



UNIVERSITÀ DEGLI STUDI DI MILANO  
FACOLTÀ DI SCIENZE MATEMATICHE,  
FISICHE E NATURALI

# VULNERABILITA' AI NITRATI TRAMITE ANALISI STATISTICA SPAZIALE



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# “Sfide Scientifiche” (anno 2000)

- Introdurre i dati del monitoraggio nelle valutazioni della vulnerabilità specifica

-Integrare le procedure con tecniche statistiche e numeriche per una migliore quantificazione dei processi

-Considerare le potenziali fonti

- Definire tecniche per la valutazione dell'affidabilità dei risultati

Research article

## Current trends and future challenges in groundwater vulnerability assessment using overlay and index methods

R.C. Gogu · A. Dassargues

**Abstract** The concept of groundwater vulnerability is a useful tool for environmental planning and decision-making. Many different methods have been developed for assessing this vulnerability. Hydrogeologists have failed to reach a consensus concerning the definitions of and reference terms for groundwater vulnerability assessment. Therefore, a review of vulnerability assessment and mapping methods providing a new classification system is necessary. This is focused on techniques that use the overlay and index class methods. New research challenges in vulnerability assessment are identified, especially the need for developing dynamic links between numerical models and overlay and index methods.

**Key words** Groundwater · Vulnerability · Overlay and index methods

### General concepts for groundwater vulnerability assessment

Vulnerability assessment of groundwater, as used in many methods, is not a characteristic that can be directly measured in the field. It is an idea based on the fundamental concept “that some land areas are more vulnerable to groundwater contamination than others” (Vrba and Zaporozec 1994). Nevertheless mapping the degree of

groundwater vulnerability to contaminants, as a function of hydrogeological conditions, shows that effective protection provided by the natural environment may vary drastically from one place to another. Often, the groundwater contamination level is determined by the natural attenuation processes, occurring within the zone located between the pollution source and the aquifer. Various natural, physical processes, and chemical reactions that operate in the soil, unsaturated, and saturated zones, may cause the pollutant to change its physical state and chemical form. These changes may attenuate the degree of pollution or change the nature of the contamination. Especially in soil and the unsaturated zone, some mechanisms may affect the contaminant concentration much more than in the saturated zone. Chemical processes can be very complex and may work individually or in combination with other processes to provide varying attenuation degrees. These reactions depend on site specific soil and aquifer characteristics as well as on the particular geochemical properties of each pollutant. Although the importance of these chemical reactions for attenuation of pollution is widely recognized and sometimes modelled, attenuation processes can be partially or completely bypassed depending on geochemical conditions in the aquifer and the infiltration conditions.

### Pollution sensitive areas

Pollution sensitive areas can be divided into three groups: naturally vulnerable areas, well-protection zones, and potential problem areas.

Naturally vulnerable areas are more sensitive zones where the soils, subsoil, and bedrock do not provide adequate protection and the potential exists for rapid transfer of pollutants to groundwater. Areas of concern are, for example, the recharge zones of shallow aquifers.

In the vicinity of pumping wells, each pollutant can potentially contaminate the pumped groundwater relatively quickly. In many countries, the methods for delineating well-protection zones are standardised using different criteria, based on the piezometric heads, on the advective transport time, on the advective-dispersion transport time or other parameters.

Overlaying maps of the most vulnerable zones, with maps showing the location of each potential contamination sources or polluting land-use activities, generates the map of potential problem areas (risk maps).

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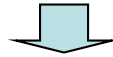
Gogu e Dassargues, 2000



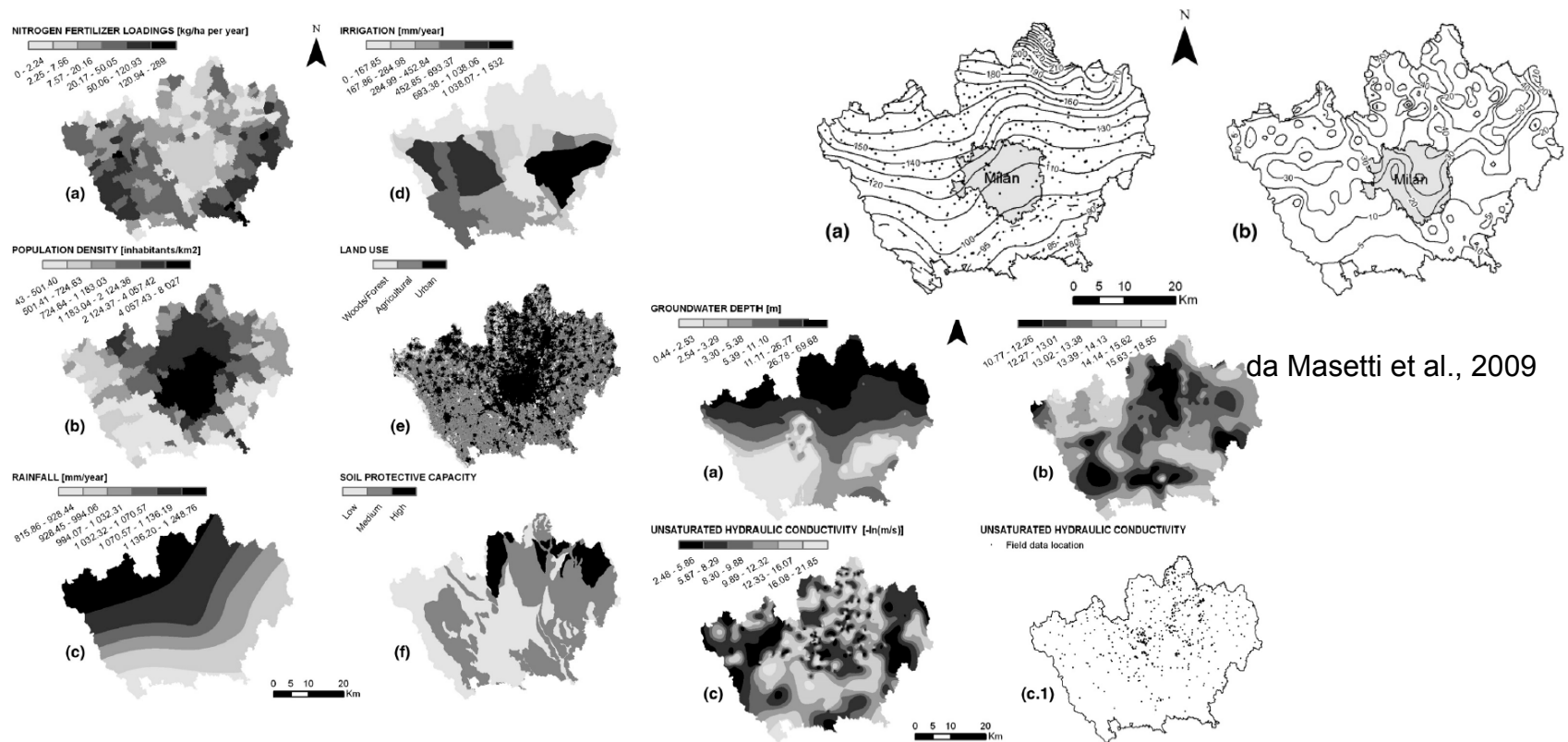
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# Metodi statistici

Si basano essenzialmente sul confronto tra la distribuzione nell'area di studio dei fattori che si ritiene siano importanti nell'influenzare la vulnerabilità dell'acquifero (predittori) e le caratteristiche qualitative della falda.



Utilizzano per la valutazione della vulnerabilità direttamente anche i dati di concentrazione dei contaminanti misurati in pozzi della falda in esame.



da Masetti et al., 2009



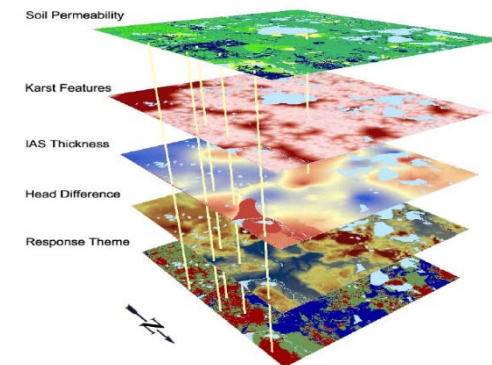
# Metodi statistici

## PRINCIPALI VANTAGGI

- 1) I predittori possono essere selezionati in funzione delle caratteristiche dell'area in esame (o dei dati disponibili);
- 2) L'importanza di ogni predittore viene valutata attraverso un processo statistico oggettivo che può permettere anche di scartare alcuni predittori se questo non risultano significativi;
- 3) I pesi dei predittori (o delle singole classi di predittori) vengono calcolati per l'area specifica e non sono quindi attribuiti a priori;
- 4) La qualità dei risultati può essere adeguatamente valutata.

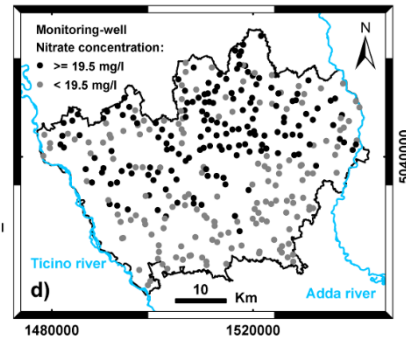
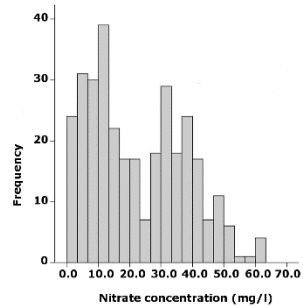
## PRINCIPALI SVANTAGGI

- 1) Richiedono solide base dati sia per il chimismo delle acque sia per la distribuzione spaziale dei predittori;
- 2) Richiedono un maggiore grado di competenze per la loro corretta applicazione.



# I dati del monitoraggio

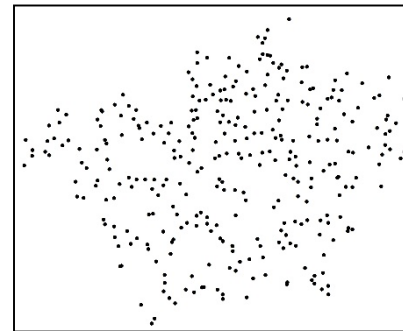
Ogni evidenza positive è rappresentata da un pozzo in cui le concentrazioni sono superiori ad un valore soglia



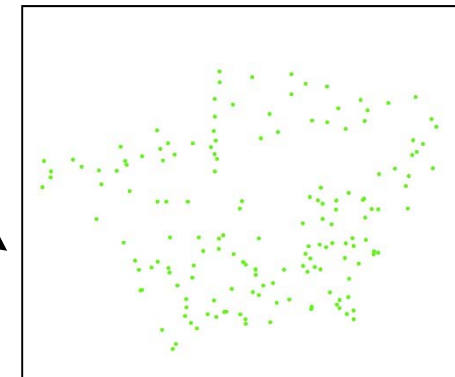
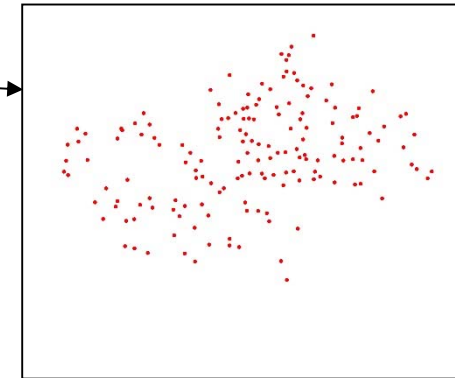
Il valore soglia può essere stabilito sulla base della distribuzione statistica dei dati o in accordo con i limiti di legge.

Pozzi impattati

Evidenze di contaminazione (positive)



Valore soglia



Pozzi non impattati

Evidenze di non contaminazione (negative)

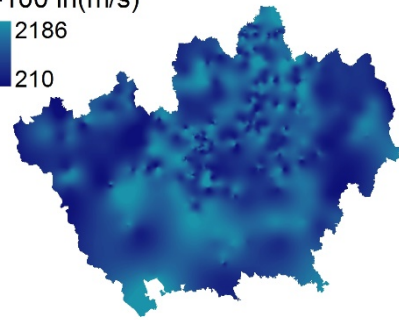


# Predittori: includere le fonti

Unsaturated hydraulic conductivity

-100 ln(m/s)

2186  
210

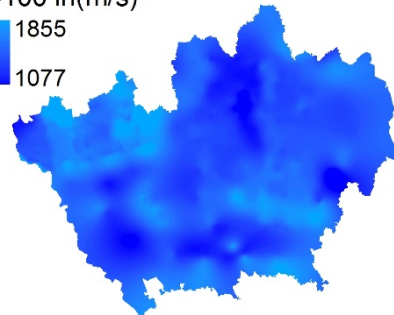


**UHC**

Groundwater velocity

-100 ln(m/s)

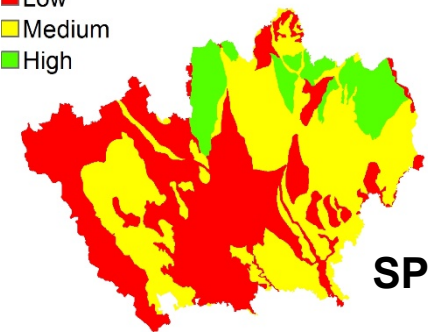
1855  
1077



**GWV**

Soil protective capacity

Low  
Medium  
High

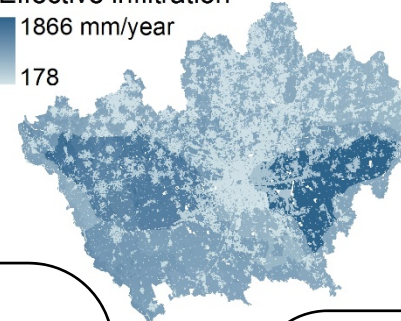


**SPC**

Effective infiltration

1866 mm/year

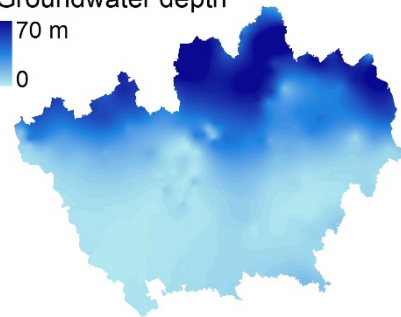
178



**EI**

Groundwater depth

70 m  
0

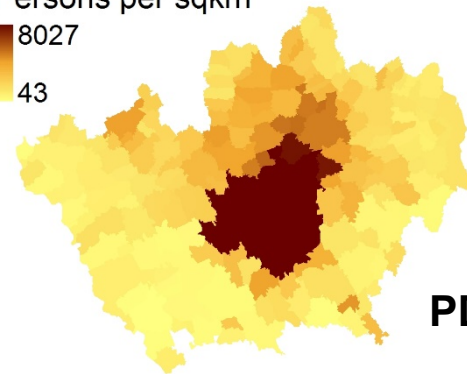


**GWV**

Population density

Persons per sqkm

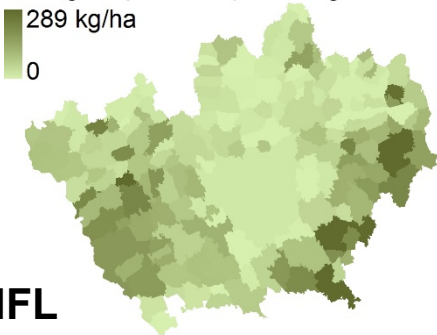
8027  
43



**PD**

Nitrogen (fertilizer) loading

289 kg/ha  
0



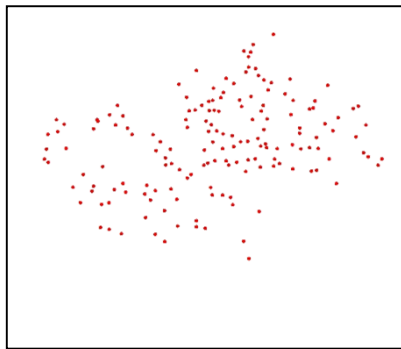
**NFL**

da Masetti et al, 2007

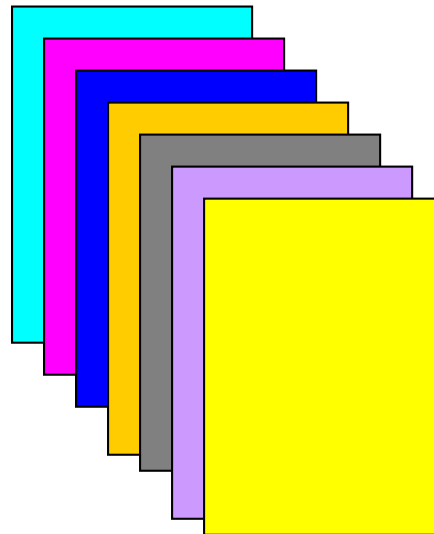


# La struttura di calcolo

Rete di monitoraggio



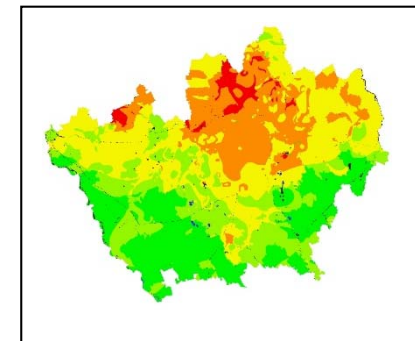
Predittori



Le più importanti variabili naturali ed antropiche che si ritiene possano influenzare la vulnerabilità nell'area di studio

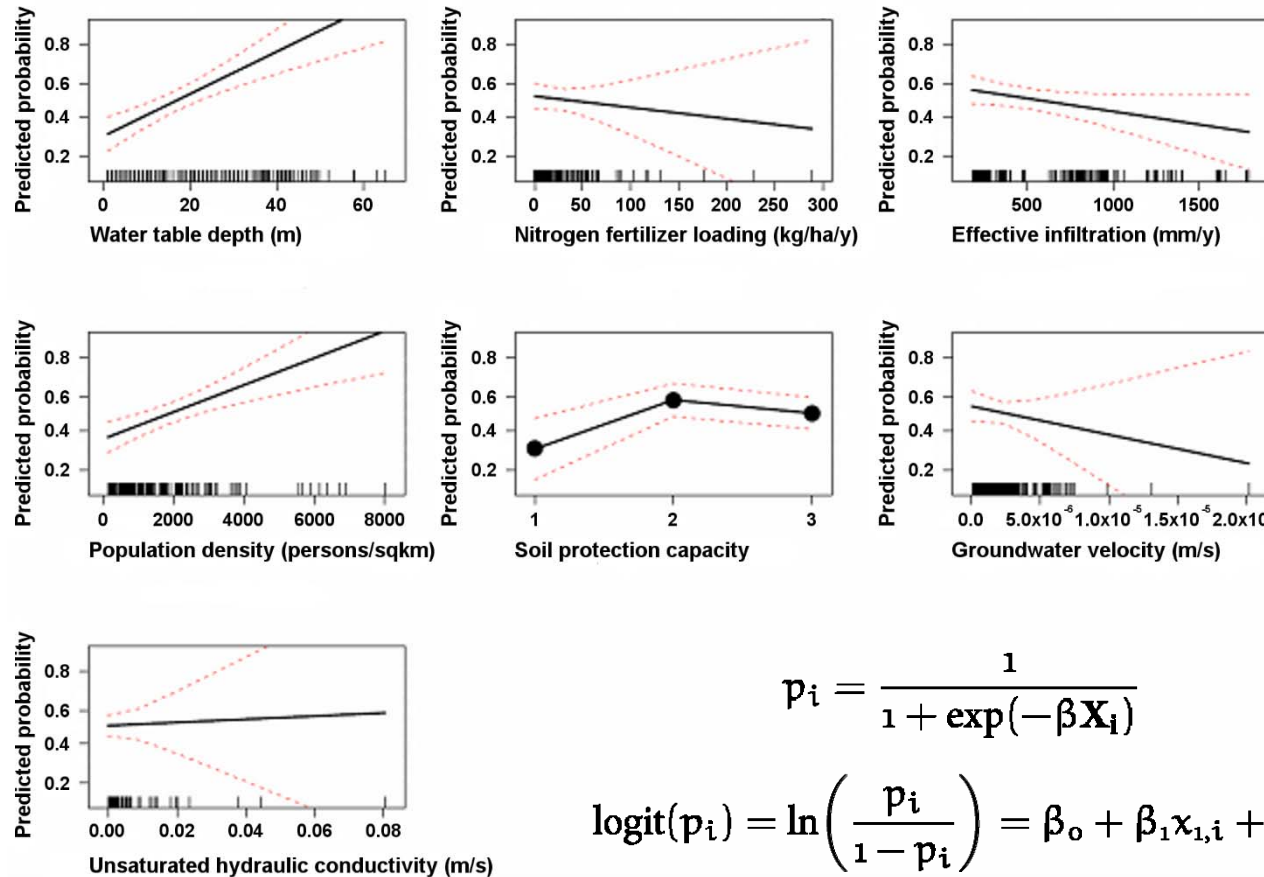
Probabilità a posteriori

Definisce la relazione spaziale esistente fra ogni predittore e la qualità delle acque sotterranee



# Risultati sui predittori: Regressione logistica

## Influenza sulla vulnerabilità e confidenza



da Sorichetta et al, 2012

$$p_i = \frac{1}{1 + \exp(-\beta X_i)}$$

$$\text{logit}(p_i) = \ln\left(\frac{p_i}{1 - p_i}\right) = \beta_0 + \beta_1 x_{1,i} + \dots + \beta_k x_{k,i}$$

- Tesoriero et al, 2000, Nolan 2001, Worrall and Besien 2005, Gardner and Vogel 2007, Sorichetta et al, 2012.....

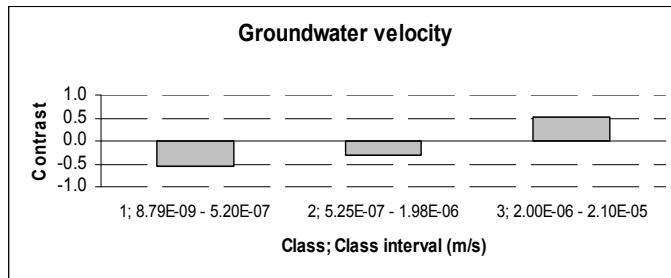
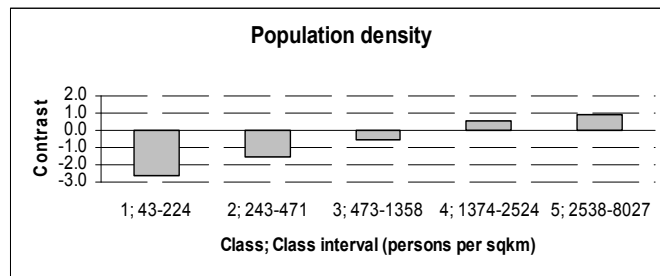
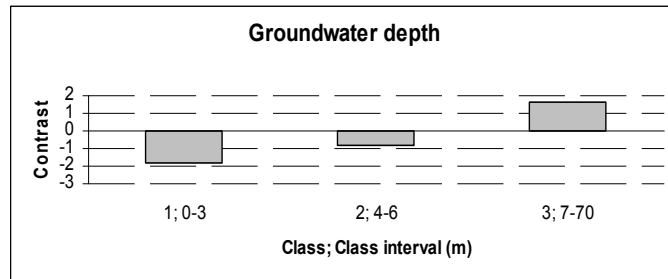




# Risultati sui predittori: Analisi Bayesiane

da Masetti et al, 2010

## Pesi e combinazioni



**Classi di predittori maggiormente associate a zone ad elevata vulnerabilità**

**Classi di predittori maggiormente associate a zone a bassa vulnerabilità**

PD (ab/kmq)	> 2500
Soggiac. (m)	> 34
Velocità GW (m/s)	> 2e-6
K zona vadosa (m/s)	> 2e-5

PD (ab/kmq)	< 400
Soggiac (m)	< 3
Velocità GW (m/s)	< 2e-6
K zona vadosa (m/s)	> 9e-5

$$\log_e O\{D | B_1^k \cap B_2^k \cap B_3^k \dots B_n^k\} = \sum_{j=1}^n w_j^k + \log_e O\{D\}$$

$$W^+ = \log_e \frac{P\{B | D\}}{P\{B | \bar{D}\}}$$

$$W^- = \log_e \frac{P\{\bar{B} | D\}}{P\{\bar{B} | \bar{D}\}}$$

- Arthur et al 2007, Masetti et al 2007,2010, Raines et al 2009, Sorichetta et al 2011...

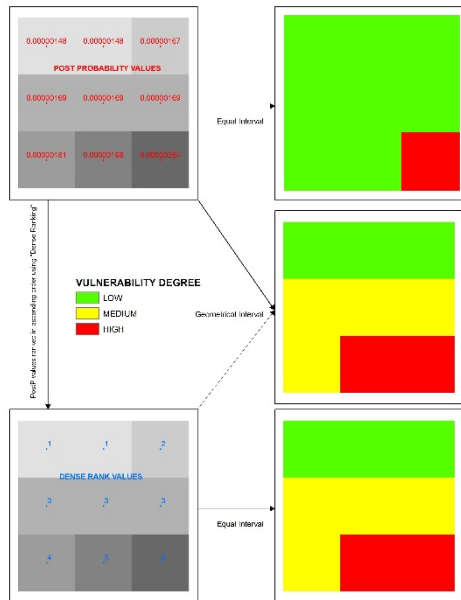


# Carte di Vulnerabilità

Vulnerability class

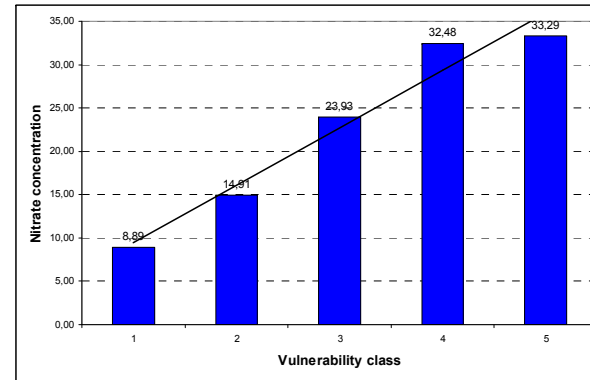


La Vulnerabilità aumenta dalla classe 1 alla 5

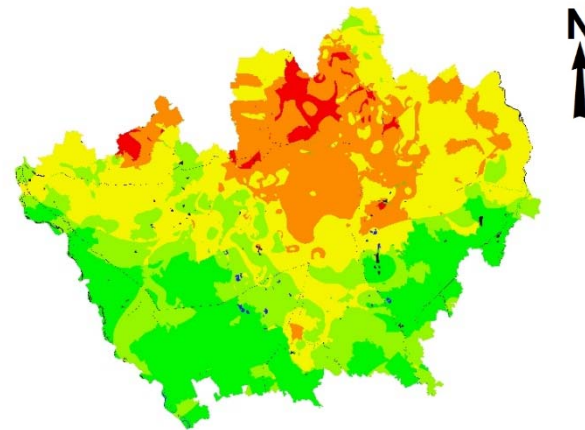
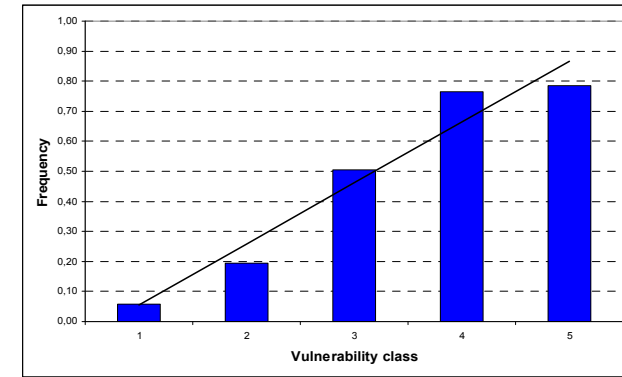


## CALIBRAZIONE

Concentrazione media

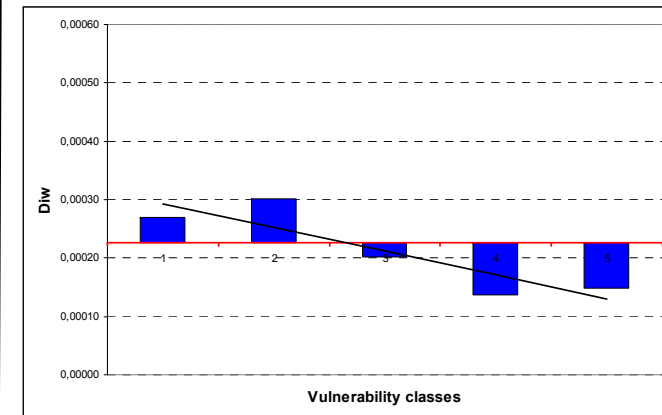


Frequenza pozzi impattati



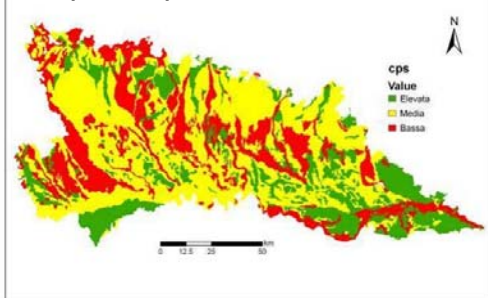
## VALIDAZIONE

Densità pozzi non impattati

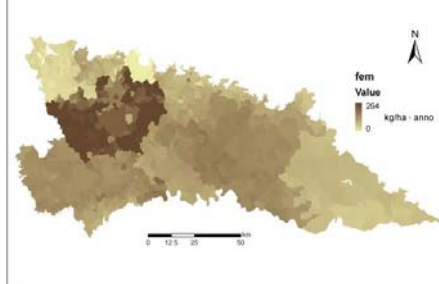


# L'ESPERIENZA LOMBARDA I

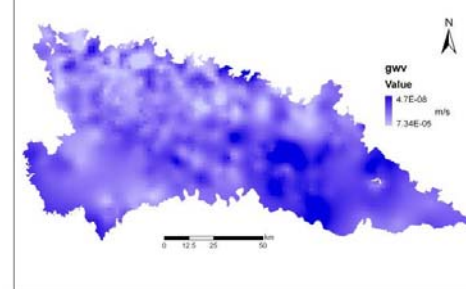
## Capacità protettiva dei suoli



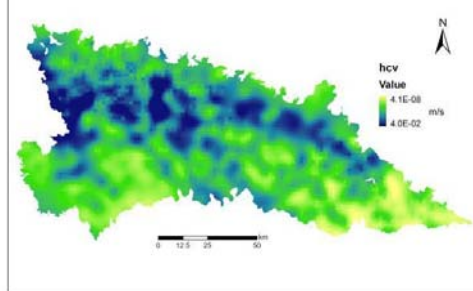
## Fertilizzanti minerali



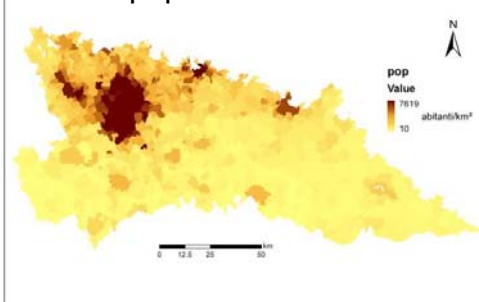
## Velocità della falda



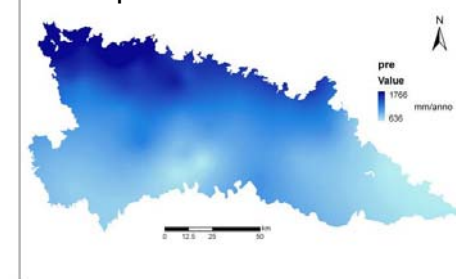
## Conducibilità idraulica zona vadosa



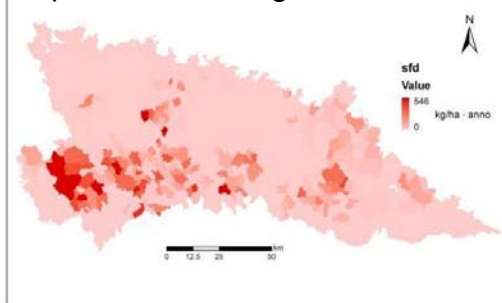
## Densità popolazione



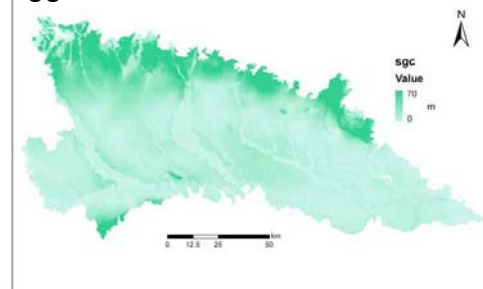
## Precipitazione



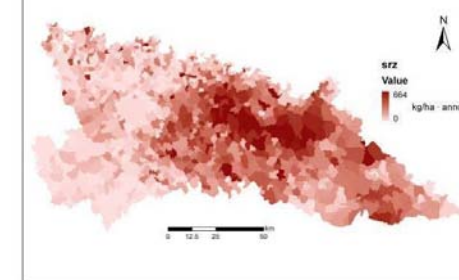
## Spandimento fanghi



## Soggiacenza

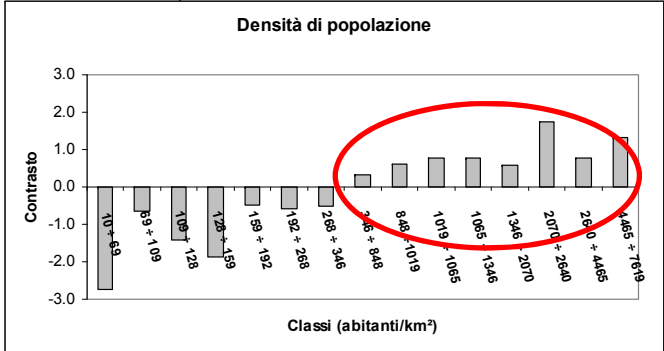
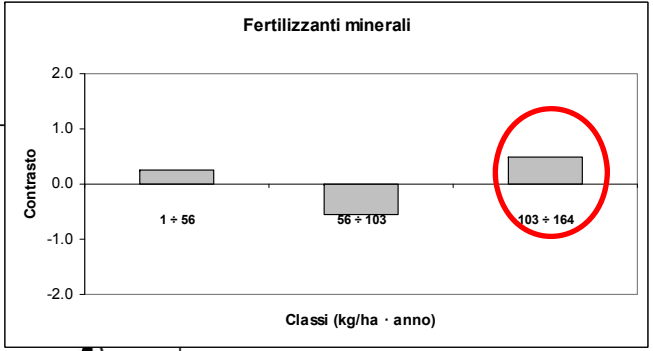
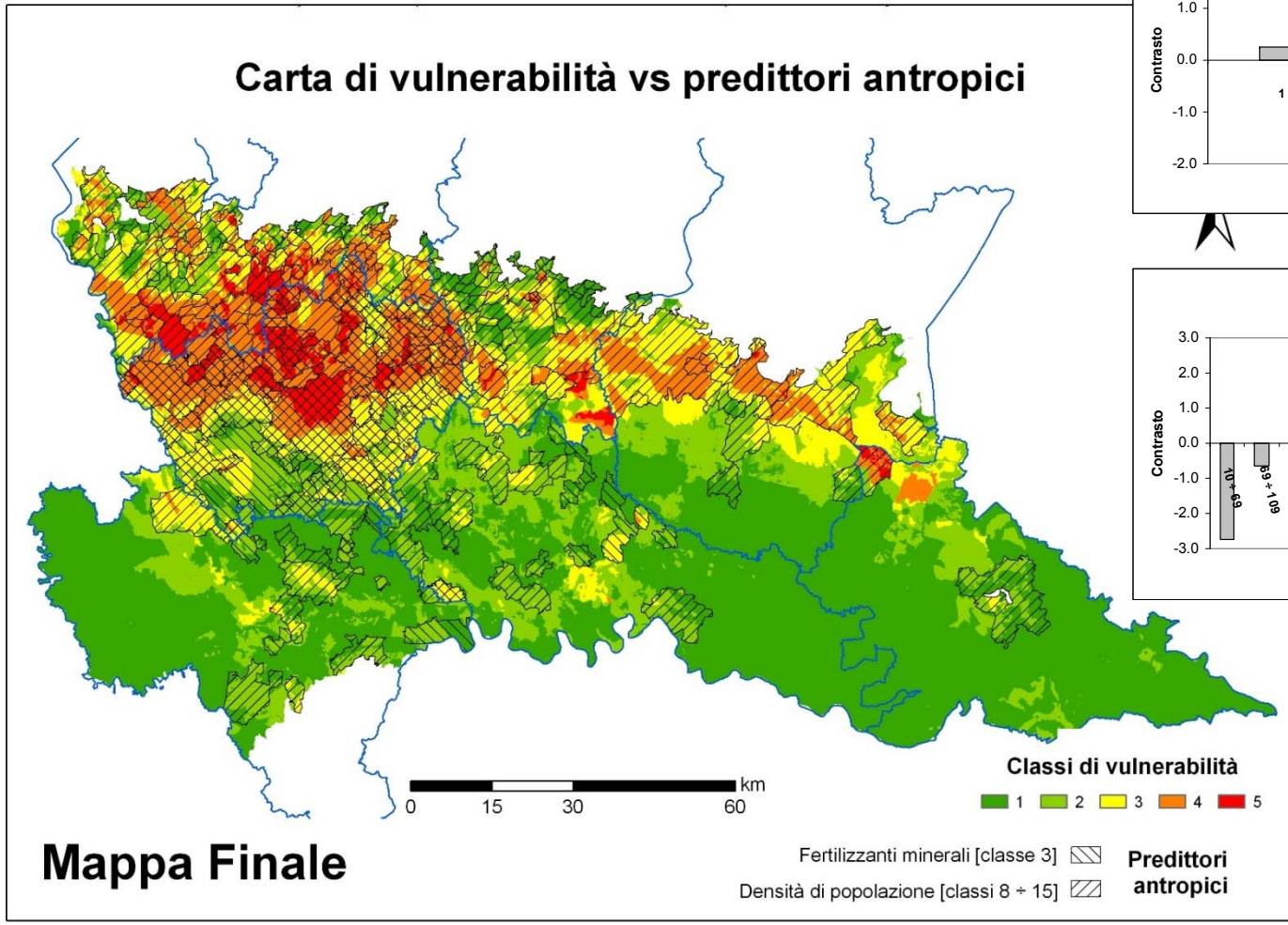


## Reflui zootecnici



# L'ESPERIENZA LOMBARDA II

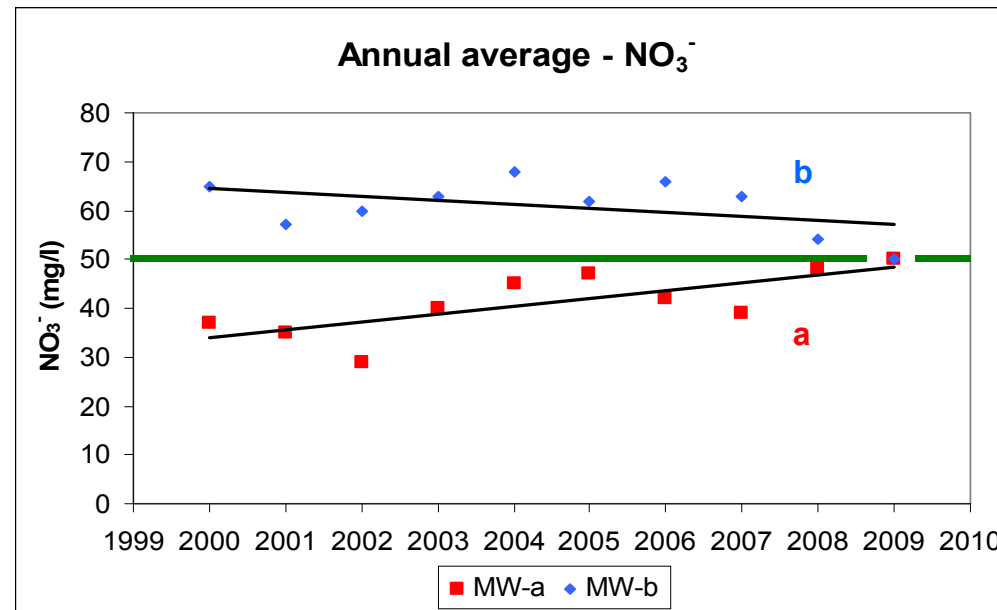
## Carta di vulnerabilità vs predittori antropici



# “Sfide normative” (anno 2006)

Groundwater Directive 2006/118/CE (D.Lgs. 30/2009):

- identificazione di significativi trends positivi di concentrazione di contaminanti negli acquiferi



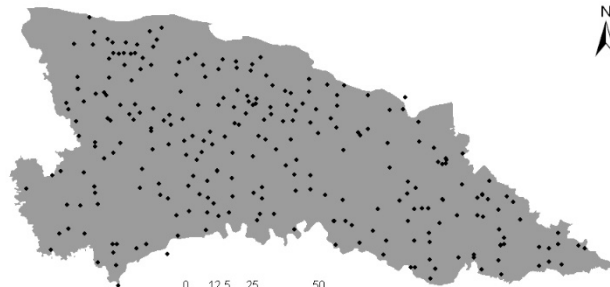
NECESSITA' DI TENERE CONTO DELLA VARIABILE TEMPO NELLA VALUTAZIONE DELLA VULNERABILITA'



# Punti di controllo (degrado qualitativo)

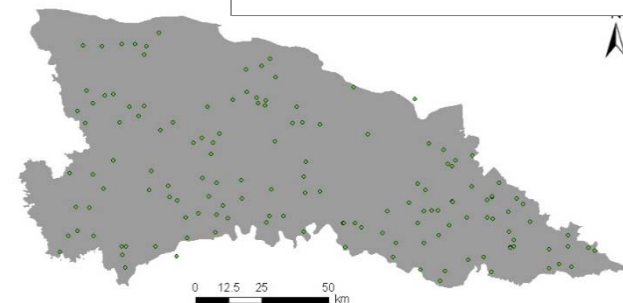
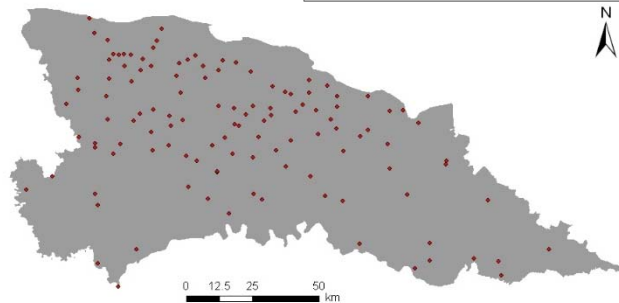
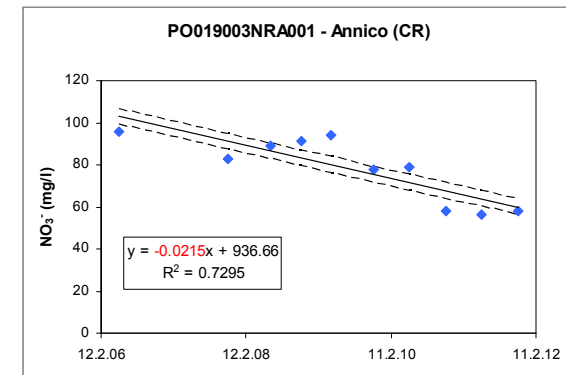
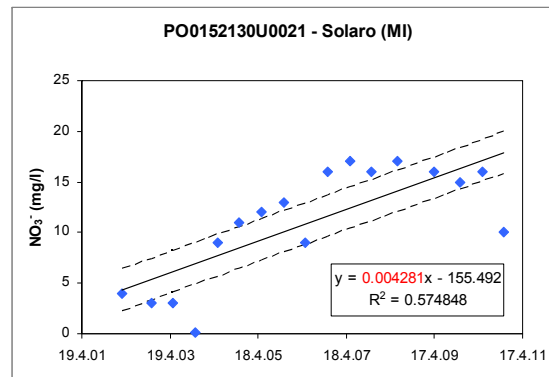


Rete di monitoraggio  
2000 ÷ 2009



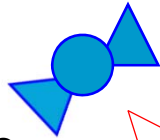
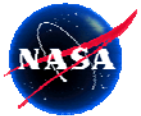
Evidenze positive  
slope > 0

Evidenze negative  
slope ≤ 0



# Dati QuikSCAT-DSM

SeaWinds  
scatterometro  
**QuikSCAT**  
satellite



Dato grezzo 30 kmq



+ Dense Sampling  
Method (**DSM**)

**Continuo**

**spazio**

Copertura mondiale

**tempo**

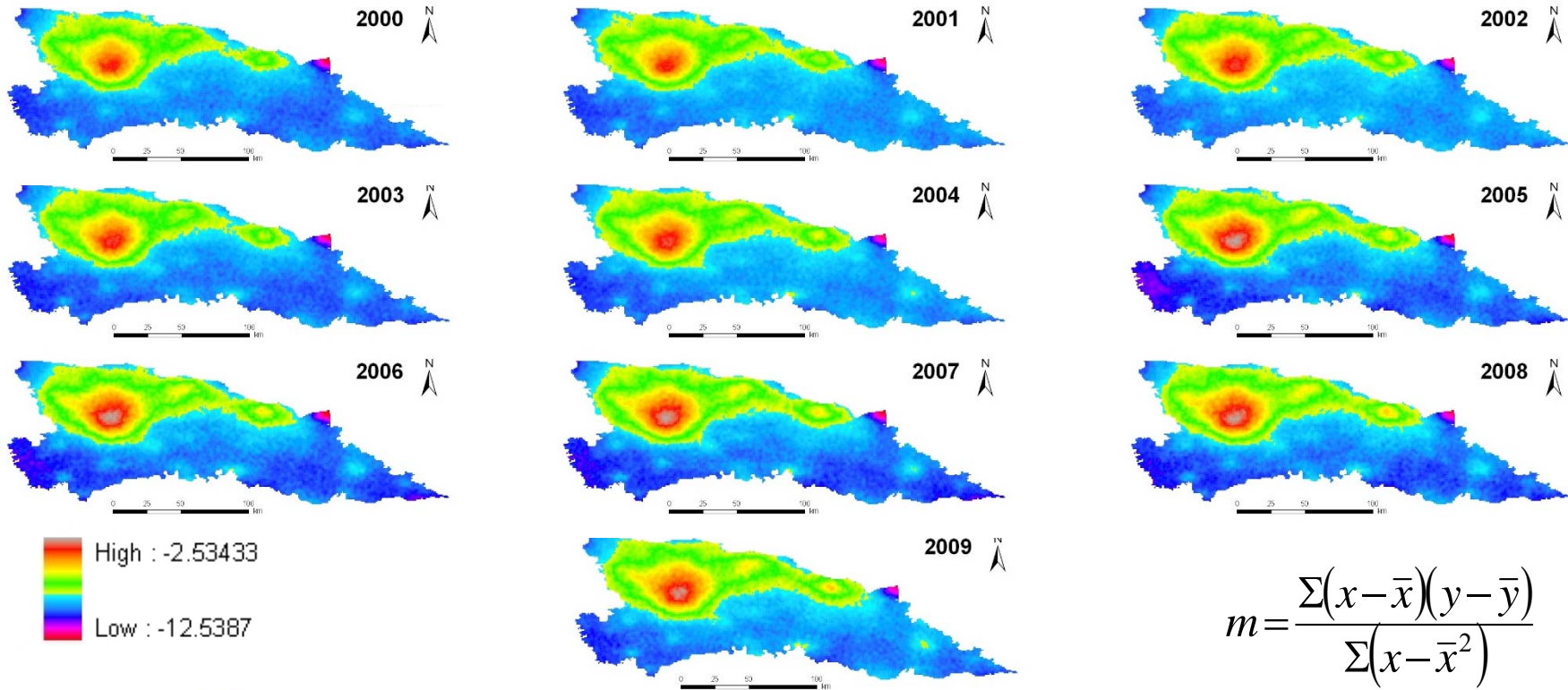
2000 ÷ 2009



1 km x 1 km



# QuikSCAT-DSM: Trend di urbanizzazione

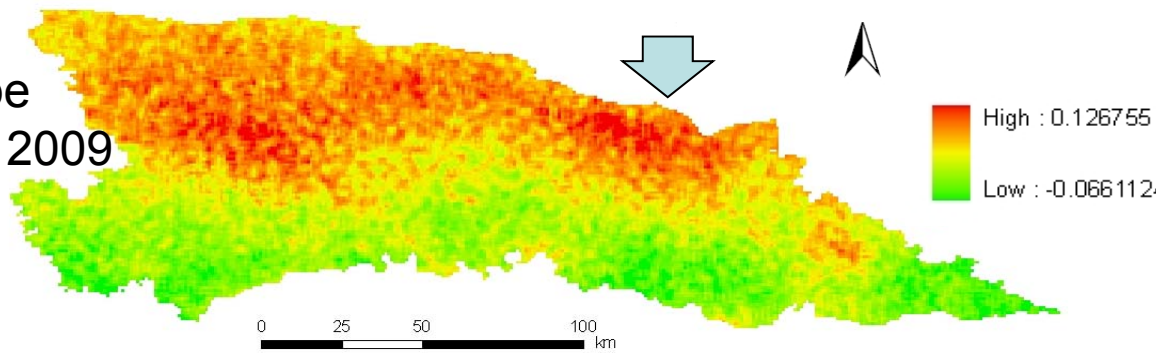


$$m = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sum(x - \bar{x})^2}$$

x = anno (2000, 2001, etc.)

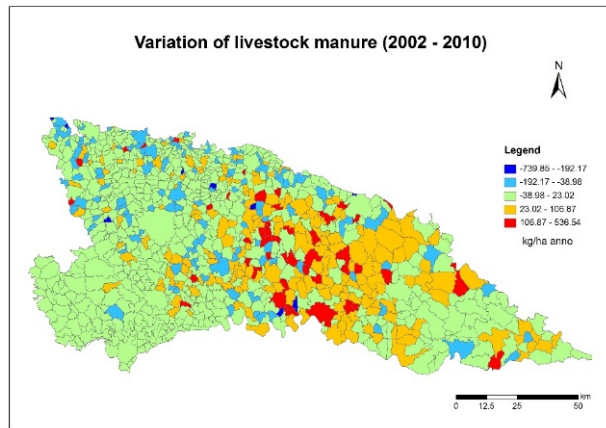
y = valore QSCAT-DSM

Slope  
2000 ÷ 2009

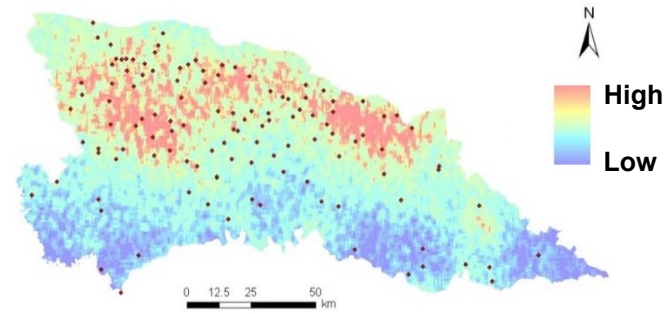




# Mappa finale e affidabilità



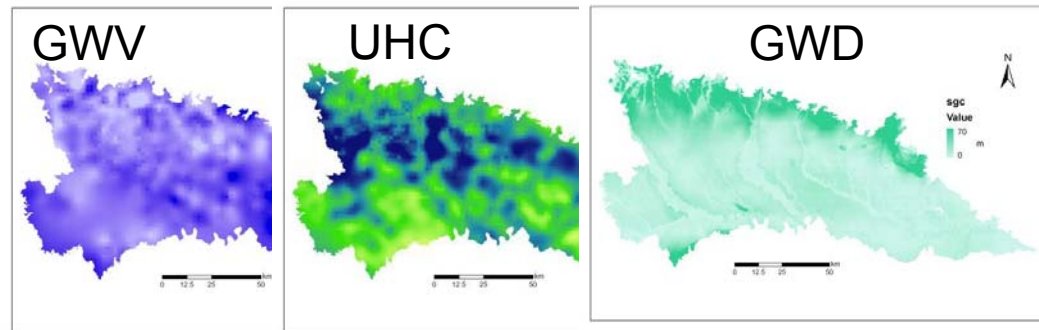
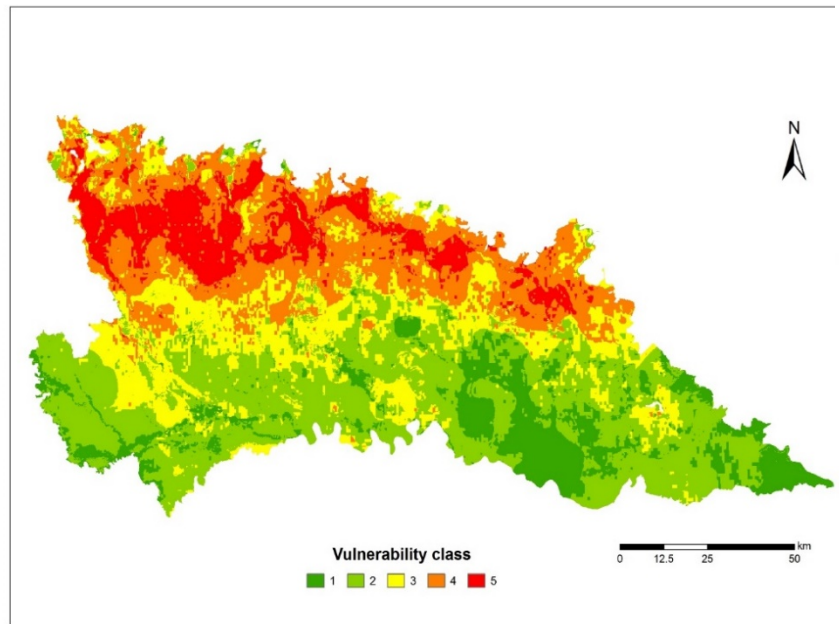
da Stevenazzi et al. (in stampa)



Slope DSM

+

GWD (soggiac.)  
GWVelocità  
UHC (K z. vad.).



***“Vulnerabilità tempo dipendente”***

Identificazione delle aree dove la combinazione di fattori naturali ed antropici comporta un diverso degrado della qualità delle acque sotterranee



# Conclusioni (parole chiave)

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- Reti di monitoraggio (valorizzazione)
- Analisi statistica spaziale (ampia versatilità)
- Variabile tempo (migliorare le tecniche)
- Dati satellitari (supporto sempre più strategico)

