A CITRINI, C CAMERA, F ALBORGHETTI, GP BERETTA

The COPA+K method: an index-based approach for the karst groundwater vulnerability assessment. The Valseriana springs case (Northern Italy)

GROUNDWATER RESOURCE AND SUSTAINABILITY

1ST DECEMBER 2021

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National Meeting on Hydrogeology
Napoli 2021

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STUDY GOALS

- apply two classical index-based methods (**EPIK and COP**) to assess the vulnerability of the study area;

- define an integrative methodology that represents the conditions of **intrinsic vulnerability** of the middle Valseriana (Northern Italy);

- delineate an approach that does not require a lot of data and expensive investigations available in order to make it applicable in mountain contexts: **COPA+K method**;

- validate this new proposed approach through **isotopic data**.

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ORIGINAL ARTICLE

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Karst groundwater vulnerability assessment: application of an integrative index-based approach to main catchments of middle Valseriana springs (Northern Italy)

Andrea Citrini[1] · Corrado A. S. Camera[1] · Francesca Alborghetti[1] · Giovanni Pietro Beretta[1]

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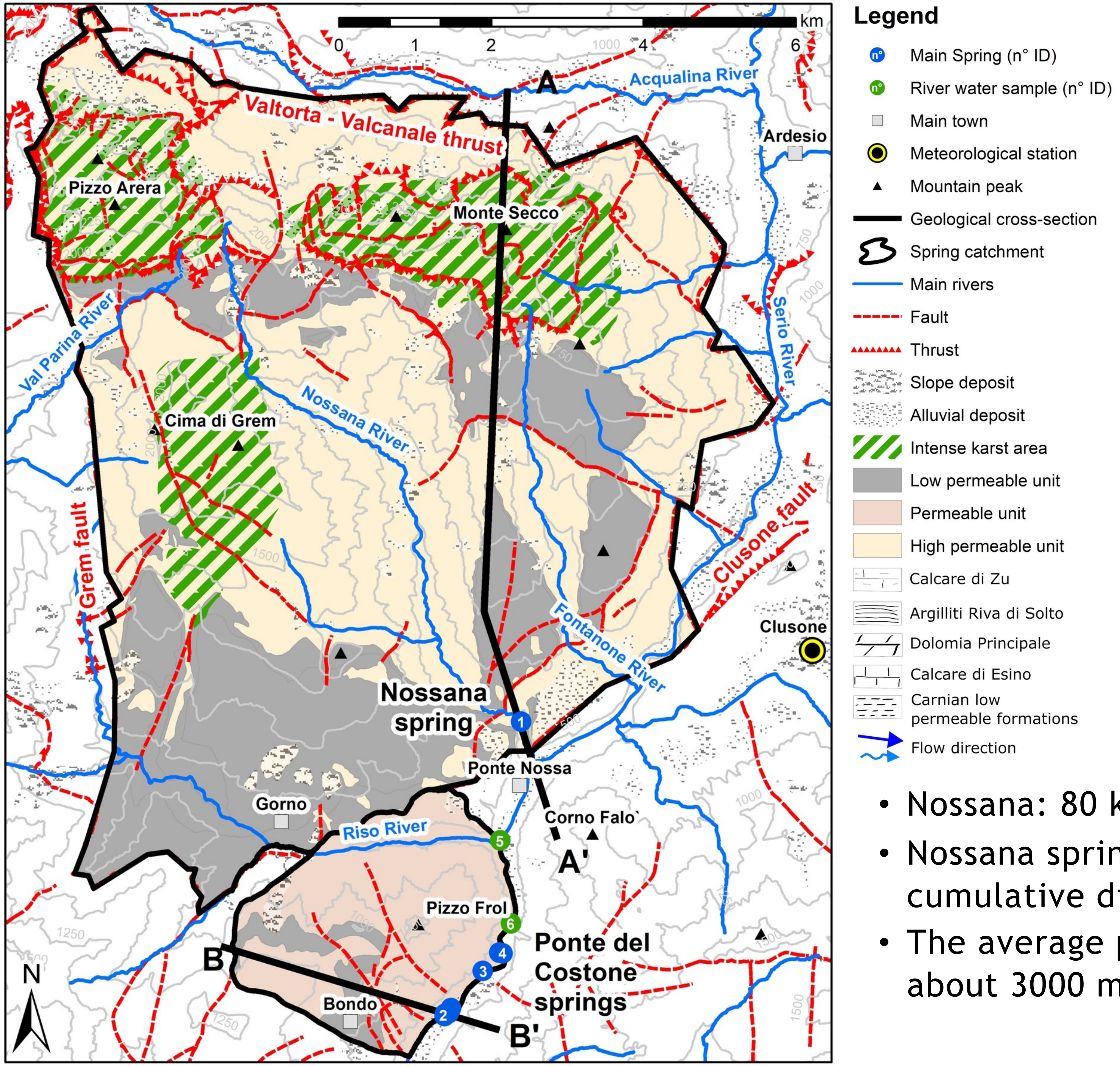
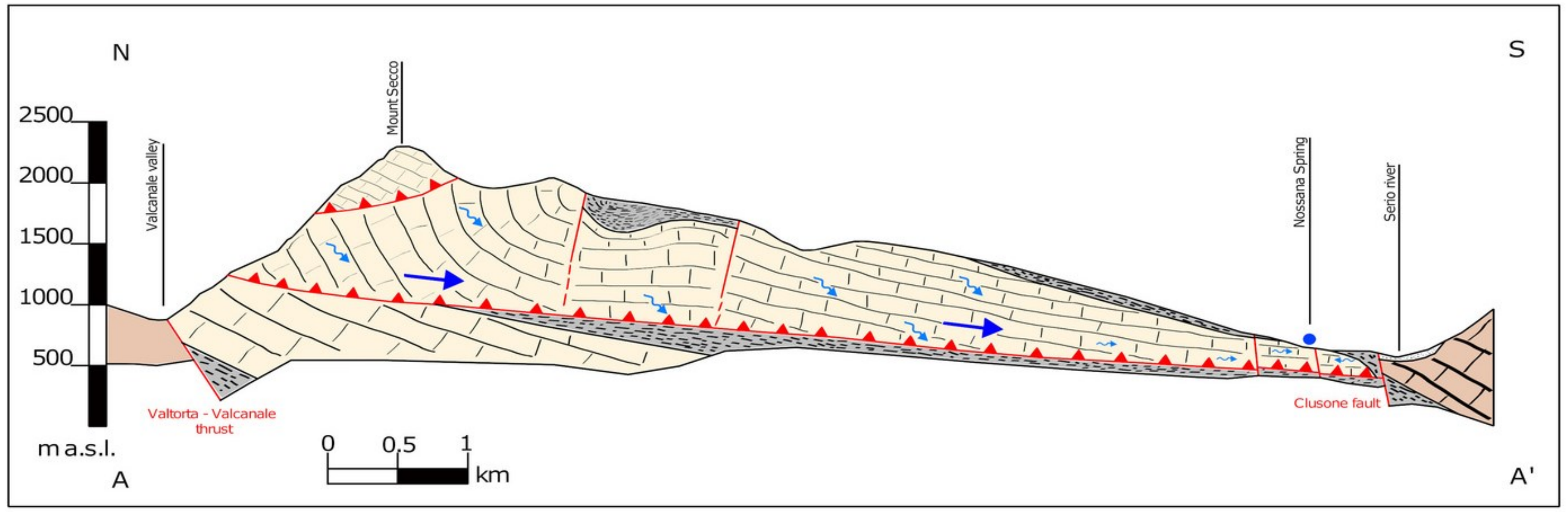
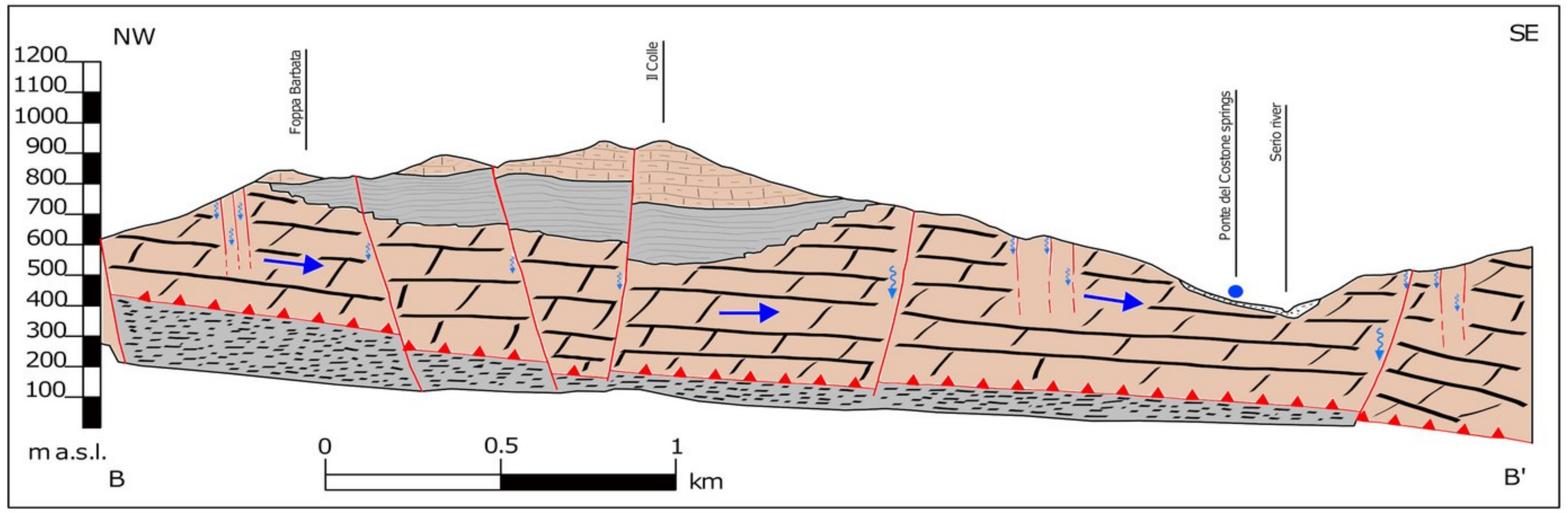
STUDY AREA







- Nossana: 80 km² Ponte del Costone: 10 km²
- Nossana spring discharge 0.5 - 18 m³s-1, the Ponte del Costone cumulative discharge 0.15 - 0.45 m³s-1
- The average precipitation is close to 2000 mm/year with peaks of about 3000 mm/year (Ceriani et al., 2000)

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AVAILABLE DATA

Geological data

The geological, geomorphological, and elevation data of the area were obtained from the Geoportale della Regione Lombardia (Regione Lombardia, 2020)

Karst network development

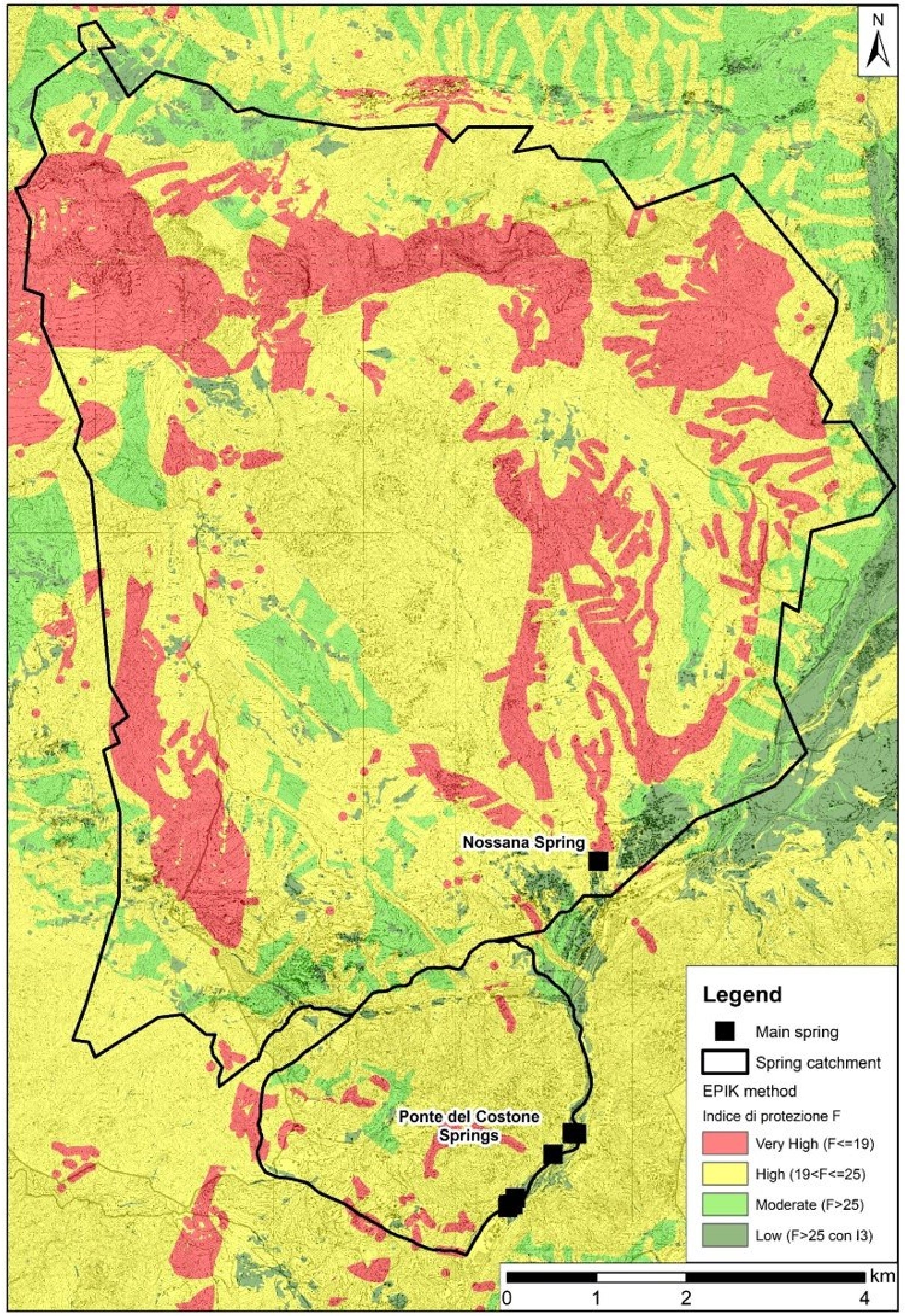
For the development of the karst network and the evaluation of the propensity to karstification of the area, the work of FSLo (2011) was exploited

Meteorological data

The meteorological data were obtained from the open-data section of the Environmental Regional Agency (ARPA Lombardia, 2020)

Isotopic data

Isotopic data obtained from the water analysis of the study area carried out (2018 - 2019) by the Università degli Studi di Milano and UniAcque S.p.a. The stable isotope data ($\delta^{18}O$ and $\delta^{2}H$) related to the waters of the springs and Serio river



COP method

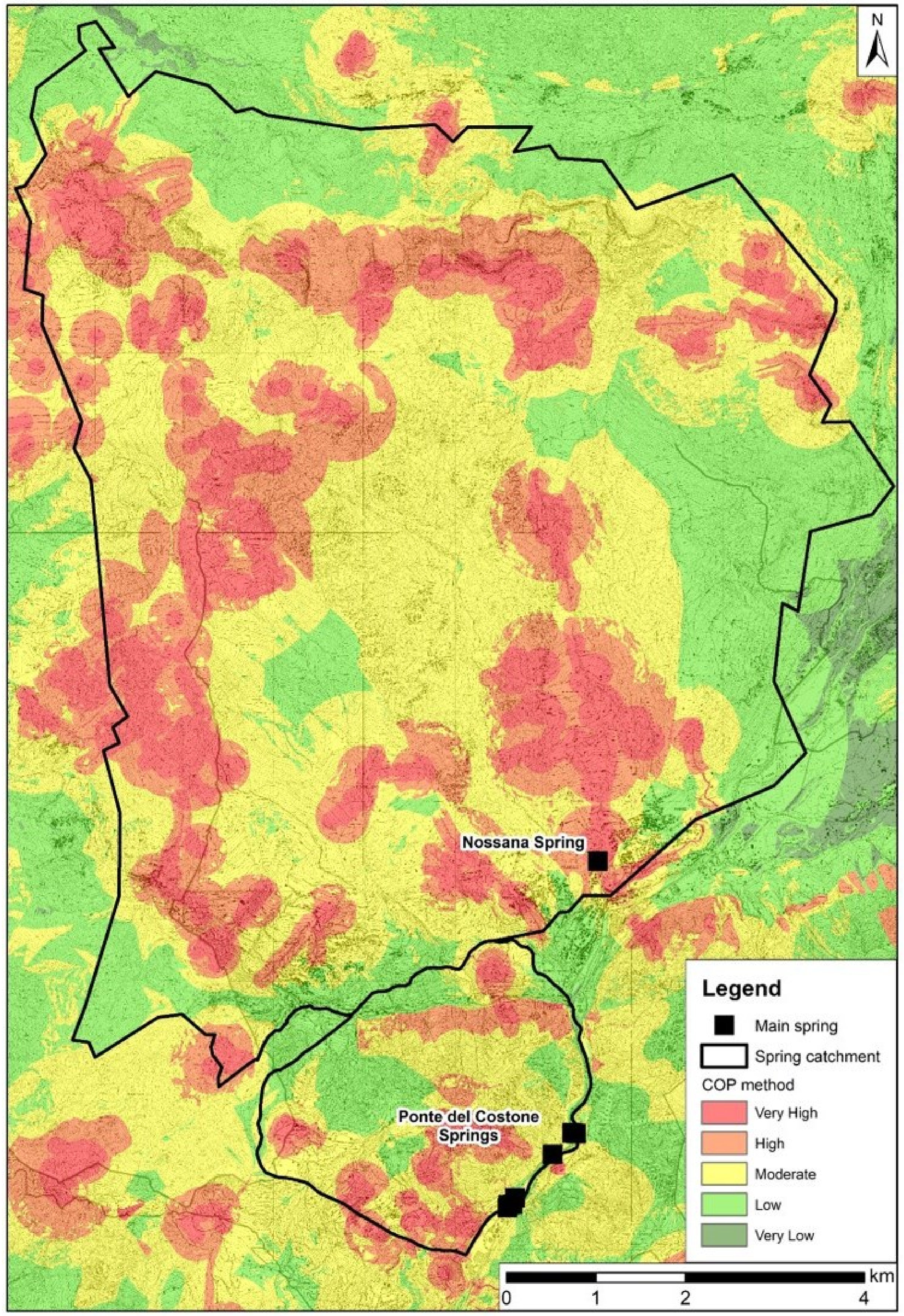
(Vías et al., 2006)

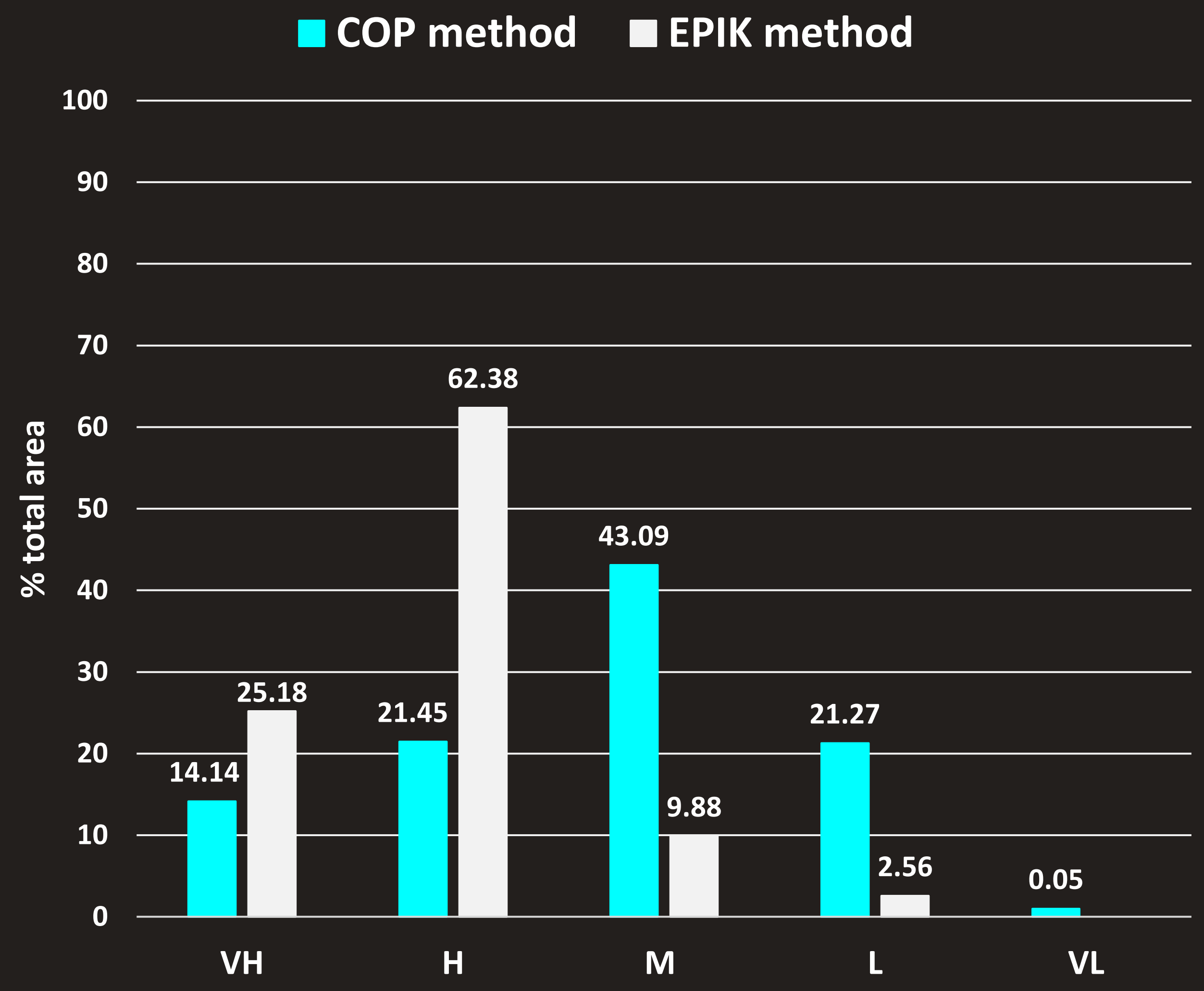
C - Concentration of flow
O - Overlaying layers
P - Precipitation

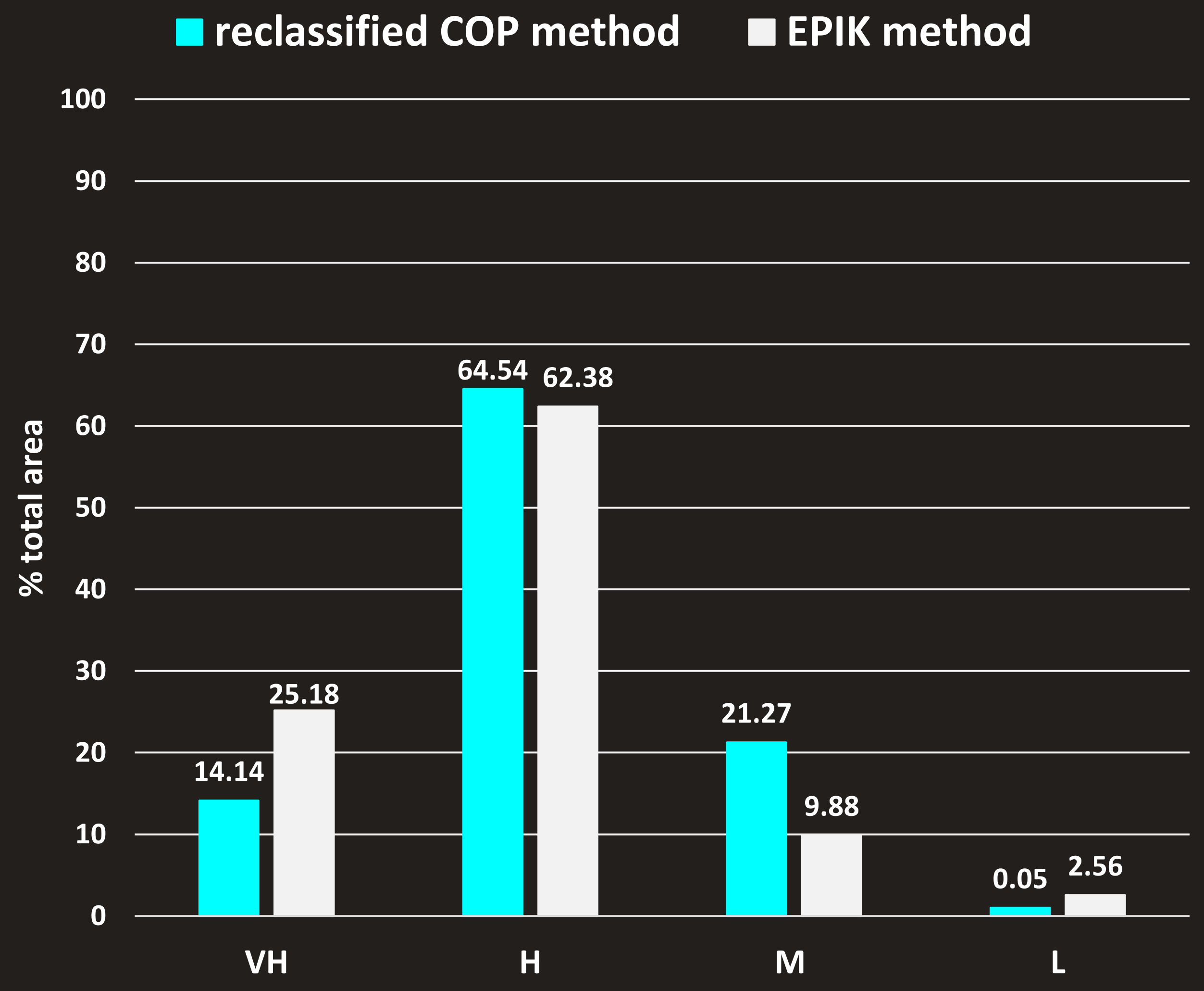
EPIK method

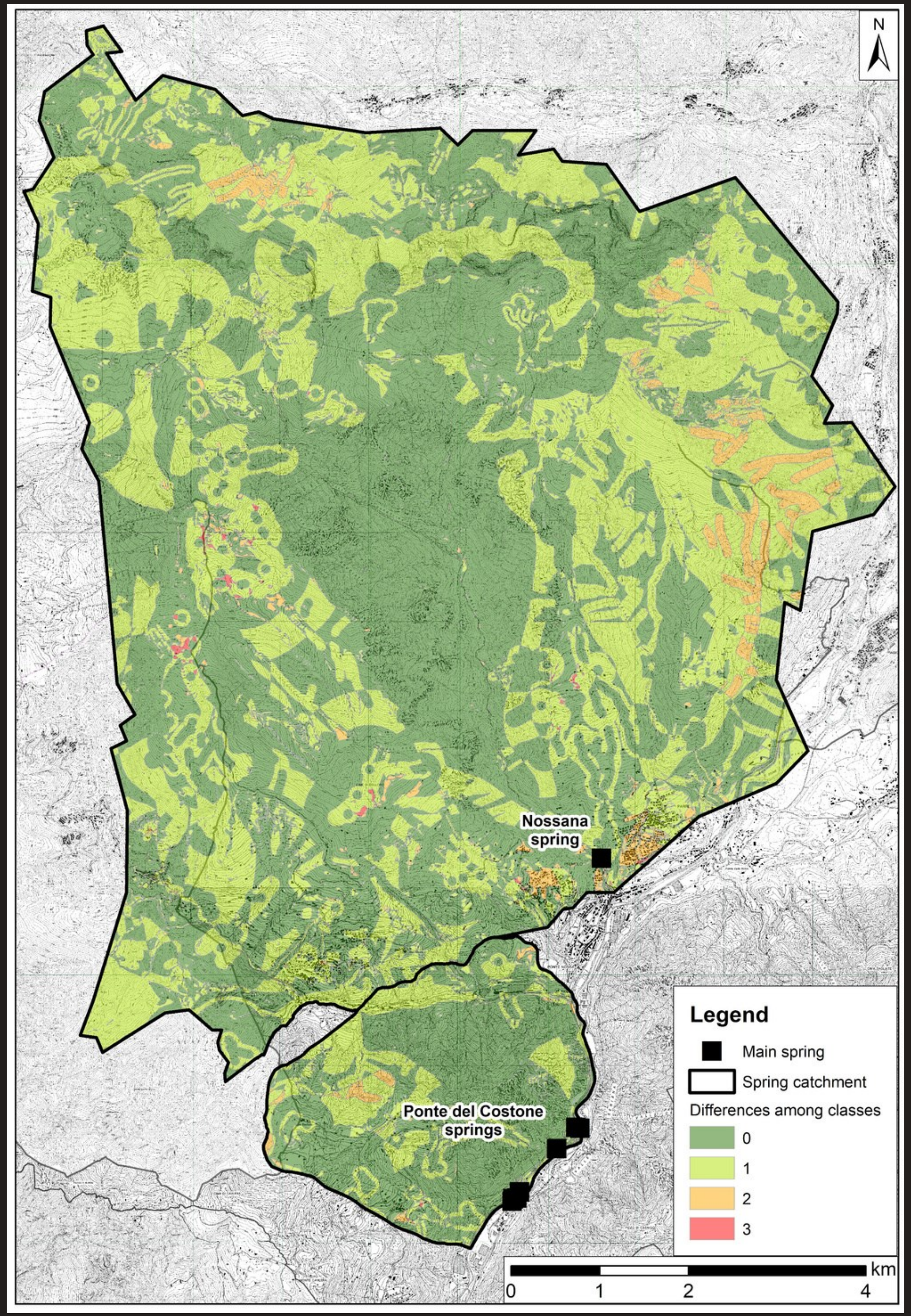
(Doerfliger et al., 1999)

E - Epikarst development
P - Protective cover conditions
I - Infiltration conditions
K- Karst network development









COMPARISON OF CLASSICAL METHODS

THE H AND M VULNERABILITY AREAS OF THE COP GENERALLY CORRESPOND TO THE H VULNERABILITY AREAS OF EPIK, WHILE THE L AND VL VULNERABILITY AREAS OF COP ARE USUALLY EQUIVALENT TO THE M AND L VULNERABILITY AREAS OF EPIK

By combining the H and M vulnerability classes of the COP method in a single H vulnerability class, the results of the two methods become more similar.

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C CONCENTRATION OF FLOW

O OVERLAYING LAYERS

P PRECIPITATION

A ASSOCIATION BETWEEN MAIN DISCONTINUITIES AND THEIR DISTANCE TO SPRING

K KARST NETWORK DEVELOPMENT

COPA+K method

C x O x P x A + K

A FACTOR

ASSOCIATION BETWEEN DISCONTINUITIES AND THEIR DISTANCE TO SPRING

A FACTOR (Association between main discontinuities and their distance to spring)

Buffer 200 m around the main discontinuities

↓

Distance to spring*	Value
Buffer from spring r= ½ catchment area (n=2)	0.2
Buffer from spring r= catchment area (n=1)	0.5
Rest of the catchment area	0.8
Rest of the area	1

$$*\text{r buffer} = \sqrt{\frac{catchment\ area/n}{\pi}}$$

↓

A SCORE	Reduction of protection
0 – 0.2	Very High
0.2 – 0.5	High
0.5 – 0.8	Moderate
0.8 – 1	Low

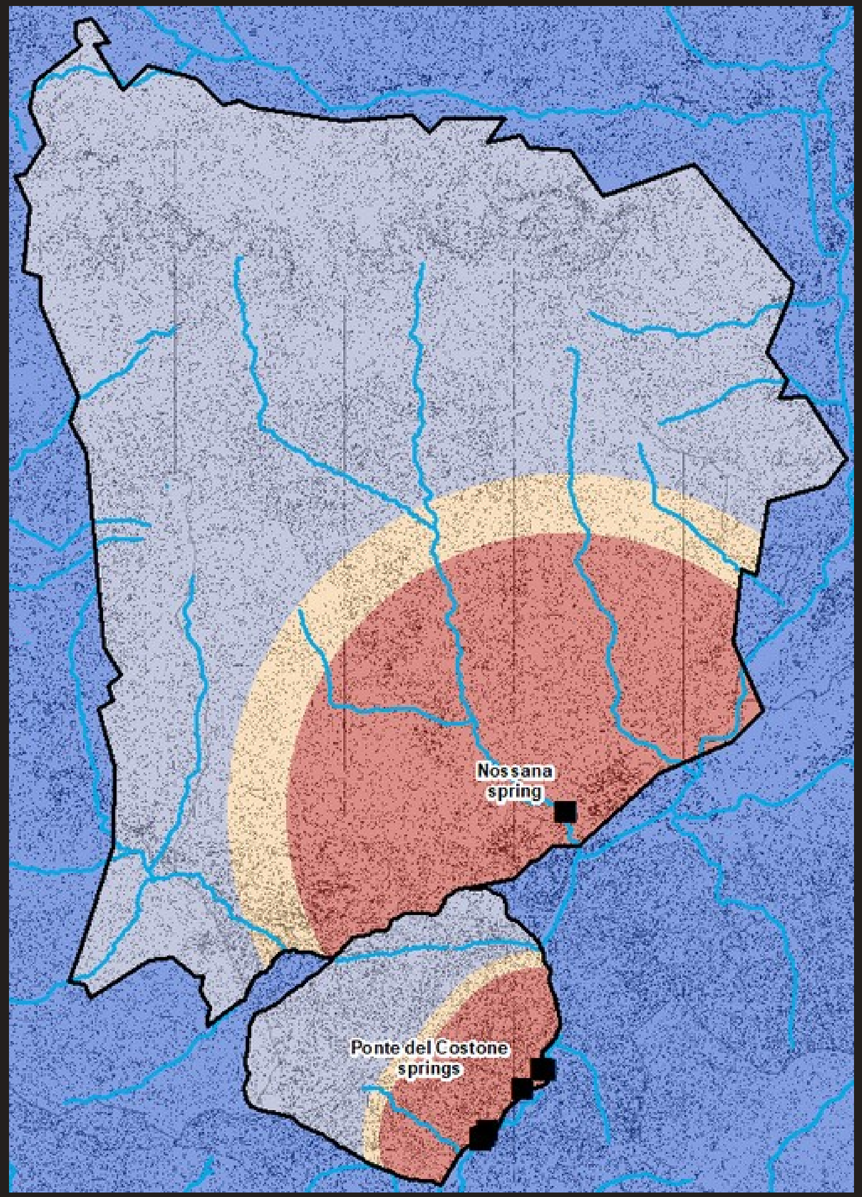
→ **A MAP**

COPA+K index

COPA+K index = C SCORE · O SCORE · P SCORE · A SCORE + K SCORE

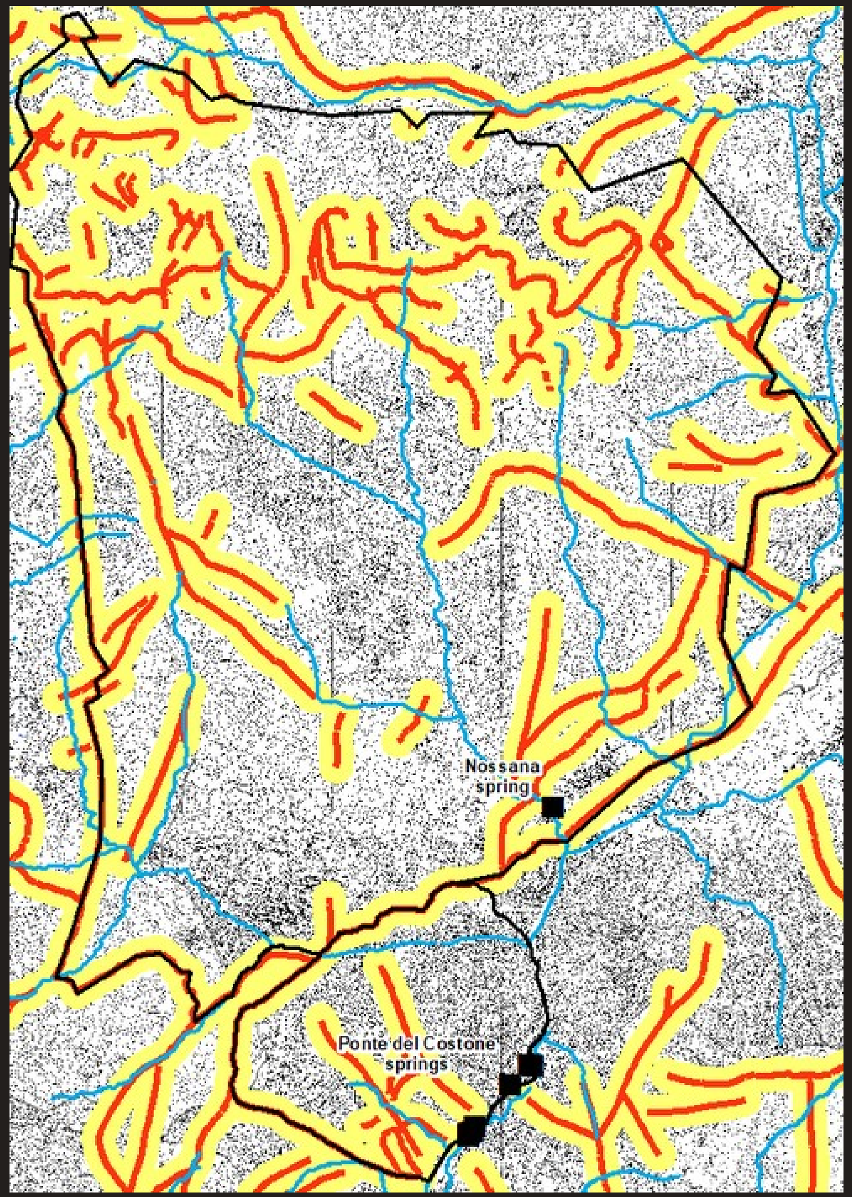
COPA+K INDEX	Reduction of protection
0 – 0.5	Very High
0.5 – 1	High
1 – 2	Moderate
2 – 4	Low
4 – 17	Very Low

→ **COPA+K MAP**

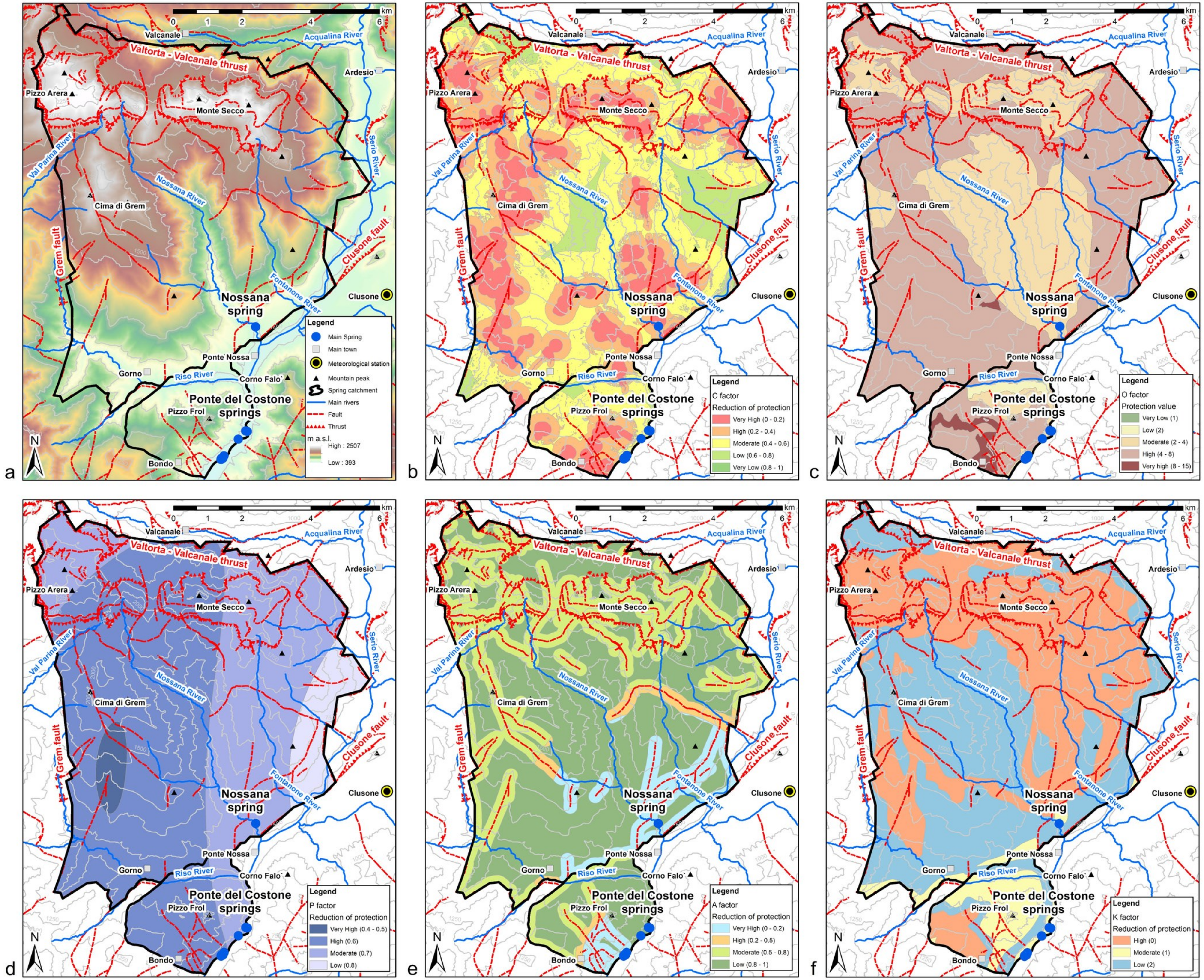


Distances to spring

$$r\ buffer = \sqrt{\frac{catchment\ area/n}{\pi}}$$



Buffer of 200 m around the main discontinuities



FACTORS

- a) Digital Elevation Model
- b) **Concentration of flow**
- c) **Overlaying layers**
- d) **Precipitation**
- e) **Association between discontinuities and their distance to spring**
- f) **Karst network development**

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O FACTOR (Overlying layers)

[O_S] Soil

Clayey	> 30 % Clay
Silty	> 70 % Silt
Sandy	Sand > 70 % Clay ≤ 15 %
Loam	Rest

Thickness \ Texture	Clayey	Silty	Loam	Sandy
> 1 m	5	4	3	2
0.5 – 1 m	4	3	2	1
< 0.5 m	3	2	1	0*

*Also 0 when no soil is present

→ [O_S]

[O_L] Lithology

Lithology and fracturation	Value
Clays	1500
Silts	1200
Marls and no – fissured metapelites and igneous rocks	1000
Marly limestones	500
Fissured metapelites and igneous rocks	400
Cemented or no – fissured conglomerates amd breccias	100
Sandstones	60
Scarcely cemented or fissured conglomerates and breccias	40
Sands and gravels	10
Permeable basalts	5
Fissured carbonated rocks	3
Karstic rocks	1

Thickness of each layer

Confining conditions (cn)	Value
Confined	2
Semi - confined	1.5
Unconfined	1

(ly) (m) (cn)

Layer index Σ (ly · m)

Layer index	Value
0 – 250	1500
250 – 1000	1200
1000 – 2500	1000
2500 – 10000	500
> 10000	400

Value Layer index · cn = [O_L]

O SCORE	Protection value
1	Very Low
2	Low
2 – 4	Moderate
4 – 8	High
8 – 15	Very High

O SCORE = [O_S] + [O_L]

→ O MAP

P FACTOR (Precipitation)

[P_Q] Quantity

Rainfall* (mm/year)	Value
> 1600	0.4
1200 – 1600	0.3
800 – 1200	0.2
400 – 800	0.3
< 400	0-4

*Average rainfall for wet years. Wet year ≥ (0.15 · x) + x

[P_I] Temporal distribution

$$\text{Temporal distribution} = \frac{P\ (mm/year)}{n°\ rainy\ days}$$

Temporal distribution (mm/day)	Value
< 10	0.6
10 – 20	0.4
> 20	0.2

P SCORE = [P_Q] · [P_I]

P SCORE	Reduction of protection
0.4 – 0.5	Very High
0.6	High
0.7	Moderate
0.8	Low
0.9 – 1	Very Low

→ P MAP

Vias et al., 2006

C FACTOR (Concentration of flow)

Shallow hole and recharge area

Distance to shallow hole (dh)

Distance to shallow hole (m)	Value	Distance to shallow hole (m)	Value
≤ 500	0	3000 – 3500	0.6
500 – 1000	0.1	3500 – 4000	0.7
1000 – 1500	0.2	4000 – 4500	0.8
1500 – 2000	0.3	4500 – 5000	0.9
2000 – 2500	0.4	> 5000	1.0
2500 – 3000	0.5		

Slope and vegetation (sv)

Slope	Vegetation cover	Value
≤ 8 %	-	1
8 %-31 %	High	0.95
	Low	0.9
31 %-76 %	High	0.85
	Low	0.8
>76 %	-	0.75

C SCORE = dh · ds · sv

Distance to sinking stream (ds)

Distance to sinking streams (m)	Value
< 10	0
10 – 100	0.5
> 100	1*

*Also 1 when no sinking streams is present

C SCORE	Reduction of protection
0 – 0.2	Very High
0.2 – 0.4	High
0.4 – 0.6	Moderate
0.6 – 0.8	Low
0.8 – 1.0	Very Low

→ C MAP

K* FACTOR (Karst network development)

From EPIK approach*

*Doerfliger, 1999

Information on karst network	K	K SCORE	Reduction of protection
Well developed karst network	K_1	0	High
Poorly developed karst network	K_2	1	Moderate
Mixed or fissured aquifer	K_3	2	Low

→ K MAP

Andreo et al., 2009

A FACTOR (Association between main discontinuities and their distance to spring)

Buffer 200 m around the main discontinuities

Distance to spring*	Value
Buffer from spring r= ½ catchment area (n=2)	0.2
Buffer from spring r= catchment area (n=1)	0.5
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Rest of the area	1

$$*r\ buffer = \sqrt{\frac{catchment\ area/n}{\pi}}$$

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→ A MAP

COPA+K index

COPA+K index = C SCORE · O SCORE · P SCORE · A SCORE + K SCORE

COPA+K INDEX	Reduction of protection
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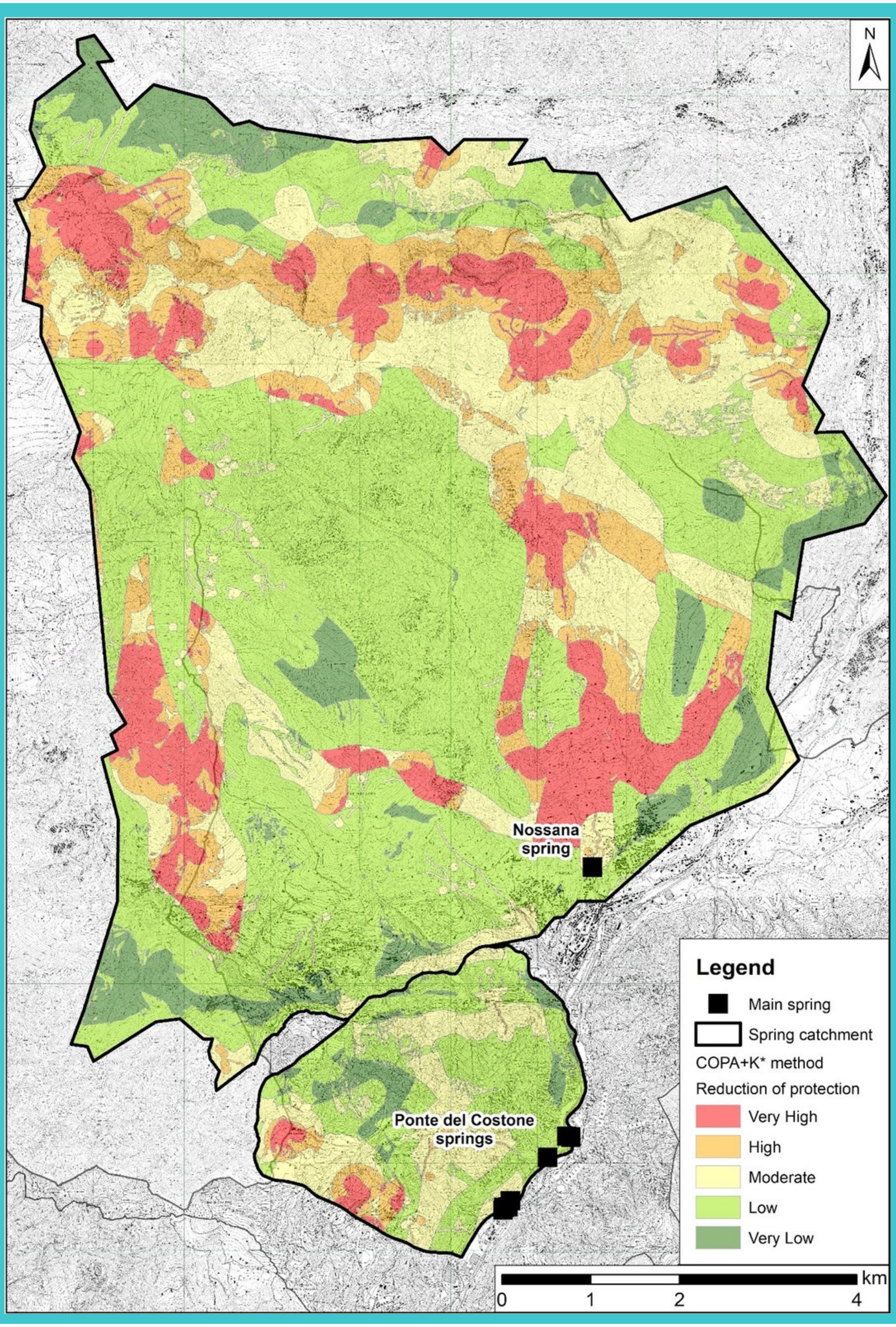
4 – 17	Very Low

→ COPA+K MAP



35.6% to 23.6%

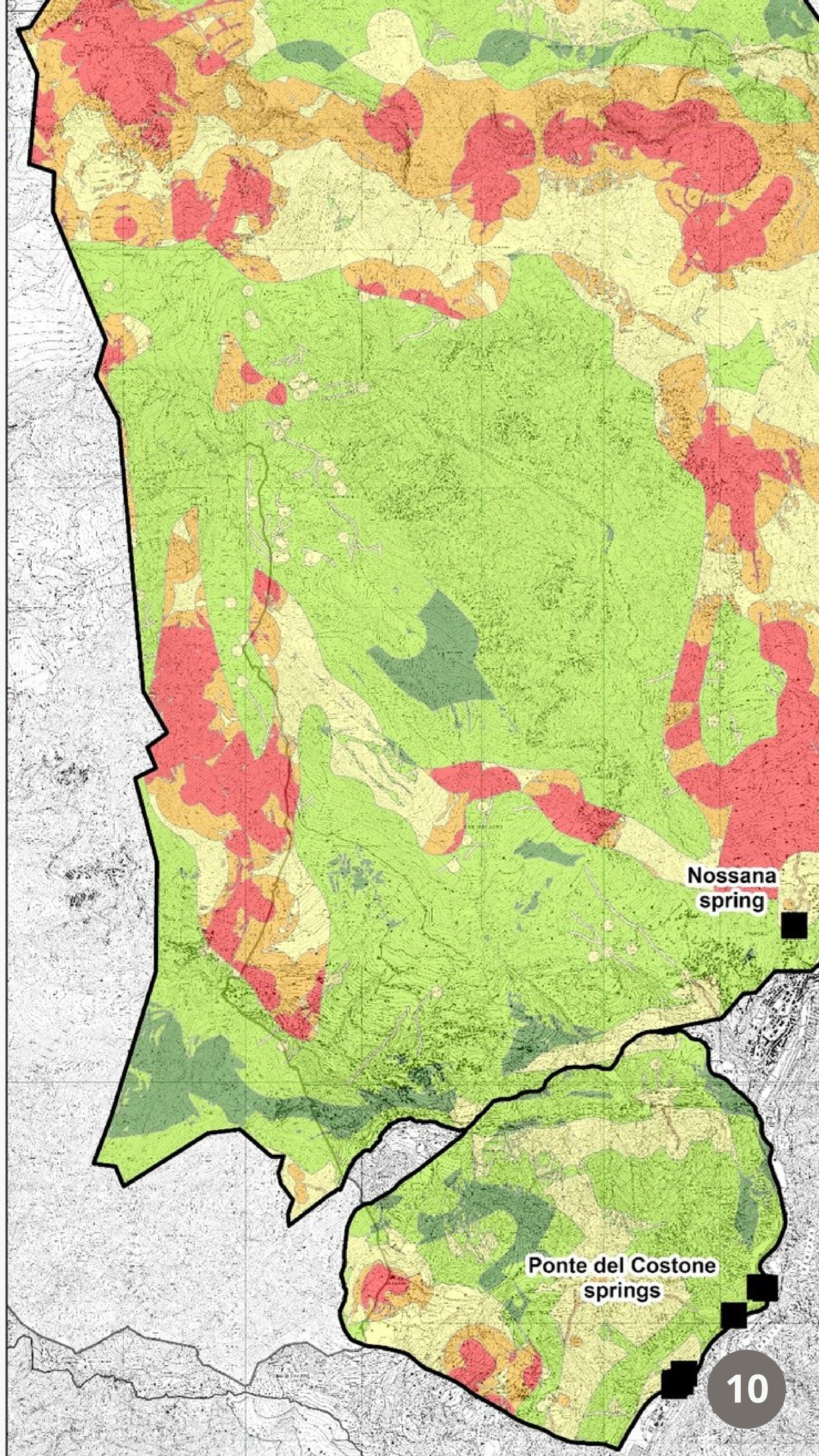
CONSIDERING THE MOST VULNERABLE CLASSES (VH AND H), THE VALUES MOVE FROM 35.6% (COP) TO 23.6% (COPA+K) OVER THE WHOLE STUDY AREA.

The COPA+K method allows the identification of more restricted areas than COP.

+12.3%

THE DIFFERENCE IN AREAL PERCENTAGE INCREASES BY 12.3% BETWEEN THE SYSTEMS, EMPHASIZING THE GREATER SUSCEPTIBILITY OF THE NOSSANA ONE

COPA+K made possible to better differentiate the areas of greatest vulnerability in the two considered catchments



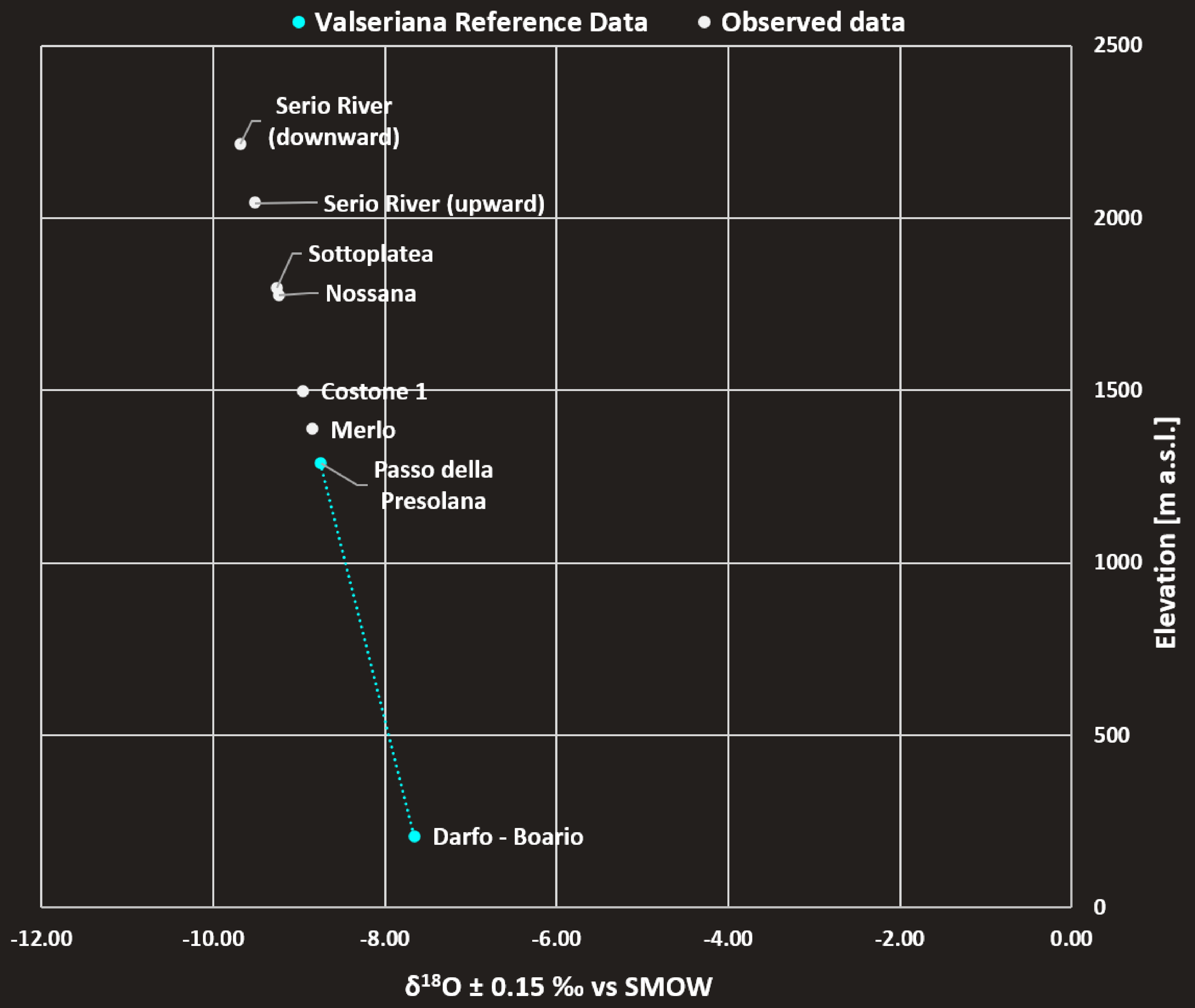
VALIDATION MAP PROCESS

- From the relationship given by the **local isotopic line**, it was possible to estimate the mean elevation of recharge areas of the Nossana and Ponte del Costone springs;
- Mean annual precipitation data from 10 ARPA meteorological stations were interpolated to obtain a gridded (50 m x 50 m) **altitude-dependent precipitation distribution** --> **TPS and IDW**;
- The **elevation values** of the high vulnerability areas and related **precipitation amounts** were extrapolated from the DTM and the precipitation distribution maps;
- After performing a **weighted average**, the mean elevations of the high vulnerability areas were obtained for the Nossana and Ponte del Costone catchments to be compared with the results of isotopic correlation.

MEAN RECHARGE ELEVATIONS

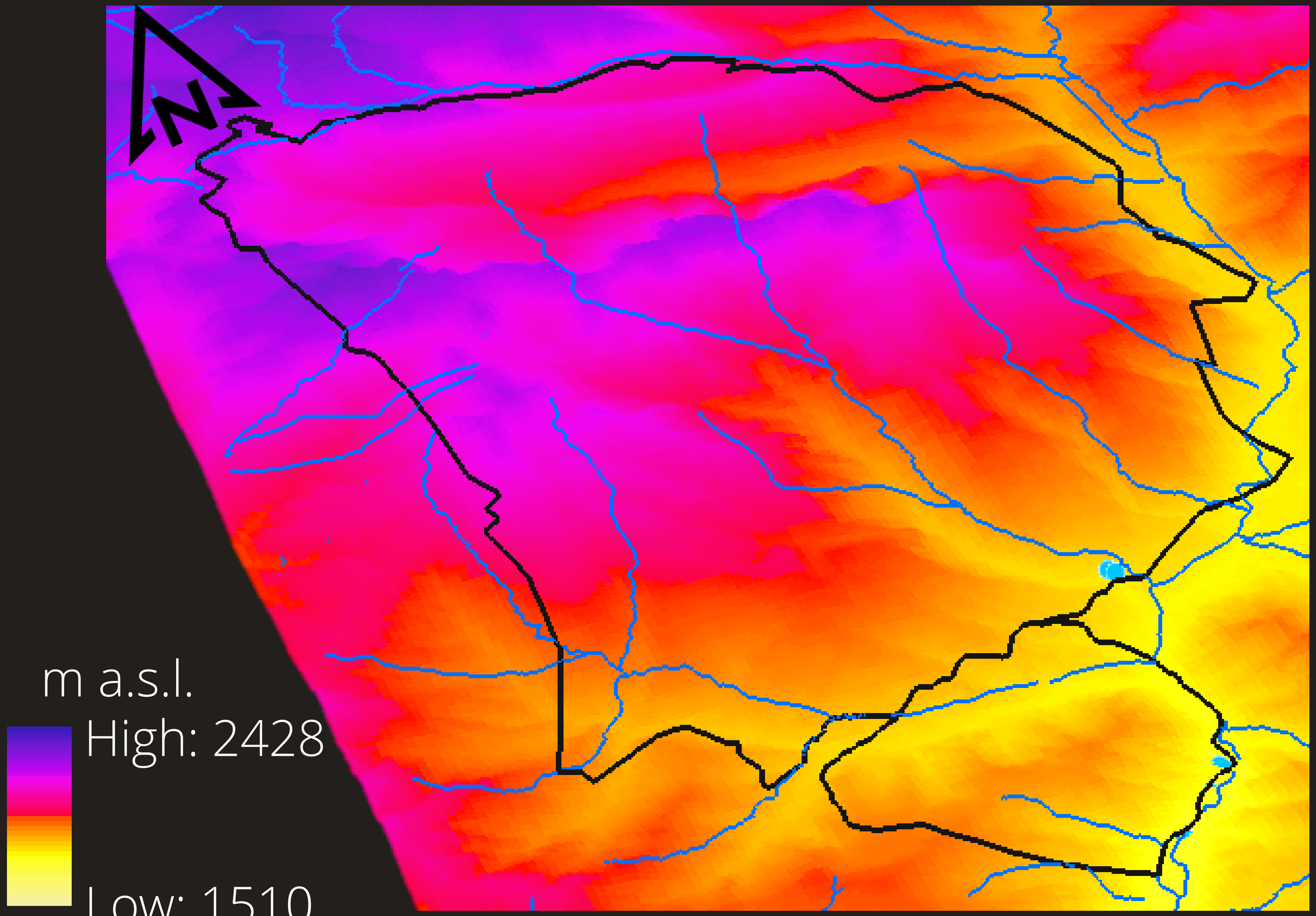
estimated by correlating $\delta^{18}O$ values with elevation

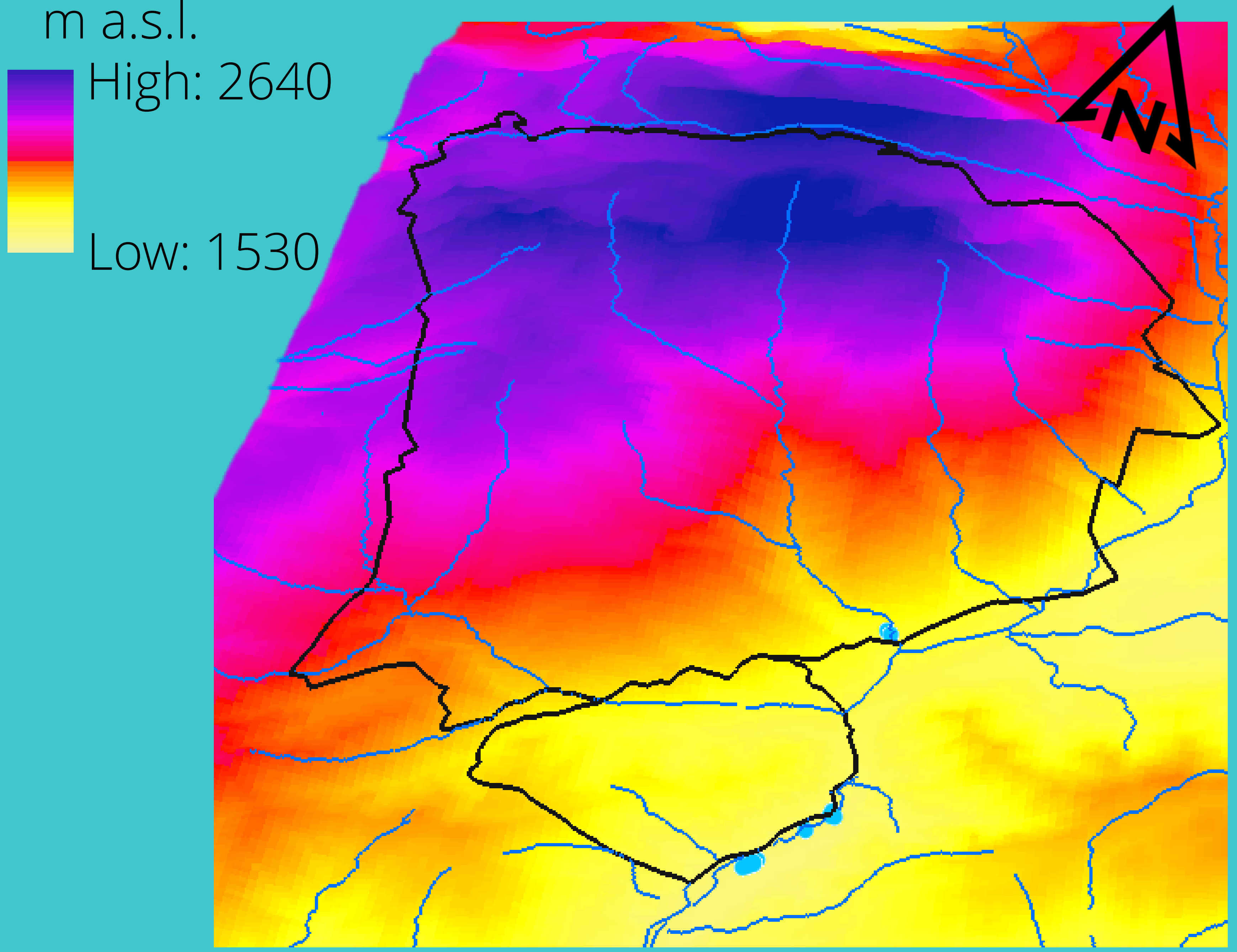
Site Name	Elevation [m a.s.l.]	$\delta^{18}O \pm 0.15$ ‰ vs SMOW	Estimate recharge area elevation [m a.s.l.]
Observed data			
Nossana	474	-9.24	1776
Costone 1	427	-8.96	1498
Merlo	435	-8.85	1389
Sottoplatea	433	-9.26	1796
Serio River (upward)	454	-9.68	2213
Serio River (downward)	431	-9.51	2044
Valseriana reference data			Isotopic gradient
Passo della Presolana	1290	-8.75	0.1/100 meters
Darfo - Boario	208	-7.66	
Equation of the linear correlation line		Elevation = -992.66 $\delta^{18}O$ -7395.8	



From Longinelli and Selmo, 2003

THIN PLATE SPLINE TPS





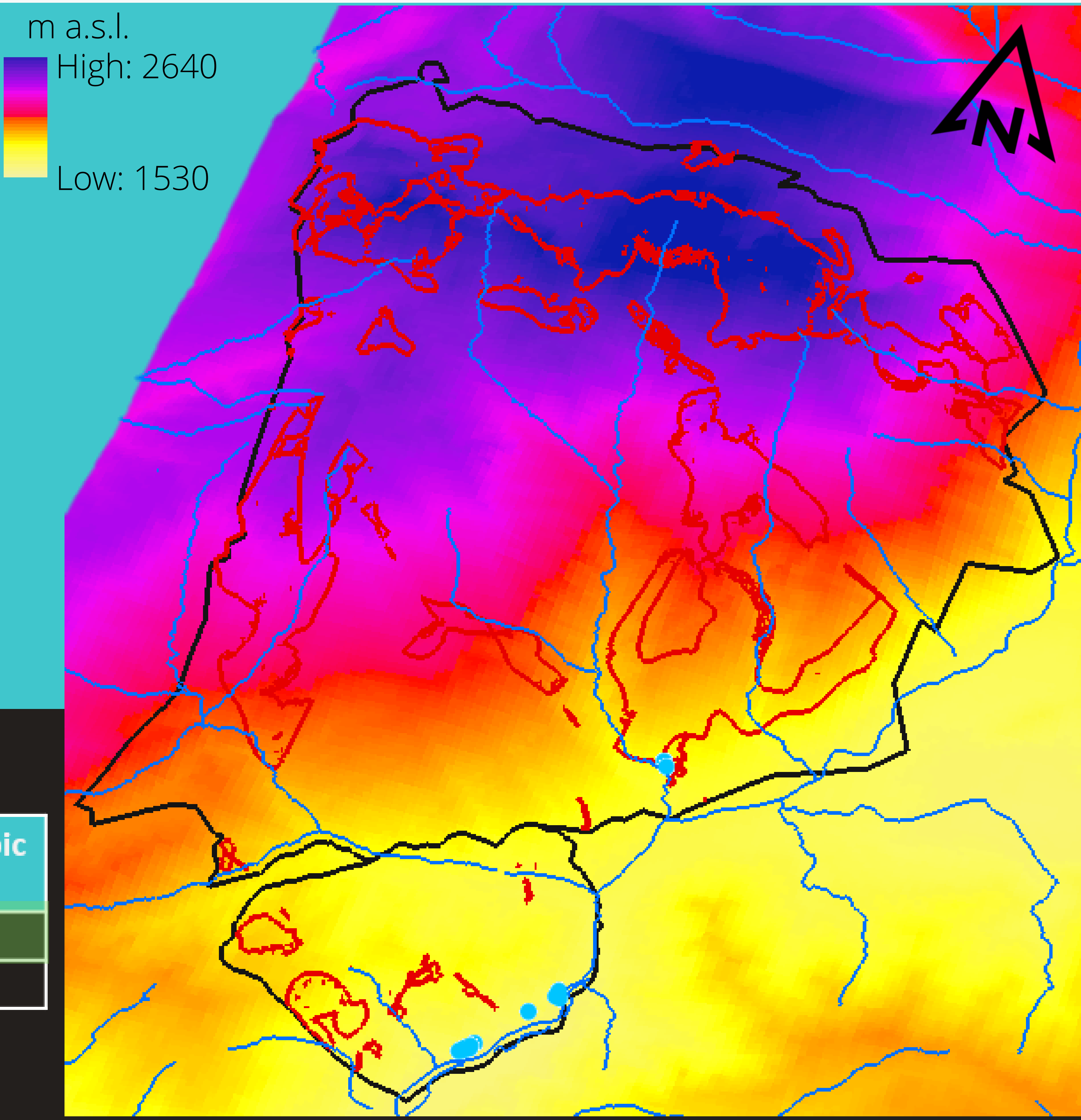
INVERSE DISTANCE WEIGHTING IDW

VALIDATION FOR THE NOSSANA CATCHMENT AREA

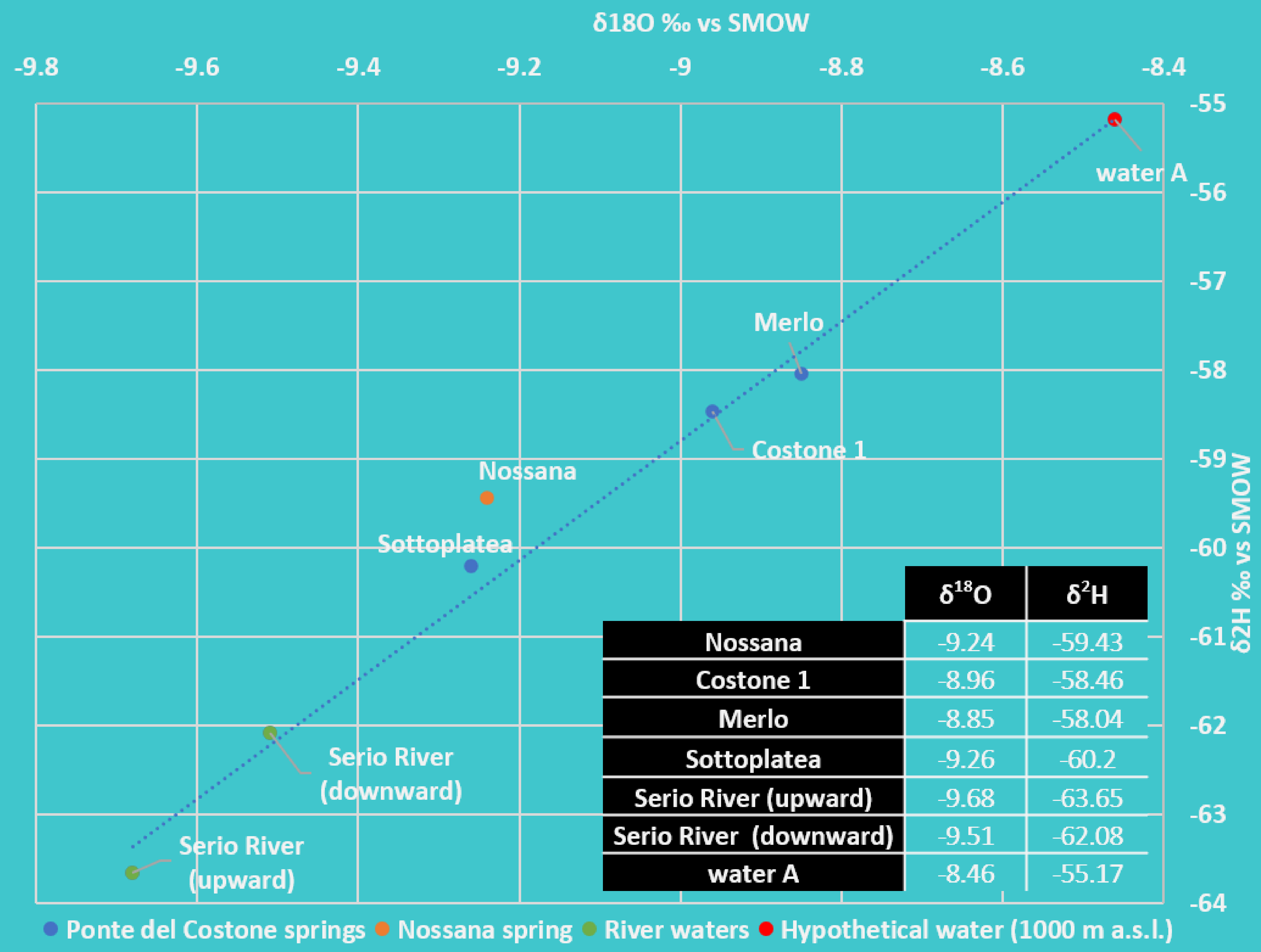
- Applying the weighted average for the TPS and IDW interpolation methods, the values are within the range of elevation estimated by isotopic correlation (**±106 m**).
- Better correlation for COPA+K method compared to COP approach.
- No correlation for Ponte del Costone catchment ⟶
  WHY???

m a.s.l.

Catchment	COP		COPA+K		Elevation by isotopic correlation
	TPS	IDW	TPS	IDW	
Nossana	1494	1513	1670	1856	1776
Ponte del Costone	736	736	923	923	1561



COMMINGLING WITH THE WATERS OF THE SERIO RIVER



	$\delta^{18}O$	$\delta^{2}H$
Nossana	-9.24	-59.43
Costone 1	-8.96	-58.46
Merlo	-8.85	-58.04
Sottoplatea	-9.26	-60.2
Serio River (upward)	-9.68	-63.65
Serio River (downward)	-9.51	-62.08
water A	-8.46	-55.17

water A → $\delta^{18}O$ value of a hypothetical recharge water A at the 1000 m elevation by exploiting local isotopic correlation.

The Ponte del Costone spring waters stand perfectly between the river waters and a hypothetical recharge water A at 1000 m (maximum catchment elevation).

The demonstration of this mixing encourages the hypothesis of the validation of the map, given the excellent result obtained for the Nossana catchment.

CONCLUSIONS

- In this study, the **COP**, **EPIK**, and the newly designed **COPA+K methods** were applied and evaluated for a groundwater vulnerability assessment on the middle Valseriana area;
- The **COPA+K** approach **allowed determining more precise areas** compared to COP (most vulnerable areas from 35.6% to 23.6%);
- **COPA+K** method **underlined the different responses** of the two considered water systems (percentage difference from 5.2% for COP to 17.5% for COPA+K approach);
- **The COPA+K vulnerability map was validated** by correlating $\delta^{18}O$ values and precipitation altitude through a local isotopic correlation from reference data;
- A **commingling** of the **Ponte del Costone springs** with the waters of the **Serio river** has been **demonstrated**;
- The **COPA+K** has been shown to be an **excellent method for** the entire karst environment of the **Pre-Alpine belt** due to its easy applicability → **NO lot of data required and LESS computational effort**.

Thank you for attention

A CITRINI, C CAMERA, F ALBORGHETTI, GP BERETTA

andrea.citrini@unimi.it

Citrini, A., Camera, C., Alborghetti, F., & Beretta, G. P. (2021). Karst groundwater vulnerability assessment: application of an integrative index-based approach to main catchments of middle Valseriana springs (Northern Italy). Environmental Earth Sciences, 80(17), 1-20.

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