New developments of global coastal groundwater salinity modelling and mapping

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EGU General Assembly 2023
Session HS8.2.6
EGU23-17249
Why this global coastal groundwater model initiative?

- We need quantified **storylines** on fresh groundwater availability under stress in coastal zones.
- Storylines should link coastal groundwater to **droughts, land subsidence, flooding, health, biodiversity**.
- Coastal fresh groundwater is the **main water resource** for ~50% of the world population in the coastal zone.
- Groundwater is important for **agriculture, industry**, as well as **ecosystems & river baseflows**.
- Resources are threatened by **excessive pumping**, climate change induced **sea-level rise**, and **sealing**.
- E.g., for **Water Peace & Security** issues, groundwater resources are often part of the water **solution**.

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**Mega cities**

50% of our drinking water is fresh groundwater

Depletion results in subsidence

Drought

Salinisation

Image credit: USGS

Image credit: Piyaset/Shutterstock.com
Possible applications coastal global groundwater model (1km$^2$ scale)

- Components:
  - groundwater quantity
  - groundwater salinity
  - subsidence (2024)
  - heat transport (later, >2024)
  - groundwater quality (later, >>2024)

- Themes like:
  - drinking water quality and health in the coastal zone
  - damages to crops (drought, salinity)
  - anthropogenic activities (limits of groundwater use, sustainable rates, sealing aquifers due to urbanization, effectiveness of regional Managed Aquifer Recharge pilots)
  - sea-level rise and climate change
  - combining land subsidence and overexploitation with salinisation
  - Submarine Groundwater Discharge, Offshore Fresh Groundwater
  - Water Peace and Security / refugee camps
Example: storyline on Pathways to demonstrate the future Mekong delta: linking groundwater extraction $\rightarrow$ subsidence $\rightarrow$ increased flood risk

Among others based on this research, ‘Decree 167’ is implemented in Vietnam in the Law of Water Resources: On developing and implementing zoning plans to restrict groundwater overexploitation!
Why now?

Creating high-resolution global 3D coastal groundwater salinity models is now possible:

1. **Parallel groundwater salinity modelling** (iMOD-WQ / SEAWAT).

2. **Fast Airborne EM groundwater salinity mapping in 3D**, (e.g., FRESHEM), citizen science data collection at high TRL.

3. **Paleo reconstructions of past hydrogeological conditions in data-poor areas**, (possible due to parallel computer), resulting in improved understanding of present groundwater salinity.

4. **More open hydrogeologic data available** (advanced text mining, open-source webportals).

5. **Advanced interpolation techniques for rapid 3D interpolation** of coastal geology and groundwater salinity, and model parameters.

6. **Fully scripted reproducible modelling workflows, clipping & refining** (e.g., iMOD-Python), aiding regular updating and stakeholder trust in model results.

7. **And: groundwater community initiatives**, like Groundwater Model Portal (GroMoPo) (e.g. poster EGU23-12340)
Parallel groundwater salinity modelling

Speed-ups up to at least 10 – >100 times, depending on cores, iterations and data exchange efficiencies

- Sand Engine: from 1hr 47min 55sec -> 2min 40sec: 40*
- NHI fresh-salt: from ~30 days to ~2days: 15*
- Island Japan: from 5d0h36m to 5m59s: 1209*

Airborne groundwater salinity mapping FRESHEM

Method:
Combination helicopter measurements with data and knowledge about subsurface and processes in fresh-saline groundwater, and geostatistical mapping via (multiple) indicator kriging.

Results:
- Mapping of 3D groundwater salinity
- Mapping of clay layers

Applications:
- strategic fresh groundwater users & policy makers
- support ASR (COASTAR) in coastal zone
- identify brackish water potential
- improve groundwater models & monitoring

International:
- Project in Flanders, Belgium
- Pilot Mekong, Vietnam
Citizen science, using simple devices and webportals
Paleo-reconstructions groundwater salinity

Parallel computer power is utilized to simulate 3D reconstructions of past hydrogeological conditions in (data-poor) areas, improving understanding of present groundwater salinity.

Delsman et al., 2014. HESS
Paleo-reconstructions groundwater salinity

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Northwest Germany

3D

Seibert et al., 2023 WRR

Denmark

3D

Meyer, et al., 2019

Origin of sources and ~age dating

Mekong delta

2D

Hung et al., 2019 JoH, RS

Nile delta

3D

Van Engelen et al., 2019. HESS
Combining groundwater salinity data

- Airborne surveys
- Webportals, text mining (pdf)
- Rapid, automated interpolations
- Paleo reconstructions modelling
- (Citizen science salinity monitoring)

Gurmessa et al., 2022, STOTEN
Thorslund et al., 2020, Sci. Data
Data mining hydrogeology

Extracting information from images.

Automated in Python using Tesseract and OpenAI API

Input image

Output text (Tesseract)

Extracted data (OpenAI)

User: "If there are coordinates in the text, extract them as minimum and maximum coordinate pairs:

System: "Example output: X: 100, 100. Y: 100, 100"
Data mining hydrogeology

Extracting information text.

Automated in Python using OpenAI API

Input text

Extracted data (OpenAI)

User: "Extract model parameters from the text in tabular format:"

System: "Example: X,Y,Z,1,2,3"
Oman case
223*274*12 cells of 1*1km^2;
Simulating groundwater salinity paleo-reconstruction (120kyrs) and 300 yrs into the future including extractions (using PCR-GLOBWB).
Computation time: < 1day, parallel on only 24 cores; using supercomputer Snellius, but even on a laptop it is doable

Test 1 Making a regional 3D groundwater salinity model

- Oman case
- 223*274*12 cells of 1*1km^2
- Simulating groundwater salinity paleo-reconstruction (120kyrs) and 300 yrs into the future including extractions (using PCR-GLOBWB).
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Test 2 Making a regional 3D groundwater salinity model

- **Tunisia-Lybia** case
- 907*747*12 cells of 1*1km²
- Simulating groundwater salinity paleo-reconstruction. For now 30-20krys BP.
- Testing parallel on 62-128 cores; using supercomputer Snellius

Situation 30000 yr BP

Automated STEPSIZE analysis!
New developments: global coastal groundwater salinity modelling

GCGM initiative

- Parallel computing
- Reproducible workflows & (python) tools
- Airborne salinity mapping, citizen science
- Advanced interpolation techniques for geology and salinity
- Paleo reconstruction salinity
- Open hydrogeologic data, webportals, text mining

Deltres

groundwater community initiatives, making the invisible visible
Thank for you attention

Questions?

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More information:

Parallel SEAWAT, imod-python and 3D viewer:

- https://oss.deltares.nl/web/imod/about-imod5
  - https://deltares.github.io/iMOD-Documentation/python_index.html
  - https://deltares.github.io/iMOD-Documentation/viewer_index.html

Reproducibility and transparency, Gitlab

- https://gitlab.com/deltares/imod/nhi-fresh-salt

- 3D Paleo-reconstruction groundwater salinity and iMOD-WQ

And PICO Zamrsky et al.: EGU23-11444 HS8.2.6

Ilja America - van den Heuvel et al

Thijs Hendrikx et al

Ignacio Farias et al

Stephan L. Seibert et al

Marc Bierkens

More information:

Parallel SEAWAT, imod-python and 3D viewer:

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Orange issues

- Calibration, validation, verification.
- Tekst mining: IPR of articles.
- Interferences with local hydrogeological communities, some same regional scale.