



Hydrogeological processes and geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystem

Authors and affiliation:
see list of authors

E-mail of lead author:
georgina.arno@icgc.cat
stefan.broda@bgr.de

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Deliverable D.7-3

Results of the vulnerability assessment of the upper aquifer to pollution at pilot areas scale: statistics and sensitivity analysis

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LIST OF AUTHORS

Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) – German Federal Institute for Geosciences and Natural Resources

Broda, S., Duscher, K., Günther, A., Reichling, J.

Bureau de Recherches Géologiques et Minières (BRGM) – French Geological Survey

Schomburgk, S.

Geologische Bundesanstalt (GBA) – Geological Survey of Austria

Schubert, G., Uhmman, A., Bottig, M., Elster, D., Berka, R.

Geološki Zavod Slovenije (GeoZS) – Geological Survey of Slovenia

Cerar, S., Meglič, P.

De Nationale Geologische Undersøgelser for Danmark og Grønland (GEUS) – Geological Survey of Denmark and Greenland

Voutchkova, D., Schullehner, J., Hansen, B.

Geological Survey of Ireland (GSI)

Hickey, C., Hunter Williams, T., Bishop, H.

Geologian Tutkimuskeskus (GTK) – Geological Survey of Finland

Luoma, S., Ikonen, J.

Hellenic Survey of Geology & Mineral Exploration (HSGME)

Kontodimos, K., Lappas, I.

Institut Cartogràfic i Geològic de Catalunya (ICGC) – Cartographic and Geological Institute of Catalonia

Arnó, G., Conesa, A., Herms, J.I.

Instituto Geológico y Minero de España (IGME) – Geological Survey of Spain

Baena-Ruiz, L., Pulido-Velázquez, D.P.

Institutul Geologic al României (IGR) – Geological Institute of Romania

Persa, D., Mercan, A.

Landesamt für Bergbau, Geologie und Rohstoffe Brandenburg (LBGR) – Brandenburg State Office for Mining, Geology and Raw Materials

Janetz, S.

Lietuvos Geologijos Tarnyba prie Aplinkos Ministerijos (LGT)

Arustienė, J.

Magyar Bányászati és Földtani Szolgálat (MBFSZ) – Mining and Geological Survey of Hungary

Gál, N.E.



**Państwowy Instytut Geologiczny - Państwowy Instytut Badawczy (PIG-PIB) – Polish Geological
Institute - National Research Institute**
Nidental, M., Jarmułowicz-Siekiera, M.



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1 INTRODUCTION

This deliverable is part of work package (WP) 7 in the overall project HOVER - Hydrogeological processes and Geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystems.

It has been promoted by the ERA-NET GeoERA (Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe). In this European project, led by the German Geological Survey (BGR), 16 geological services from 13 different countries participate. It focuses on the harmonized vulnerability to pollution assessment and mapping of the upper aquifer at both pan-European scale and national/cross-border and regional scale in 12 pilot areas.

Deliverable D.7-3 is the third report of the following four HOVER-WP7 deliverables:

- Deliverable D.7-1. Comparison of internationally commonly applied index methodologies for assessing the vulnerability of the upper aquifer to pollution. (Broda et al., 2019).
- Deliverable D.7-2. Compilation of the examination results of the data sets of input data for the respective methodologies assessing vulnerability of the upper aquifer to pollution. (Broda et al., 2020).
- Deliverable D.7-3. Results of the vulnerability assessment of the upper aquifer to pollution at pilot areas scale: statistics and sensitivity analysis (Arnó et al., 2021).
- Deliverable D.7-4. Delivering of cross sections and maps of extend of selected aquifers in specific national pilot areas. (Pulido et al., 2020).

Deliverable D.7-3 describes the workflow and methodologies used to first obtain the final DRASTIC and COP vulnerability indexes which are comparable between pilots and also with the pan-European DRASTIC map and second to analyze, from a numerical point of view, the results by computing main statistical parameters and by performing a sensitivity analysis of the 7 DRASTIC parameters indexes.

The sources of the input data used for the vulnerability assessment in the individual pilot areas are documented in deliverable D.7-2.

This D.7-3 PDF report is complemented and needs to be visualized jointly with the dashboard report made in PowerBI application which is available [here](#). It permits to create interactive visualizations and filters which allow end users to create their own reports and visualizations.

Appendix A includes the final DRASTIC and COP indexes assessments (A1 for DRASTIC and A2 for COP) and Appendix B shows the spatial distributions of the sensitivity and the effective weight indexes computed. Appendix C shows the screenshots of the D.7-3 powerBI dashboard report.



2 WORKFLOW AND METHODOLOGIES

In a previous step (Broda et al., 2019) two index methods were identified from a set of proposed approaches to evaluate the intrinsic groundwater vulnerability. The DRASTIC method (Aller et al., 1987) was used for the continent-wide evaluation and for non-karstic regions in the pilot areas. In those parts of the pilot regions with karstic features dominating groundwater flow, the COP approach (Vías et al., 2006) was applied.

For the application of both methods a set of spatially distributed input data were required. Documentation of the input data/input layers that were used for the pan-European and the pilot scale vulnerability assessments and pilot areas geological and hydrogeological descriptions are included in Broda et al. (2020).

As input DRASTIC and COP layers were prepared based on the same ratings and weights of source datasets according to given classification schemes, DRASTIC and COP indexes values were calculated obtaining comparable results between each pilot and also with the pan-EU DRASTIC map.

The vulnerability maps obtained are important tools for groundwater management, through which specific high vulnerability areas can be identified and preventive or corrective actions can be taken at different scales for their protection. In HOVER WP7 pilot area scales range from 1:10.000 up to 1:250.000.

At this point DRASTIC and COP vulnerability assessments maps of the 12 pilot areas were analyzed from a statistical point of view. Furthermore, for the vulnerability DRASTIC assessment, a map single parameter removal sensitivity analysis has also been performed to study the contribution of each individual variables.

It should be pointed out that the two intrinsic vulnerability assessment methods only consider the natural intrinsic factors and are independent to the source of contamination. For this reason, the vulnerability maps depend mainly on the hydrodynamic characteristics of each region and it is not easy to establish a validation method that considers the specificities of each site.

Some validation tests have been carried out in the framework of HOVER WP7 project considering the land use spatial distribution maps of some pilots and nitrate concentrations data. Correlation obtained with the vulnerability assessment maps (DRASTIC and COP) was very low. Contaminant loading for many years (in some areas more than 30) and local and regional hydrogeological conditions determine that the actual distribution of nitrates concentrations in groundwater is related with many other processes.

2.1 *DRASTIC and COP vulnerability index assessment*

After obtaining the input data, DRASTIC and COP vulnerability indexes were calculated according to the two original methods selected (Broda et al., 2020) by geoprocessing data based on GIS techniques.

DRASTIC vulnerability index (DVI) is an index methodology based on the natural characteristics of media. It contemplates seven different parameters: depth to groundwater level (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of the vadose zone (I), hydraulic conductivity of the aquifer (C). Every parameter has a weight and a rating depending on their relative impact to potential contamination as follows:



$$DVI = 5D \times 4R \times 3A \times 2S \times 1T \times 5I \times 3C$$

The COP method is a parametric model specifically developed for karstic systems that takes into account the kind of preferent flow, concentrated or diffusive (C factor), the unsaturated zone of the overlying layers (O factor) and the different climatic conditions (Precipitation, P factor).

To obtain comparable results between pilot areas, DRASTIC index spatial representation considers five classes which are the maximum value of DRASTIC methodology (230) minus the minimum value of DRASTIC methodology (23) divided by 5. For the COP index, the original method (Vías et al., 2006), also five classes of vulnerability are proposed (see Figure 1).

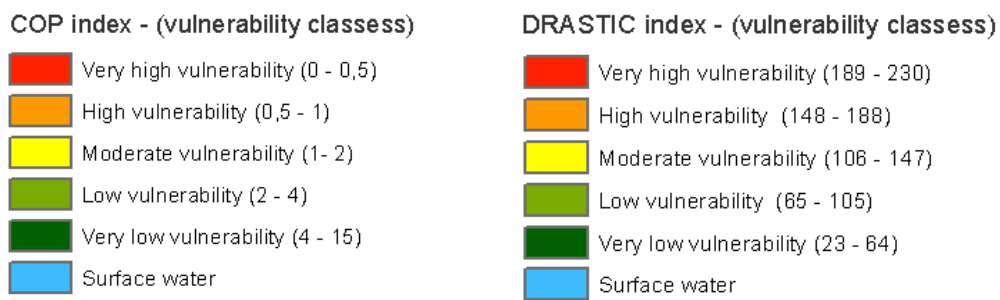


Figure 1: Classification of vulnerability indexes for the DRASTIC and COP methods.

The results are shown in Appendix A1 (for DRASTIC) and A2 (for COP). They are also available at the [EGDI platform](#).

2.2 Statistical analysis of DRASTIC and COP results

To get a general overview of the vulnerability assessment made in each pilot and to have numerical comparable results between them, a GIS computation was used to obtain the mean, median, minimum (Min), maximum (Max) values, the standard deviation (σ_v) and the variation coefficient (C_v) for each pilot and for both the final vulnerability DRASTIC and COP indexes. Statistics were also computed for each input parameter indexes.

DRASTIC and COP index (V)	DRASTIC and COP input parameters indexes (P)
mean (\bar{V})	mean (\bar{P})
median (\tilde{V})	median (\tilde{P})
minimum (V_{\min})	minimum (P_{\min})
maximum (V_{\max})	maximum (P_{\max})
standard deviation (σ_v)	standard deviation (σ_p)
variation coefficient (VC_v)	variation coefficient (PC_v)

Figure 2: Main statistical parameters calculated for the vulnerability indexes (DRASTIC and COP methods) and also for the corresponding parameters indexes of each method.



The variation coefficient (Cv) is defined as:

$$VC_v = \left(\frac{\sigma_v}{\bar{V}} \right) 100 (\%) \quad \text{and} \quad PC_v = \left(\frac{\sigma_p}{\bar{P}} \right) 100 (\%)$$

Where \bar{V} is the mean value of the vulnerability index and \bar{P} the mean value of the parameter index considered.

Cv indicates, in a relative way, the degree of values variability so for $Cv < 80\%$ the dataset could be classified as homogeneous and the mean values representative while for $Cv > 80\%$ mean values could be considered not representative enough as dataset is classified as heterogeneous. The higher variability of the parameters implies a greater contribution toward the variation of the vulnerability index and reverse.

Table 1: Main statistics of the DRASTIC and COP vulnerability indexes for each pilot.

Pilot area	Country	Participant	Area (km ²)	Cell size (m)	Scale	Parameter	Mean	STD	Cv (%)
Atalanti alluvial aquifer	Greece	HSGME	54	50	1:10K	DRASTIC	112	14	12
Boyne	Ireland	GSI	2.627	10	-	DRASTIC	125	26	21
Catalunya	Spain	ICGC	32.112	50	1:100K	DRASTIC	99	30	30
						COP	2	2	81
Cobadin-Mangalia	Romania	IGR	2.192	50	1:200K	DRASTIC	100	16	16
						COP	3	1	39
Finland	Finland	GTK	338.440	200	1:200K	DRASTIC	124	24	19
Lower Oder/Odra river German part	Germany	BGR-LBGR	4.553	200	1:250K	DRASTIC	120	23	19
Lower Oder/Odra river Polish part	Poland	PIG-PIB	2.821	200	1:250K	DRASTIC	127	34	27
Rockingham	Ireland	GSI	15	10	-	COP	1	1	115
						DRASTIC	130	31	23
Slovenia	Slovenia	GeoZS	20.273	100	1:250K	COP	1	1	105
						DRASTIC	139	15	11
Tønder	Denmark	GEUS	293	100	1:25K	DRASTIC	139	15	11
Traun-Enns-Platte	Austria	GBA	810	100	1:100K	DRASTIC	135	30	22
						DRASTIC	103	22	22
Upper Guadiana Basin	Spain	IGME	14.093	100	1:50K	COP	3	2	57
						DRASTIC	103	22	22

2.3 Map single-parameter removal sensitivity analysis for the DRASTIC method

Input layers of each pilot area have been generated according to available and/or accessible data sources. This suggests the results analysis or interpretation that can be done for a region or pilot area cannot be extrapolate to other areas as they have different hydrogeological conditions and source data.

In order to establish the relationship between the vulnerability obtained and the parameters considered a map single-parameter removal sensitivity analysis was performed. The method, based on Lodwick et al. (1990), Napolitano et al. (1996) and Adeyinka (2020), was developed for weighted sum intersection overlays and can be easily applied to the DRASTIC expression (not valid for the COP method).



This sensitivity analysis allows to study the contribution of individual variables (input parameters) one by one, on the resultant output of an analytical model. Two parameters were calculated:

The sensitivity index (S) for each parameter: it is usually used to determine if all the parameters contribute equally and sometimes it is analysed jointly with the Pairwise correlation matrix between the analysed parameters (see Figure 3 *Figure 1*):

- a) The effective parameter weight (W) which allows to compare the real weight that each parameter had in each pilot area with the theoretical weight assigned by the DRASTIC method.

Sensitivity parameter index (S)	Effective parameter weight (W)
Identifies the sensitivity of the vulnerability towards removing one or more maps from the vulnerability analysis. It is computed as follows:	Contribution of each parameter in the final DRASTIC vulnerability index (effective weight). It is computed as follows:
$S = \left(\frac{ V - V' }{V} \right) \times 100$	$W = 100P_r P_w / V$
S; sensitivity index measure expressed as variation index (for each parameter) V and V'; unperturbed and perturbed vulnerability N and n; number of parameters used to compute V and V' respectively	W; effective weight of each parameter P _r and P _w ; ratings and weight values of each parameter respectively V; the overall vulnerability index

Figure 3: Sensitivity analysis index (S) and effective parameter weight (W) definitions and formulas to perform the map single-parameter removal sensitivity analysis.

At the end 7 maps (one by each DRASTIC parameter) and their main statistics were computed for the “S” index (Sd, Sr, Sa, Ss, St, Si, Sc) and 7 maps (one by each DRASTIC parameter) and their main statistics were computed for the “W” index (Wd, Wr, Wa, Ws, Wt, Wi, Wc).

To complement the statistical analysis, pairwise correlations between the 7 parameters for each pilot were calculated. The correlation matrix for each pilot area (square table that shows the correlation coefficients between several pairwise combination of variables) are included in the PowerBI report and show the relationship between the seven DRASTIC parameters between each other. Values meaning are:

- -1 indicates a perfectly negative linear correlation between two variables.
- 0 indicates no linear correlation between two variables.
- 1 indicates a perfectly positive linear correlation between two variables.
- NaN values correspond to correlations which one or both variables are constant within the pilot area.

The further away the correlation coefficient is from zero, the stronger the relationship between the two variables.

3 RESULTS

Once the analysis has been completed, all the information acquired has been processed with the PowerBI Desktop Application, which enables data for a further exploration and visualization.

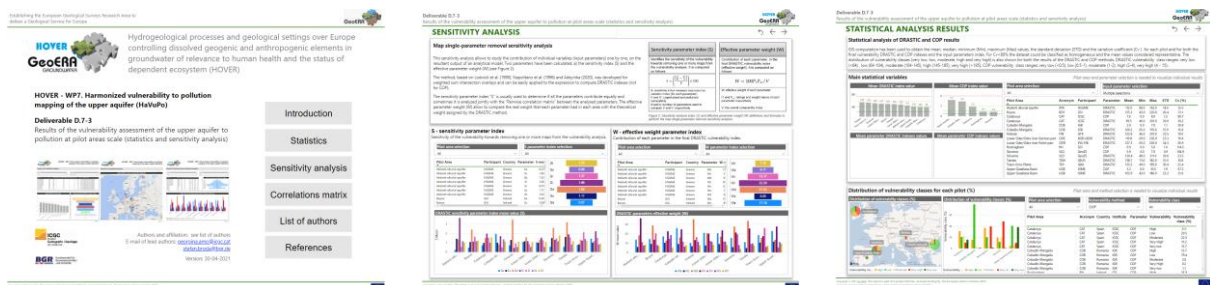


Figure 4: Screenshots of the PowerBI report of D.7-3.

Users can use interactive graphs, filters and maps to visualize local or global results and to create an overall or detailed report. This way, the application turns into a management tool of the project information which can be used for decision-making, both at environmental protection actions and the improvement / optimization of input data.

It contains six pages or dashboards. The first one “Get started” has an interactive index to move within the PowerBI report, and the second one “Introduction” describes the framework and main goals of HOVER - WP7 project. The “Statistical analysis”, “Sensitivity analysis” and the “Pairwise correlation matrix” pages summarize the obtained results from a numerical point of view. Finally, the “List of authors” and “References” are listed in the PowerBI.

For one or more pilot areas the distribution of vulnerability classes (%) and the mean, minimum, maximum, the standard deviation and the variation coefficient values of the vulnerability indexes and parameters considered can be visualized.

The Sensitivity analysis jointly with the Pairwise correlation matrix gives a general idea of which are the most significant parameters in each pilot depending on the hydrogeological settings and the available input data. Thus, the trend of S and W parameter indexes (from the highest to the lowest values) are different from one pilot to another so conclusions have to be drawn from a detailed hydrogeological knowledge of each site. For instance, the D (depth to water table) could have a great impact on the final DVI indicating that having available groundwater level measurements could be critical to enhance the results or to necessary to take improvement actions in critical areas / subareas or to concentrate on obtaining higher quality information about some characteristic or parameter of the system. In summary, it gives an idea about where to focus future efforts in a more efficient way.

The effective parameter element weight (W) informs about the real weight of each of the DRASTIC parameters which can be compared with the theoretical weight assigned by the DRASTIC method.

It should be noted that the effective weight obtained vary according to the pilot area. The reason is that the weight of them dependent not only on the value of the parameter but also on the value of the rest of them (which can be different in each context or area).



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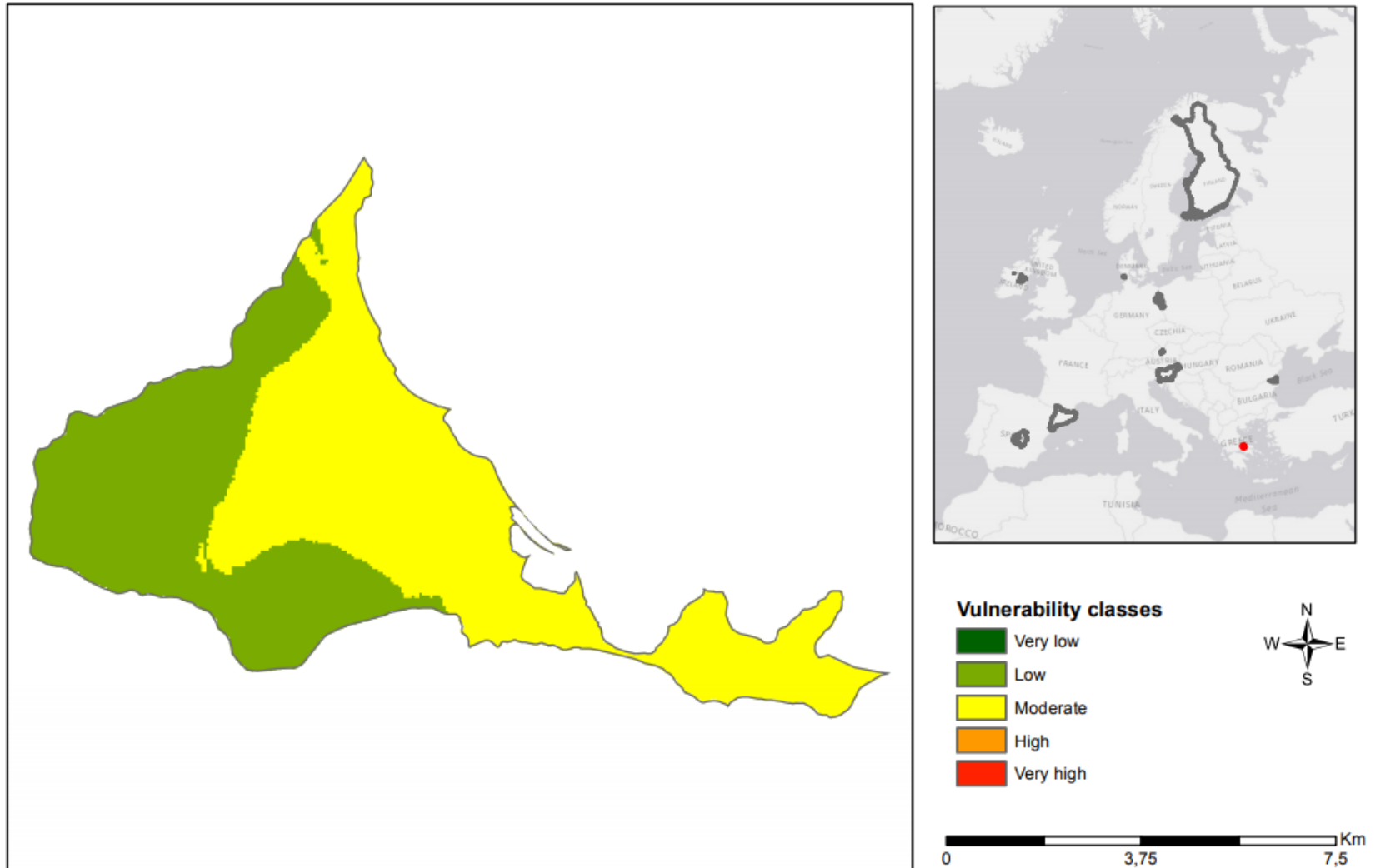
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<https://doi.org/10.1007/s10040-006-0023-6>



APPENDIX A1: VULNERABILITY INDEXES .DRASTIC ASSESSMENTS

Pilot area Atalanti alluvial aquifer (Greece) - HSGME

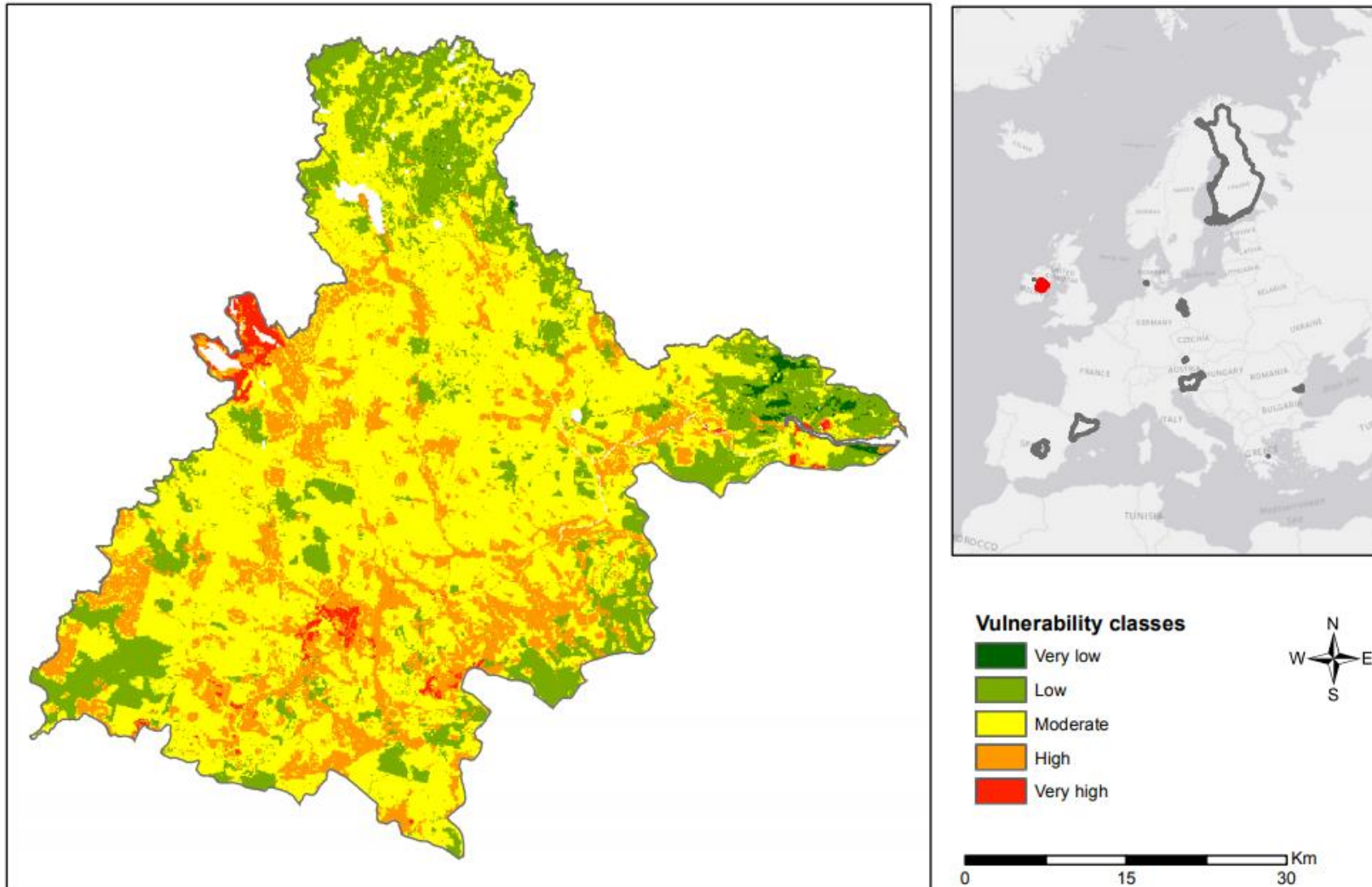
DRASTIC vulnerability index spatial distribution





Pilot area Boyne (Ireland) - GSI

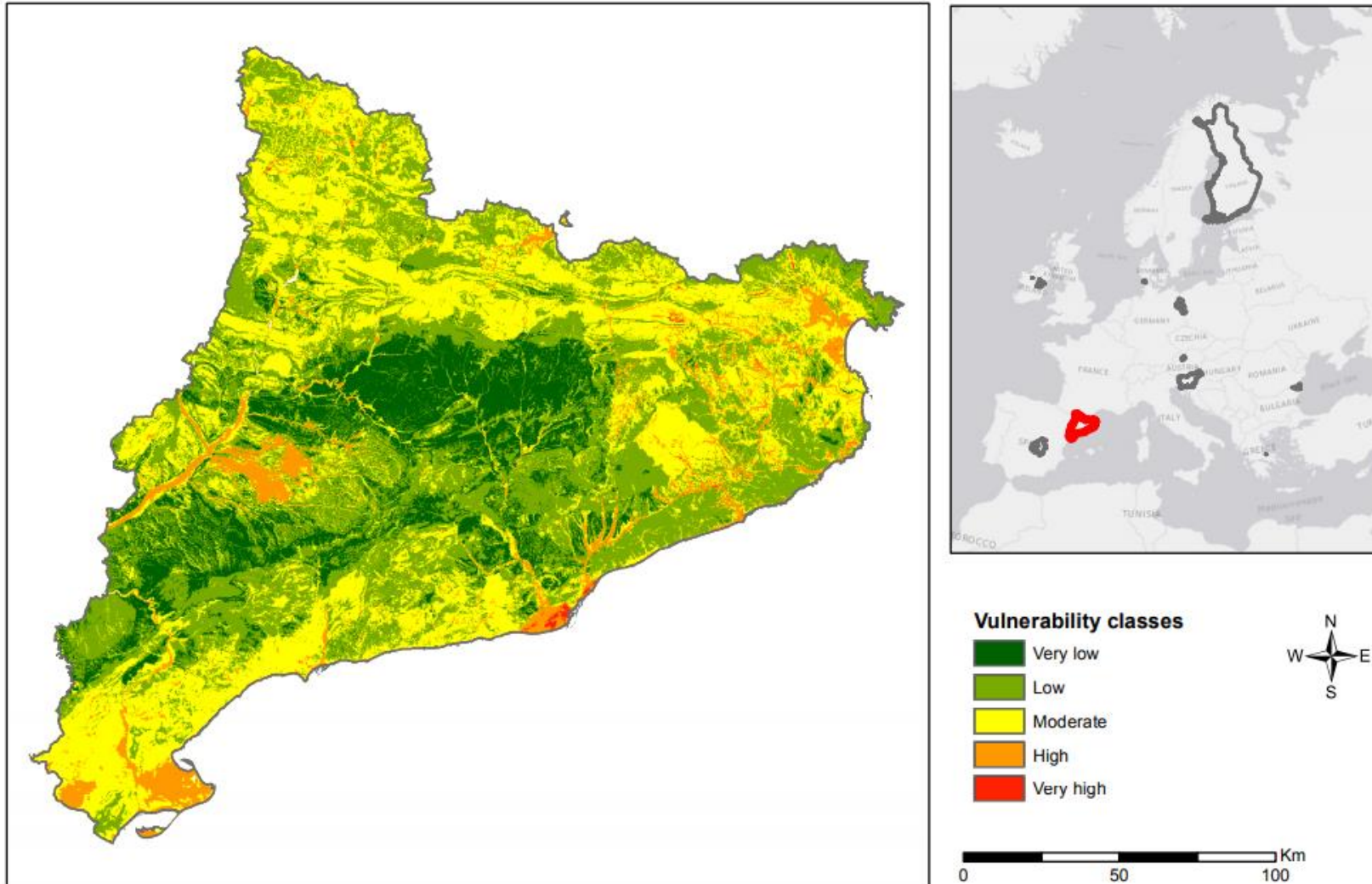
DRASTIC vulnerability index spatial distribution





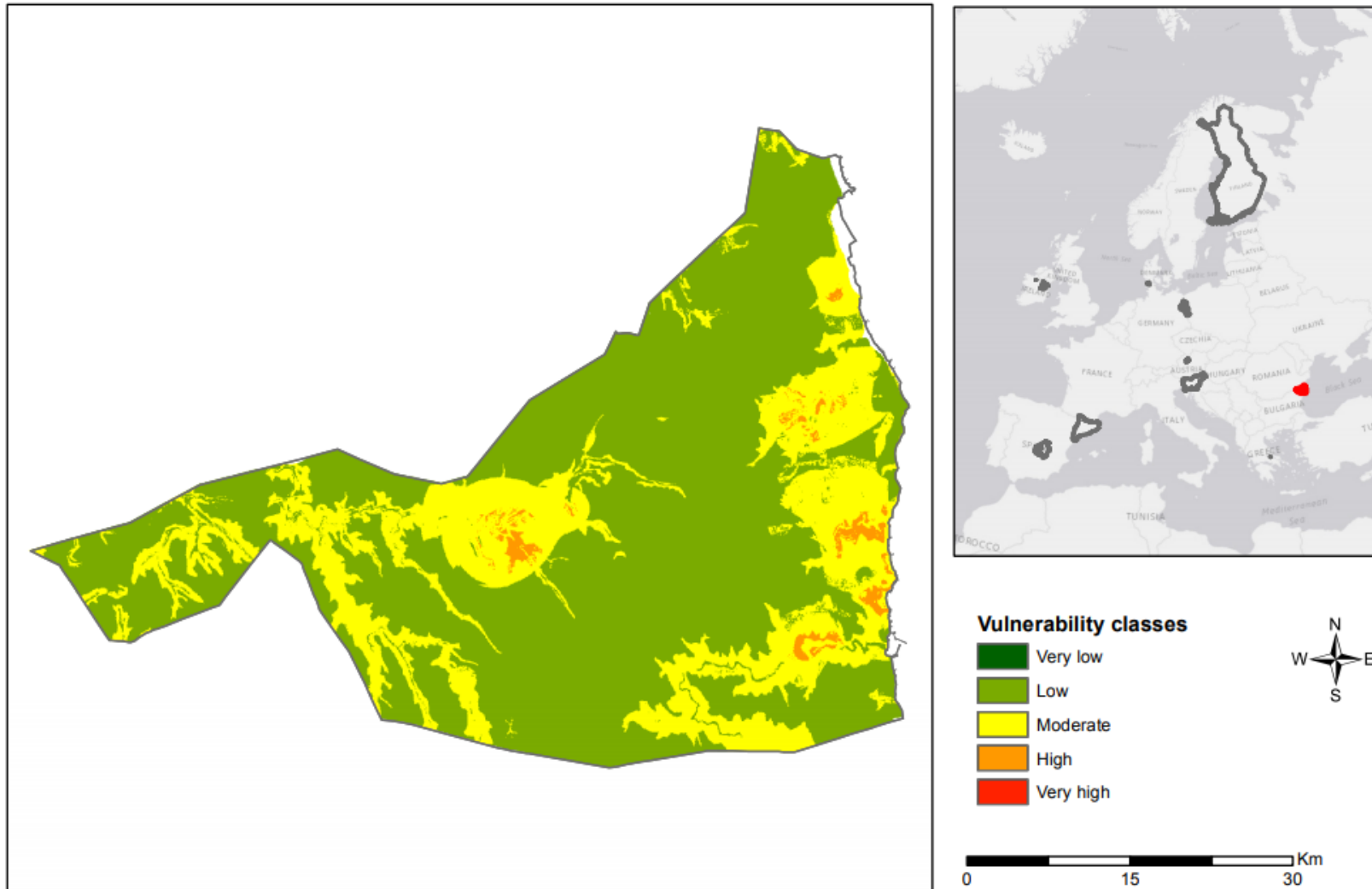
Pilot area Catalonia (Spain) - ICGC

DRASTIC vulnerability index spatial distribution





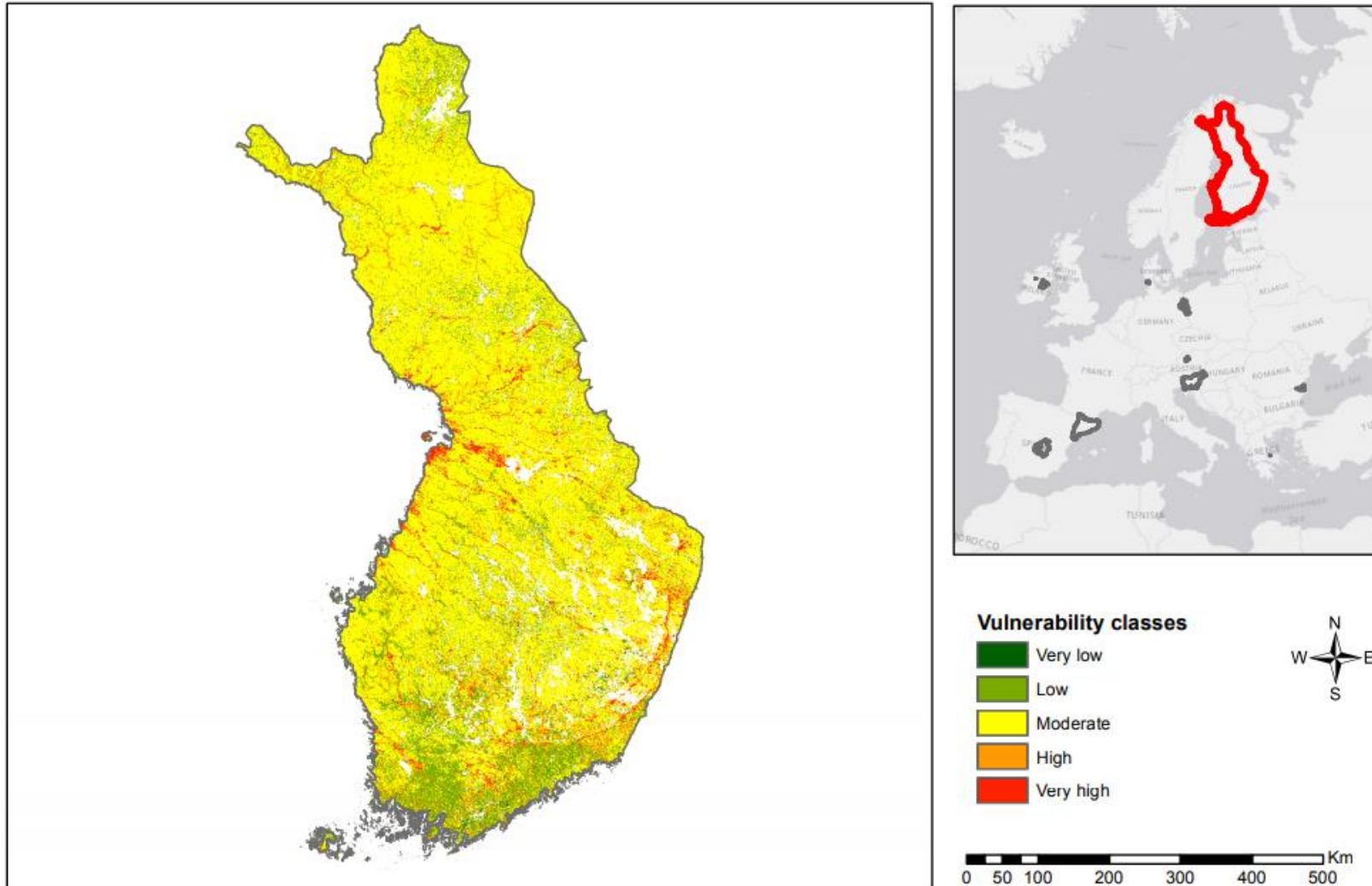
Pilot area Cobadin-Mangalia (Romania) - IGR
DRASTIC vulnerability index spatial distribution





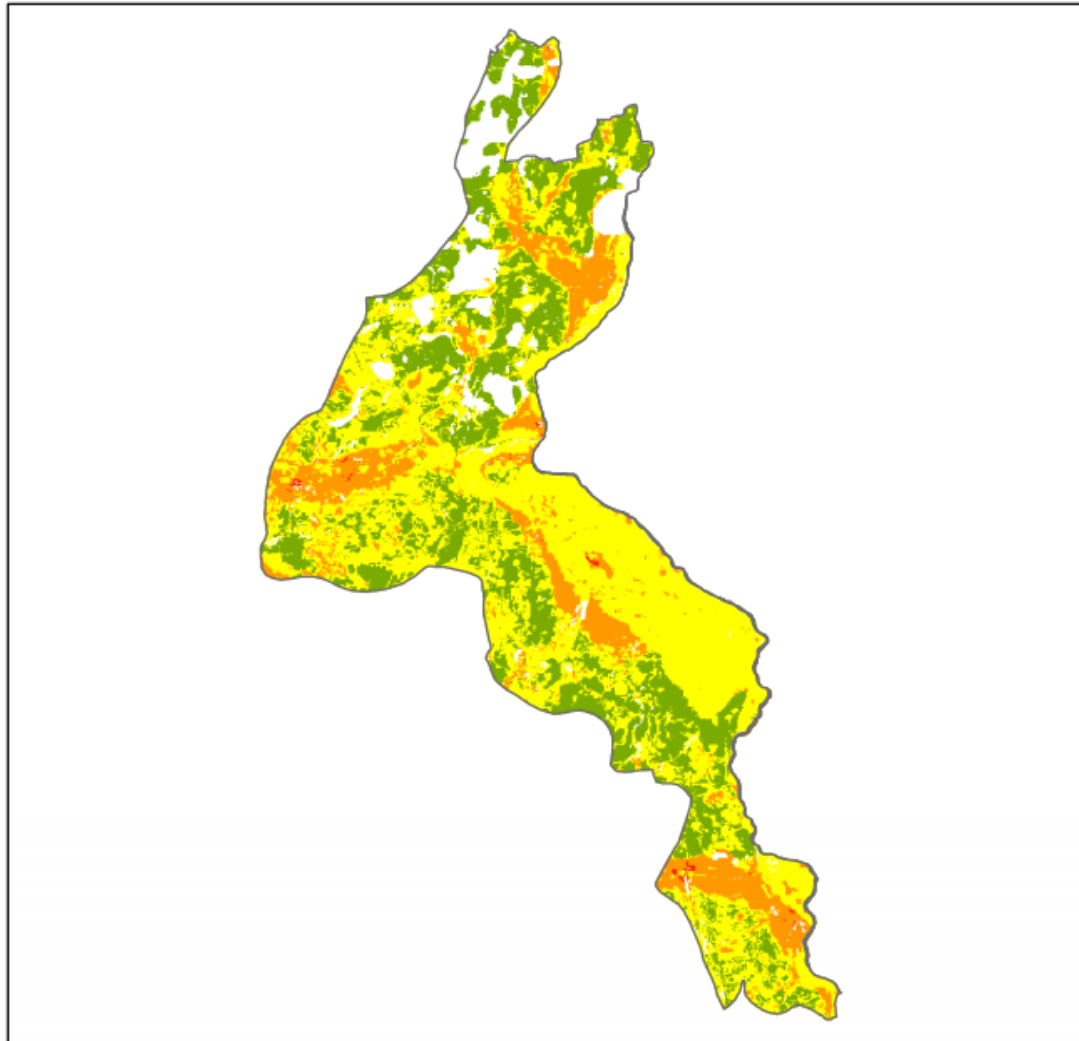
Pilot area Finland (Finland) – GTK

DRASTIC vulnerability index spatial distribution



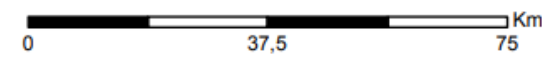


**Pilot area Middle and Lower Oder/Odra river (German part) – PGI/LBGR/BGR
DRASTIC vulnerability index spatial distribution**



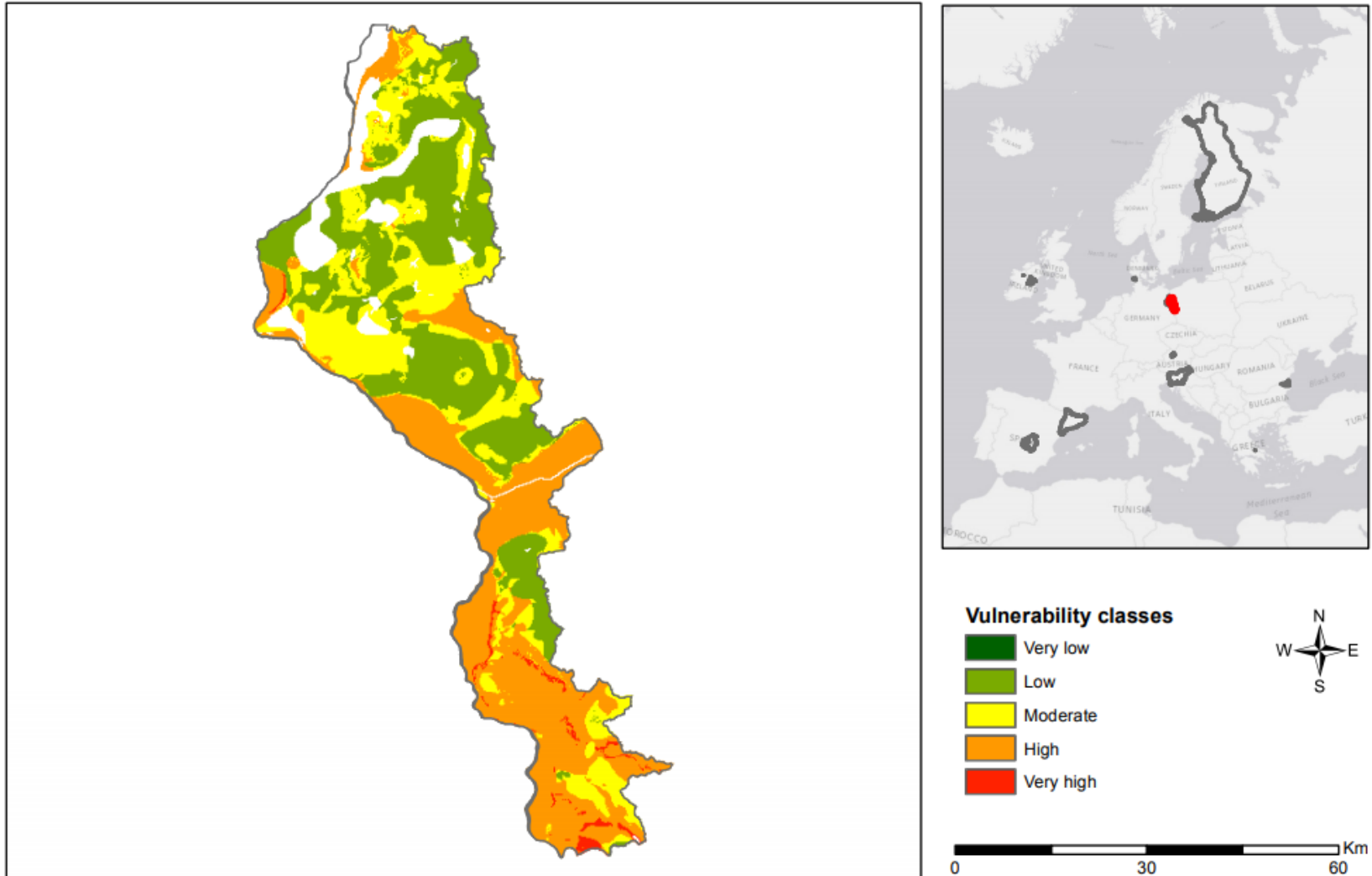
Vulnerability classes

- Very low
- Low
- Moderate
- High
- Very high





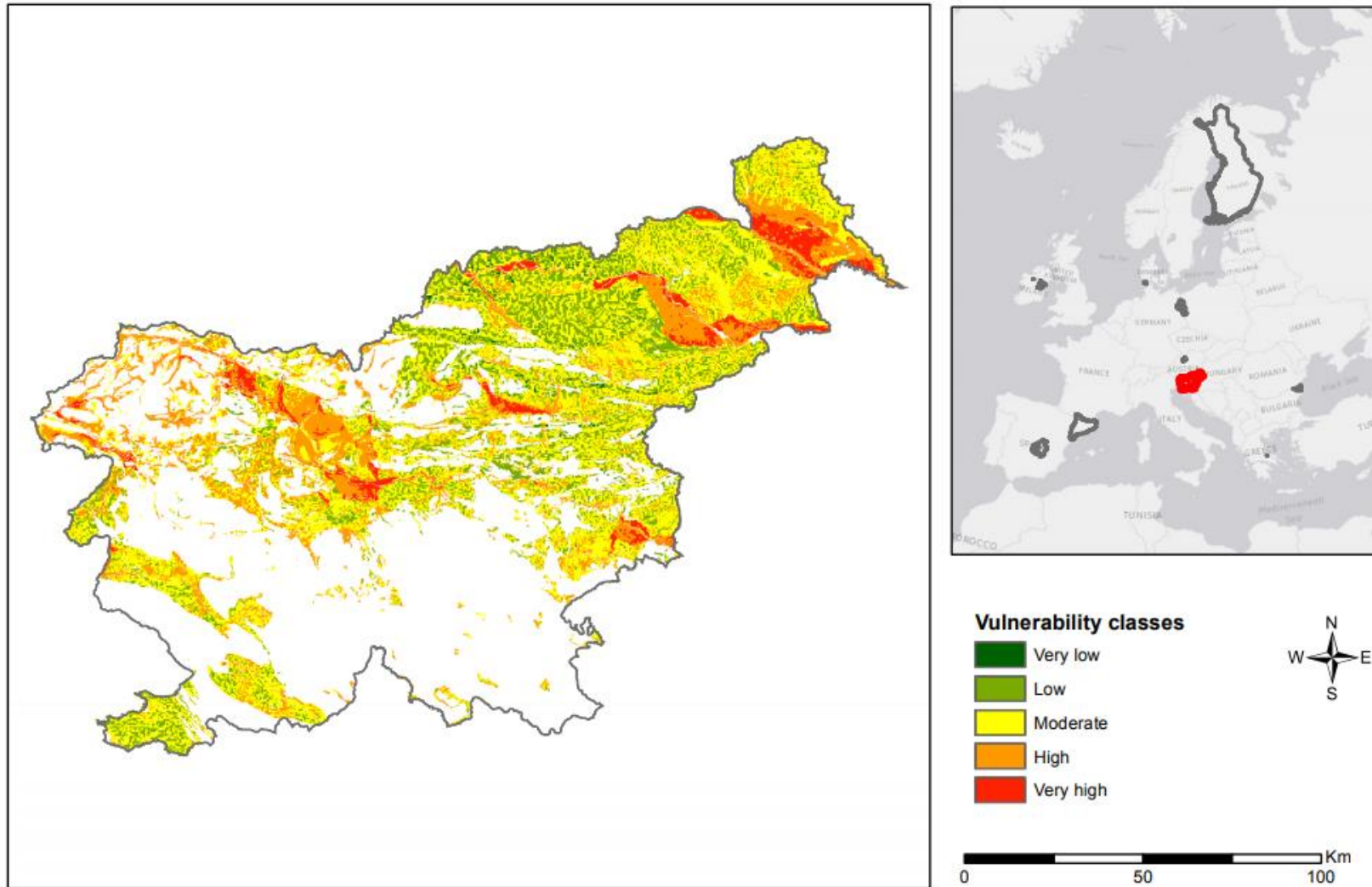
Pilot area Middle and Lower Oder/Odra river (Polish part) – PGI/LBGR/BGR
DRASTIC vulnerability index spatial distribution





Pilot area Slovenia (Slovenia) – GeoZS

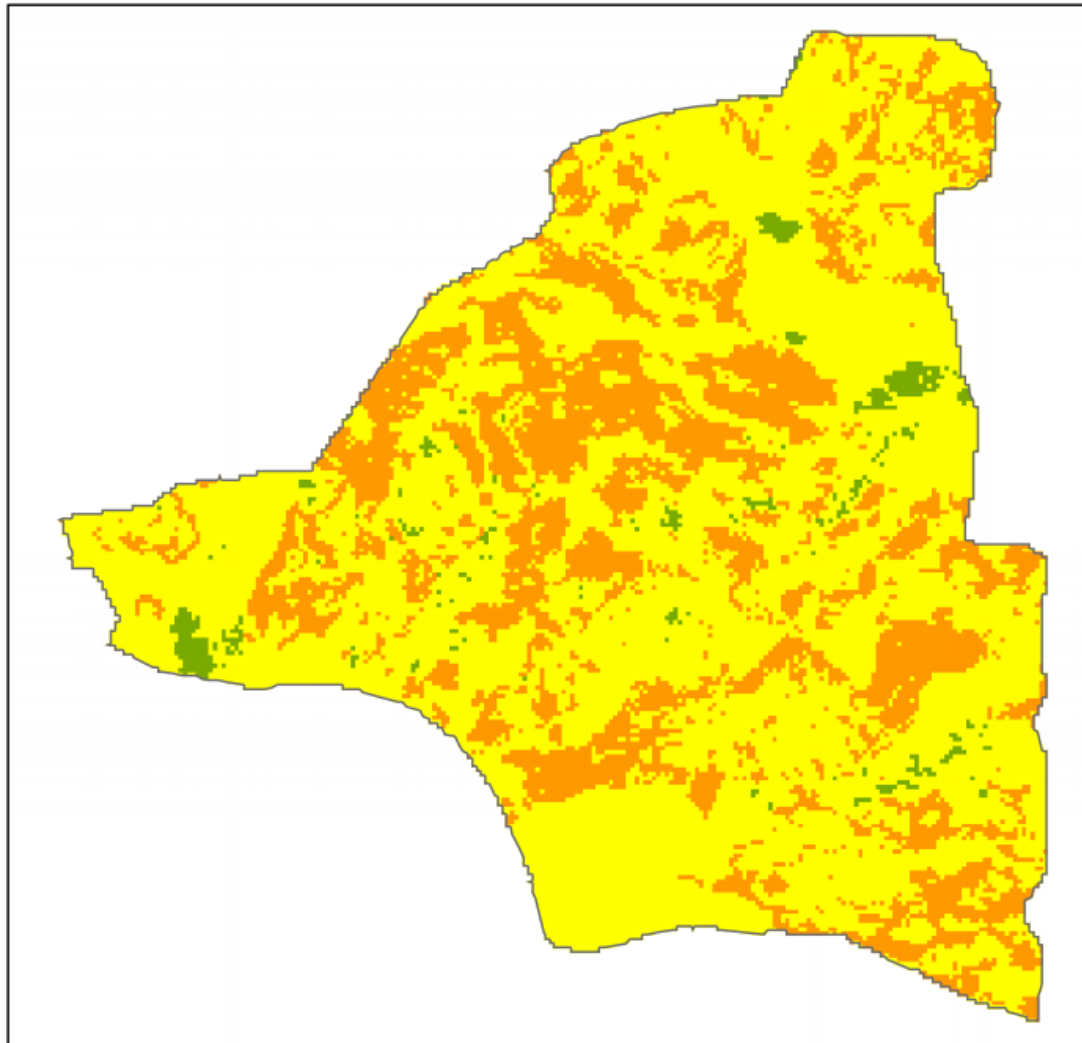
DRASTIC vulnerability index spatial distribution





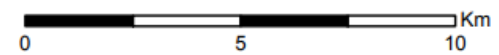
Pilot area Tønder (Denmark) – GEUS

DRASTIC vulnerability index spatial distribution



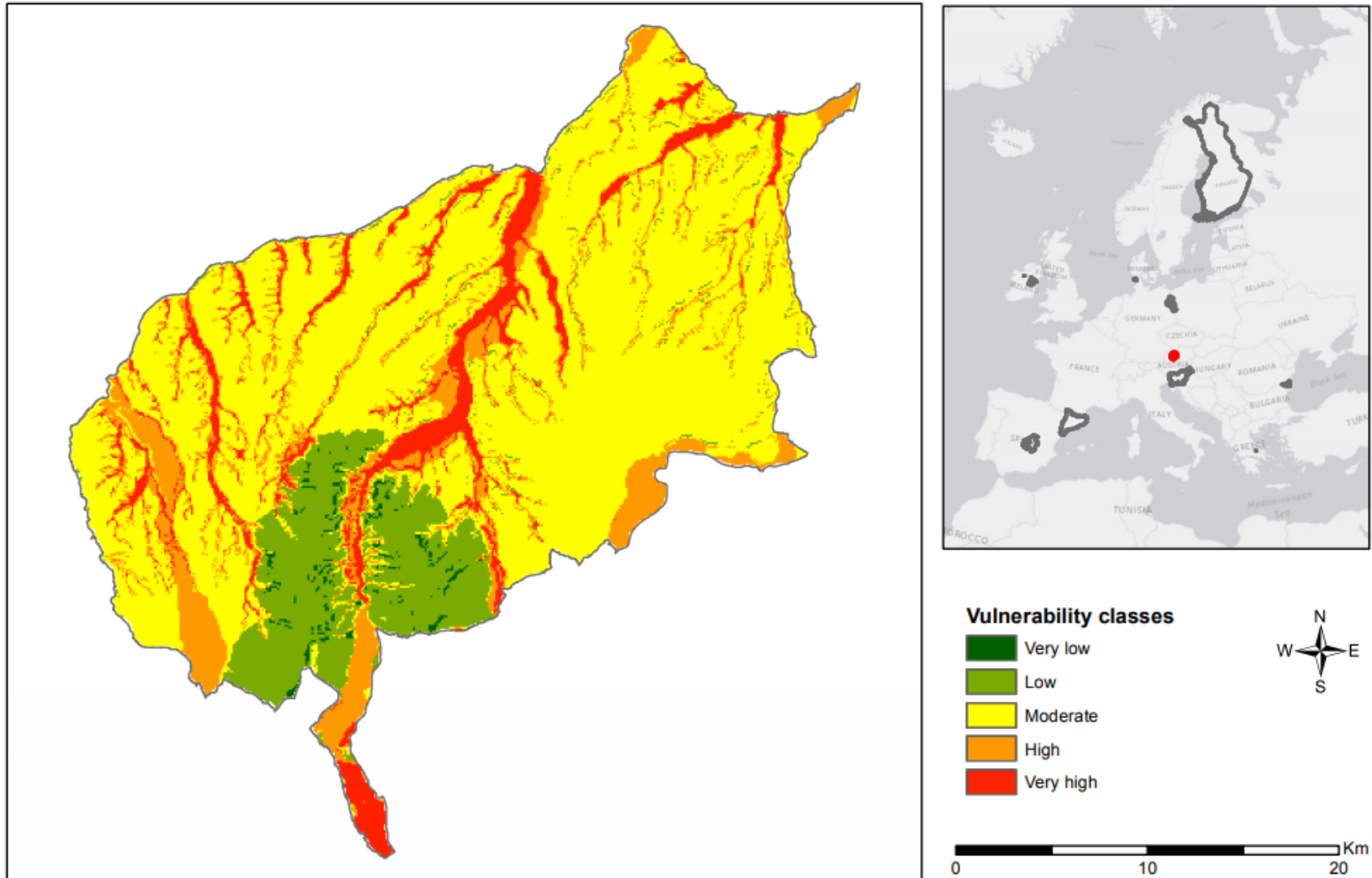
Vulnerability classes

- Very low
- Low
- Moderate
- High
- Very high



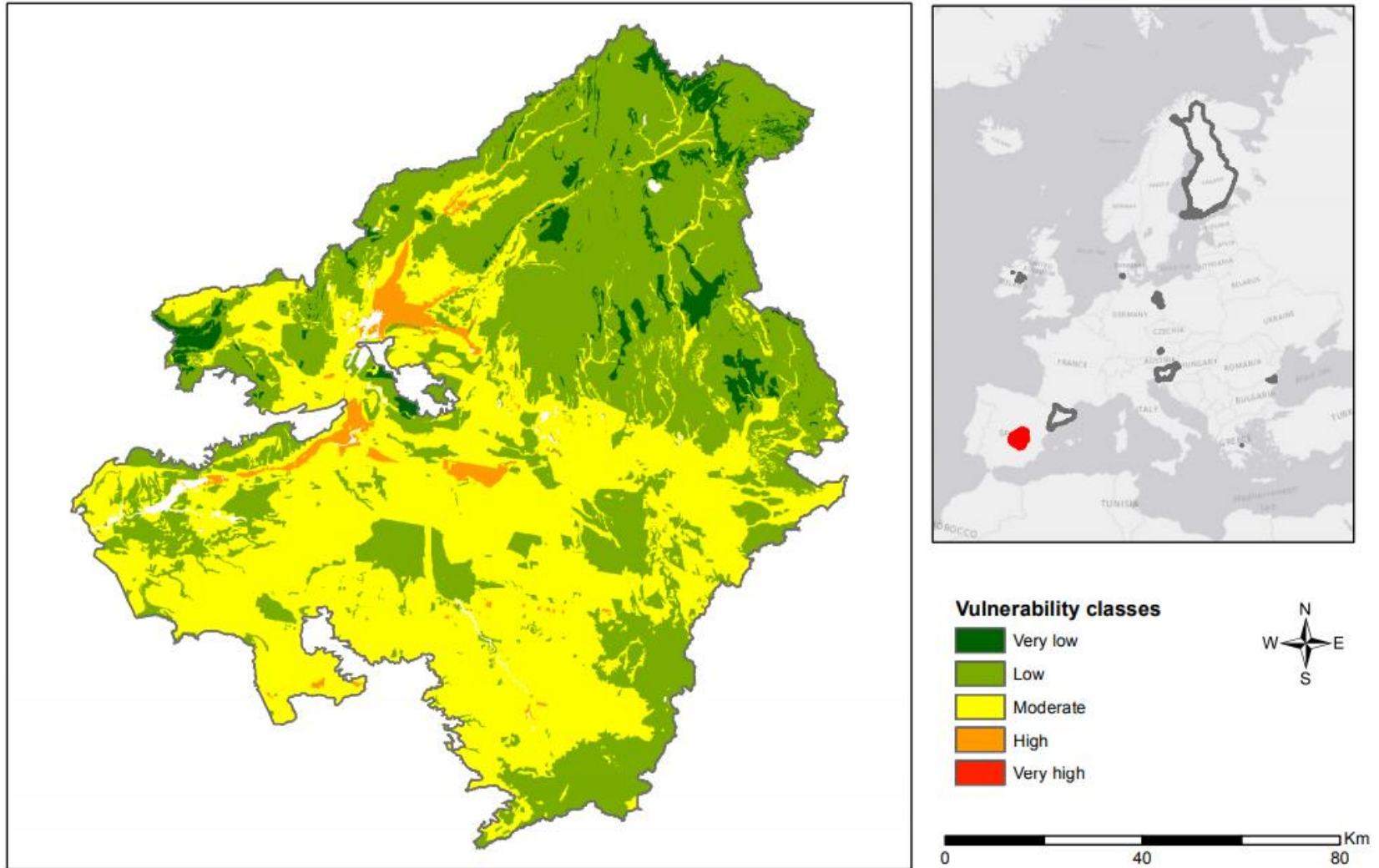


Pilot area Traun-Enns-Platte (Austria) – GBA
DRASTIC vulnerability index spatial distribution





Pilot area Upper Guadiana Basin (Spain) – IGME
DRASTIC vulnerability index spatial distribution

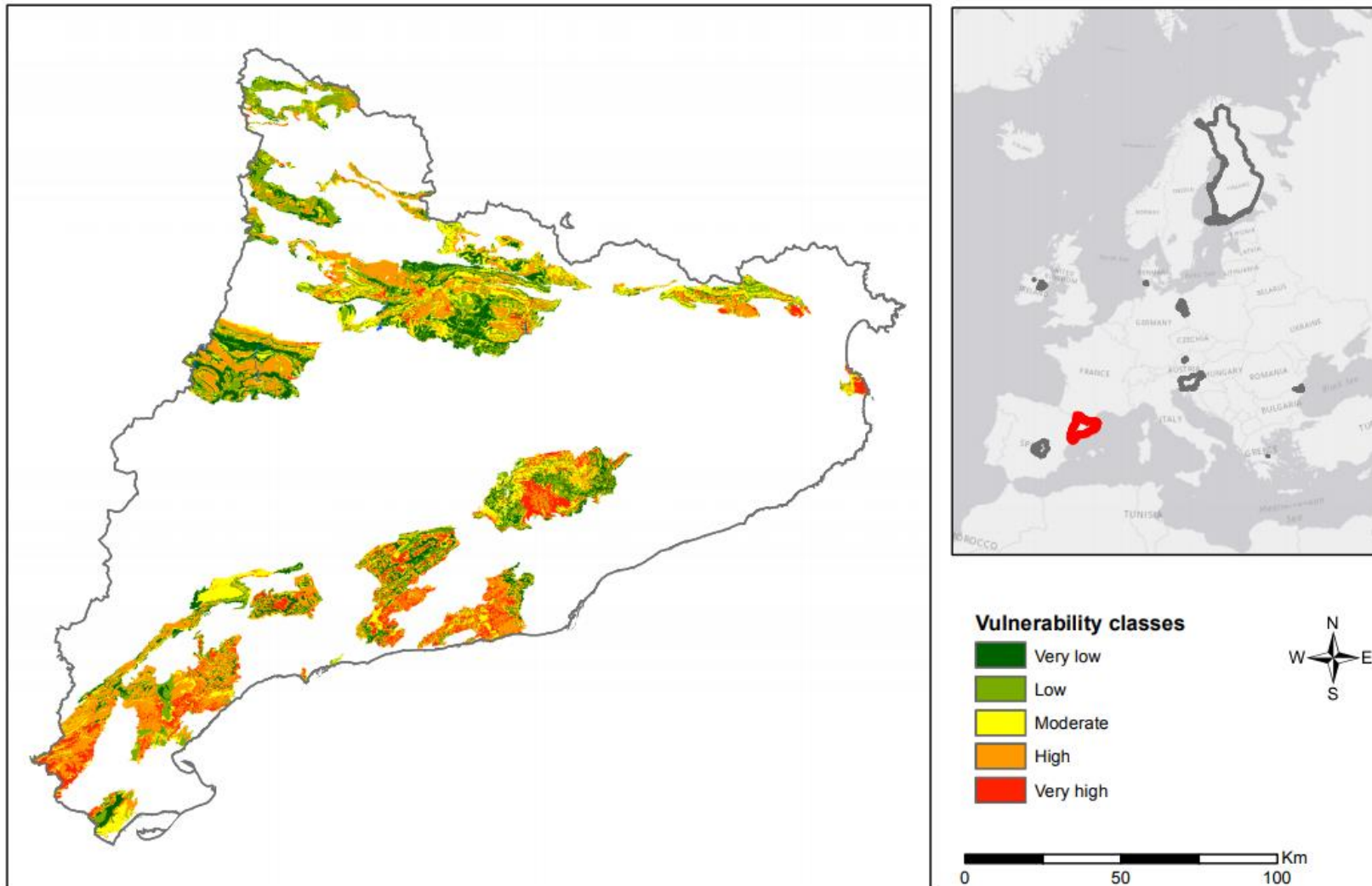




APPENDIX A2: VULNERABILITY INDEXES .COP ASSESSMENTS

Pilot area Catalonia (Spain) - ICGC

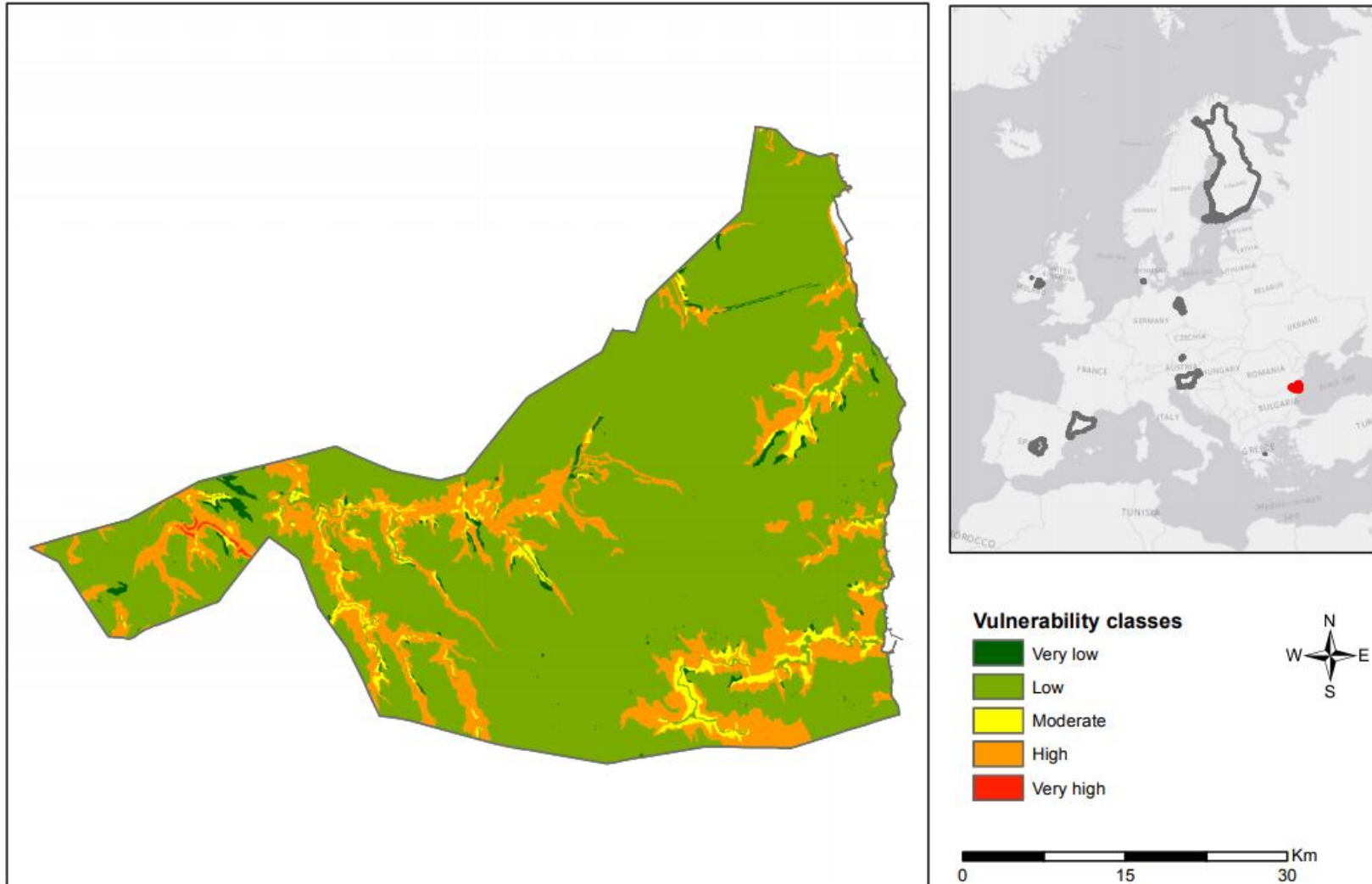
COP vulnerability index spatial distribution





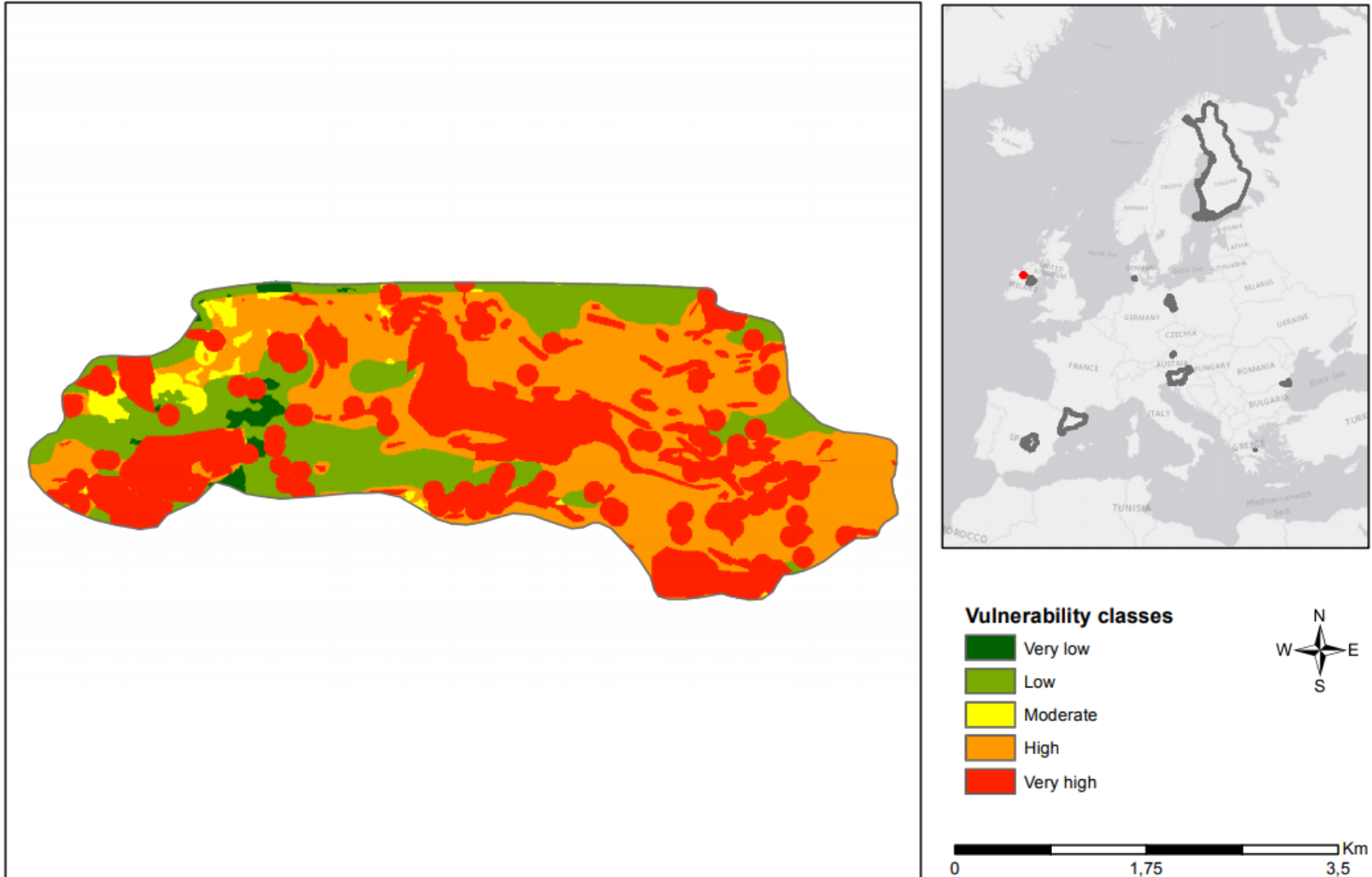
Pilot area Cobadin-Mangalia (Romania) - IGR

COP vulnerability index spatial distribution



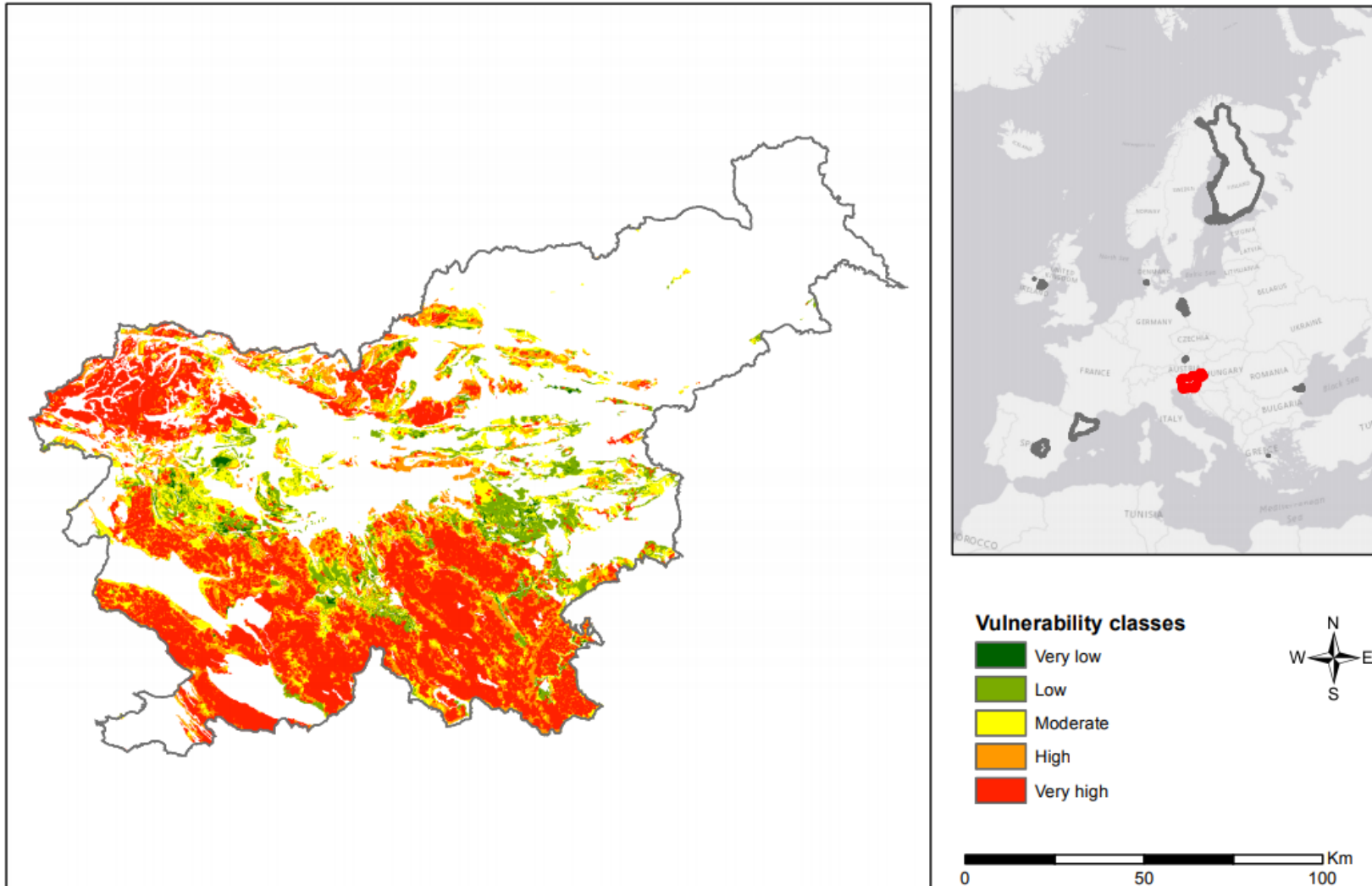


Pilot area Rockingham (Ireland) - GSI
COP vulnerability index spatial distribution



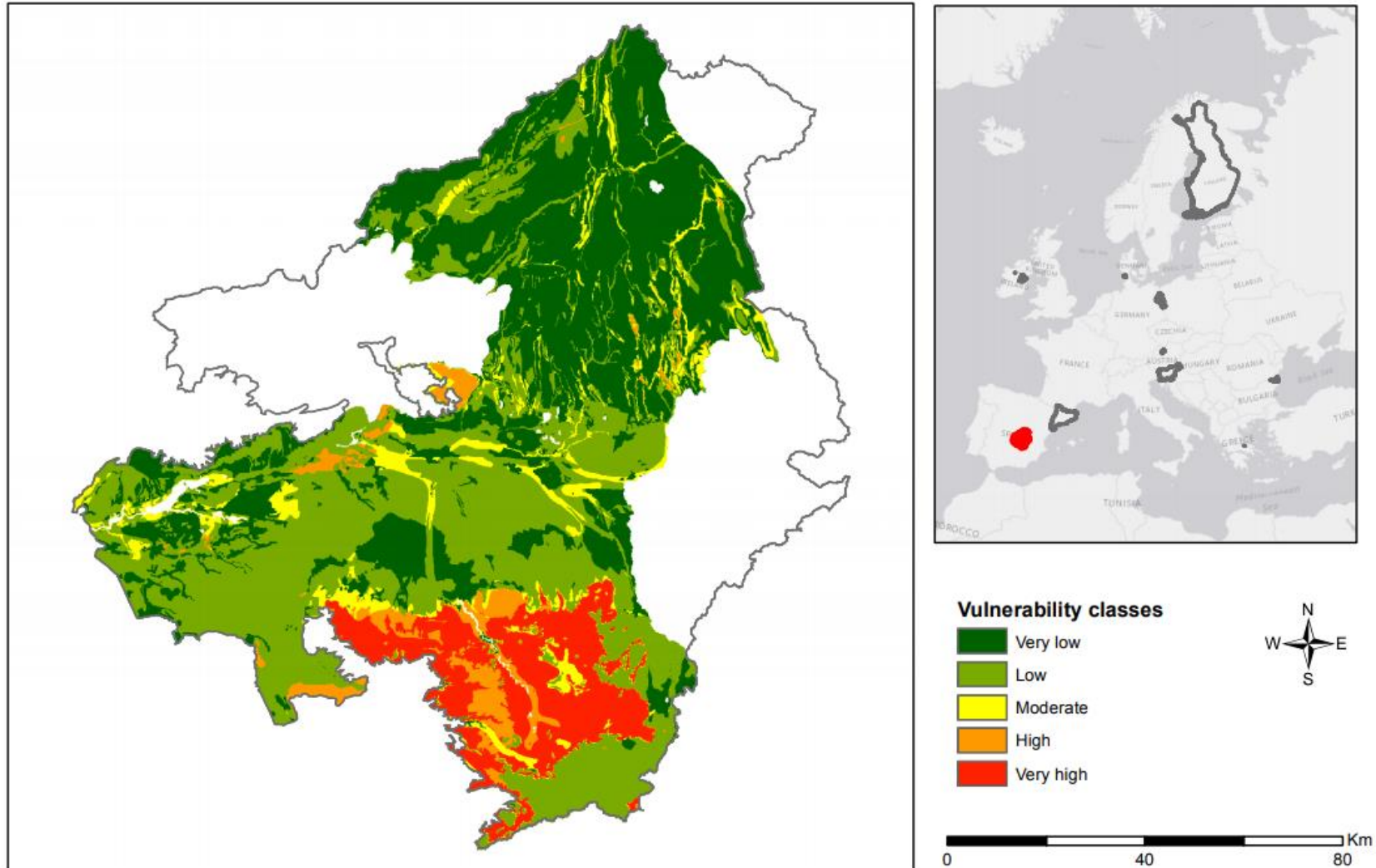


Pilot area Slovenia (Slovenia) – GeoZS
COP vulnerability index spatial distribution





Pilot area Upper Guadiana Basin (Spain) – IGME
COP vulnerability index spatial distribution

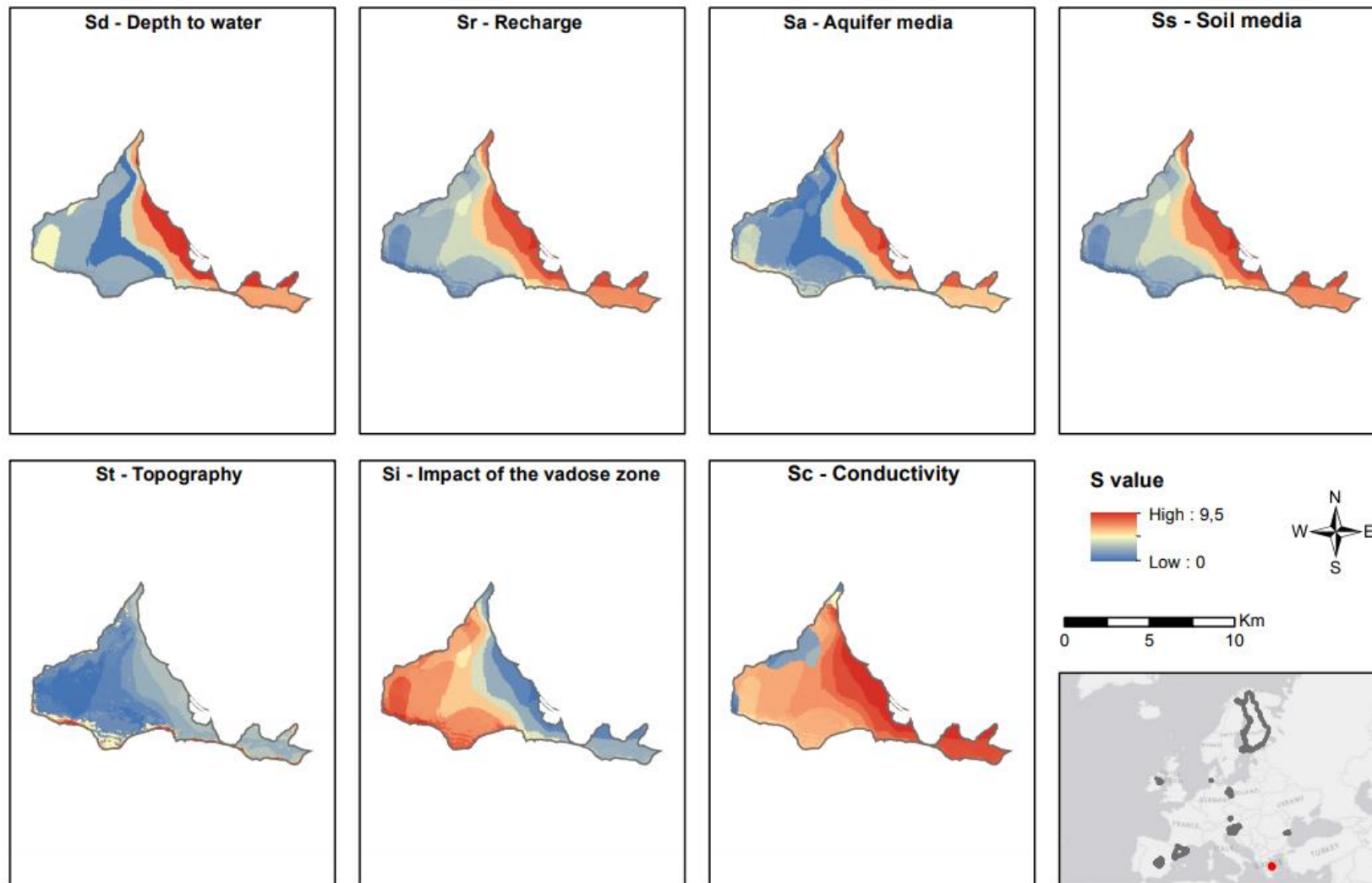




APPENDIX B1: SPATIAL DISTRIBUTION OF THE SENSITIVITY INDEX (S)

Pilot area Atalanti alluvial aquifer (Greece) - HSGME

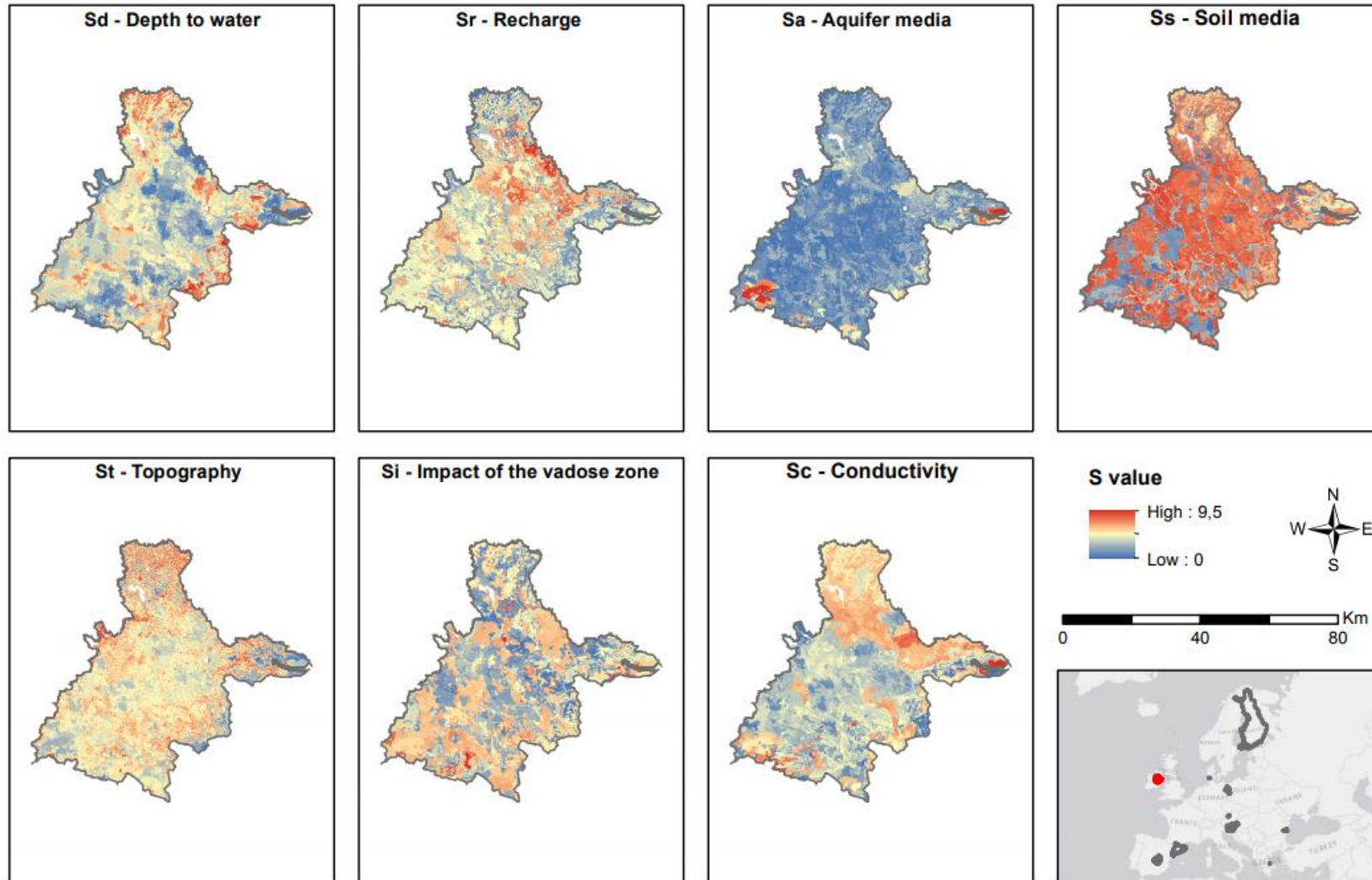
Spatial distribution of the Sensitivity index (S)





Pilot area Boyne (Ireland) - GSI

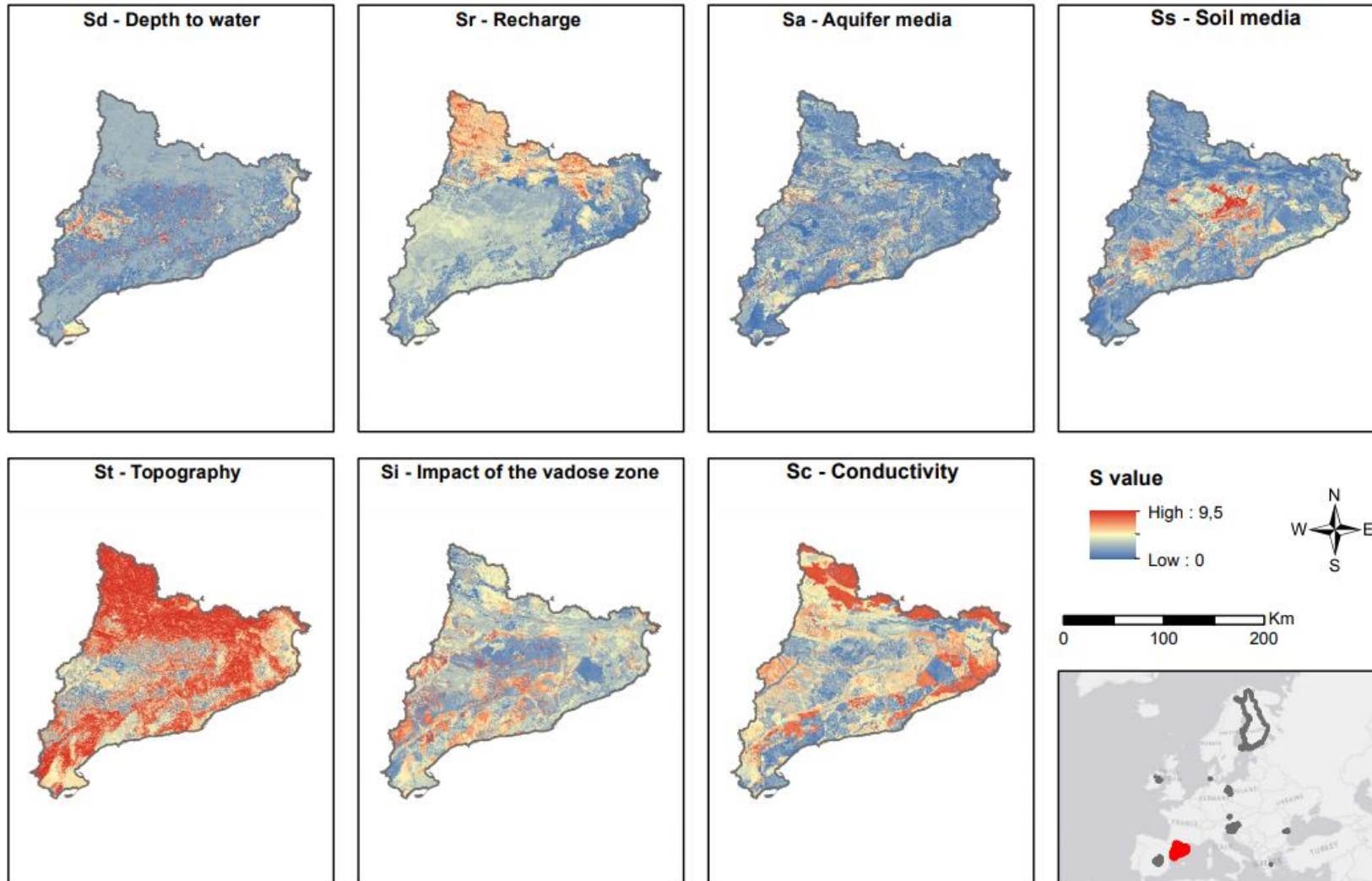
Spatial distribution of the Sensitivity index (S)





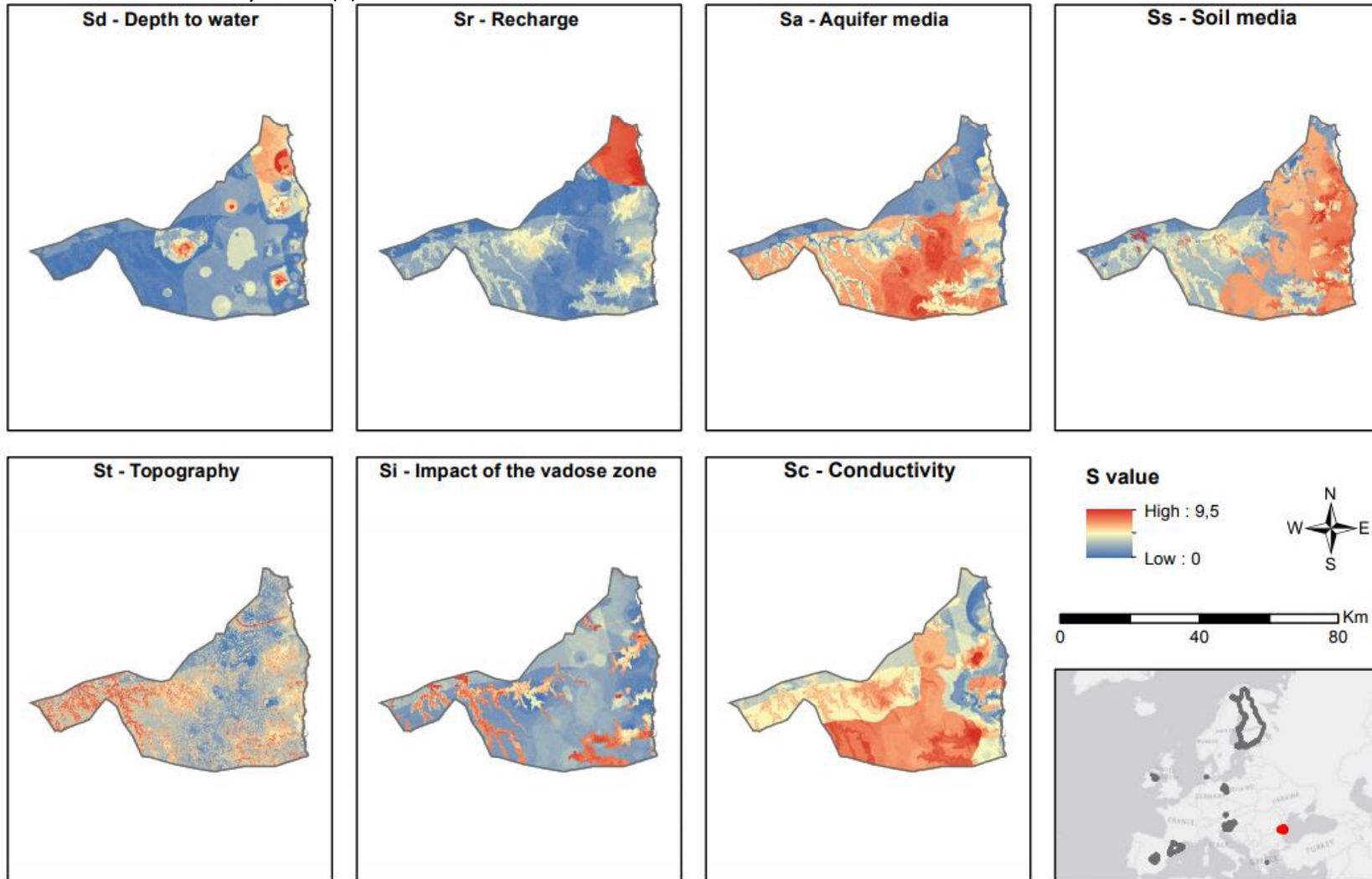
Pilot area Catalonia (Spain) - ICGC

Spatial distribution of the Sensitivity index (S)





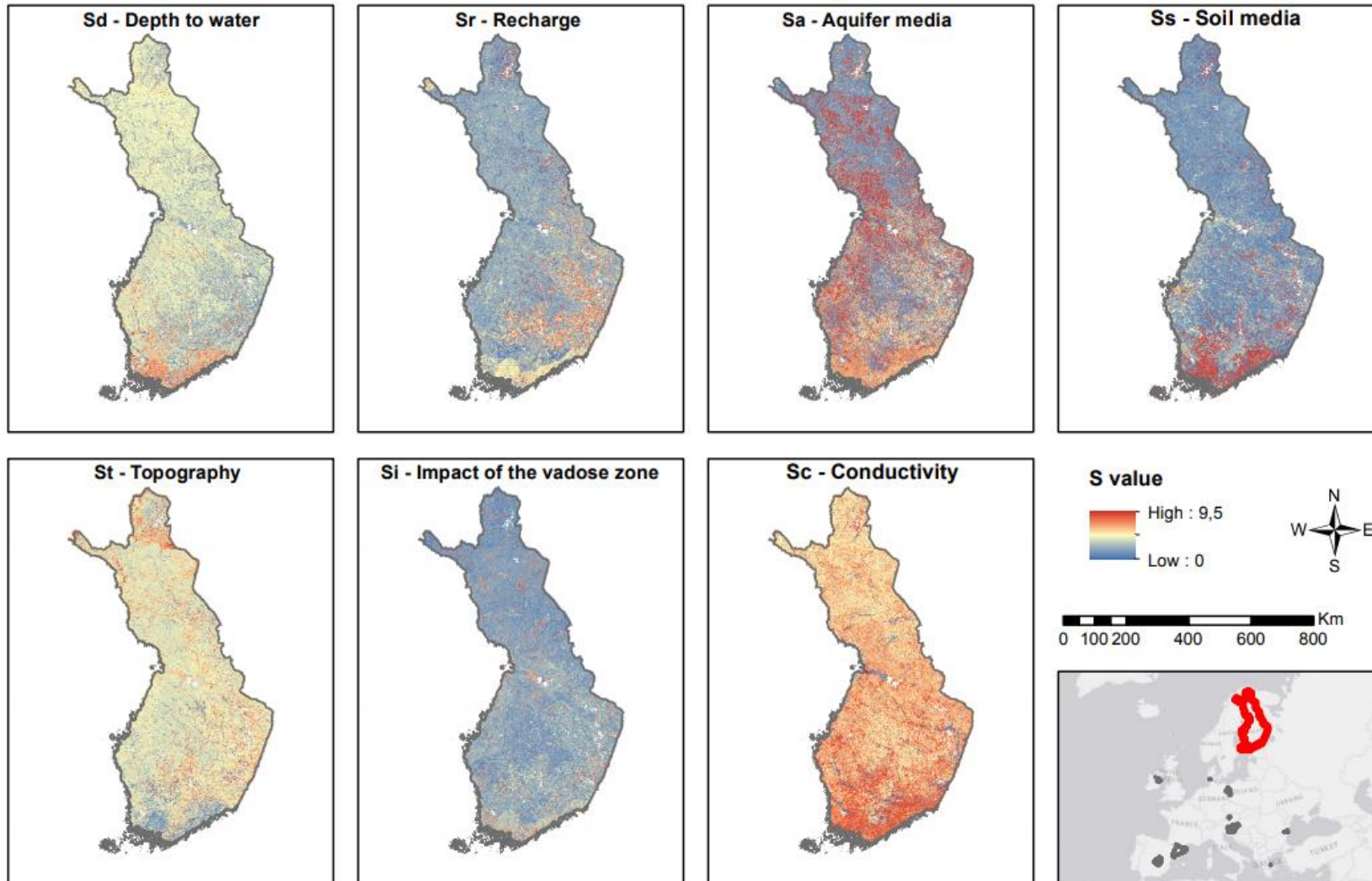
Pilot area Cobadin-Mangalia (Romania) - IGR
Spatial distribution of the Sensitivity index (S)





Pilot area Finland (Finland) – GTK

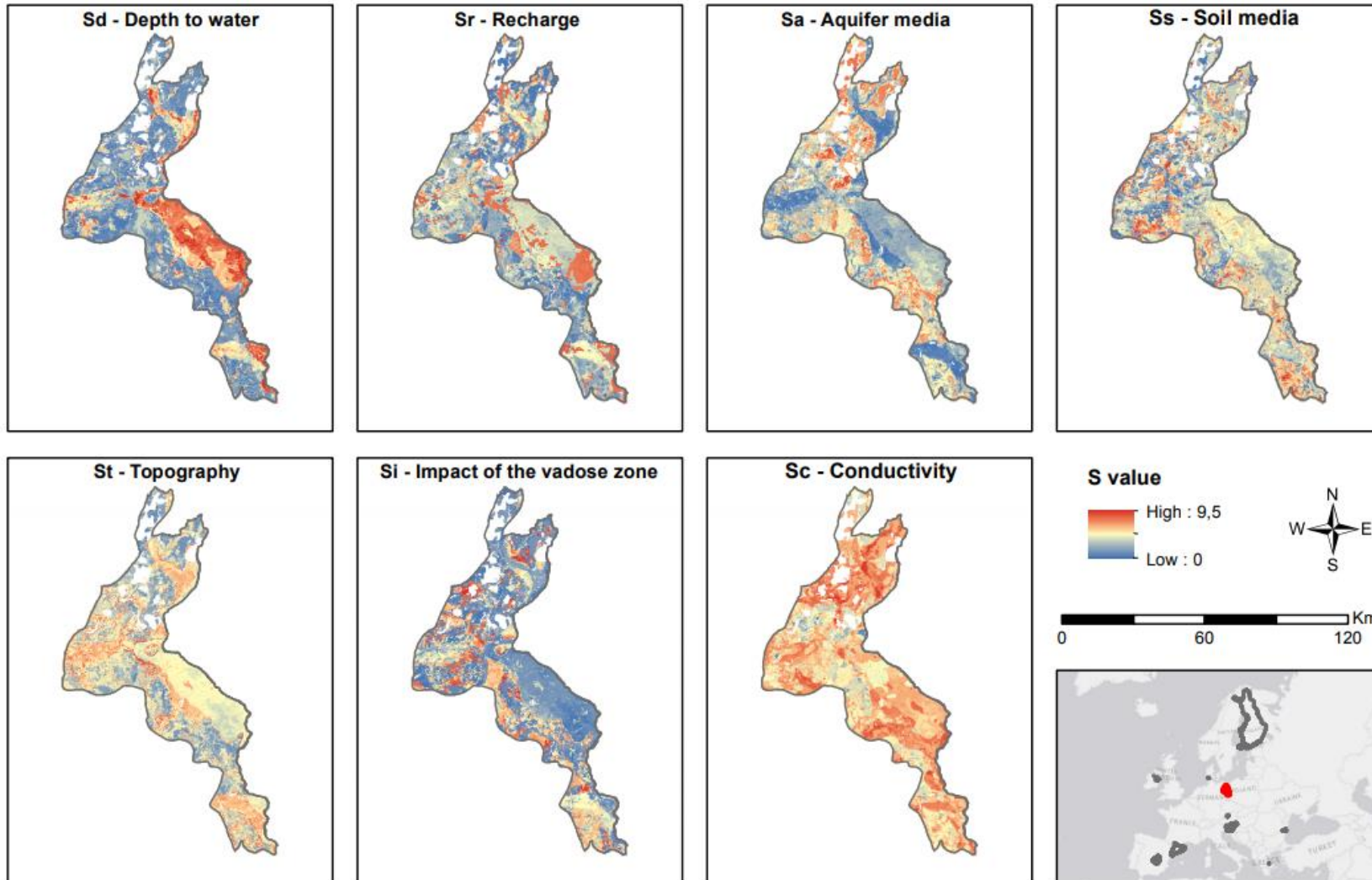
Spatial distribution of the Sensitivity index (S)





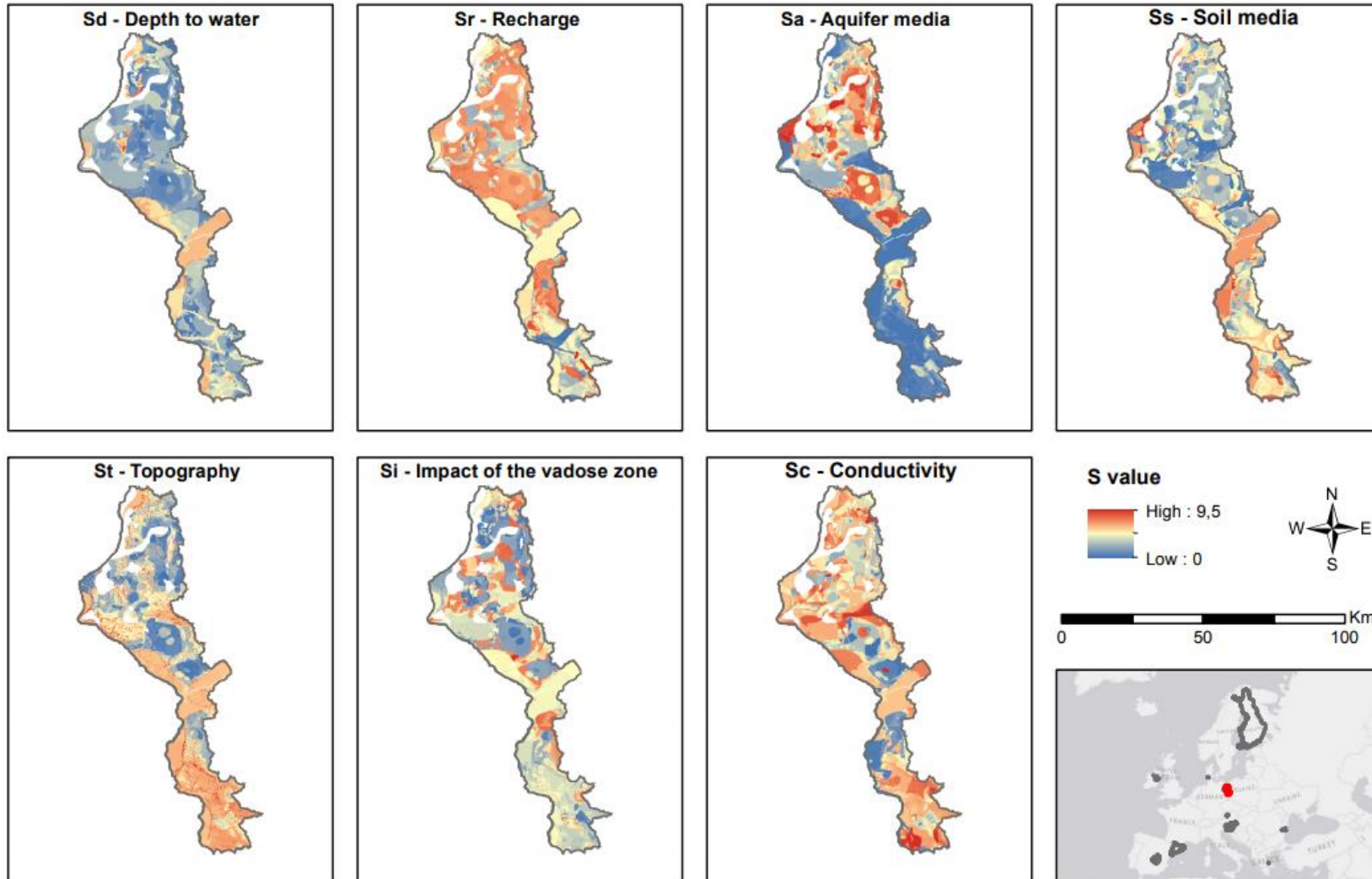
Pilot area Middle and Lower Oder/Odra river (German part) – PGI/LBGR/BGR

Spatial distribution of the Sensitivity index (S)





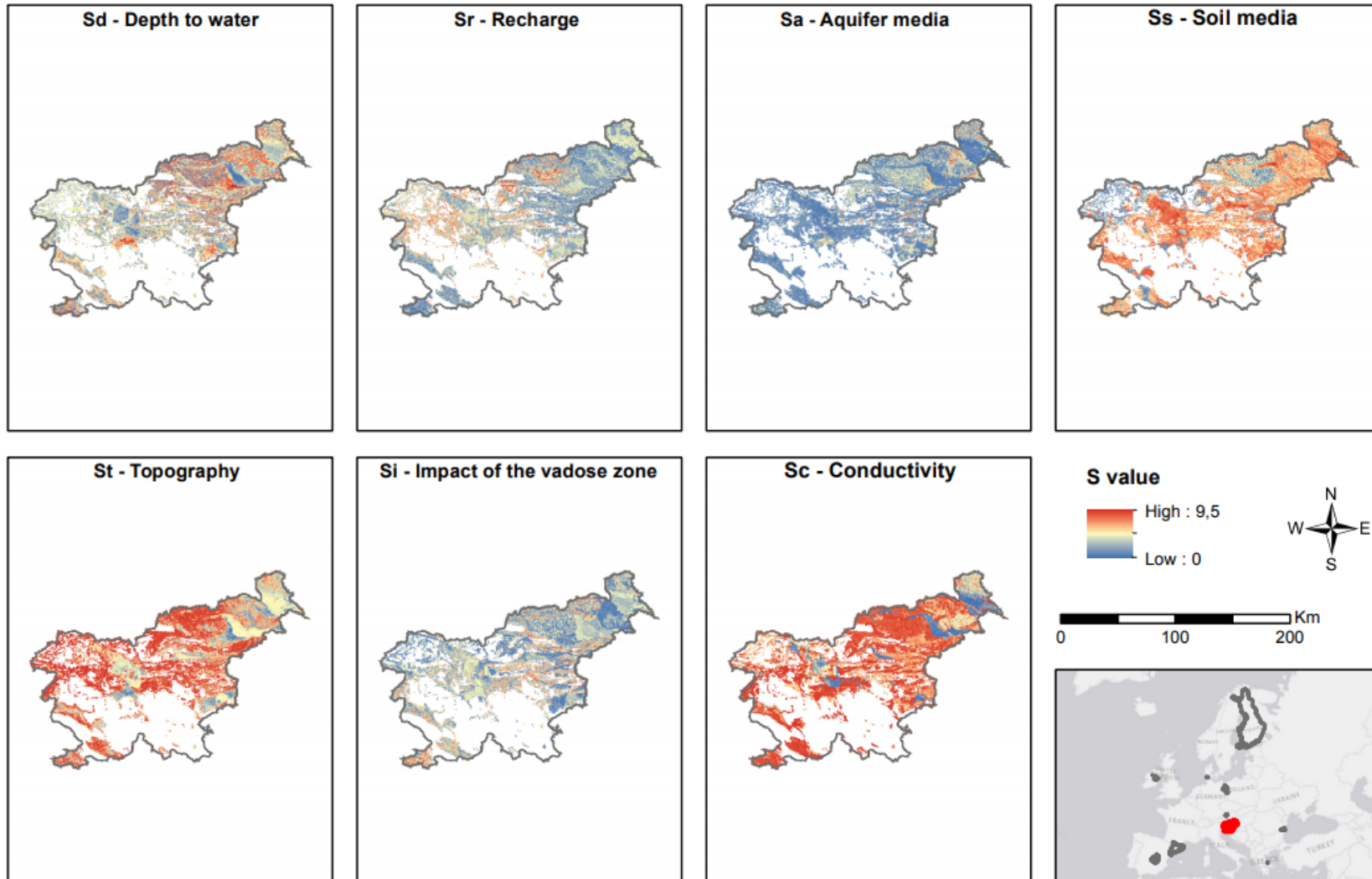
Pilot area Middle and Lower Oder/Odra river (Polish part) – PGI/LBGR/BGR
Spatial distribution of the Sensitivity index (S)





Pilot area Slovenia (Slovenia) – GeoZS

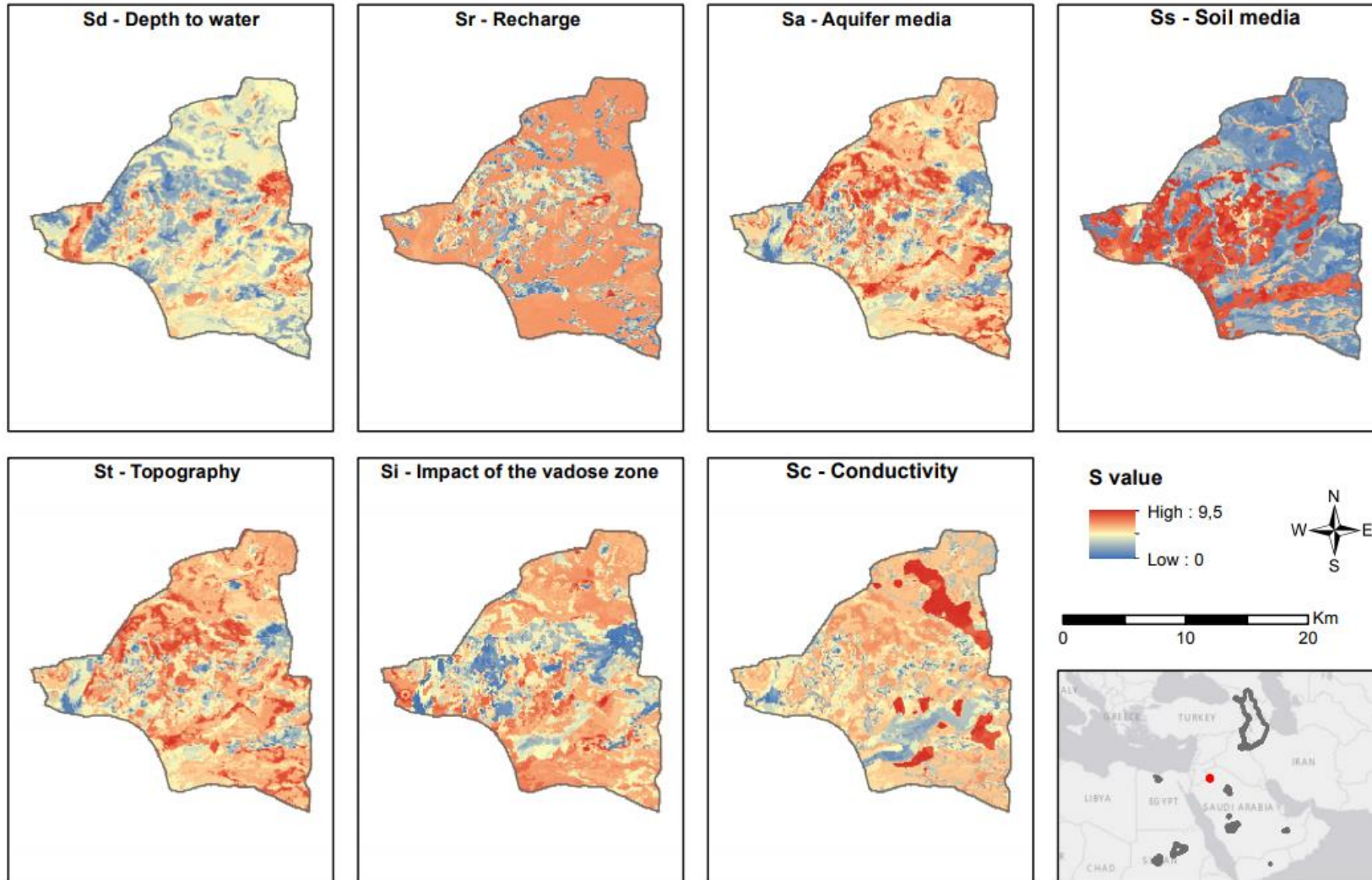
Spatial distribution of the Sensitivity index (S)





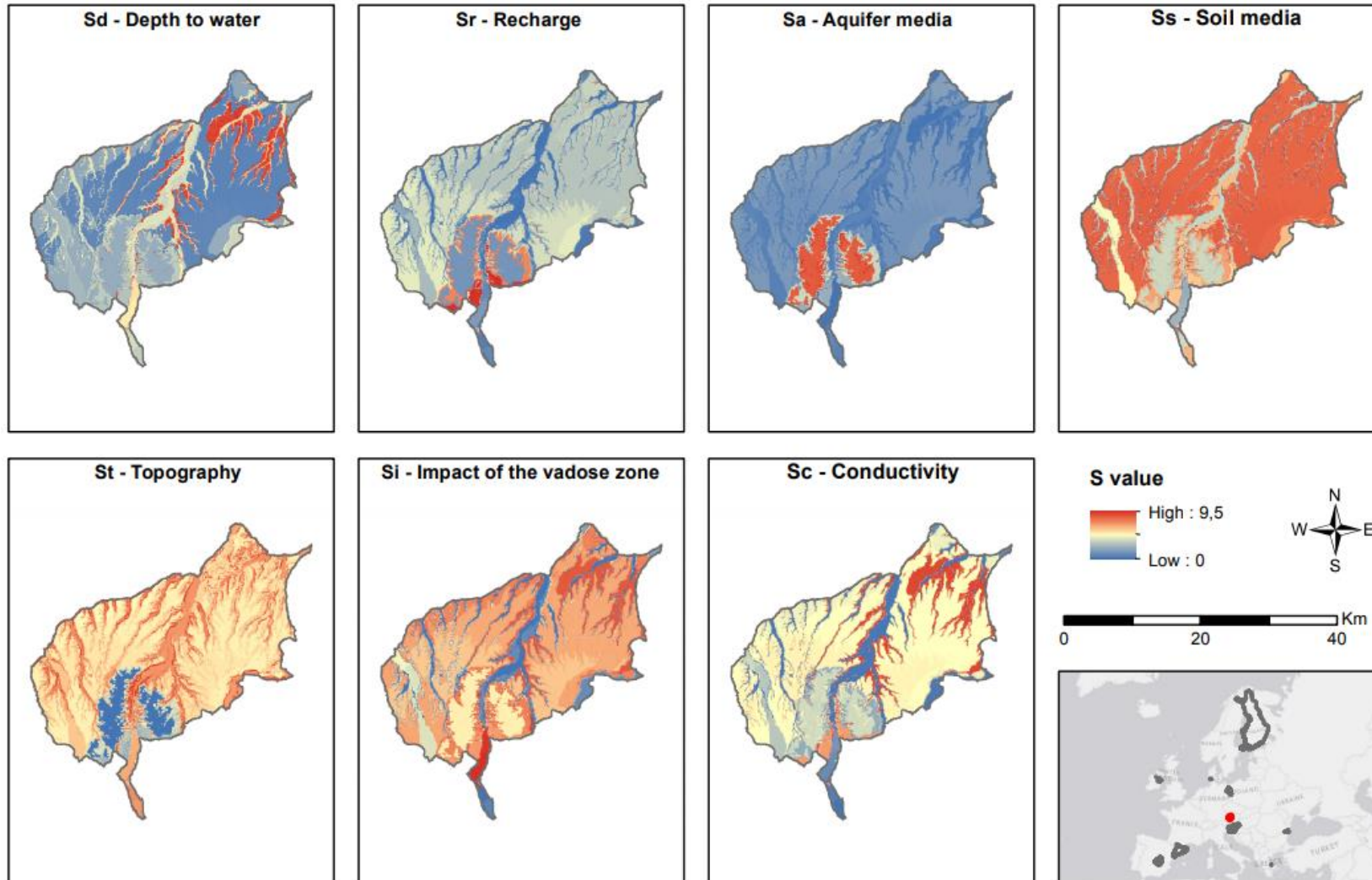
Pilot area Tønder (Denmark) – GEUS

Spatial distribution of the Sensitivity index (S)





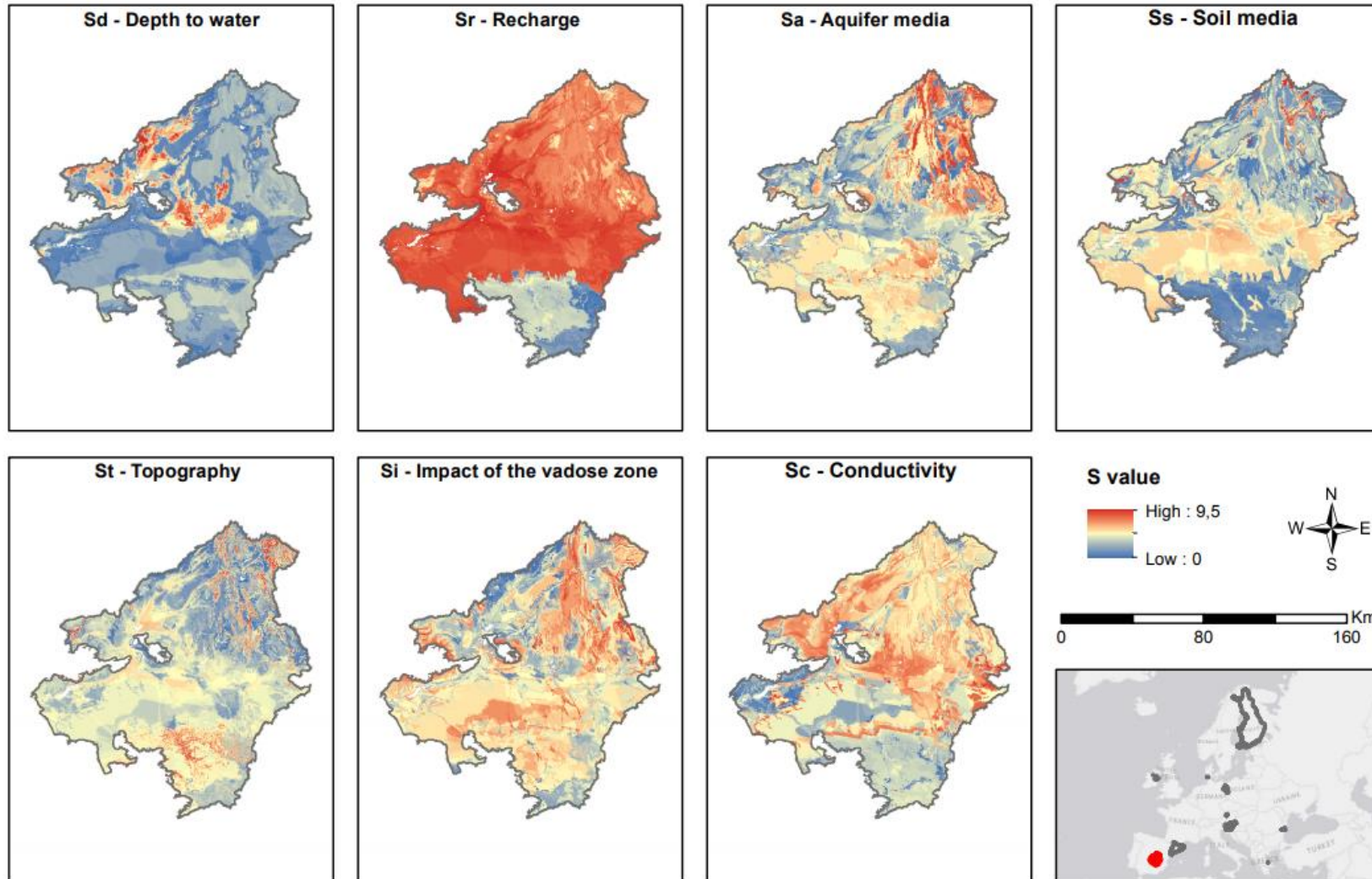
Pilot area Traun-Enns-Platte (Austria) – GBA
Spatial distribution of the Sensitivity index (S)





Pilot area Upper Guadiana Basin (Spain) – IGME

Spatial distribution of the Sensitivity index (S)

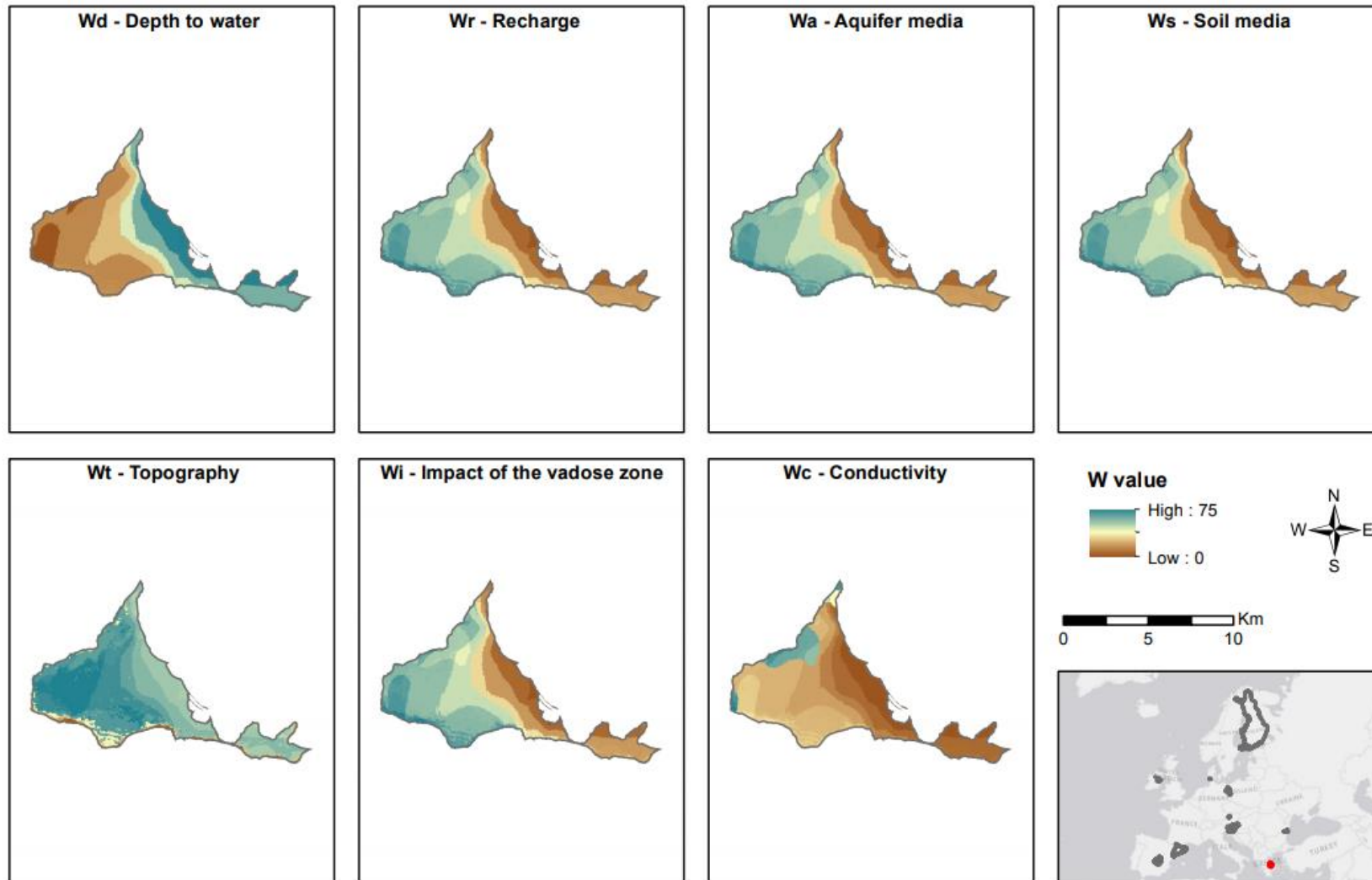




APPENDIX B2: SPATIAL DISTRIBUTION OF THE EFFECTIVE WEIGHT INDEX (W)

Pilot area Atalanti alluvial aquifer (Greece) - HSGME

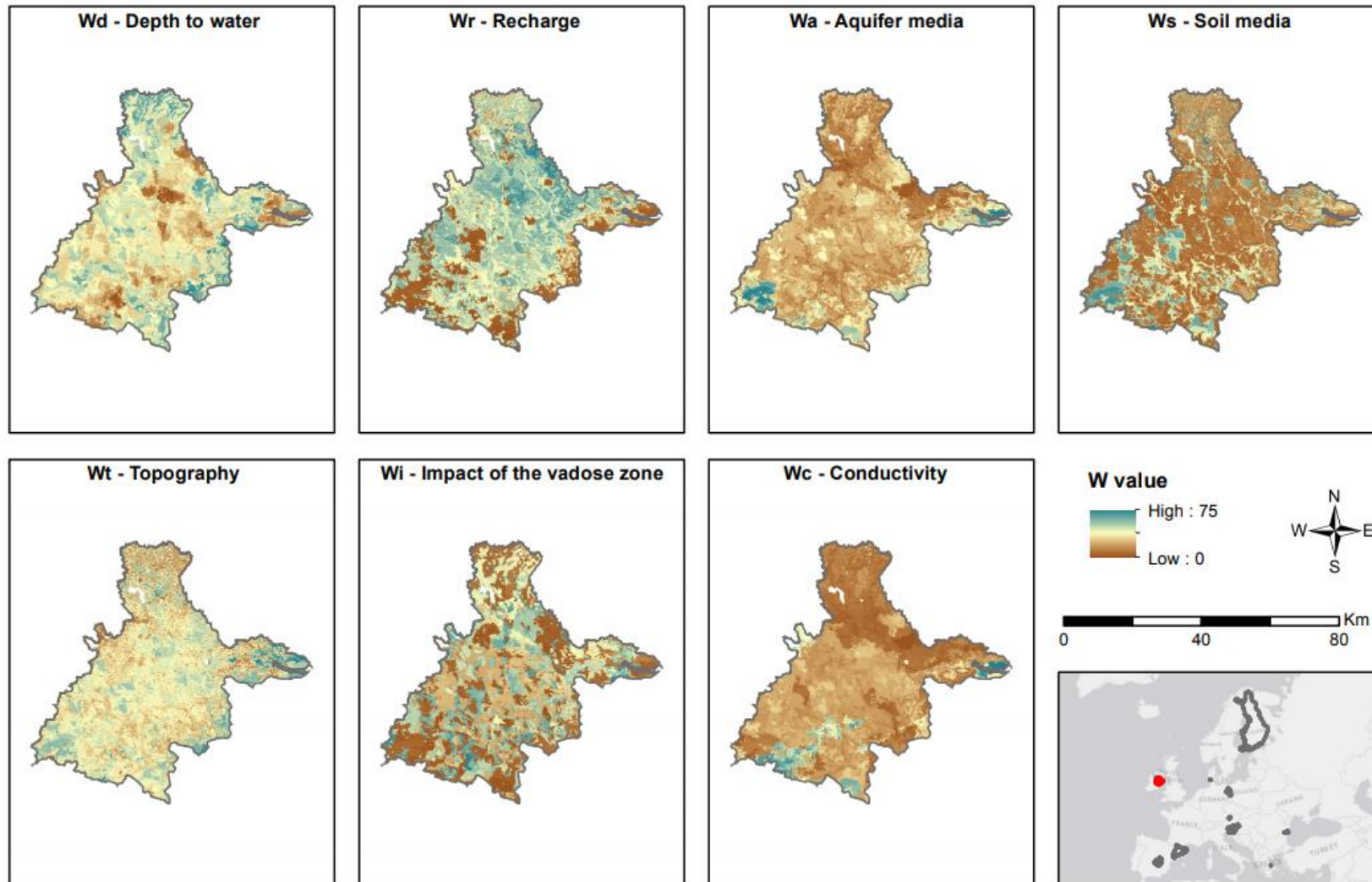
Spatial distribution of the effective Weight index (W)





Pilot area Boyne (Ireland) - GSI

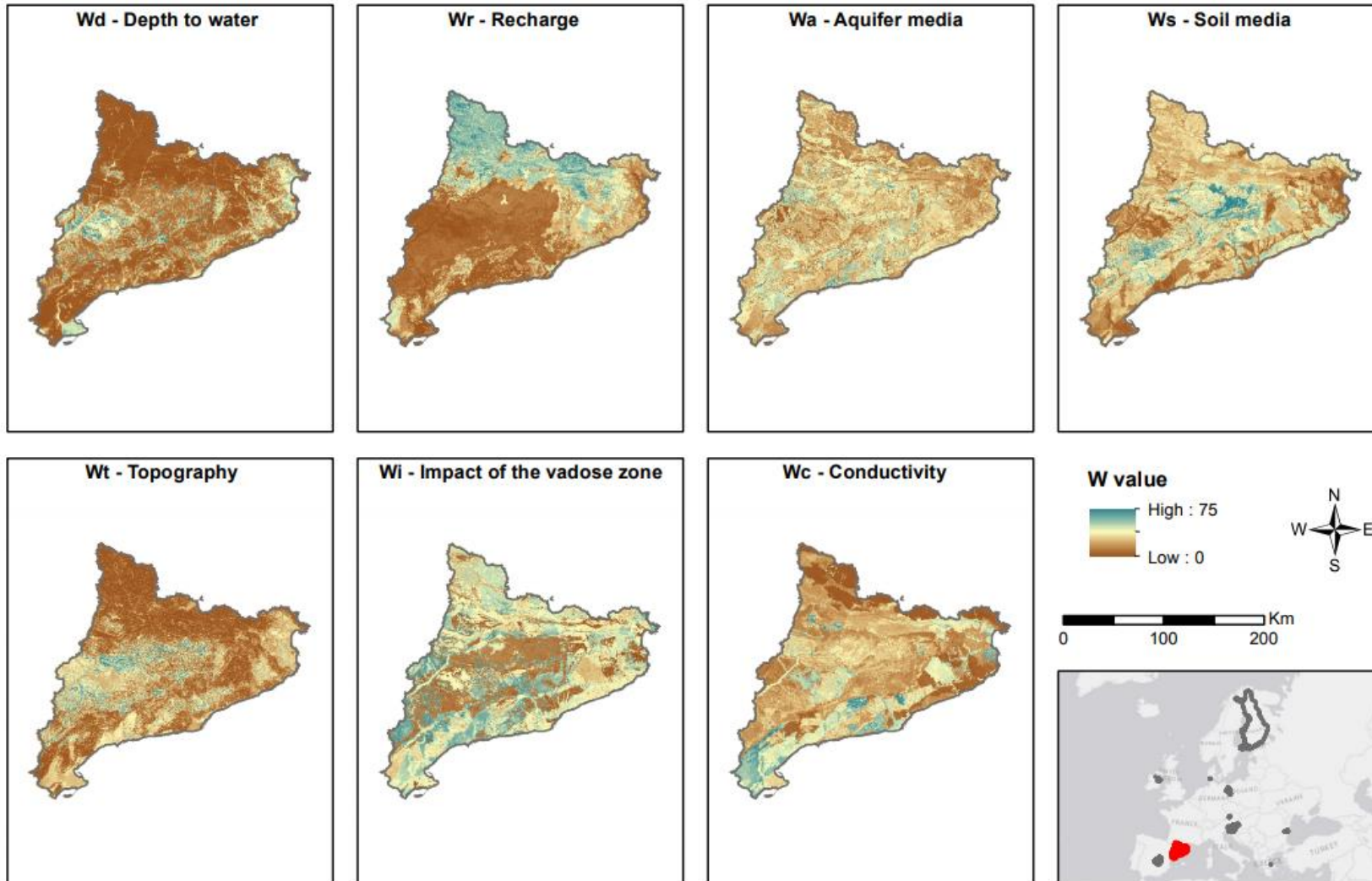
Spatial distribution of the effective Weight index (W)





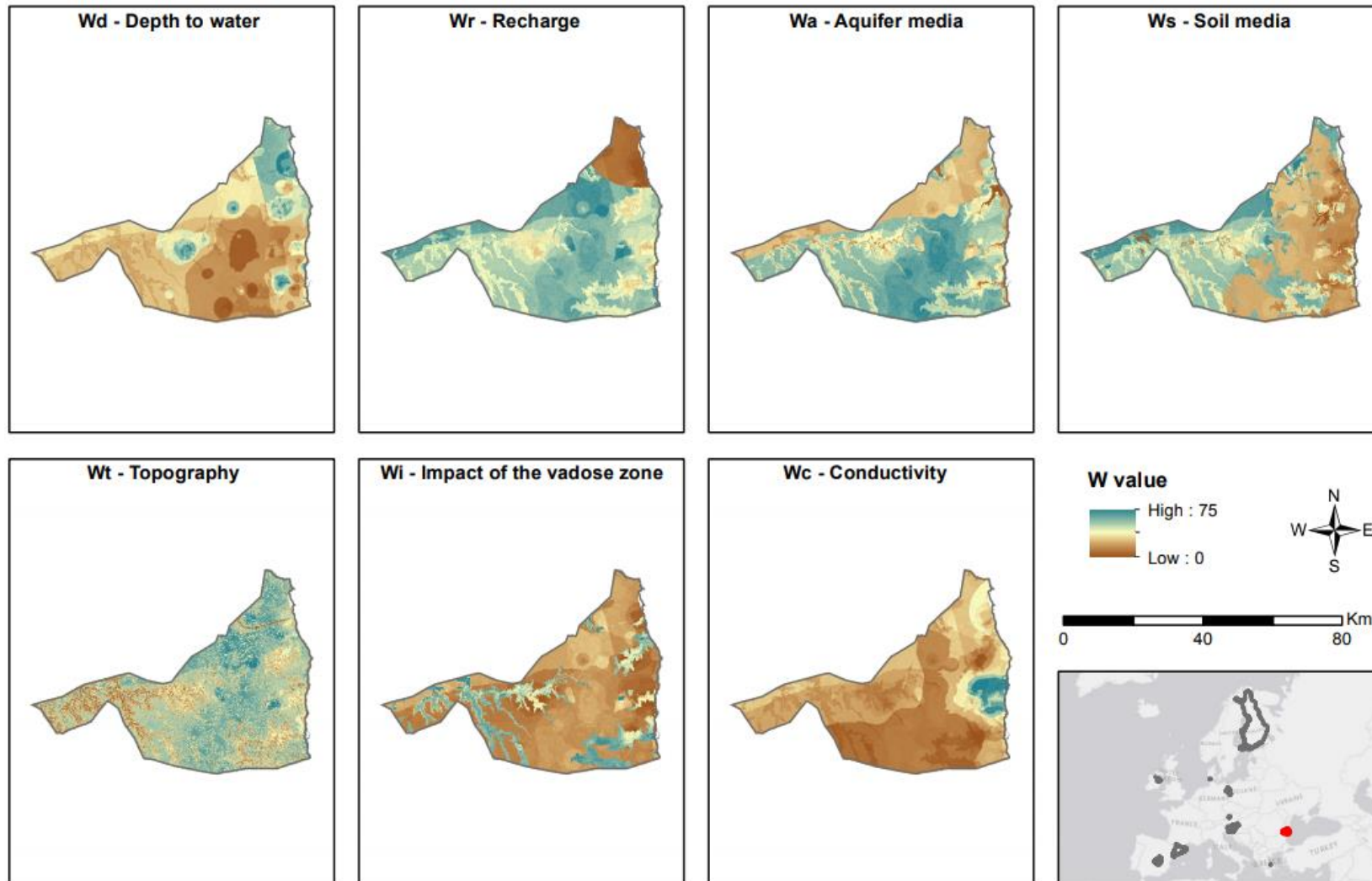
Pilot area Catalonia (Spain) - ICGC

Spatial distribution of the effective Weight index (W)





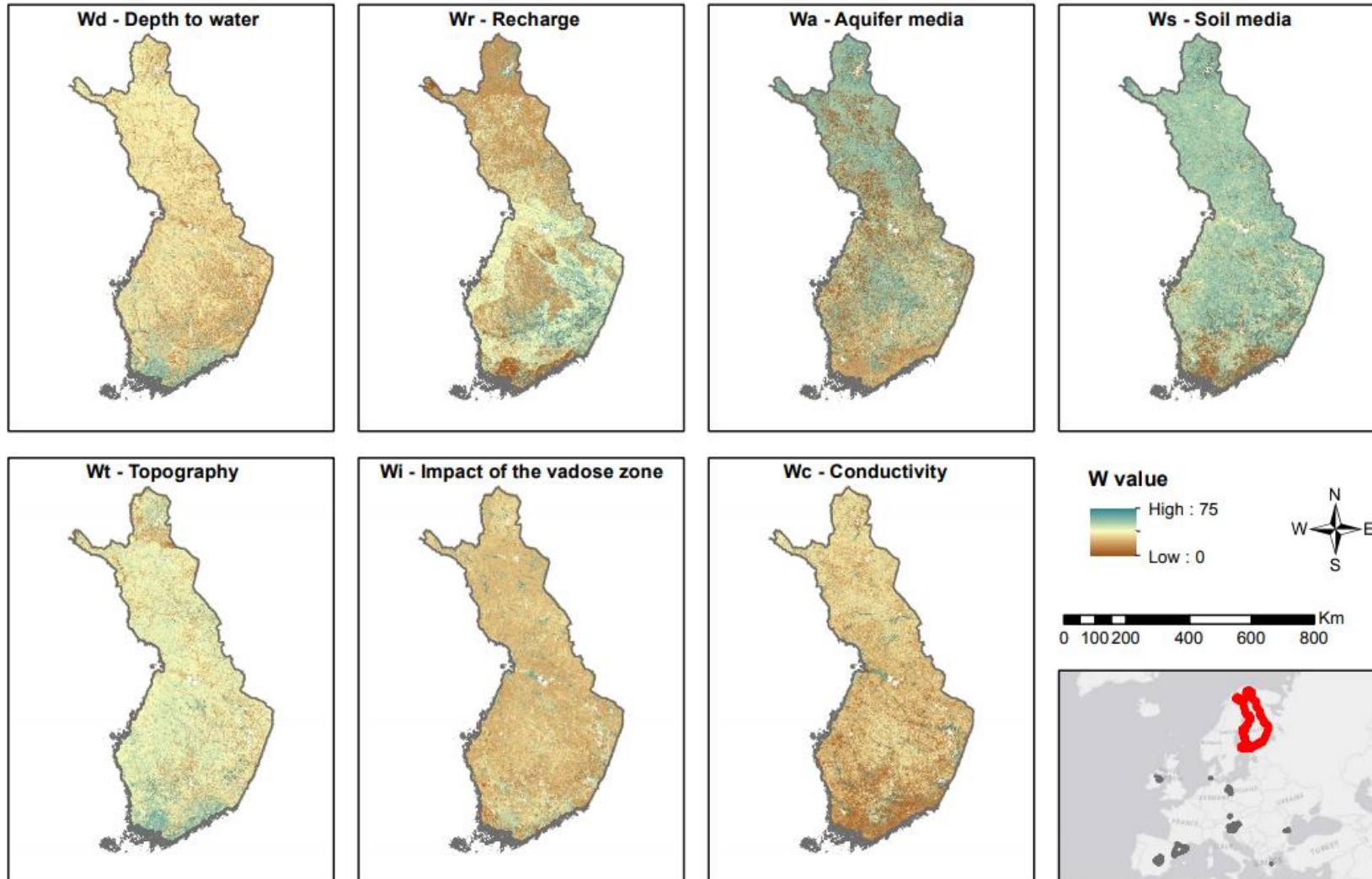
Pilot area Cobadin-Mangalia (Romania) - IGR
Spatial distribution of the effective Weight index (W)





Pilot area Finland (Finland) – GTK

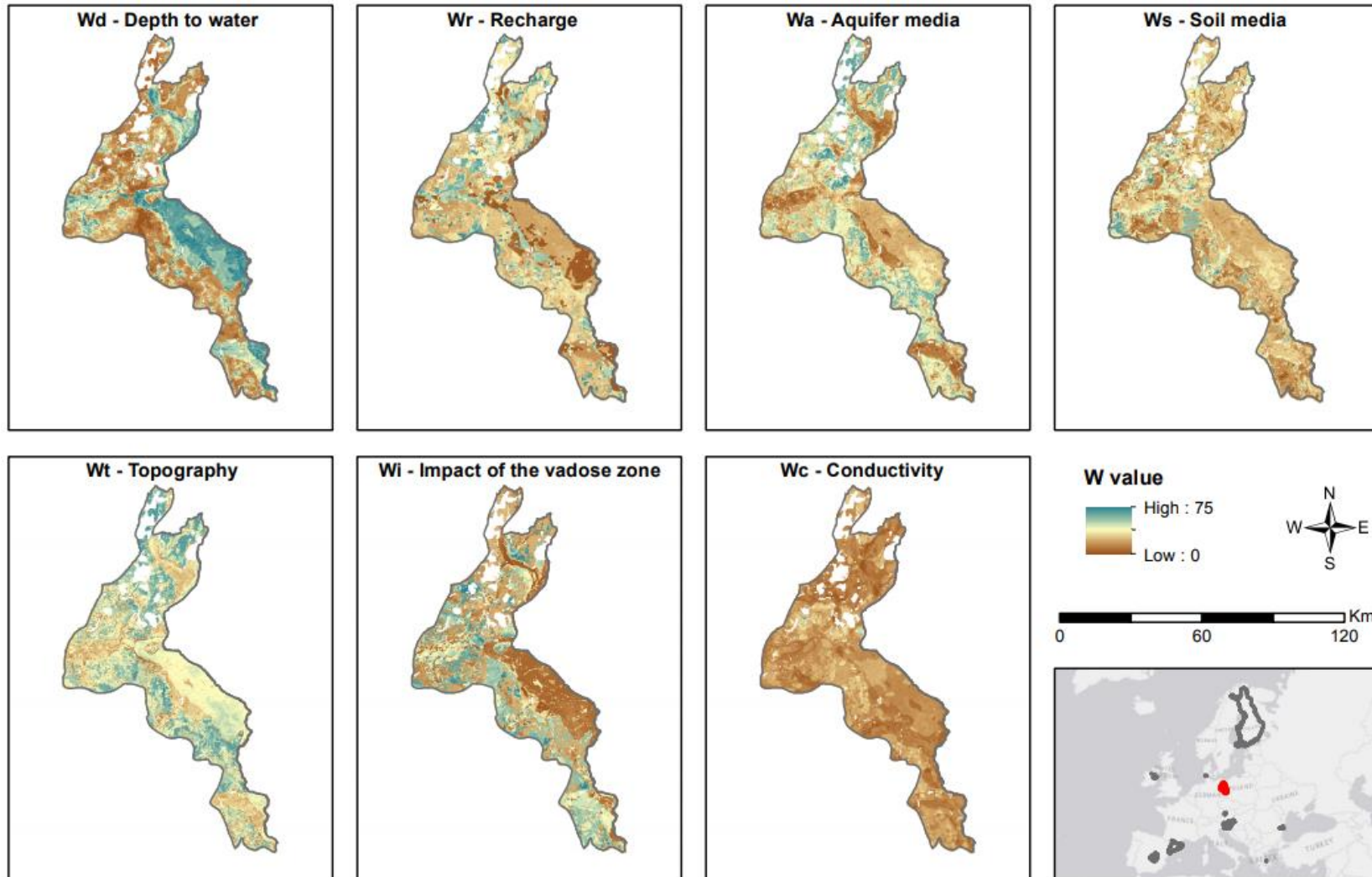
Spatial distribution of the effective Weight index (W)





Pilot area Middle and Lower Oder/Odra river (German part) – PGI/LBGR/BGR

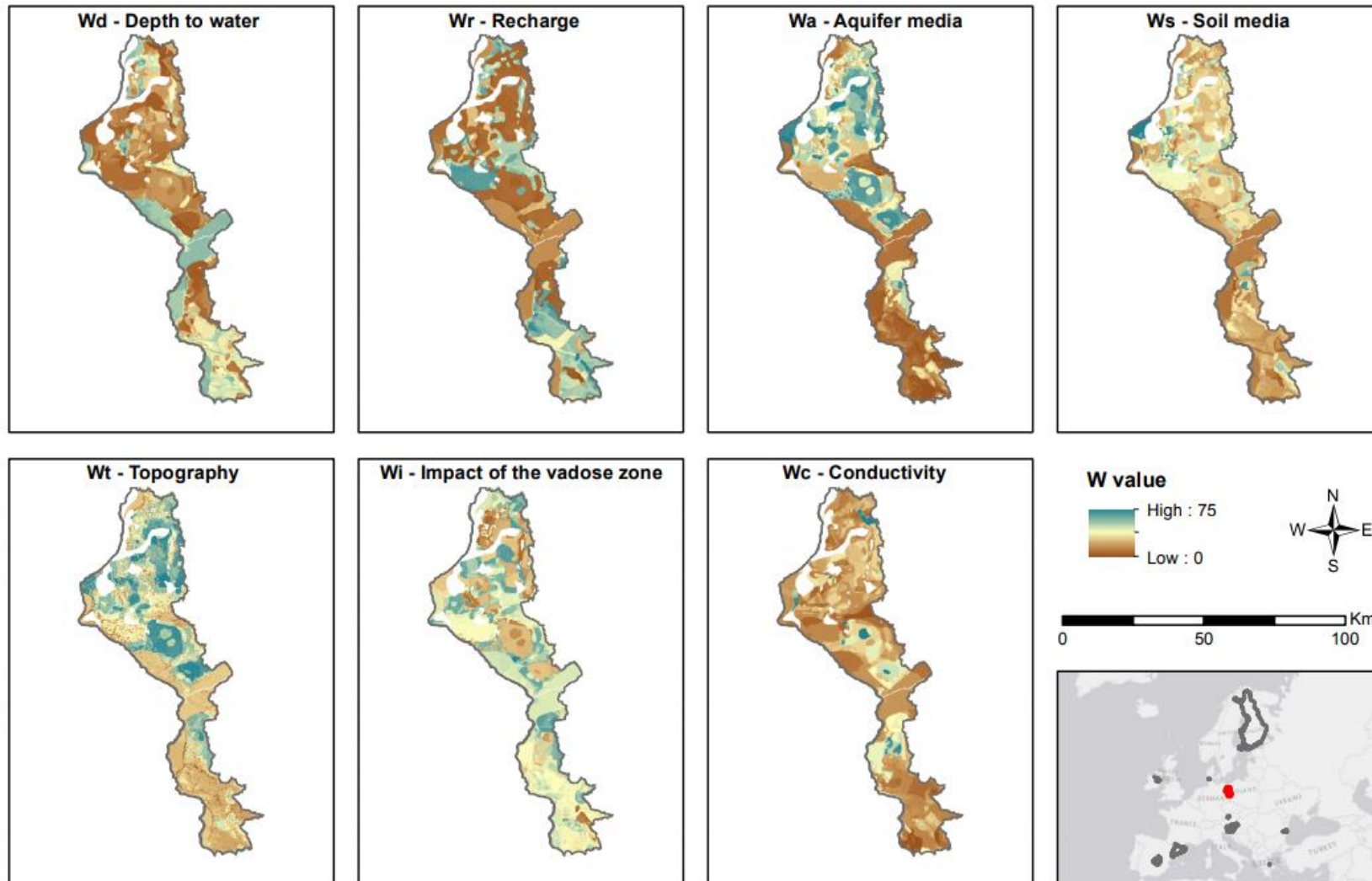
Spatial distribution of the effective Weight index (W)





Pilot area Middle and Lower Oder/Odra river (Polish part) – PGI/LBGR/BGR

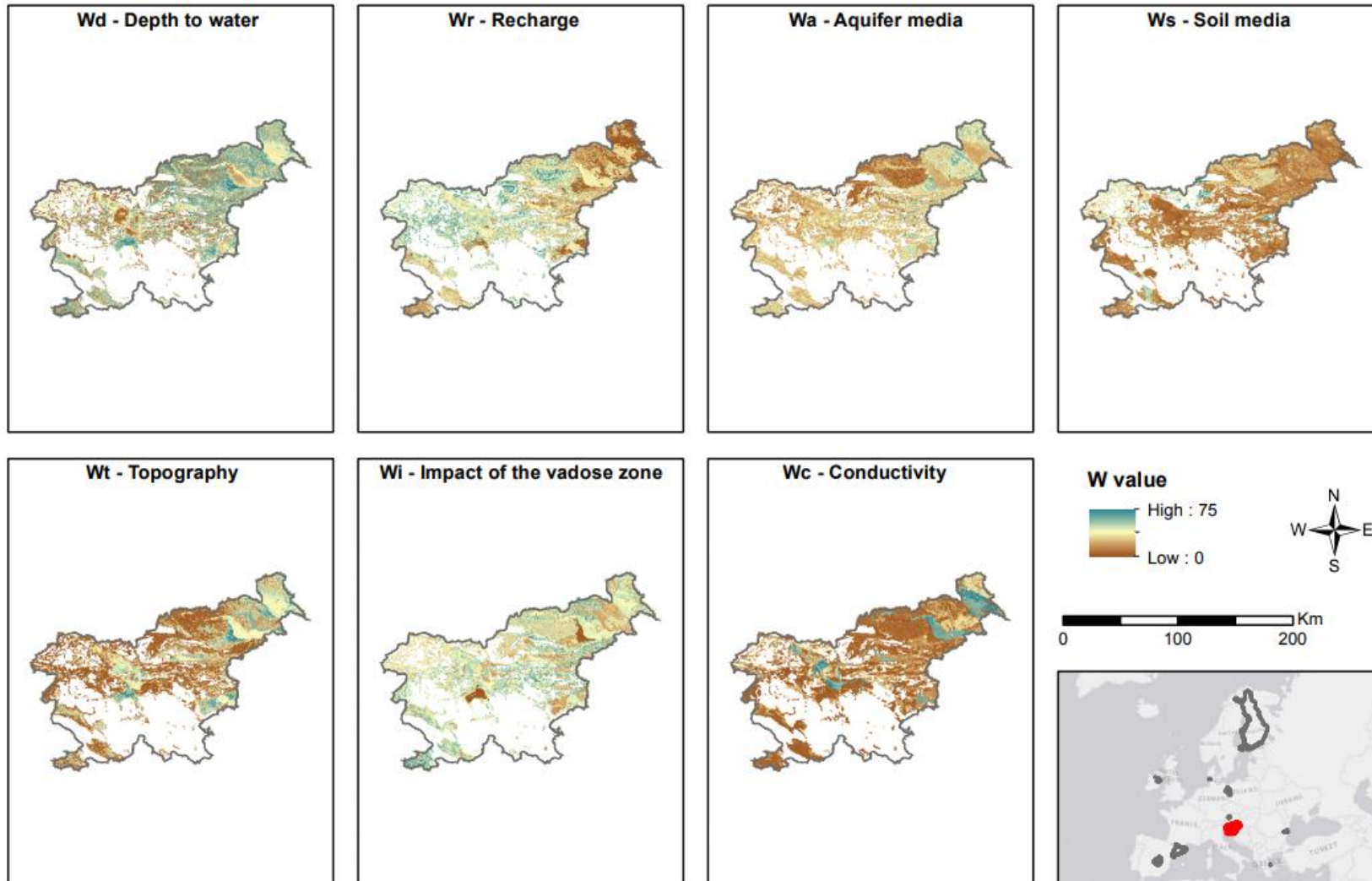
Spatial distribution of the effective Weight index (W)





Pilot area Slovenia (Slovenia) – GeoZS

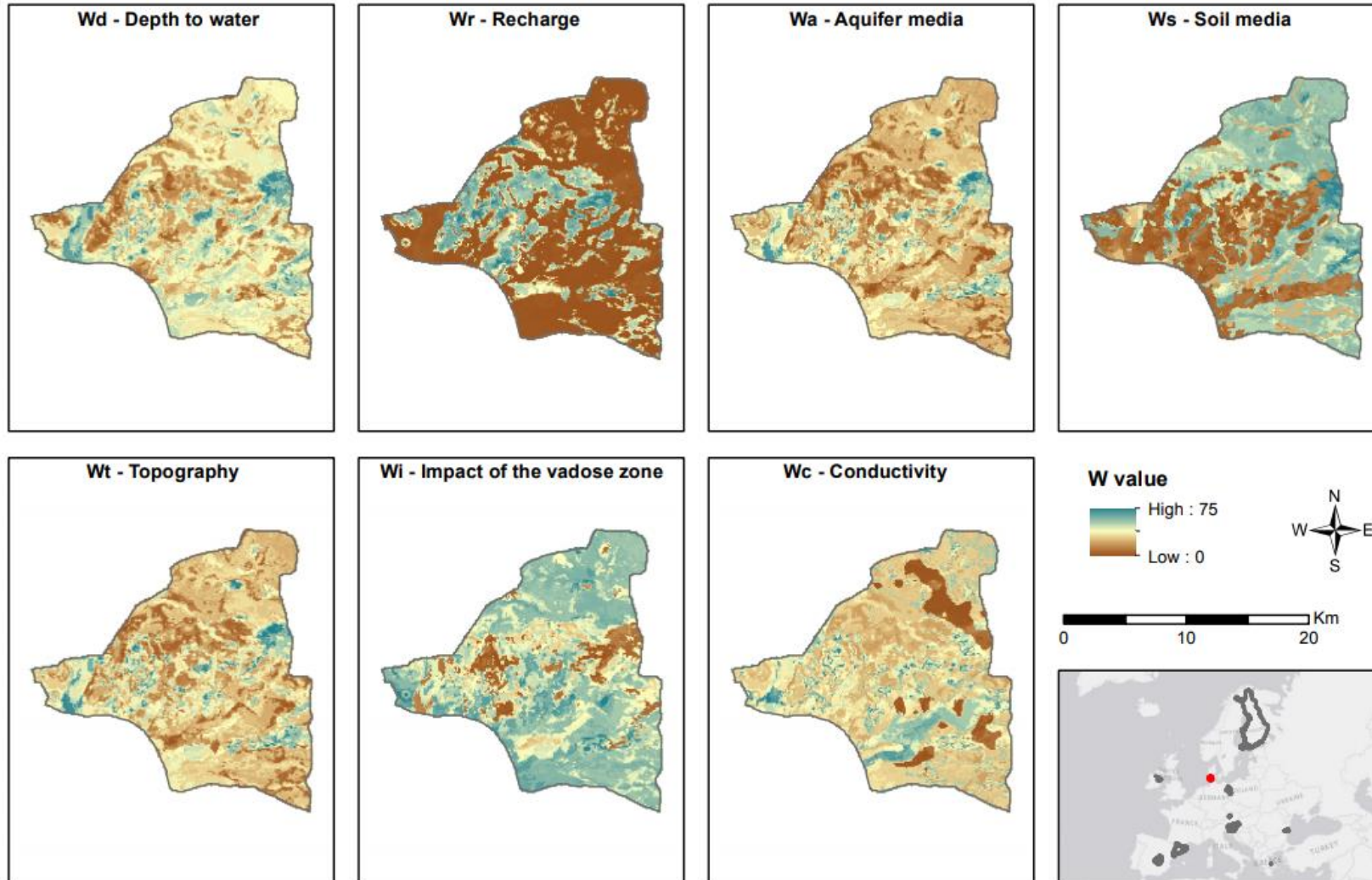
Spatial distribution of the effective Weight index (W)





Pilot area Tønder (Denmark) – GEUS

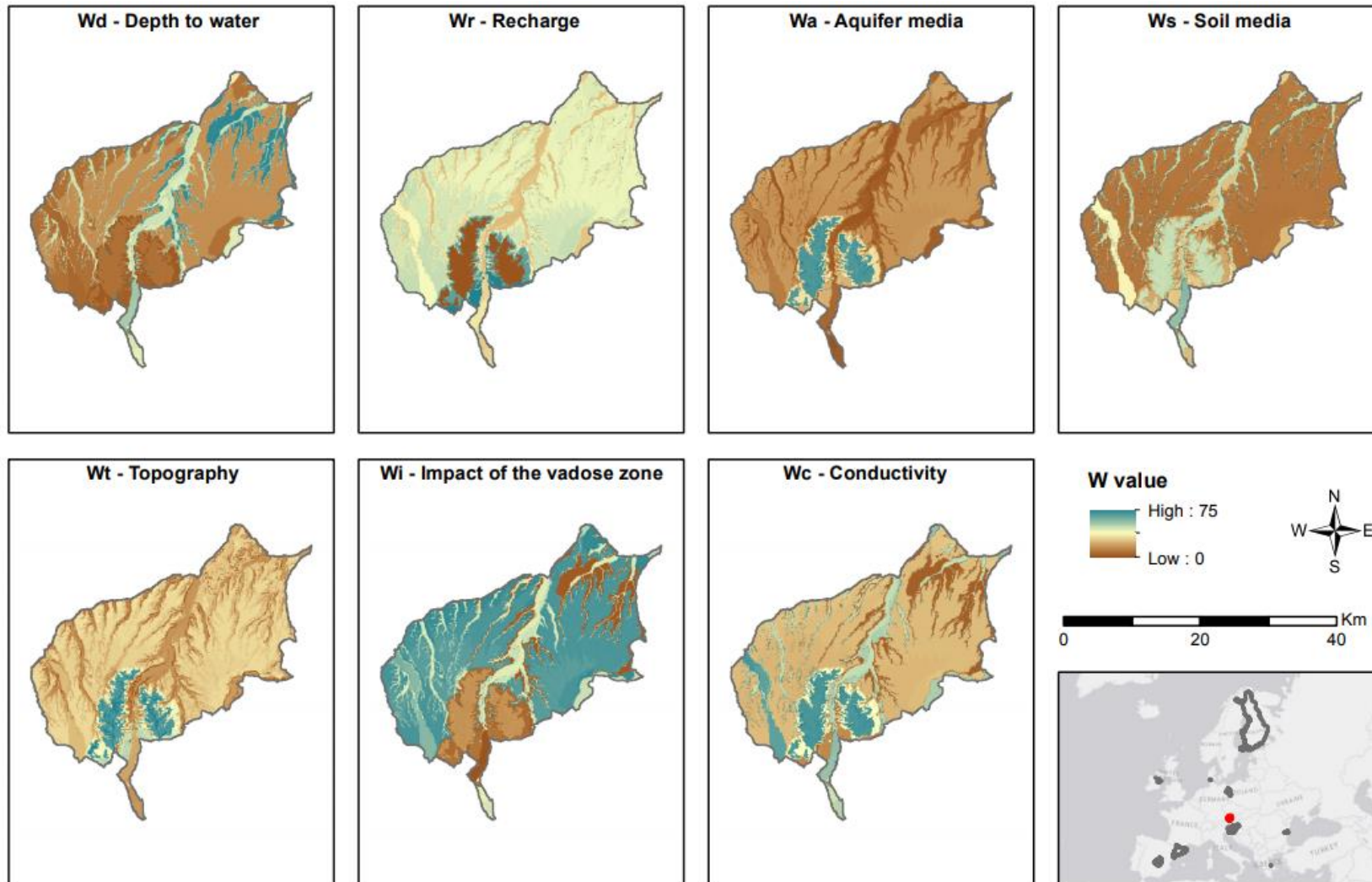
Spatial distribution of the effective Weight index (W)





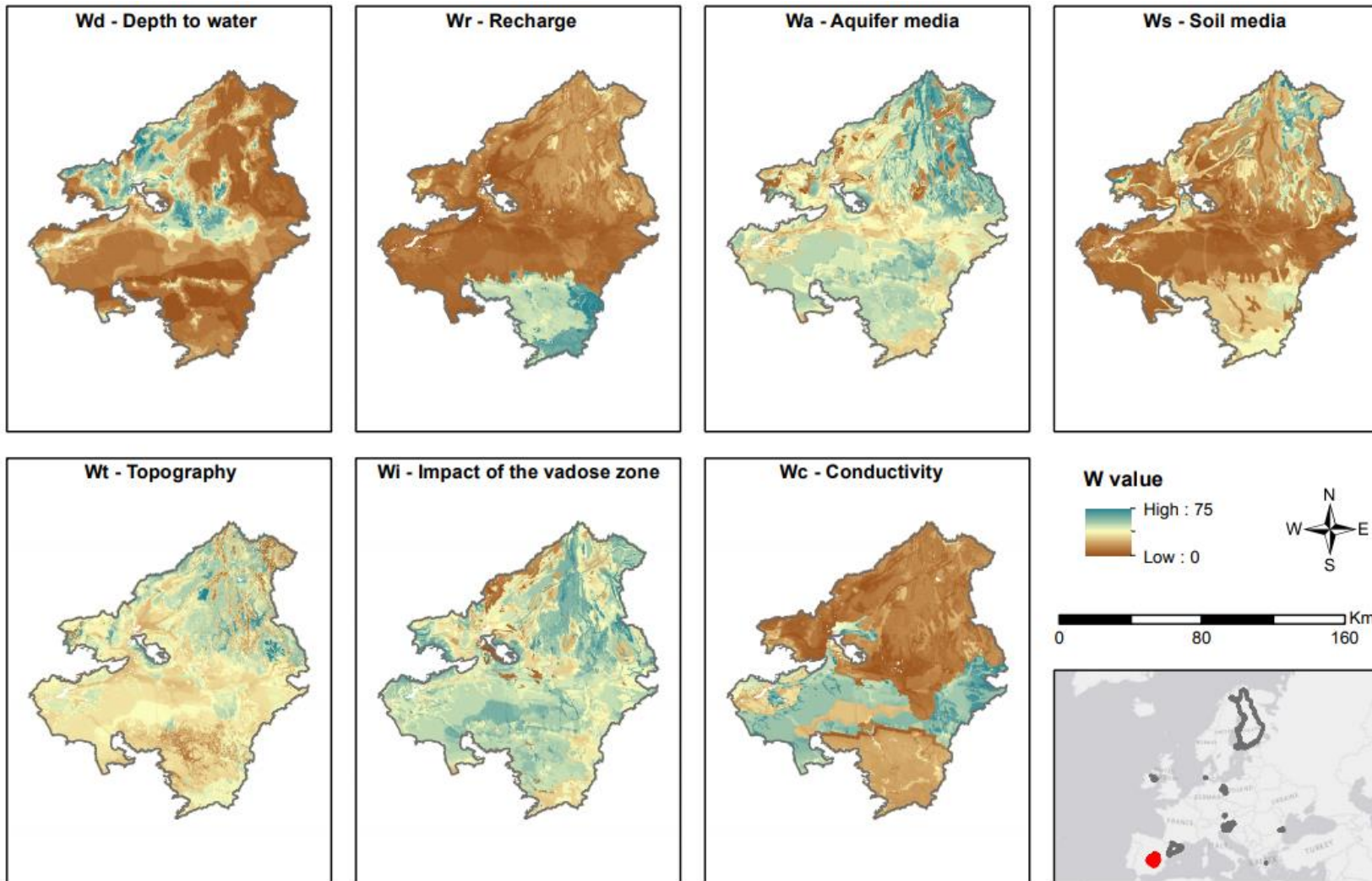
Pilot area Traun-Enns-Platte (Austria) – GBA

Spatial distribution of the effective Weight index (W)





Pilot area Upper Guadiana Basin (Spain) – IGME
Spatial distribution of the effective Weight index (W)





APPENDIX D: POWERBI REPORT SCREENSHOTS

Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe



Hydrogeological processes and geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystem (HOVER)

HOVER - WP7. Harmonized vulnerability to pollution mapping of the upper aquifer (HaVuPo)

Deliverable D.7-3

Results of the vulnerability assessment of the upper aquifer to pollution at pilot areas scale (statistics and sensitivity analysis)



Authors and affiliation: see list of authors
E-mail of lead authors: georgina.arno@icgc.cat
stefan.broda@bgr.de

Version: 25-05-2021

Introduction

Statistics

Sensitivity analysis

Correlation matrix

List of authors

References



Deliverable D.7-3

Results of the vulnerability assessment of the upper aquifer to pollution at pilot areas scale (statistics and sensitivity analysis)



INTRODUCTION

Project framework

This deliverable 7.3 is part of work package (WP) 7 named **Harmonized vulnerability to pollution mapping of the upper aquifer (HaVuPo)** in the overall project HOVER (Hydrogeological processes and Geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystems).

It was promoted by the ERA-NET GeoERA (Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe). In this European project, led by the German Geological Survey (BGR), 16 geological services from 13 different countries participated.

[Click here for more information about the HOVER project and access the reports deliverables D.7-1, D.7-2 and D.7-4](#)

Main goals

- WP7 of the GeoERA HOVER project deals with groundwater vulnerability assessment to pollution of the shallow upper aquifer
- Vulnerability across Europe was assessed applying the DRASTIC method (Aller, L, 1987) in 11 pilot areas and the COP method (Vías J.M., 2006) for karst systems in 5 pilot areas (see Figure 1). DRASTIC was also applied for the vulnerability assessment at a small scale to obtain a pan-European overview (not included in this D.7-3).
- Obtain comparable results for which input DRASTIC and COP layers were prepared based on the same ratings and weights.

[Input layers and vulnerability index maps are available at the EGD platform website](#)

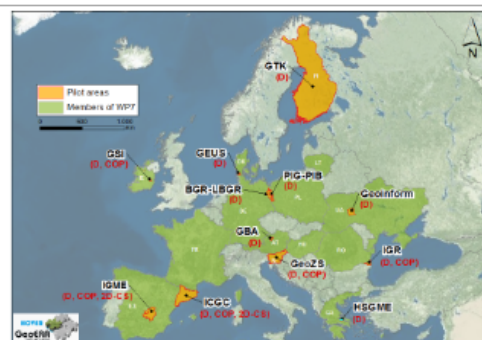


Figure 1: HOVER WP7 partners and demonstration pilot areas indicating the vulnerability assessment methods applied (D = DRASTIC and COP).

PILOT AREA	PARTICIPANT	COUNTRY	AREA [km2]	CELL SIZE [m]	DRASTIC	COP
Alluvial aquifer Atalanti	HSGME	Greece	54	50	X	-
Boyne	GSI	Ireland	2627	10	X	-
Catalonia	ICGC	Spain	32112	50	X	X
Cobadin-Mangalia	IGR	Romania	2192	50	X	X
Finland	GTK	Finland	338440	200	X	-
Lower Oder/Odra river German part	BGR-LBGR	Germany	4553	200	X	-
Lower Oder/Odra river Polish part	PIG-PIB	Poland	2821	200	X	-
Rockingham	GSI	Ireland	15	10	-	X
Slovenia	GeoZS	Slovenia	20273	100	X	X
Tønder	GEUS	Denmark	293	100	X	-
Traun-Enns-Platte	GBA	Austria	810	100	X	-
Upper Guadiana basin	IGME	Spain	14093	100	X	X
Total			418283			

Deliverable D.7-3 contents

- Results of the DRASTIC and COP methods are presented by performing a simple statistical analysis of the input data and the final vulnerability indexes for each pilot.
- For the vulnerability DRASTIC assessment, the results of a map single parameter removal sensitivity analysis are also shown to study the contribution of individual variables.
- Using PowerBI Desktop Application, results are shown in three dashboards (statistical analysis, sensitivity analysis and Pairwise correlation matrix) by using interactive visualizations and filters which allow end users to create their own reports and visualizations.

Deliverable D.7-3

Results of the vulnerability assessment of the upper aquifer to pollution at pilot areas scale (statistics and sensitivity analysis)



STATISTICAL ANALYSIS RESULTS

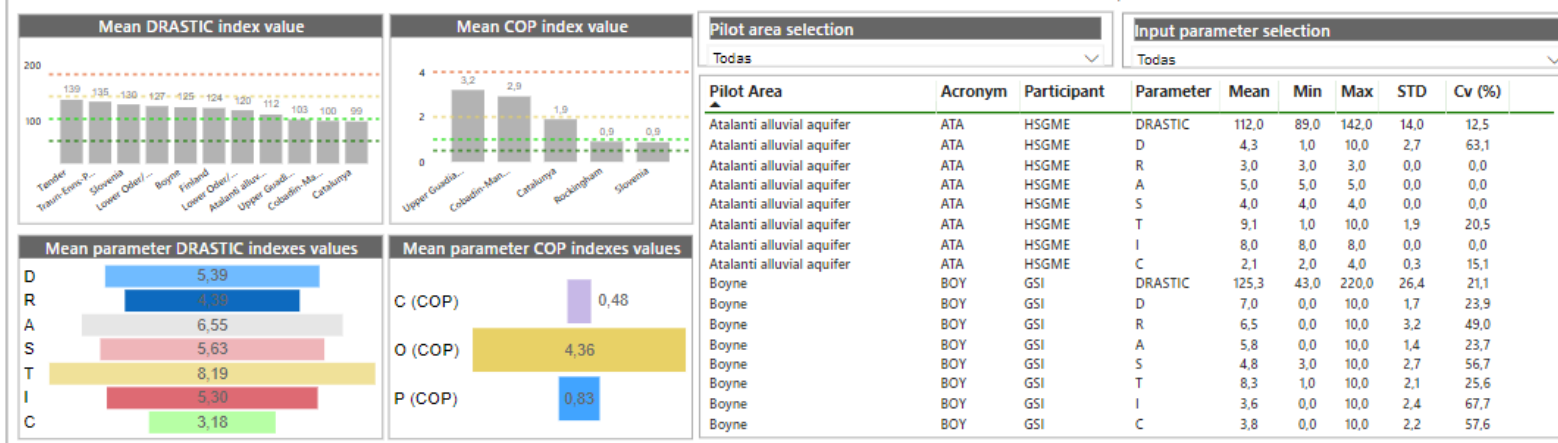


Statistical analysis of DRASTIC and COP results

GIS computation has been used to obtain the mean, median, minimum (Min), maximum (Max) values, the standard deviation (STD) and the variation coefficient (Cv) for each pilot and for both the final vulnerability DRASTIC and COP indexes and the input parameters index. For $Cv < 80\%$ the dataset could be classified as homogeneous and the mean values considered representative. The distribution of vulnerability classes (very low, low, moderate, high and very high) is also shown for both the results of the DRASTIC and COP methods. DRASTIC vulnerability class ranges: very low (<64), low (64-104), moderate (104-145), high (145-185), very high (>185). COP vulnerability class ranges: very low (<0.5), low (0.5-1), moderate (1-2), high (2-4), very high (4-15).

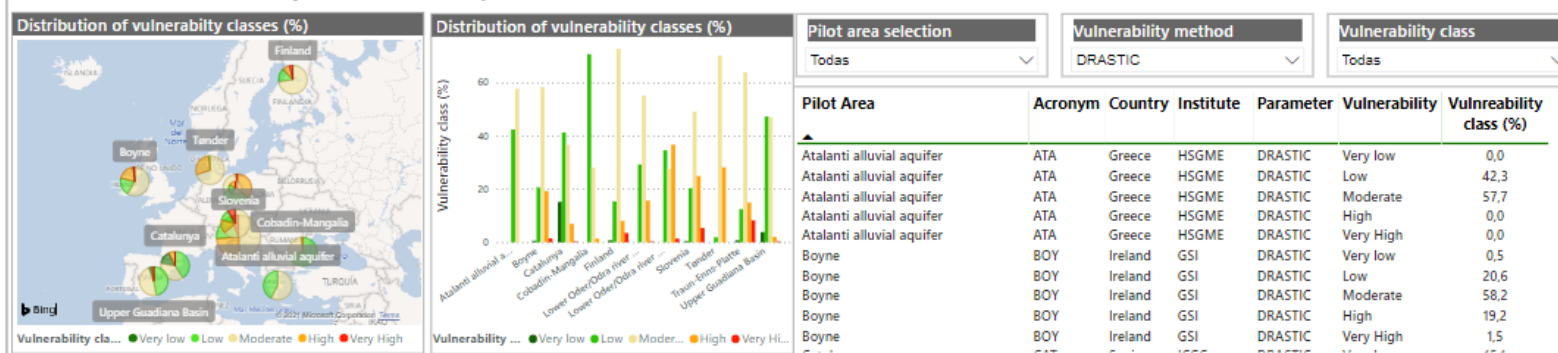
Main statistical variables

Pilot area and parameter selection is needed to visualize individual results



Distribution of vulnerability classes for each pilot (%)

Pilot area and method selection is needed to visualize individual results



Deliverable D.7-3

Results of the vulnerability assessment of the upper aquifer to pollution at pilot areas scale (statistics and sensitivity analysis)



SENSITIVITY ANALYSIS



Map single-parameter removal sensitivity analysis

This sensitivity analysis allows to study the contribution of individual variables (input parameters) one by one, on the resultant output of an analytical model. Two parameters have been calculated: a) the sensitivity index (S) and the effective parameter weight (W) (see Figure 2).

The method, based on Lodwick et al. (1990), Napolitano et al. (1996) and Adeyinka (2020), was developed for weighted sum intersection overlays and can be easily applied to the expression to compute DRASTIC indexes (not for COP).

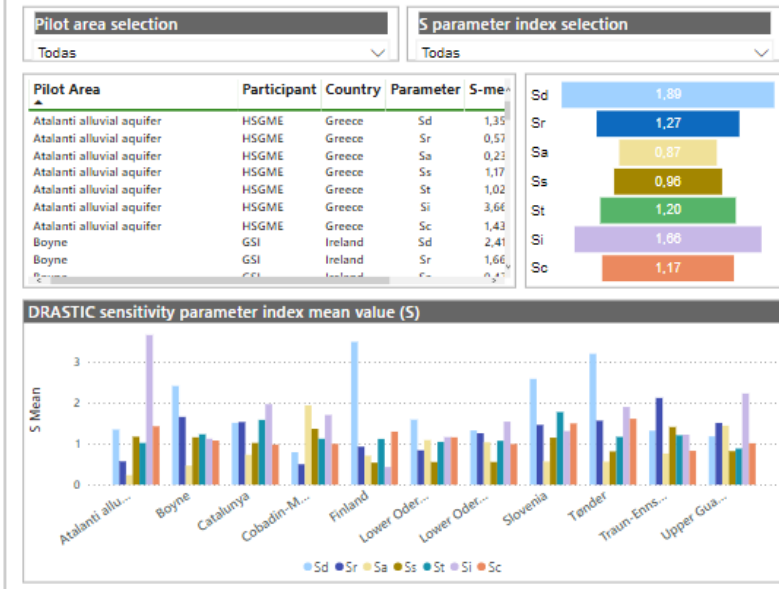
The sensitivity parameter index "S" is usually used to determine if all the parameters contribute equally and sometimes it is analyzed jointly with the "Pairwise correlation matrix" between the analysed parameters. The effective parameter weight (W) allow to compare the real weight that each parameter had in each area with the theoretical weight assigned by the DRASTIC method.

Sensitivity parameter index (S)	Effective parameter weight (W)
Identifies the sensitivity of the vulnerability towards removing one or more maps from the vulnerability analysis. It is computed as follows:	Contribution of each parameter in the final DRASTIC vulnerability index (effective weight). It is computed as follows:
$S = \left(\frac{V - \frac{V'}{n}}{V} \right) \times 100$	$W = 100P_r P_w / V$
S; sensitivity index measure expressed as variation index (for each parameter) V and V'; unperturbed and perturbed vulnerability N and n; number of parameters used to compute V and V' respectively	W; effective weight of each parameter P _r and P _w ; ratings and weight values of each parameter respectively V; the overall vulnerability index

Figure 2: Sensitivity analysis index (S) and effective parameter weight (W) definitions and formulas to perform the map single-parameter removal sensitivity analysis.

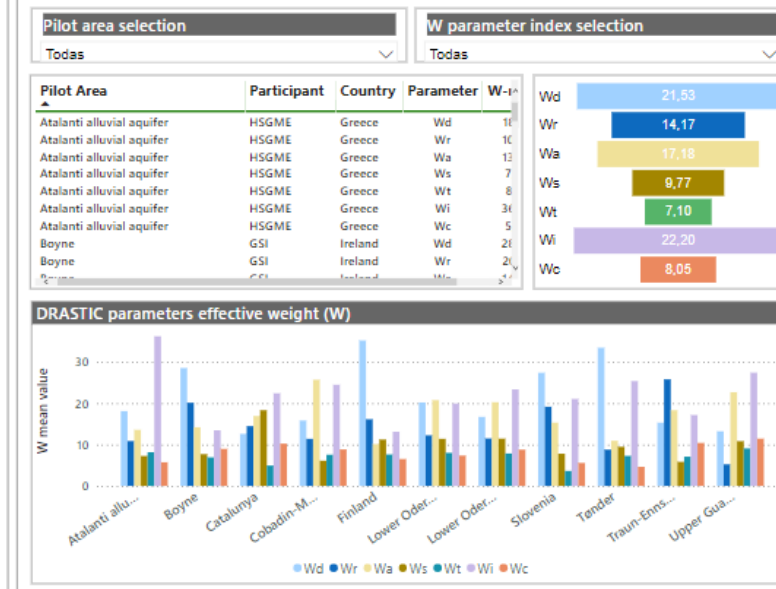
S - sensitivity parameter index

Sensitivity of the vulnerability towards removing one or more maps from the vulnerability analysis.



W - effective weight parameter index

Contribution of each parameter in the final DRASTIC vulnerability index.





Deliverable D.7-3

Results of the vulnerability assessment of the upper aquifer to pollution at pilot areas scale (statistics and sensitivity analysis)



PAIRWISE CORRELATION MATRIX



Pairwise DRASTIC parameters correlation matrix

The Pairwise correlation matrix measures the strength of the relationship between two variables (i.e. DRASTIC input parameters). Positive values indicates positive linear correlation between two variables, whereas negative values indicates negative linear correlation. The correlation is high if values approach 1.0 and -1.0. NaN values correspond to correlations which one or both variables are constant within the pilot area.

Pilot area selection
 All

Pilot Area	Acronym	Participant	Country	Parameter	D	R	A	S	T	I	C
Atalanti alluvial aquifer	ATA	HSGME	Greece	D	1.00						
Atalanti alluvial aquifer	ATA	HSGME	Greece	R	NaN	1.00					
Atalanti alluvial aquifer	ATA	HSGME	Greece	A	NaN	NaN	1.00				
Atalanti alluvial aquifer	ATA	HSGME	Greece	S	NaN	NaN	NaN	1.00			
Atalanti alluvial aquifer	ATA	HSGME	Greece	T	0.17	NaN	NaN	NaN	1.00		
Atalanti alluvial aquifer	ATA	HSGME	Greece	I	NaN	NaN	NaN	NaN	NaN	1.00	
Atalanti alluvial aquifer	ATA	HSGME	Greece	C	-0.18	NaN	NaN	NaN	-0.04	NaN	1.00
Boyne	BOY	GSI	Ireland	D	1.00						
Boyne	BOY	GSI	Ireland	R	0.06	1.00					
Boyne	BOY	GSI	Ireland	A	-0.01	-0.10	1.00				
Boyne	BOY	GSI	Ireland	S	0.07	-0.15	0.12	1.00			
Boyne	BOY	GSI	Ireland	T	0.07	-0.07	0.24	0.02	1.00		
Boyne	BOY	GSI	Ireland	I	0.03	0.36	0.12	0.36	-0.04	1.00	
Boyne	BOY	GSI	Ireland	C	-0.02	-0.01	0.58	0.10	0.16	0.08	1.00
Catalunya	CAT	ICGC	Spain	D	1.00						
Catalunya	CAT	ICGC	Spain	R	-0.23	1.00					
Catalunya	CAT	ICGC	Spain	A	0.08	0.26	1.00				
Catalunya	CAT	ICGC	Spain	S	-0.39	0.36	0.08	1.00			
Catalunya	CAT	ICGC	Spain	T	0.49	-0.40	0.00	-0.58	1.00		
Catalunya	CAT	ICGC	Spain	I	0.13	0.15	0.31	-0.01	0.12	1.00	
Catalunya	CAT	ICGC	Spain	C	0.26	0.01	0.44	-0.18	0.26	0.30	1.00
Cobadin-Mangalia	COB	IGR	Romania	D	1.00						
Cobadin-Mangalia	COB	IGR	Romania	R	-0.40	1.00					
Cobadin-Mangalia	COB	IGR	Romania	A	-0.23	0.35	1.00				
Cobadin-Mangalia	COB	IGR	Romania	S	0.08	0.11	0.06	1.00			
Cobadin-Mangalia	COB	IGR	Romania	T	0.00	-0.09	-0.04	-0.16	1.00		
Cobadin-Mangalia	COB	IGR	Romania	I	0.19	0.11	0.08	0.17	-0.17	1.00	
Cobadin-Mangalia	COB	IGR	Romania	C	0.24	-0.12	-0.05	-0.15	0.03	-0.01	1.00
Finland	FIN	GTK	Finland	D	1.00						
Finland	FIN	GTK	Finland	R	0.00	1.00					





Deliverable D.7-3

Results of the vulnerability assessment of the upper aquifer to pollution at pilot areas scale (statistics and sensitivity analysis)



LIST OF AUTHORS



Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) – German Federal Institute for Geosciences and Natural Resources

Broda, S., Duscher, K., Günther, A., Reichling, J.

Bureau de Recherches Géologiques et Minières (BRGM) – French Geological Survey

Schomburgk, S.

Geologische Bundesanstalt (GBA) – Geological Survey of Austria

Schubert, G., Uhmann, A., Bottig, M., Elster, D., Berka, R.

Geološki Zavod Slovenije (GeoZS) – Geological Survey of Slovenia

Cerar, S., Meglič, P.

De Nationale Geologiske Undersøgelser for Danmark og Grønland (GEUS) – Geological Survey of Denmark and Greenland

Voutchkova, D., Schullehner, J., Hansen, B.

Geological Survey of Ireland (GSI)

Hickey, C., Hunter Williams, T., Bishop, H.

Geologian Tutkimuskeskus (GTK) – Geological Survey of Finland

Luoma, S., Ikonen, J.

Hellenic Survey of Geology & Mineral Exploration (HSGME)

Kontodimos, K., Lappas, I.

Institut Cartogràfic i Geològic de Catalunya (ICGC) – Cartographic and Geological Institute of Catalonia

Arnó, G., Conesa, A., Herms, J.I.

Instituto Geológico y Minero de España (IGME) – Geological Survey of Spain

Baena-Ruiz, L., Pulido-Velázquez, D.

Institutul Geologic al României (IGR) – Geological Institute of Romania

Persa, D., Mercan, A.

Landesamt für Bergbau, Geologie und Rohstoffe Brandenburg (LBGR) – Brandenburg State Office for Mining, Geology and Raw Materials

Janetz, S.

Lietuvos Geologijos Tarnyba prie Aplinkos Ministerijos (LGT)

Arustienė, J.

Magyar Bányászati és Földtani Szolgálat (MBFSZ) – Mining and Geological Survey of Hungary

Gál, N.E.

Państwowy Instytut Geologiczny - Państwowy Instytut Badawczy (PIG-PIB) – Polish Geological Institute - National Research Institute

Nidental, M., Jarmułowicz-Siekiera, M.





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