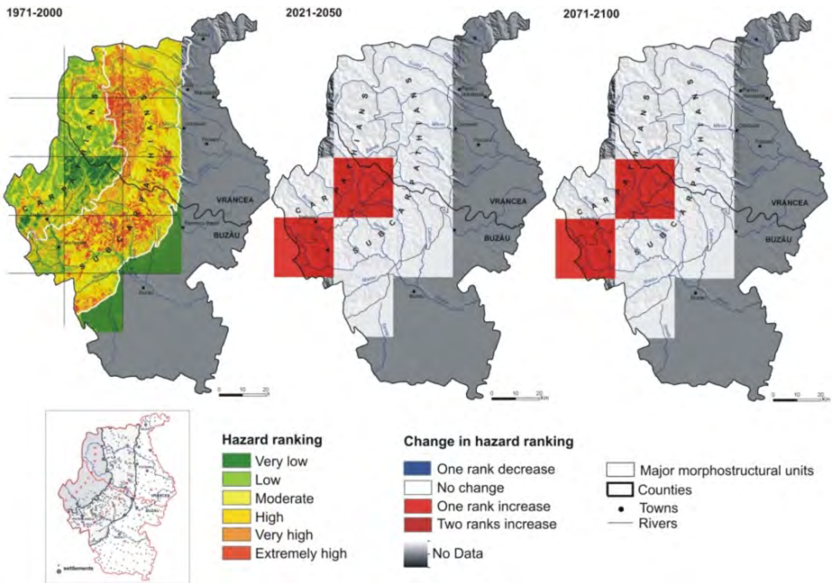
CNRM RCP8.5



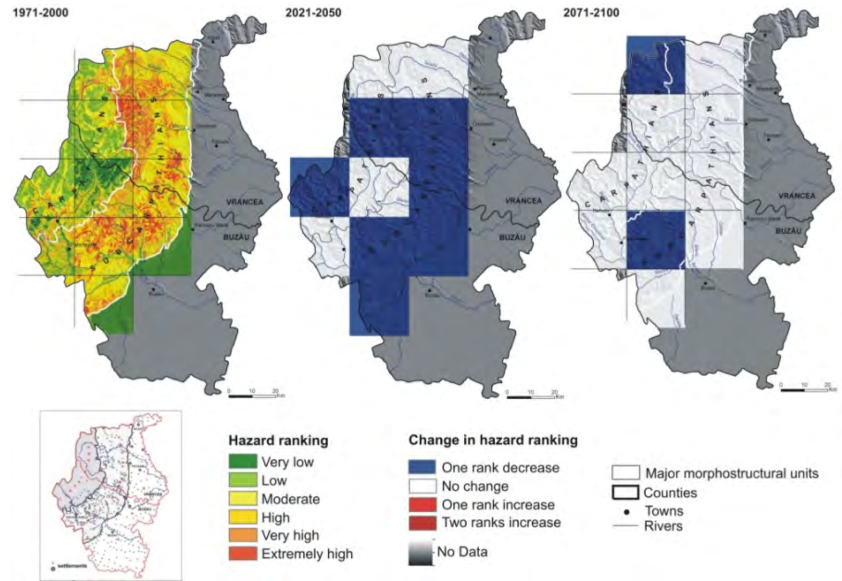
Same analysis for HAD 45,85 and ECE26

RESULTS: CHANGES IN HAZARD

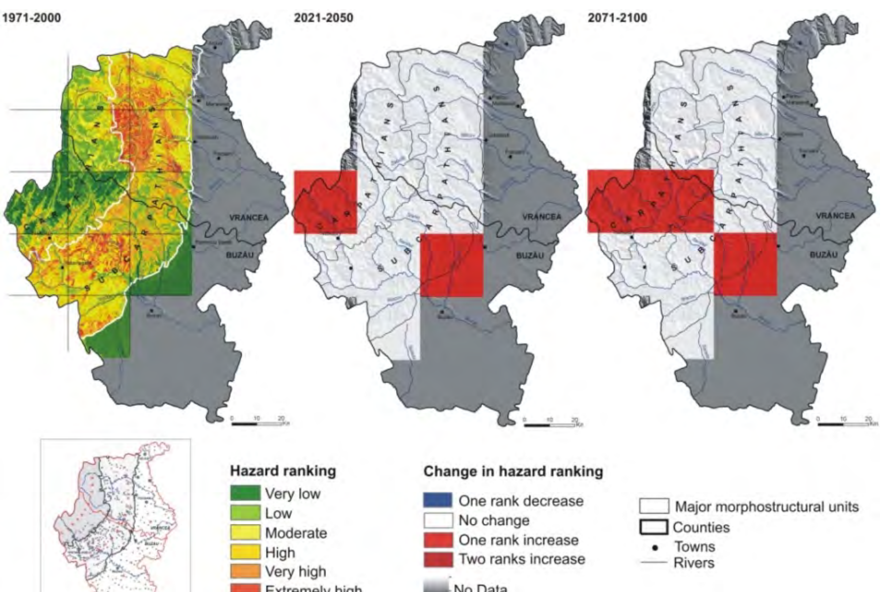
ECE RCP4.5



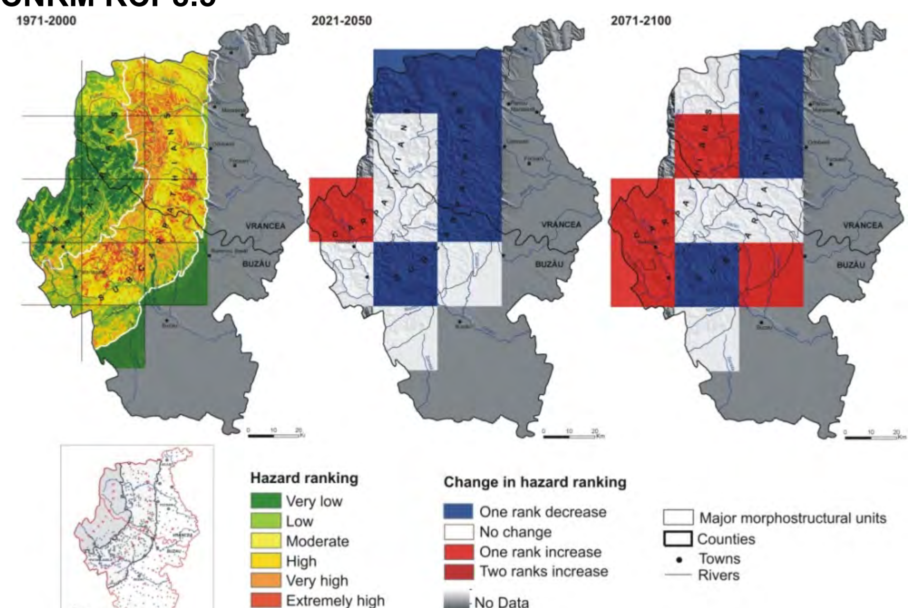
ECE RCP8.5



CNRM RCP4.5



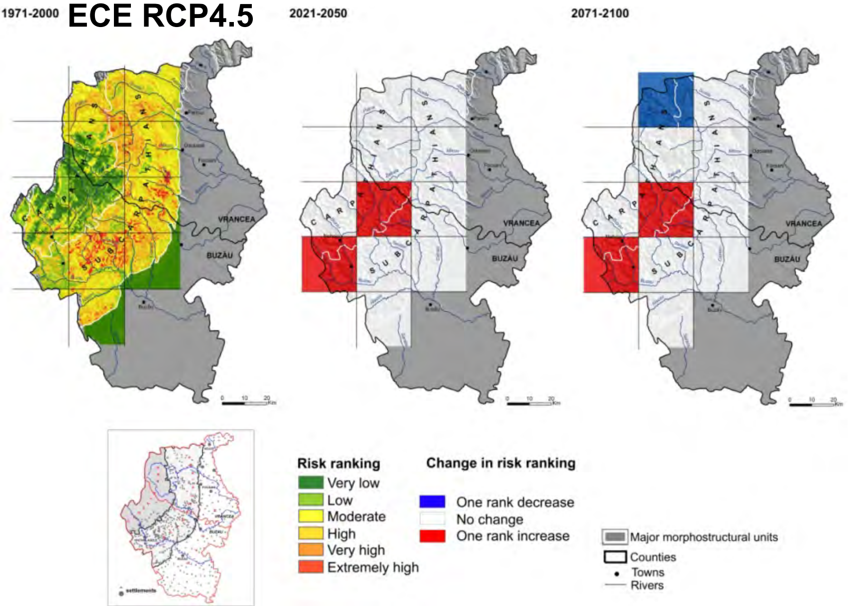
CNRM RCP8.5



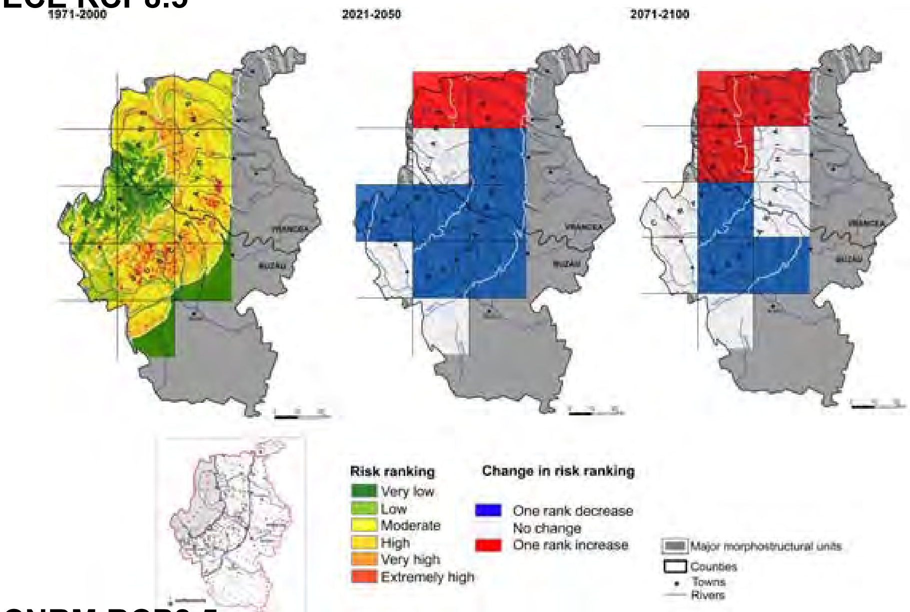
Same analysis for HAD 45,85 and ECE26

CHANGES IN RISK: RESULTS

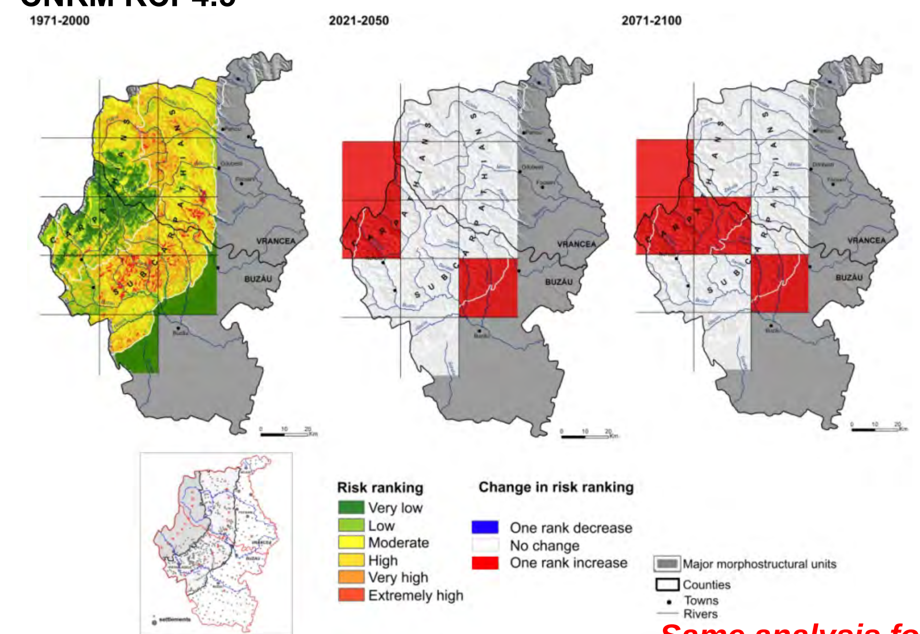
ECE RCP4.5



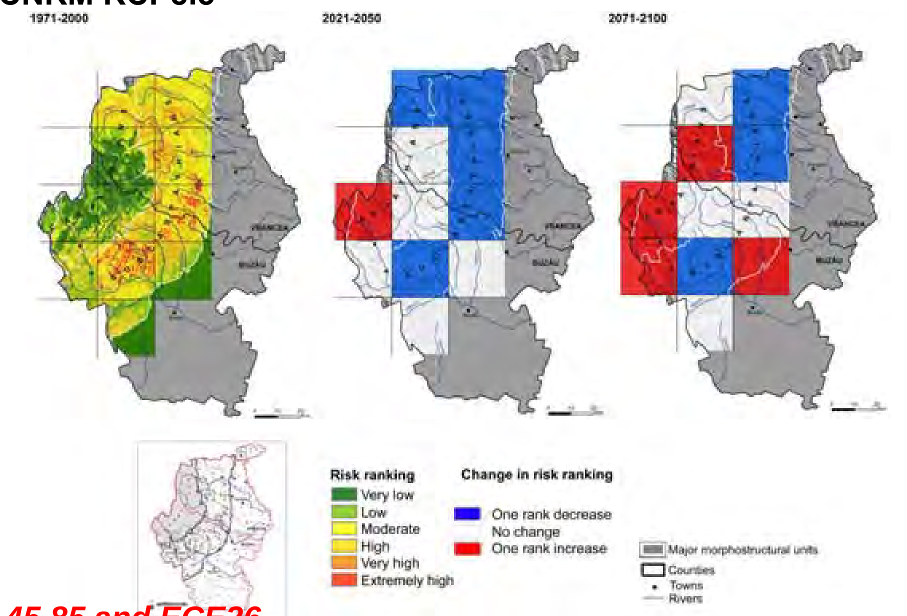
ECE RCP8.5



CNRM RCP4.5

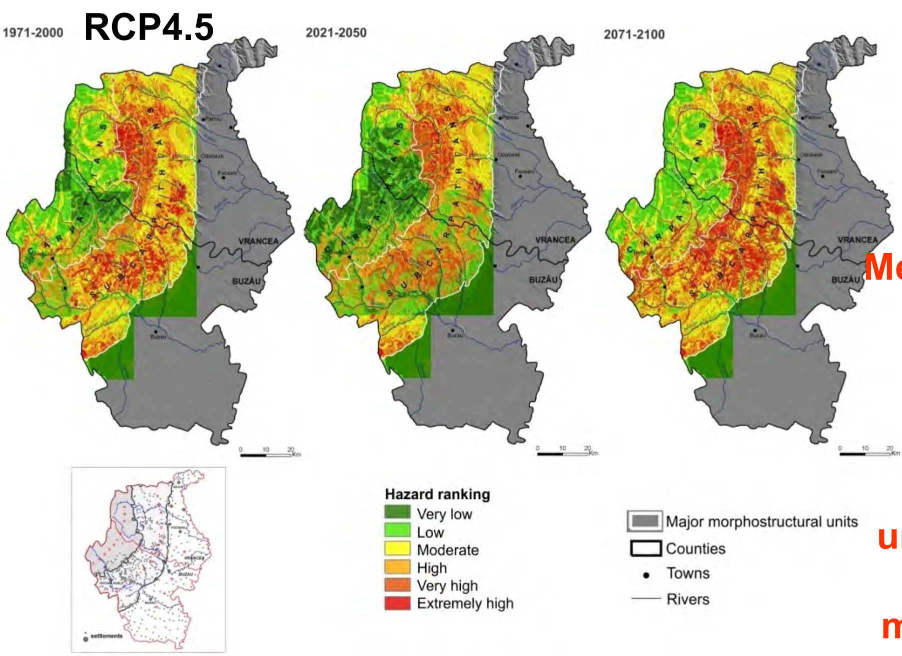


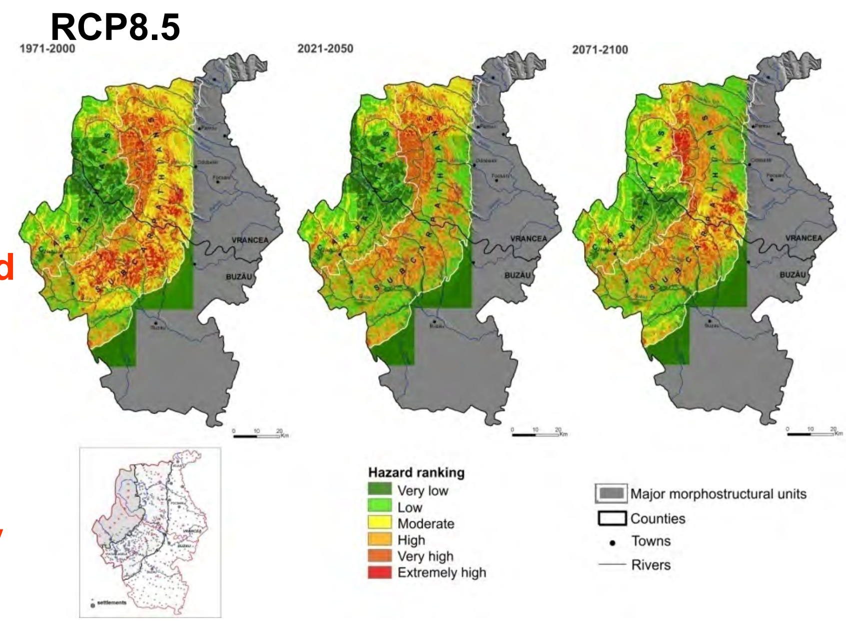
CNRM RCP8.5



Same analysis for HAD 45,85 and ECE26

RESULTS: MEAN HAZARD AND UNCERTAINTY

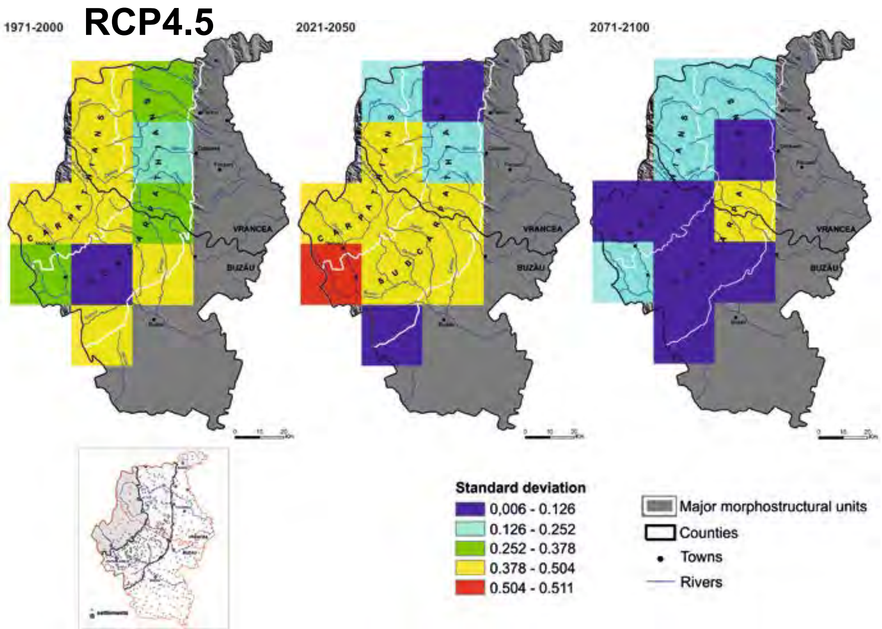


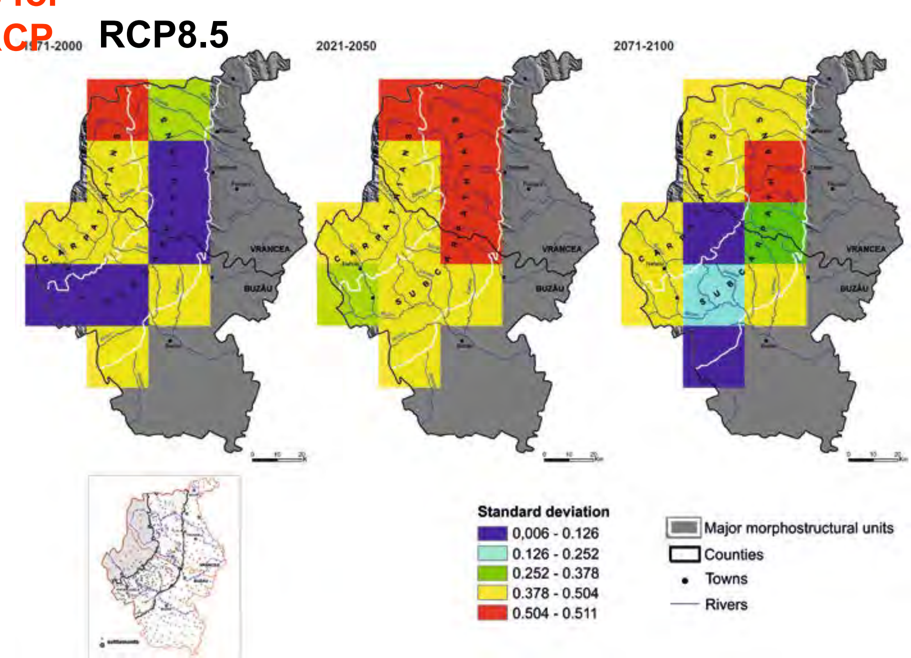


Mean hazard class

and

hazard uncertainty across models for each RCP

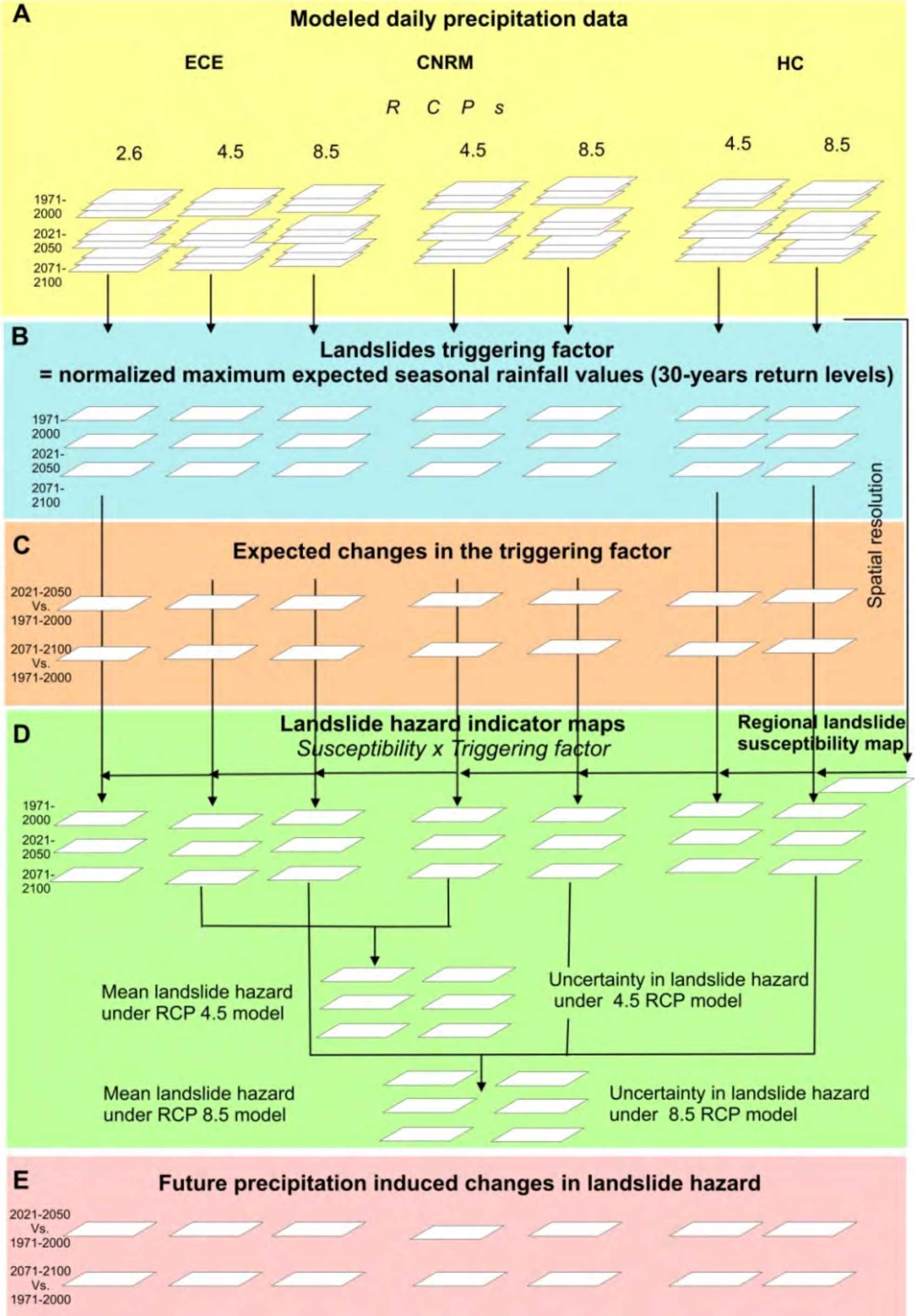




ECLISE

QUICK OVERVIEW

Flowchart methodology for the assessment of the effects of projected precipitation change on landslide hazard



CONCLUSIONS AND PERSPECTIVES

• **Methodological framework** to estimate possible changing patterns of landslide hazard and risk as a response to climate change scenarios

• Proposed approach is capable of being used to assess the impacts of climate change on landslide hazard and risk. The downscaled data has still too many uncertanties to be used for predictive purpose. Only preliminary results:

• **Predicted Changes**:

- **RCP 45: intensification of the triggering factor in the first future horizon**; pronounced **hazard increase for the first future horizon**;
- **RCP 85**: ECE and CNRM models show a **decrease of the triggering factor in the first future period** followed by an increase which brings the **situation in the far future close to the present state**; **overall reduction in hazard in the near future**, **but a return to the present situation in the far future**,
- Changes in hazard do not always reflect changes in the triggering factor (since the expert matrix controls the class changes)

• **Uncertainties** (std. dev.) across models within each RCP are **mainly due to the HC model** which outputs rather different extreme seasonal precipitations than ECE and CNRM:

- **highest uncertainties for RCP 85 (near future),** in the NE;
- **lowest uncertainties for RCP 45 (far future) because all models are consistent in predicting higher extreme values compared to the local normal and therefore higher hazard**

CONCLUSIONS AND PERSPECTIVES

- **Scale** (small, coarse resolution: 25 km)

- **Intended improvements**:
  - Perform **correction with observation data**
  - For increasing scale (finer resolution) application: **further downscaling** on the modeled data for a intermediate level hazard and risk zoning (through quantitative methods)
  - Include **other global changes**, beside climate changes, like: land-use, demographical, economical etc. changes
  - More attention to assess uncertainties which could propagate throughout the analysis (susceptibility analysis, identifying 30-y return levels, combining maps containing different detail, applying classifications at each stage for further use in the analysis, expert-based semi-quantitative methods prone to bias) → how to better incorporate them into communicated results?

- **Alternative quantitative approach**:
  - **1 recent seasonal regional landslide event (magnitude = # landslides/ land unit/ season) = scenario**
  - Collecting a database on municipality level damages /type of element at risk, from that scenario
  - Monetary valuation of the elements at risk at municipality level → monetary consequences at municipality level
  - Assessing vulnerability by comparing loss due to the event / value of the element (0-1) (Remondo et al., 2008)
  - finding rainfall amount-duration thresholds **for the same landslide event** → exceedance probability for each climate model data series