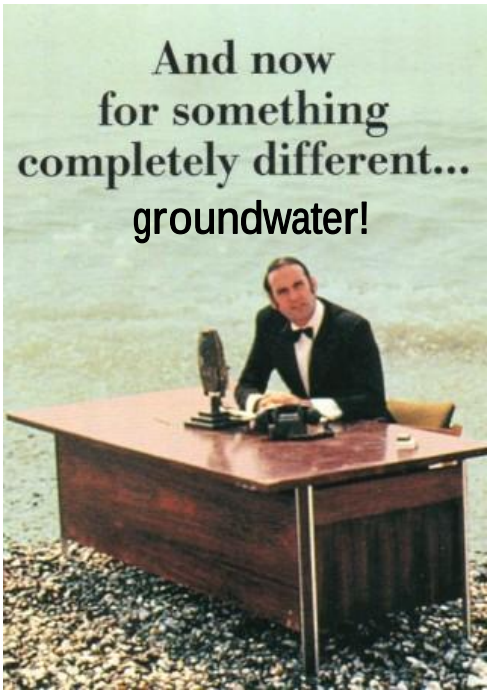

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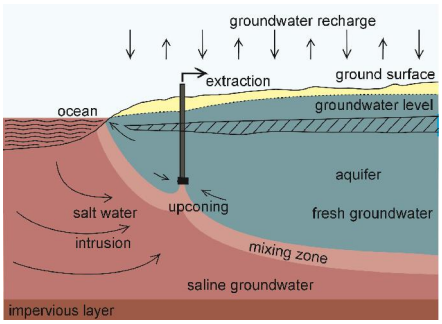
Global Quick Scan of the Vulnerability of Groundwater systems to Tsunamis*

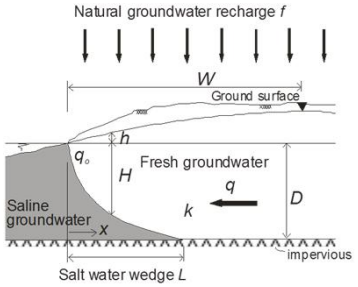
**or other flooding events*

Daniel Zamrsky, Marta Faneca Sànchez, **Gualbert Oude Essink**
Gualbert Oude Essink
Subsurface and Groundwater Systems
Deltares, The Netherlands
freshsalt.deltares.nl

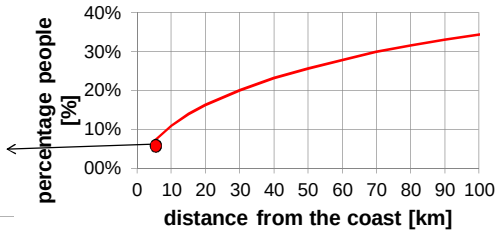
- *Sense of Urgency*
- *Intro saline groundwater*
- *Approach*
  vulnerability index
  modelling salt groundwater
- *Results*

Groundwater in the coastal zone





500 million people in the first 5km from the coastline



In 1 liter ocean water about 35 grams salt

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In 1 liter drinking water only 0.15 grams salt is allowed

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Every year, about 2 million people die from diarrhea, caused by bad drinking water quality

Groundwater is an important source of drinking water in underdeveloped countries due to its quantity and high quality (now 30% and increasing)

What will happen when a disaster like a tsunami hits a coastal area?

Salinization of groundwater by tsunami inundations might lead to a temporal stop of groundwater extractions in affected areas

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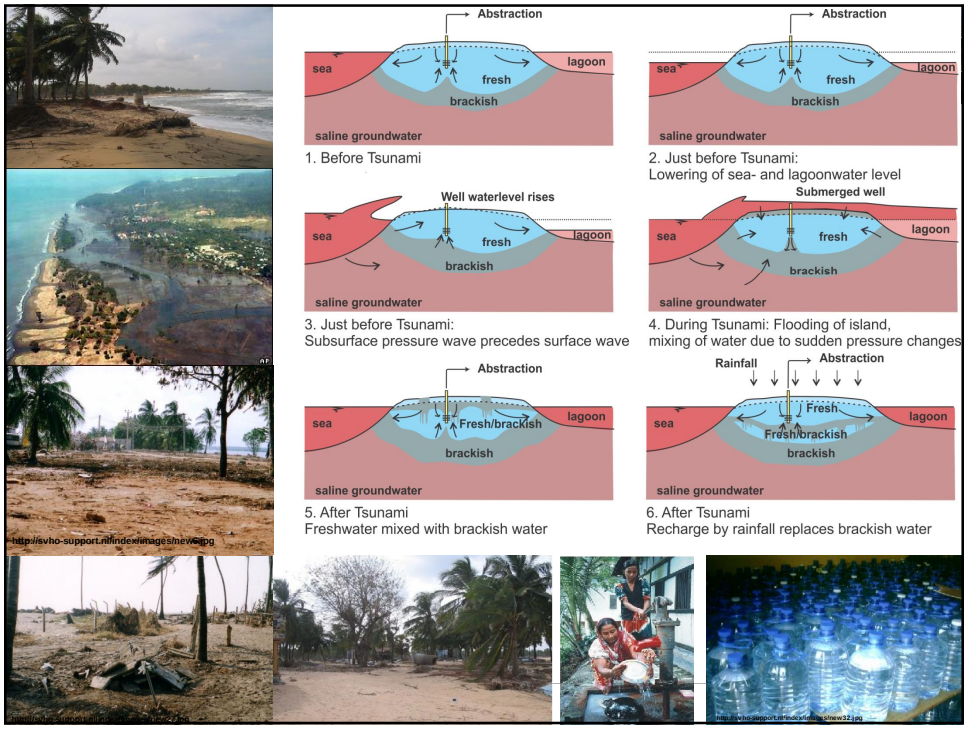
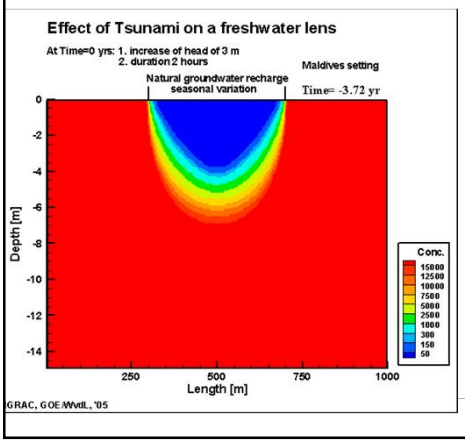
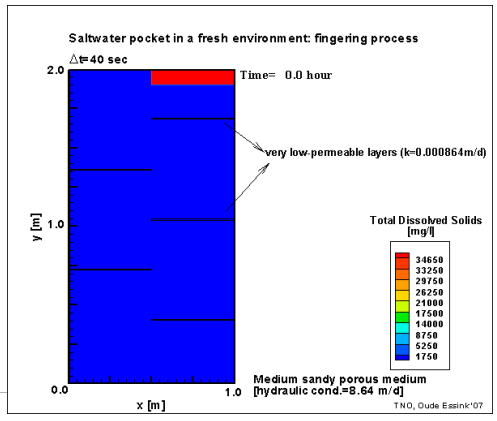


Salinisation process of fresh groundwater reserves

Impression of relevant salinisation processes in coastal aquifers:

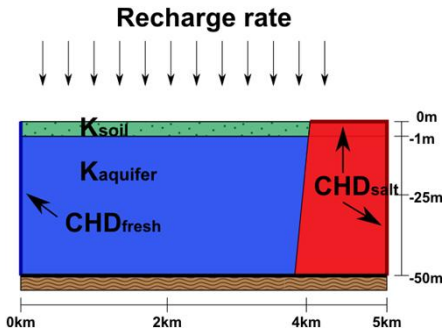
- Saline fingering processes in the subsoil
- Contamination freshwater lens after sea water flooding

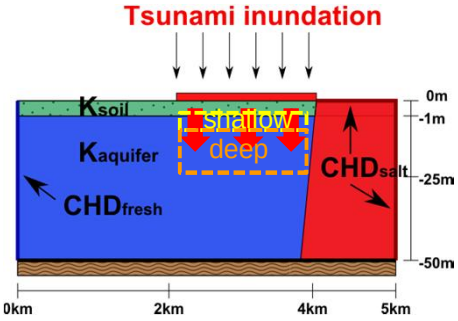




Concept 2D modelling variable-density groundwater flow and coupled salt transport

Normal system





- Focus on coastal fresh groundwater resources, deep and shallow
- How long does it takes before the groundwater system is fresh again, available for groundwater extractions?

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Using global datasets in the analysis

- **SRTM – DEM of the world**
  - Used to create:
    - *Slope*
    - *Distance to coast*
- **Resampling**
  - Different resolution of other original datasets (e.g. population density)

Name	Type	Resolution
SRTM	raster	90 m
Population density	raster	≈ 4.6 km
*Land use**	raster	300 m
Soil map	raster	≈ 1 km
Precipitation	raster	≈ 1 km
Tsunami occurrence	point shape file	-
*Bathymetry**	raster	≈ 1 km
GDP	raster	≈ 1 km

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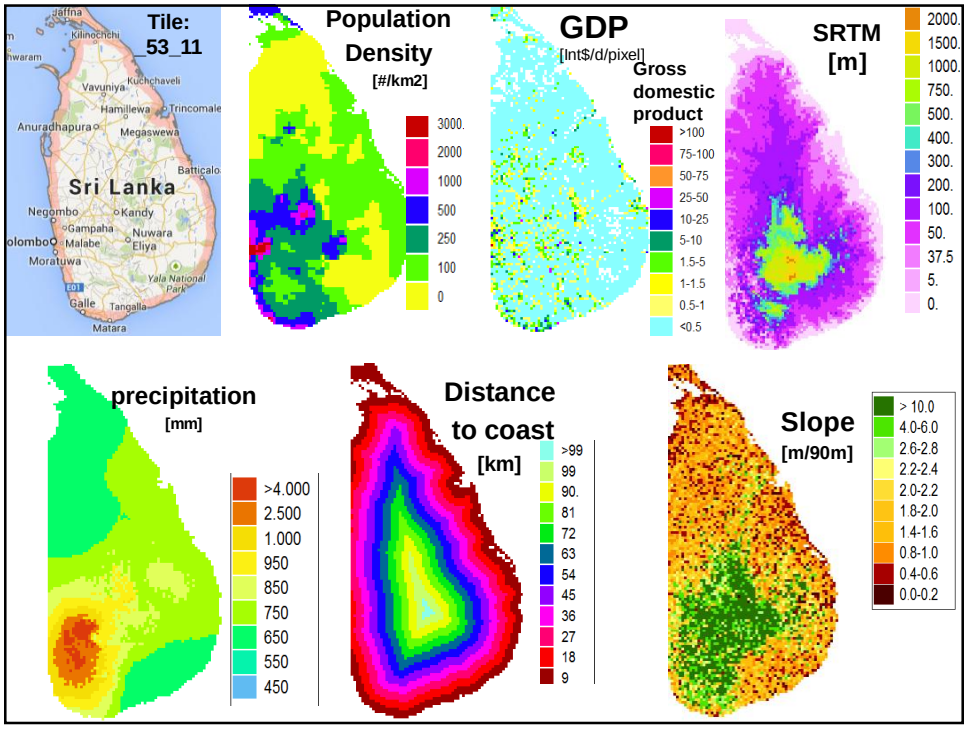
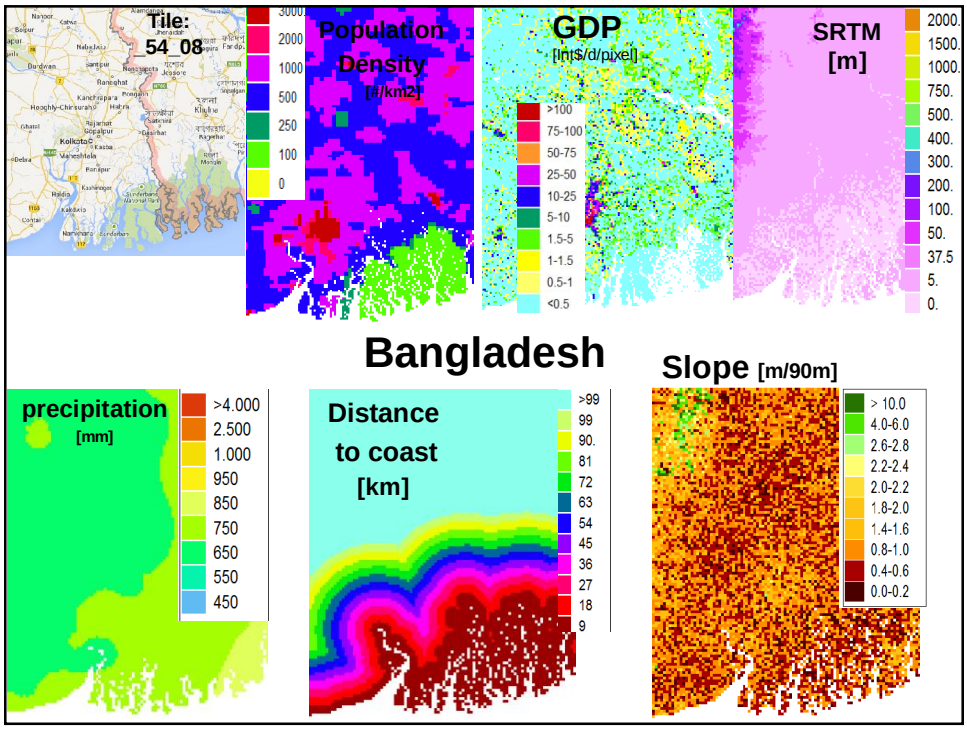

Tile:
53_11
Sri Lanka
Population
Density
[#/km2]
3000.
2000
1000
500
250
100
0
GDP
[Int$/d/pixel]
Gross
domestic
product
>100
75-100
50-75
25-50
10-25
5-10
1.5-5
1-1.5
0.5-1
<0.5
SRTM
[m]
2000.
1500.
1000.
750.
500.
400.
300.
200.
100.
50.
37.5
5.
0.
precipitation
[mm]
>4.000
2.500
1.000
950
850
750
650
550
450
Distance
to coast
[km]
>99
99
90.
81
72
63
54
45
36
27
18
9
Slope
[m/90m]
> 10.0
4.0-6.0
2.6-2.8
2.2-2.4
2.0-2.2
1.8-2.0
1.4-1.6
0.8-1.0
0.4-0.6
0.0-0.2


Tile:
54_08
Population
Density
[#/km2]
GDP
[Int$/d/pixel]
SRTM
[m]
Bangladesh
Slope [m/90m]
precipitation
[mm]
Distance
to coast
[km]

Methodology Vulnerability Index

- Combine topography, tsunami risk and socio-economic factors (poverty)
- Topographical vulnerability index: ***Elevation, Slope, Distance to coast***
- Determine simple equation and ranges of values
  - Literature review (e.g. regional studies Indonesia)
  - Tsunami inundation extents and affected areas in history

Elevation	ID_{elev}
Slope	ID_{slope}
Distance to coast	ID_{dist}

$$vulnerability\ index = 4 * ID_{elev} + ID_{dist} + ID_{slope}$$

Final index	Variable ID values and ranges					
Variable / ID	1	2	3	4	5	30
Topographical elevation (m above sea level)	min - 8	8 - 16	16 - 24	24 - 32	32 - 40	>40
Topographical slope (°)	0 - 1	1 - 2	2 - 3	3 - 4	4-5	>5
Distance to coast (pixels)	0 - 7	7 - 15	15 - 25	25 - 40	40 - 55	>55
Distance to coast (m)	0 - 540	540 - 1350	1350 - 2250	2250 - 3600	3600 - 4950	>4950

Vulnerability level	Sum of IDs	Vuln. ID
Very high	6 - 9	1
High	10 - 14	2
Medium	15 - 19	3
Low	20 - 24	4
Very low	25 - 29	5
None	>30	6

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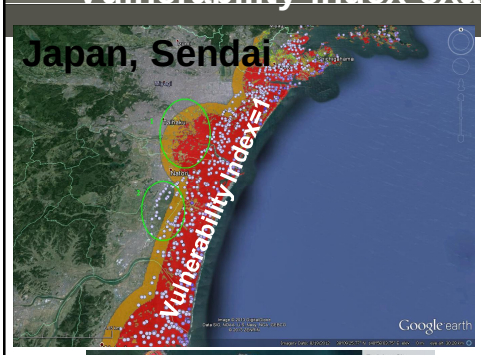
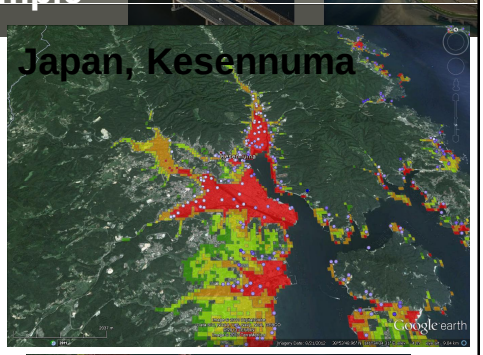
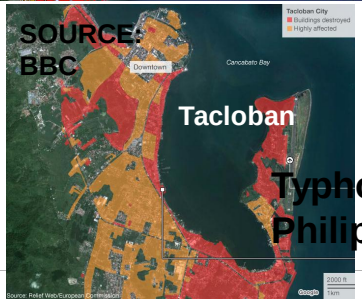
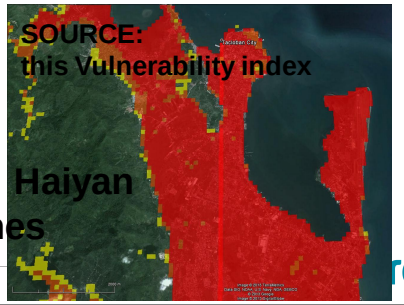
Vulnerability index example









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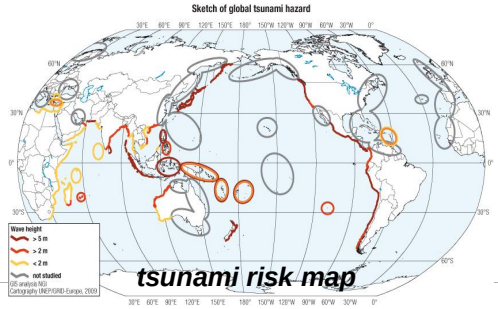
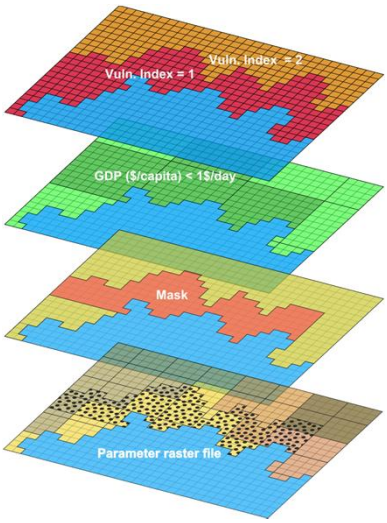
Socio-economic factor and parameter values statistics

- **Focus on poor areas (1$/day per capita)**
  - Combining the pop. density and GDP datasets
- **Parameter statistics for chosen areas**
  - Soil types
  - Precipitation
  - Population density

Input to model (total # simulations : 96)



tsunami risk map



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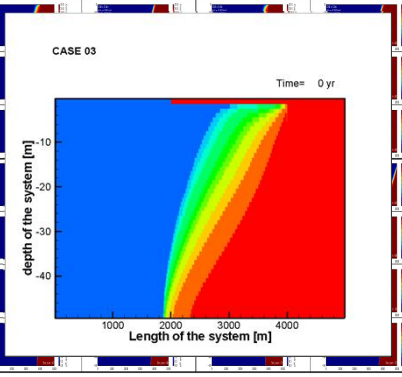
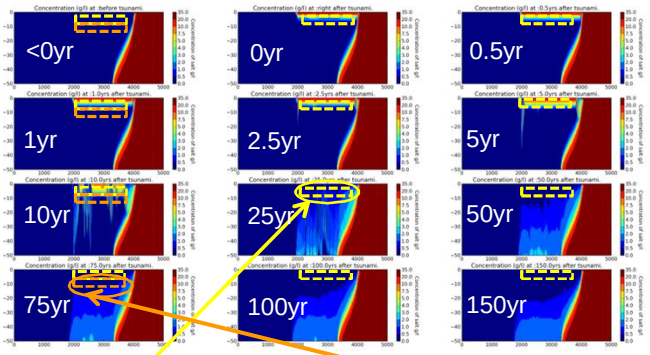
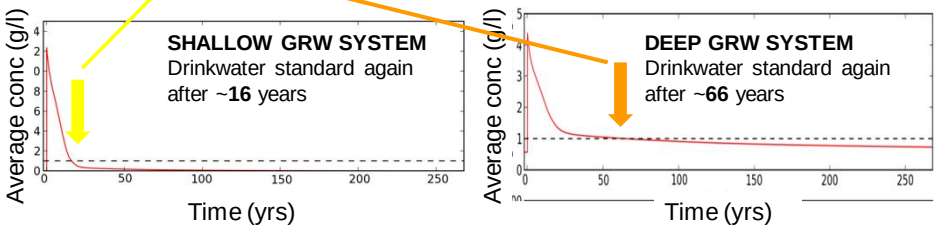
Variable parameters	Value			
	A	B	C	D
Recharge (fresh) (m/d)	0.0001	0.001	0.0025	0.005
CHD fresh (m)	1.0	5.0	15.0	-
K soil (m/d)	0.005	0.05	5.0	50.0
K aquifer (m/d)	1.0	100.0	-	-



Results of one case



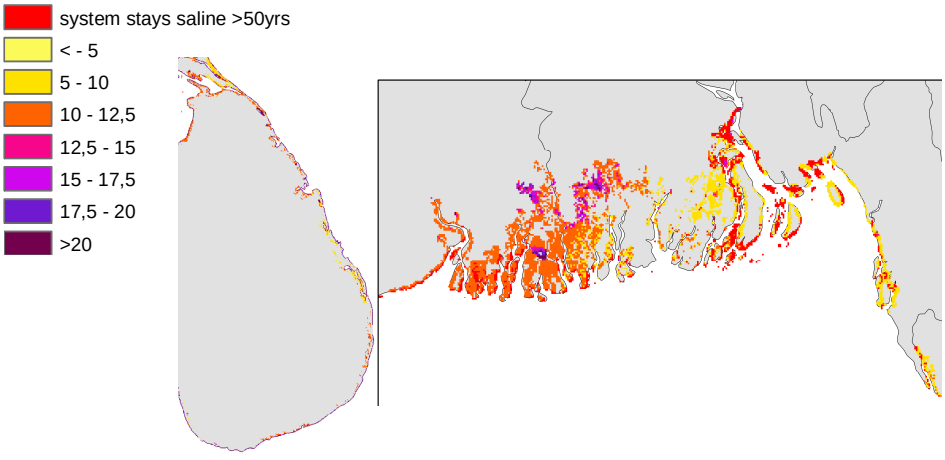
Salt water fingers intrude the groundwater system the coming tens of years



Back to the Map!

- Shallow groundwater system
- GDP<1 US$/day/capita

Legend Time (yrs) before the shallow coastal groundwater system is fresh enough again for drinking water extraction



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Concluding

Approach

- Assessing vulnerability index on global scale possible with free accessible datasets and tools
- Methodology tested in some regional studies and shows good fit with tsunami run-up measurements

On fresh water resources:

- After a tsunami, groundwater in the coastal zone may stay salty and not drinkable for many many years

We want:

- Test approach in one specific regional area

We need:

- Global dataset on geology

Next steps:

- Upscale to other flooding events (e.g. storm surges)
- Climate Change, Global Change (groundwater extractions)
- 3D approach for the top 25 deltas worldwide

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Dec. 2004 Sri Lanka

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Result:

- Tsunami vulnerability index map, from coastal groundwater perspective
- Global coastal groundwater salinisation assessment under tsunami* conditions

**and other flooding events*