Examples and considerations of spatial prediction modeling of geogenic groundwater contamination

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GAP
Groundwater
Assessment
Platform

Geogenic (natural) groundwater contamination

- Up to 10% of the global groundwater is contaminated by high levels of arsenic (As) or fluoride (F)
- Over 400 million people globally are exposed

Arsenic (As)
causes skin lesions,
pulmonary disorders,
internal cancers

WHO: 10 μg/L

~220 million people

Fluoride (F)
causes dental mottling &
decay,
crippling skeletal deformation

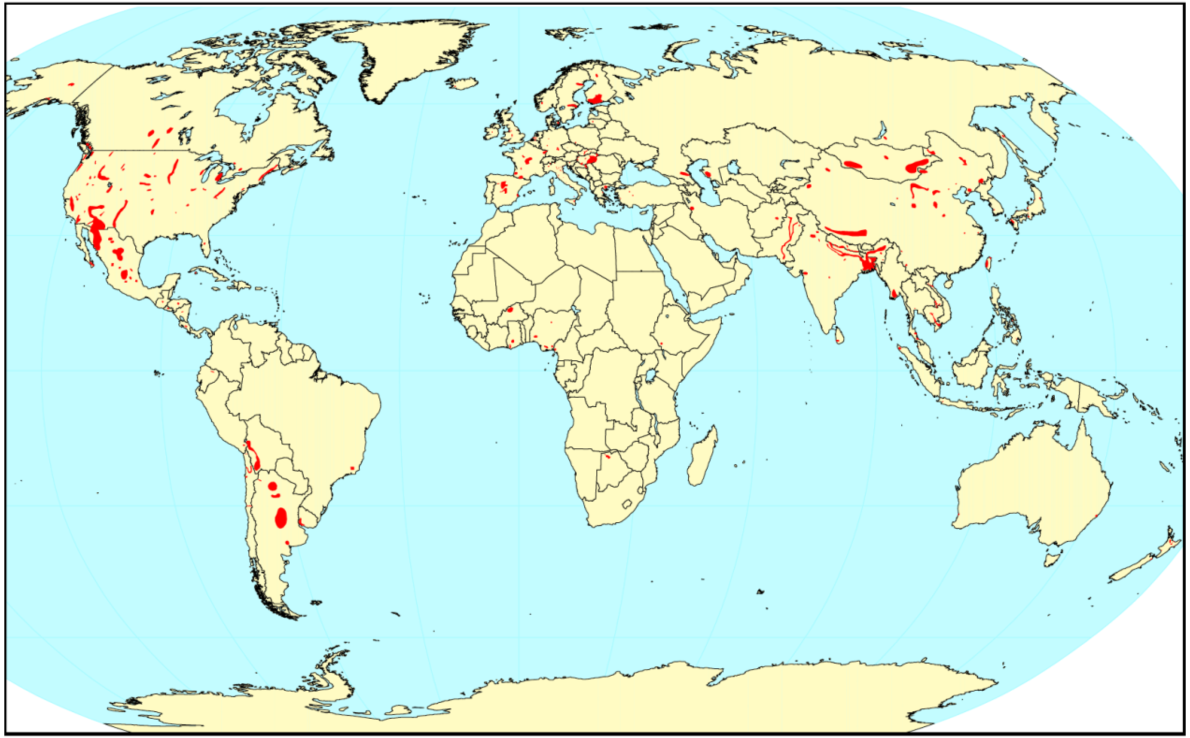
WHO: 1.5 mg/L

~200 million people

→ Geochemistry, occurrence and distribution, impact on population, mitigation measures

Geogenic arsenic in groundwater resources

- Naturally occurring around the world
- Exposure via drinking water & crops
- Difficult to detect/measure
- New affected areas continually found



Ravenscroft et al., 2008

Common conditions

Overarching factors influencing As groundwater contamination

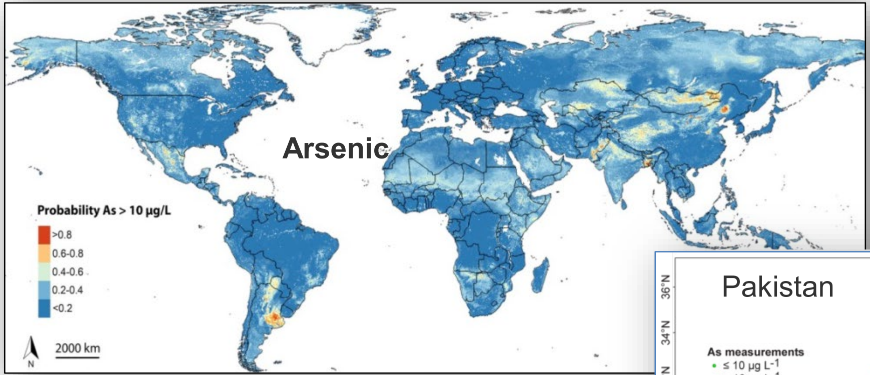
- Low-oxygen (reducing) aquifers
- Organic-rich sediments
- Young sediments (Holocene)
- Low-lying areas (predominantly young river deltas)

➡ Is it possible to forecast water quality and delineate safe and unsafe areas ??

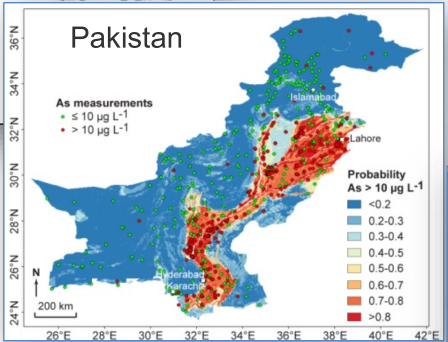
Southeast Asia delta plains

Hug et al., ES&T **2008**

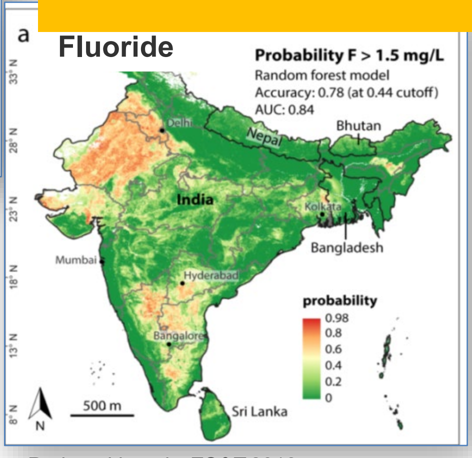
Prediction map examples



Podgorski et al., *Science* 2020



Podgorski et al., *Science Advances* 2017



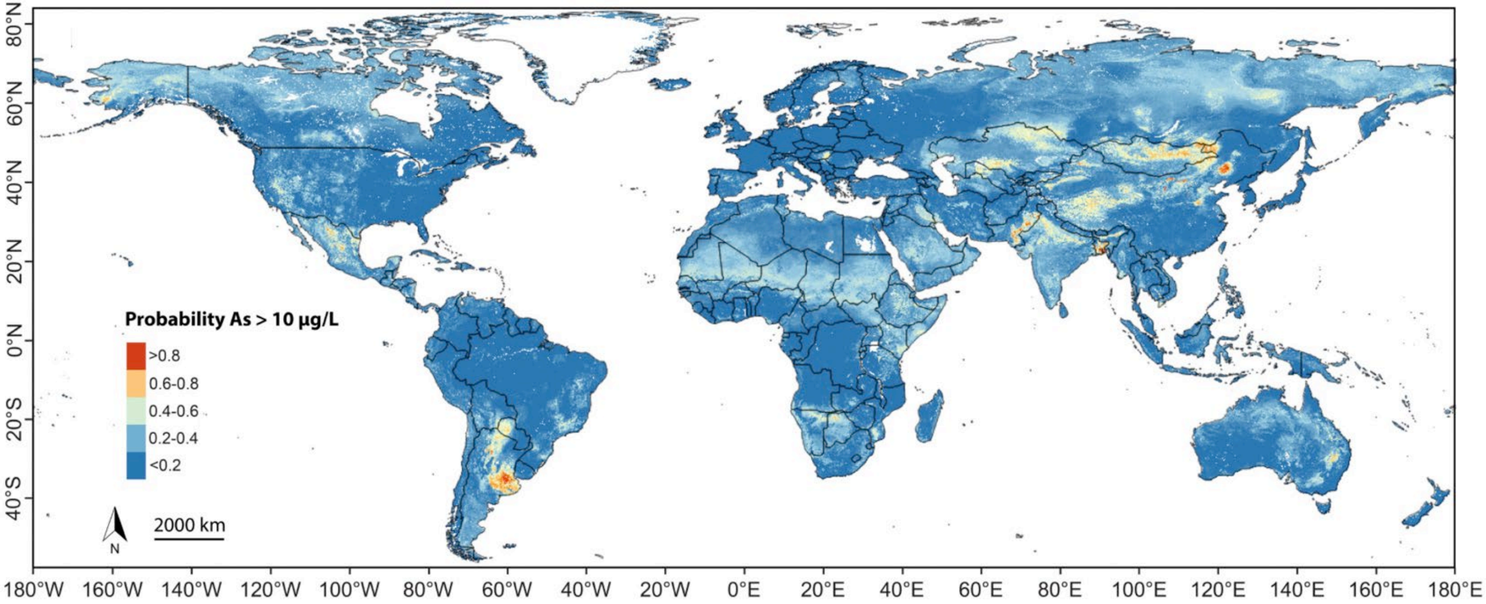
Podgorski et al., *ES&T* 2018

Impacts:
- Increased awareness
- Political discussions
- Follow-up studies
- Targeted sampling campaigns

Predictor variables:
- Geology
- Soil pH
- Soil texture
- Soil type
- Aridity
- Slope
- Cropland
- Irrigation

Groundwater arsenic model (10 µg/L)

Created with machine learning (random forest)



Podgorski and Berg, *Science* **2020**

11 independent variables:

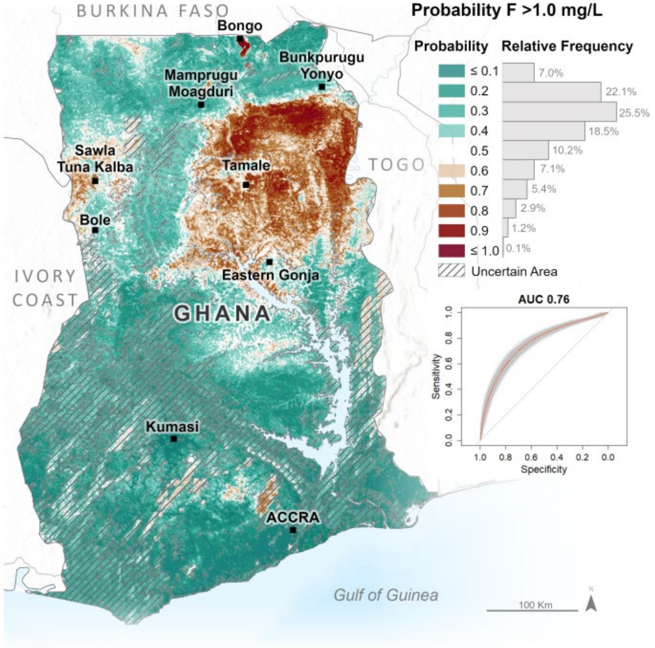
Climate: actual evapotranspiration, aridity, potential evapotranspiration, precipitation, Priestley-Taylor coefficient, temperature

Soil: clay content, fluvisols, soil pH, sand content

Topography: topographic wetness index

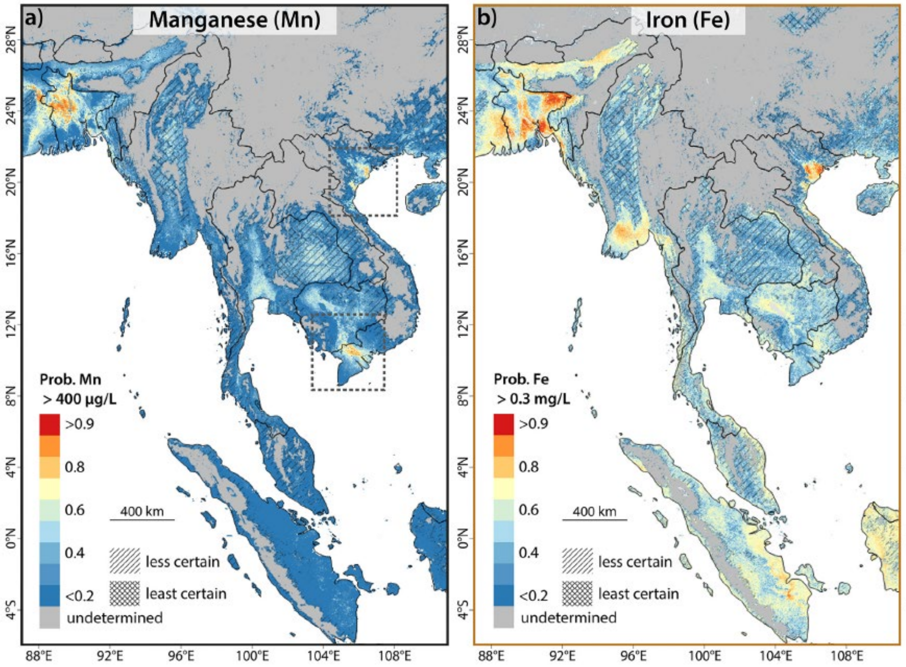
Recent work

Fluoride in Ghana



Araya et al., *Water Research* 2022

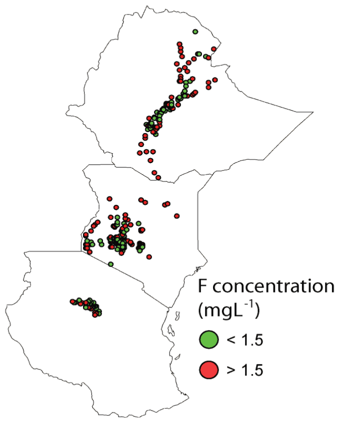
Manganese and iron in Southeast Asia



Podgorski et al, *STOTEN* 2022

Concept of geostatistical prediction modelling

Concentration data → Geo-statistical modeling → Identifying risk areas → Mitigation



Groundwater data

GIS data

Combining geochemical and statistical expertise

Risk maps

Relevant geospatial data
- Increasingly available in digital GIS format
- Often free of charge
- Resolution and coverage increasing

General modeling process

1. Collect data points of contaminant concentrations
   - Cover area of map to be developed
   - Possibly convert to binary format
   - Should cover range of values
2. Assemble predictor variables
   - Based on known or suspected relationships with contaminant
   - Spatially continuous
   - Should contain wide range of values
3. Statistical modeling (e.g. R, python)
   - Free, many different packages available
4. Apply model to predictors -> create map

Statistical modeling algorithms

Find relationships between predictor variables and contaminant concentration

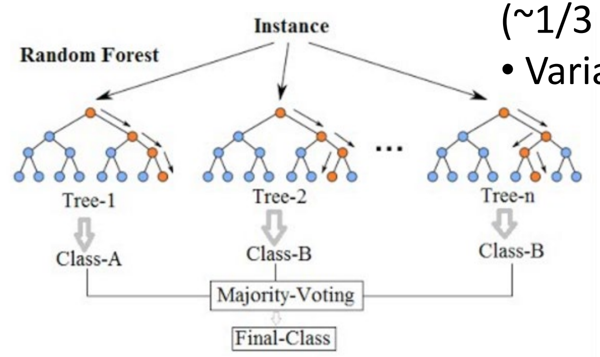
→Logistic regression

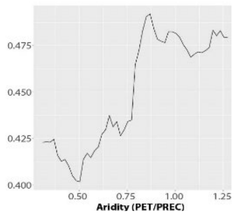
$$P = \frac{e^{(\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k)}}{1 + e^{(\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k)}}$$

P: probability
$x_1, \ldots, x_k$: predictor variables
$\beta_1, \ldots, \beta_k$: regression coefficients

→Random forest

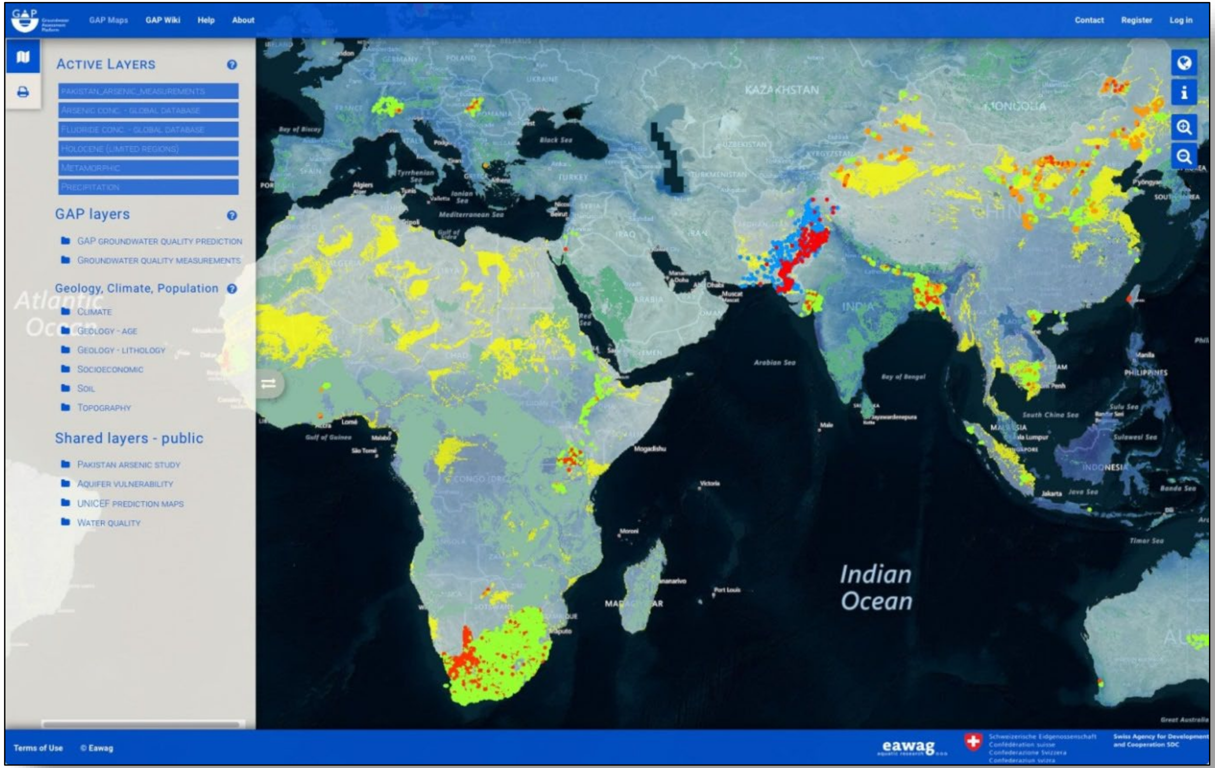
- Ensemble (average) of decision trees
- Randomness introduced to avoid overfitting:
  - random subset of possible predictor variables at each node
  - random selection with replacement of data rows used in each tree (~1/3 of data row not present in a given tree)
  - Variable importance, partial dependence plots





Also: generalized boosted regression models, neural networks, support vector machines eawag aquatic research

GAP Groundwater Assessment Platform



- Visualize groundwater data
- Upload and view own data
- Create own predictive maps
- Share data and models with other users or publicly

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Swiss Agency for Development and Cooperation SDC

www.gapmaps.org

Thank you

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