Recent advances in the use of process-based groundwater vulnerability for risk mapping

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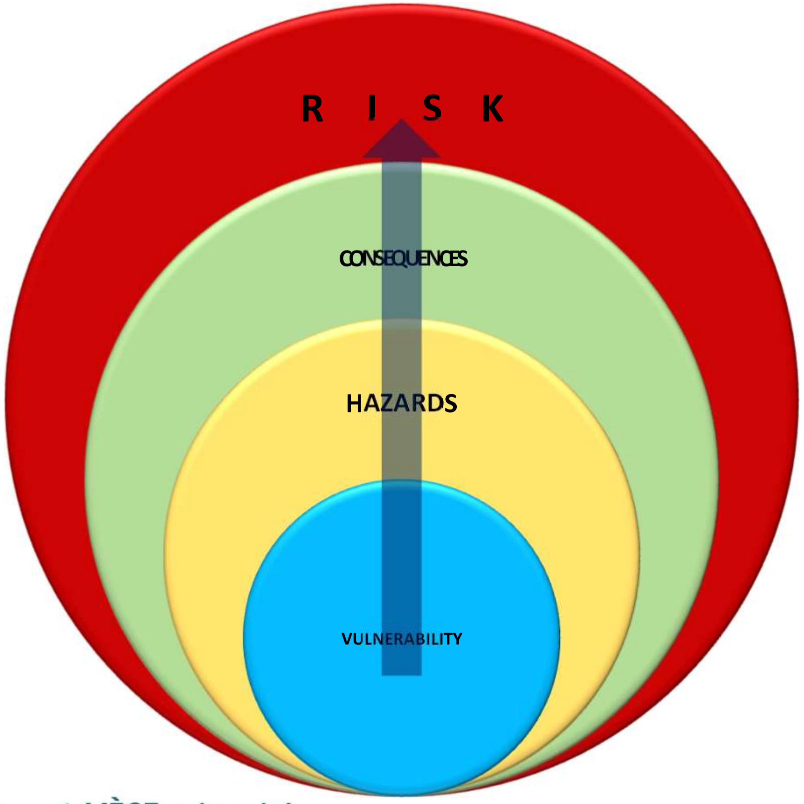
General Context

In urbanised area, groundwater resources are exposed to many different potential point and diffuse pollution sources → needs for efficient tools for the evaluation of the risk of groundwater pollution, including groundwater vulnerability maps and regional risk assessment tools



Risk = Relative Measure of the possible contamination of groundwater as a result from a hazardous event. It can be evaluated by a simple combination of Hazard, Vulnerability and Consequences.

Consequences on groundwater bodies are evaluated considering socio economical indicators.

Hazard = event or continuing process, which if it occurs, will lead to circumstances having the potential to degrade, directly or indirectly, the quality of the environment/ groundwater body (Pidgeon et al., 1992).

Vulnerability is defined by two notions:

- The **Intrinsic Vulnerability** of groundwater that considers only the geological, hydrological and hydrogeological features of the area and it is thus independent from the specific pollutant
- The **Specific Vulnerability** of groundwater that considers the specific properties of a contaminant or group of contaminant with the same behavior, linked to the intrinsic vulnerability of the area (ZwahlenF.(ed),2003).

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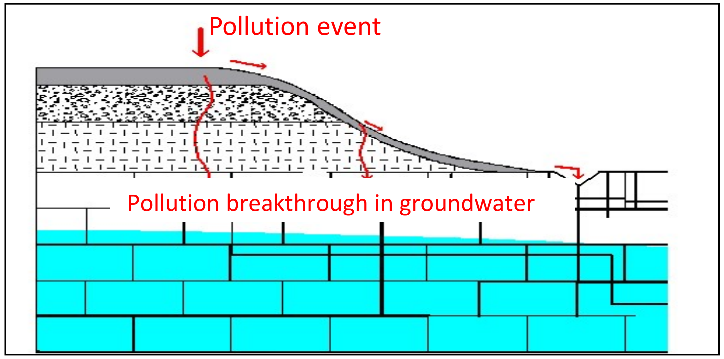
The APSÛ method for process-based vulnerability assessment (Popescu et al. 2019)

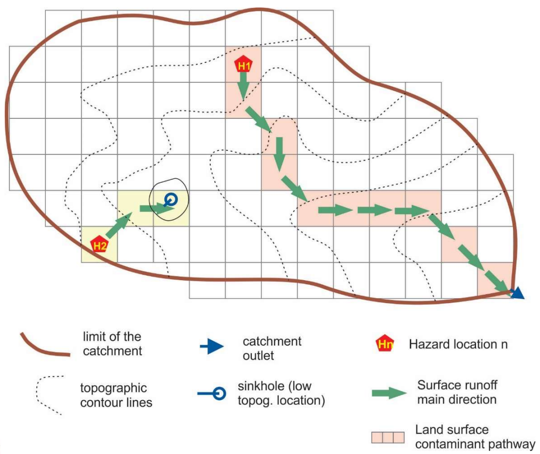
Process-based approach following the general concepts of the COST620 Action (Daly et al. 2002)



Adapted from N. Goldscheider

Degree of vulnerability	High	Moderate	Low
minimal travel time	Short (e.g. 24h)	Medium (e.g. 50 d)	long
Concentration level / attenuation	high	medium	low
duration	long	medium	short

LAND SURFACE HAZARD



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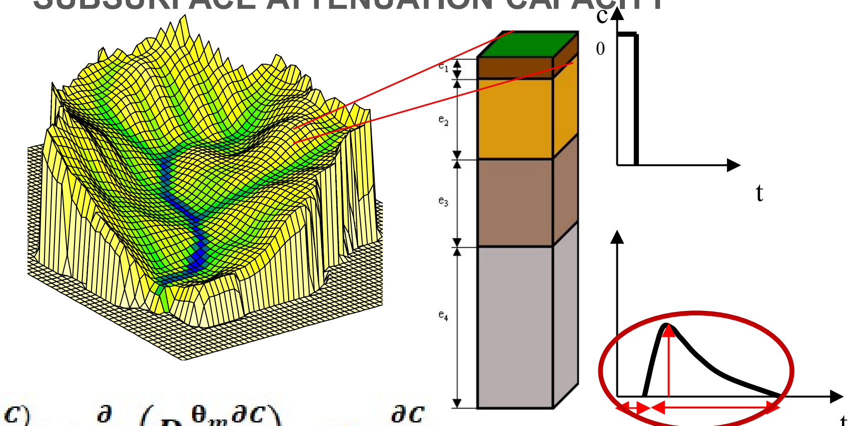
SUBSURFACE ATTENUATION CAPACITY



$$\frac{\partial(\theta_m C)}{\partial t} = \frac{\partial}{\partial z}\left(D\frac{\theta_m \partial C}{\partial z}\right) - q_D\frac{\partial C}{\partial z}$$

The APSÛ method for process-based vulnerability assessment (Popescu et al. 2019)

The Apsû method can also account for specific vulnerability assessment considering the specific fate of pollutants (sorption, degradation)

Types of pollutant(s)
- Pollutant properties K_{oc}, μ ($T_{1/2}$)
- Soil organic matter…
- …

Table

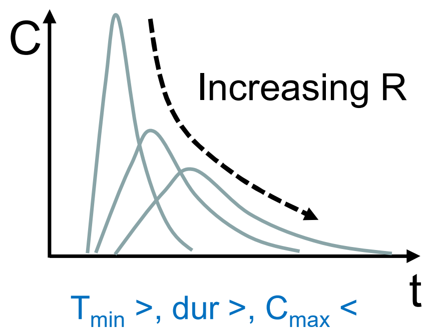
Feuil1$

LITHO_I	LITHO_NAME	POLL_ID	POLL_NAME	DEGRAD	RETAR	OBJECTID
12	Sols limoneux à	4	Simazine	0	8,0687	4
12	Sols limoneux à	5	Glyphosate	0	45,26	5
12	Sols limoneux à	6	Benzene	0	4,59	6
12	Sols limoneux à	7	Benzoapyrene	0	54376	7
12	Sols limoneux à	8	Naphtalene	0	82,56	8
12	Sols limoneux à	9	Trichlorobenzene	0	136,94	9
12	Sols limoneux à	10	Trichlorethylene	0	5,9	10
12	Sols limoneux à	11	1_2_dichloroethane	0	2,03	11
12	Sols limoneux à	12	EC10_EC12	0	137,58	12
12	Sols limoneux à	13	EC16-EC21	0	862,79	13
13	Sols limono-caillo	1	Atrazine	0	7,21	14
13	Sols limono-caillo	2	Bentazone	0	4,44	15
13	Sols limono-caillo	3	Diuron	0	51,52	16
13	Sols limono-caillo	4	Simazine	0	9,08	17

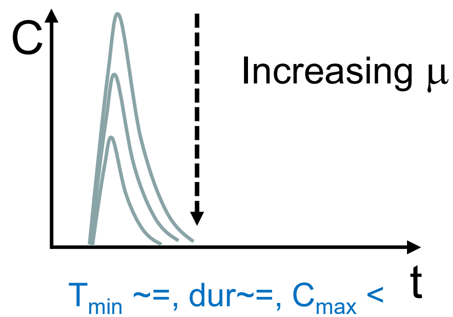
1 (0 out of 19 Selected)

$$\frac{R\,\partial(\theta_m C)}{\partial t} = \frac{\partial}{\partial z}\left(D\frac{\theta_m \partial C}{\partial z}\right) - q_D\frac{\partial C}{\partial z} - \mu C$$

Specific vulnerability criteria
- Tmin, Cmax and Duration still possible
- Better : M_{out}/M_{in}



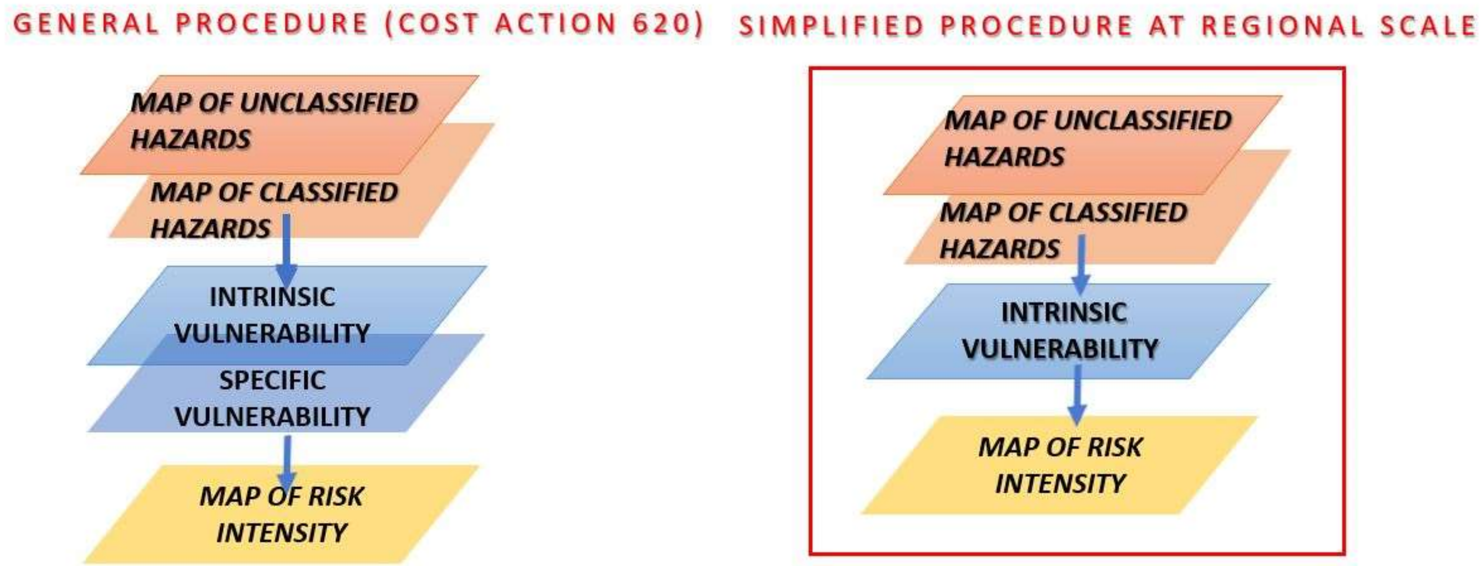
T_{min} >, dur >, C_{max} <
M =



T_{min} ~=, dur~=, C_{max} <
M <

General methodogy adopted from COST ACTION 620

<u>BASED ON</u>: ***HAZARD – PATHWAY – TARGET MODEL (Daly et al., 2002)***



(Adapted from Zwahlen F. (ed), 2003)

RISK INTENSITY = INTRINSIC VULNERABILITY X HAZARDS

TOTAL RISK = RISK INTENSITY X CONSEQUENCES

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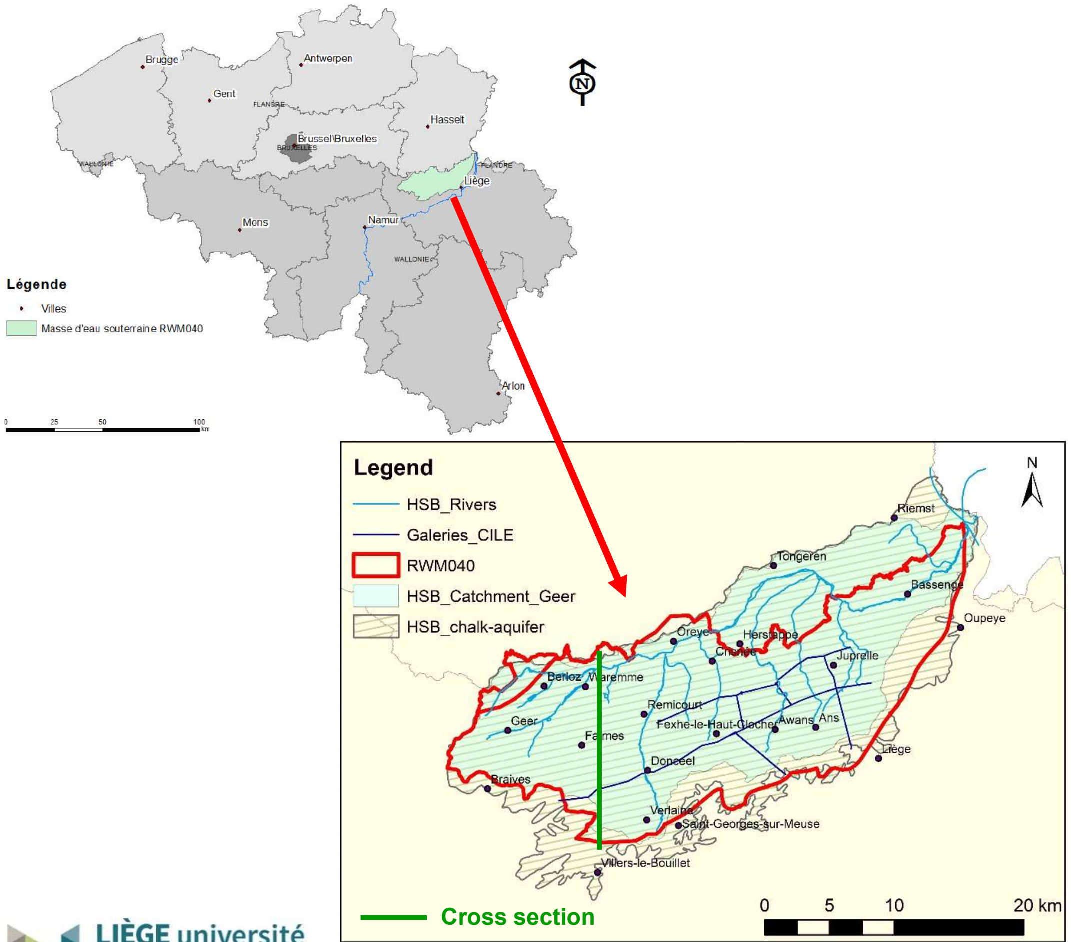
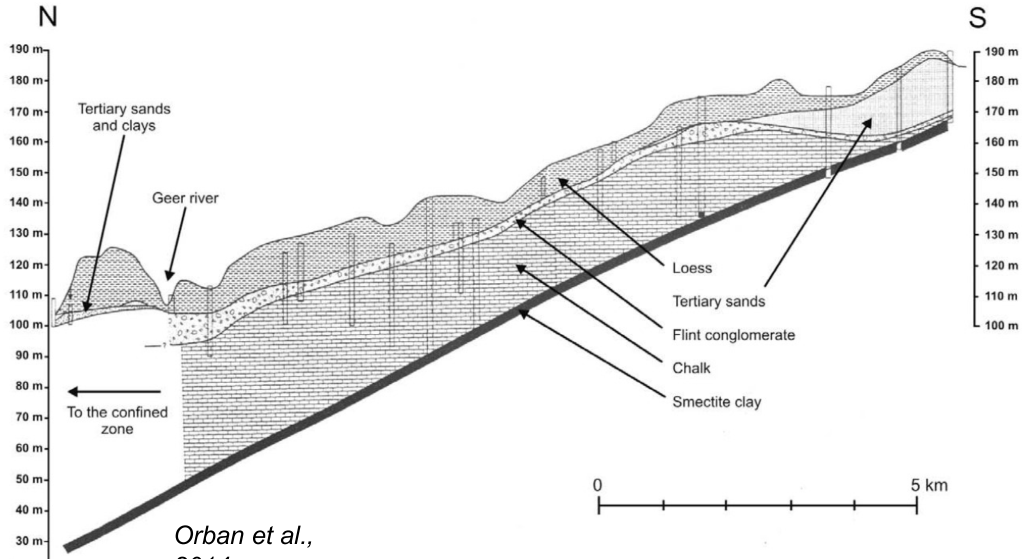
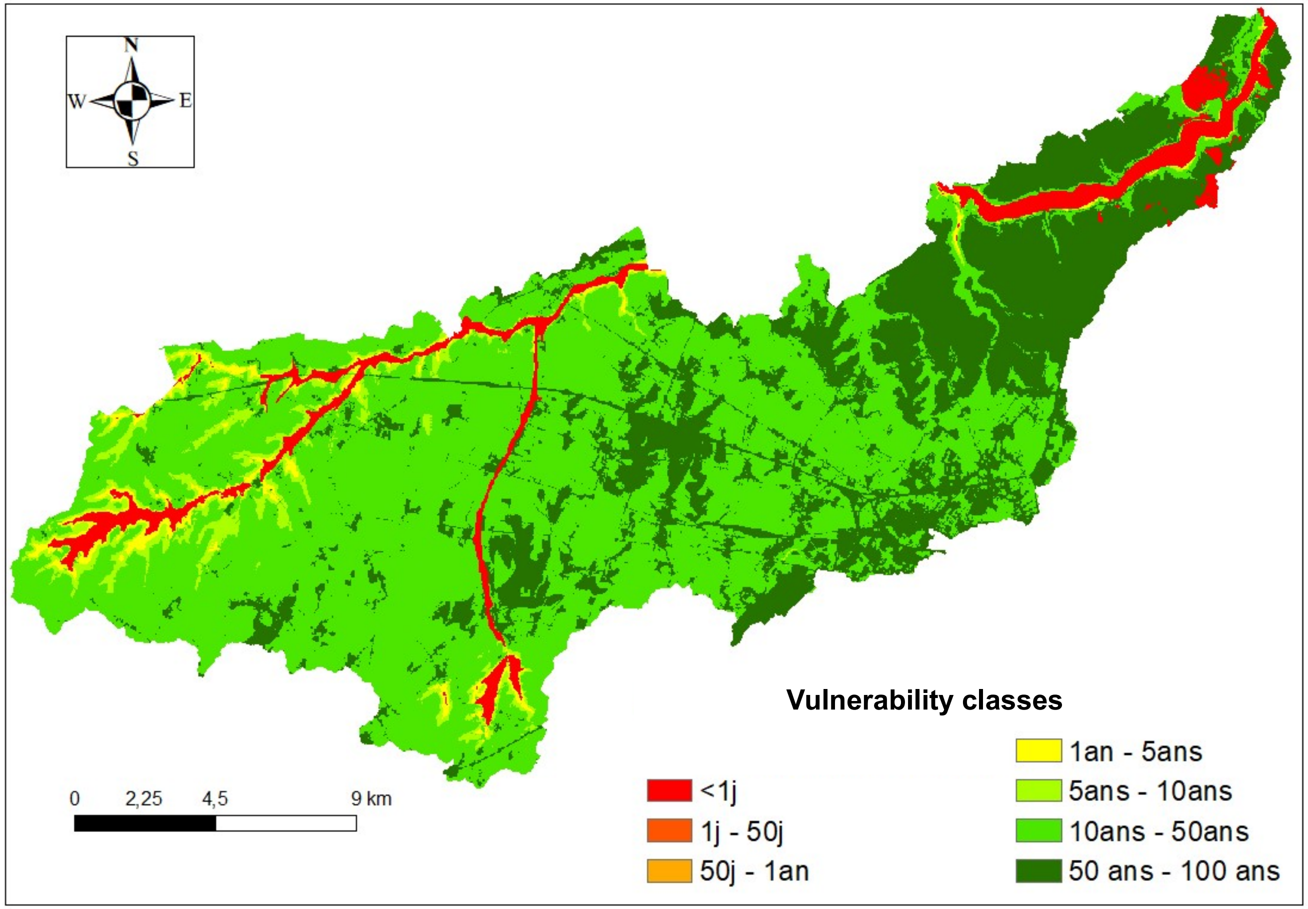
Supporting case study : the Hesbaye chalk aquifer in Belgium





Orban et al., 2014

Intrinsic vulnerability map based on minimal travel times



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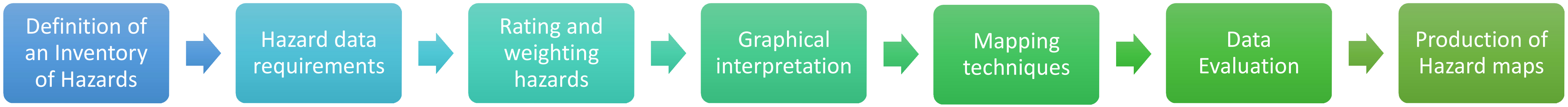
Hazard mapping in a seven steps procedure



CREATION OF THE INVENTORY: DATABASES SELECTION AND INVESTIGATION

- Land use map of Wallonia [COSW] (Version 2_07)
- PASH – Waste water sanitation network (SPGE)
- BDES – Database on potentially polluted soils
  - Environnemental Permits (RGPE- Permis d’environnement)
  - SAR (Site à réaménager) Inventory
  - SAR-CHST (Centre d’Histoire des Sciences et des Techniques)
- REGINE - Environnemental database on manufacturing companies
- SEVESO III SITES
- Railway and road network
- …

Service public de Wallonie

DGO 3

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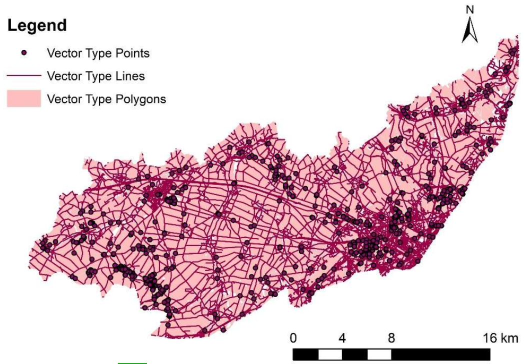
From the Inventory of Hazards to the Total Risk Map

IAH BRUSSELS BELGIUM 2021
Inspiring Groundwater

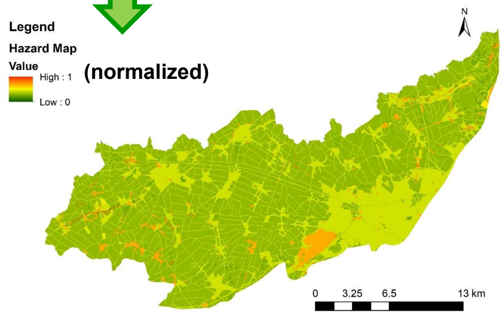
(1)



$$HAZARD\ INDEX\ (HI) = H \times Q_n \times R_f$$

Hazard Index	Hazard Level	Hazard Class
0-24	1	very low
>24-48	2	low
>48-72	3	moderate
>72-96	4	high
>96-120	5	very high

(2)



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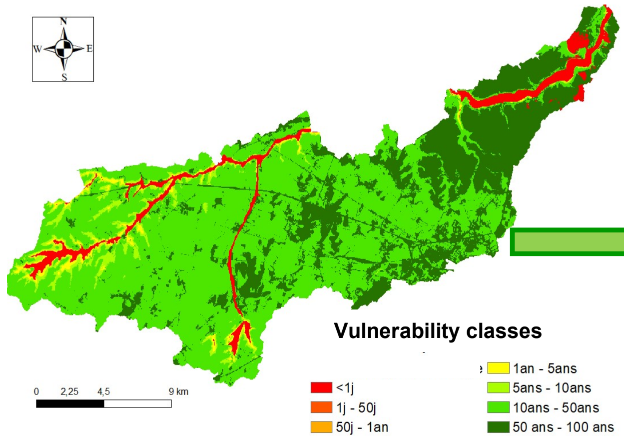

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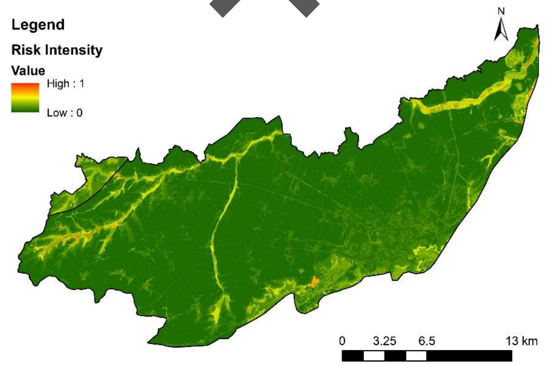
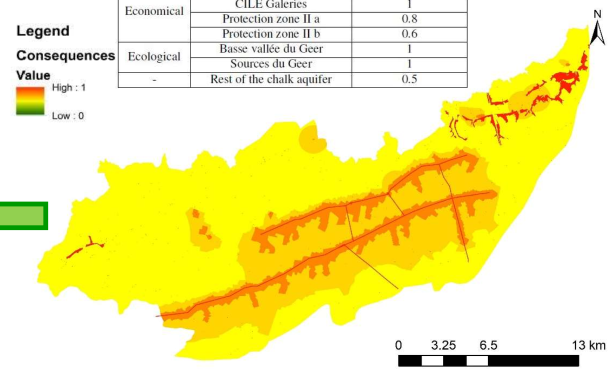


(5)

	Type	Consequence Index
Economical	Captages (Abastraction wells)	1
	CILE Galeries	1
	Protection zone II a	0.8
	Protection zone II b	0.6
Ecological	Basse vallée du Geer	1
	Sources du Geer	1
-	Rest of the chalk aquifer	0.5



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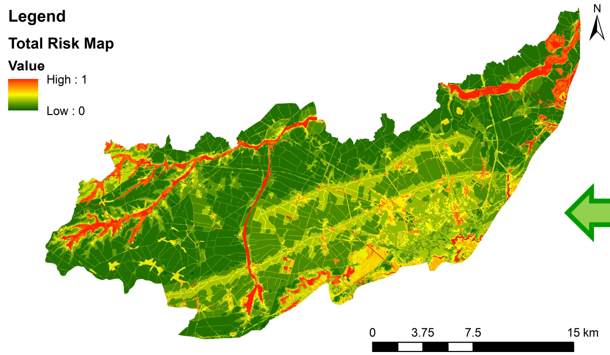

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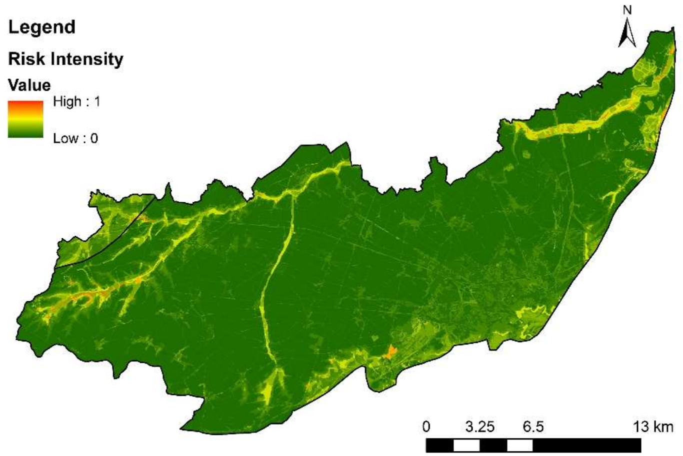
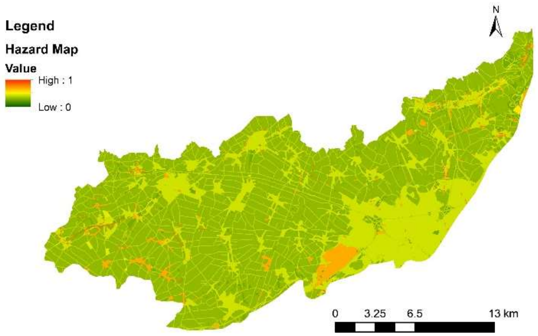
Discussion



Intensive agriculture prevailing in the catchment of the Hesbaye chalk aquifer (significant nitrate and pesticides groundwater contaminations)

➔ **The Risk intensity map is « too much green »!**

OK, but how can we explain this?

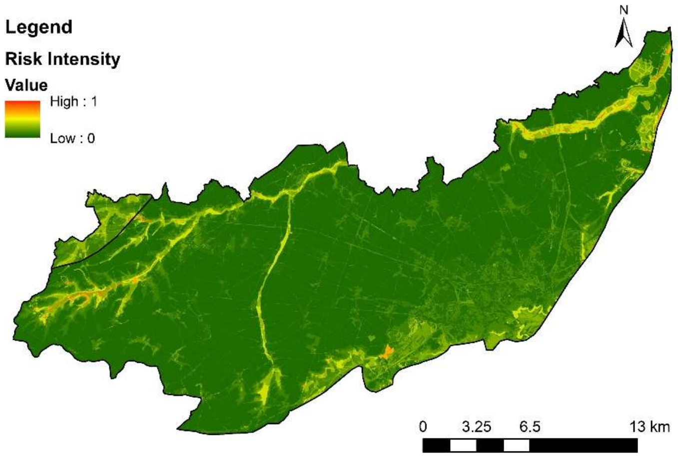


First, the Hazard map very « green » for a basin where agriculture is a strong pressure on groundwater (nitrate, pesticides…)

➔ COST620 hazard classification for agriculture probably too much green …

Needs maybe to be revised or at least adapted to the context of Wallonia

Discussion



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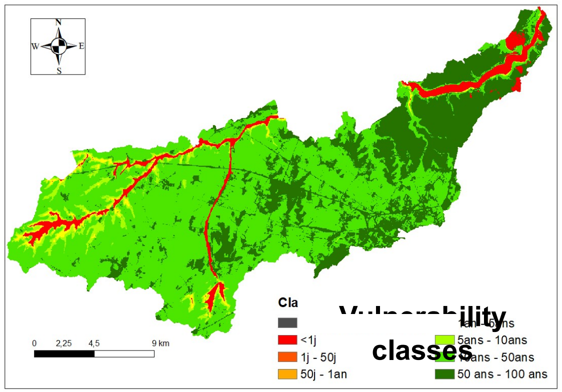


At the same time, the intrinsic vulnerability map based on travel time also turns the colours into green!

Nitrate and fertilisers = **continuous sources** of pollution

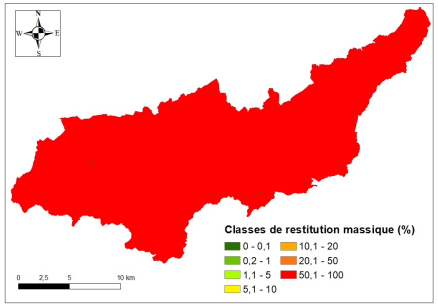
➔ Minimal travel time criterion not adapted to such pollution scenarios!

What can we do to fix this problem?

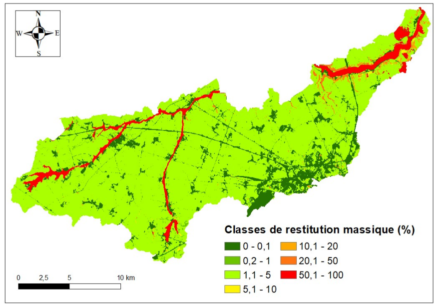
Maybe adapt the COST620 classification to better reflect existing groundwater pollution scenarios

But also, use specific vulnerability maps based on the relative quantity of pollutants reaching the groundwater table!

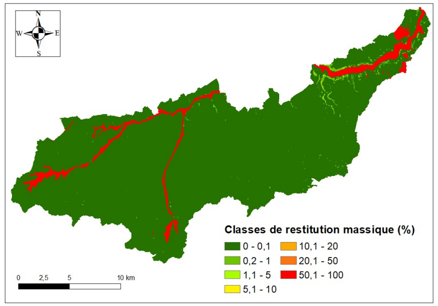
nitrate



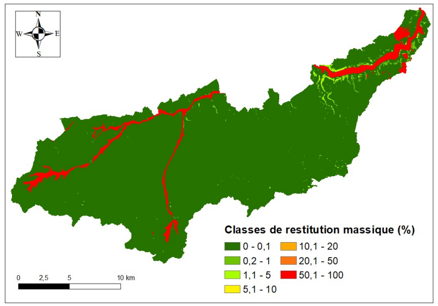
Atrazine



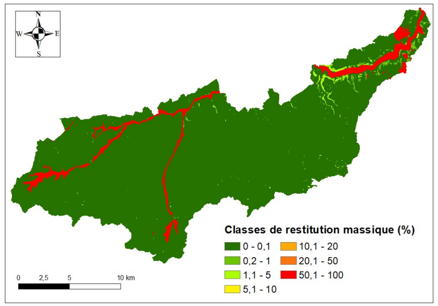
Bentazone



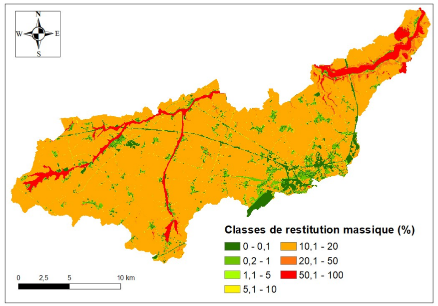
Glyphosate



EC10-EC12



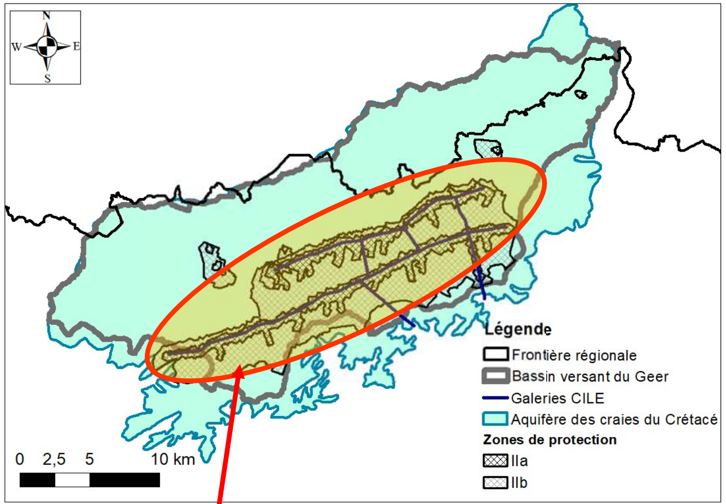
Trichloroethene



And what can we do with our intrinsic vulnerability map?

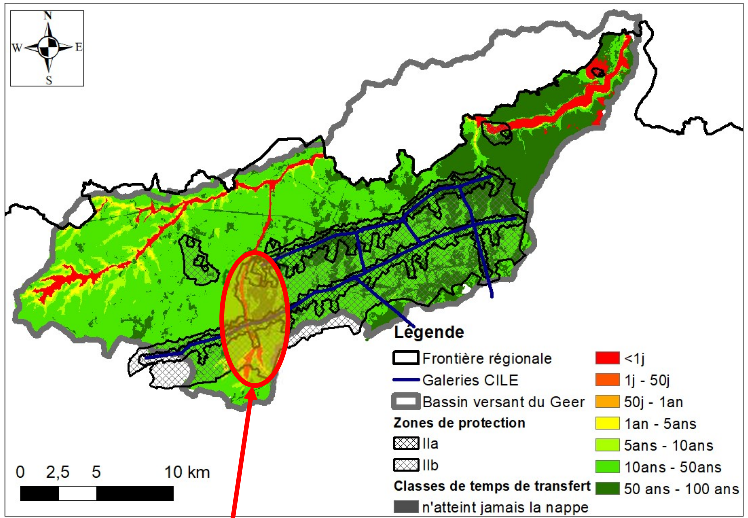
→ Use it as a first screening approach to classify territories and groundwater catchment areas in terms of their relative sensitivity to different types of pollutants

→ Use it to define **groundwater – scale protection zones**



Protection zones of the CILE drainage galleries exploiting the chalk aquifer = almost 1/3 of the aquifer with restrictions and compliance works
→ Huge costs of millions of euros!

Combined with the information provided by the intrinsic vulnerability map



Only a small part of the protection zones needs special attention in terms of short pollutants travel times to the drainage galleries

Conclusions – Take home messages

- Use of physically-based criteria for groundwater vulnerability assessment already showed its advantages over classical weighting and rating methods … Here, its combination with risk maps has allowed to demonstrate that risk maps maybe completely meaningless …

- For risk assessment, a better cartography of risks would arise from the following combination: Activity → Hazard → pollutant → specific vulnerability → Total risk

  Activity – pollutant matrix!

- The intrinsic vulnerability map (minimal travel time) remains useful as a complementary information for the generalization of protection zones to the scale of the investigated aquifer.