Estimation of shallow groundwater temperatures in Saxony-Anhalt, Germany

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1 Motivation and aims

- Groundwater temperature (GWT) is an important parameter for **groundwater quality** and **ecosystems**
- Mapping GWT can help identifying locations of **shallow geothermal potential**
- Estimations based on satellite data can **complement point interpolation**

- First-time analysis of **shallow GWT** in the state of **Saxony-Anhalt**, Germany
- Calculation of **estimated GWT** (eGWT) with remote sensing data
- Evaluation of the **influence of land cover** on the GWT distribution and the estimation results

? Subsurface warming

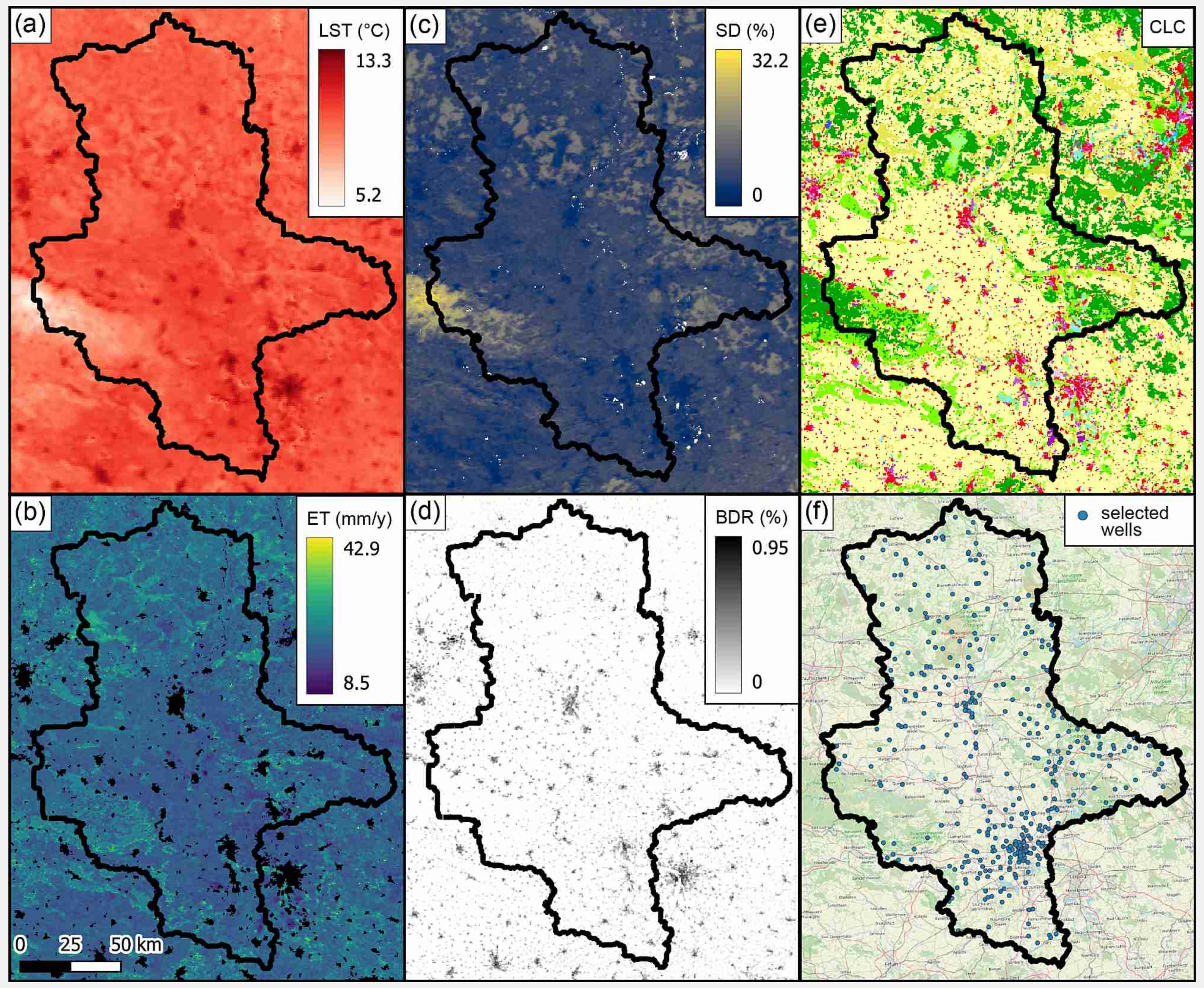
In the past decades, increasing groundwater temperature was observed globally. Due to the coupling of atmospheric and subsurface temperatures, climate change yields an equal impact above and below ground, albeit with a delay. Additionally, many other structures, such as basements, tunnels, and sewer networks, act as heat sources and cause local temperature anomalies. In cities, where such heat sources accumulate, subsurface urban heat islands with intensities of up to 7 K occur.

3 Calculation of eGWT

- Satellite and GWT data is **averaged** over the years **2007 - 2022**
- Satellite data is scaled to **500 x 500 m resolution**
- **Land cover** classes are **simplified** into groups
- Direct derivation of eGWT from **LST underestimates GWT** by almost 1 K
- **Multiple linear regression** of ET, SD and BDR to calculte the offset between LST and GWT:

$$eGWT = LST + 0.021 \cdot ET + 0.075 \cdot SD + 2.232 \cdot BDR + 0.289$$

2 Input data



Remote sensing

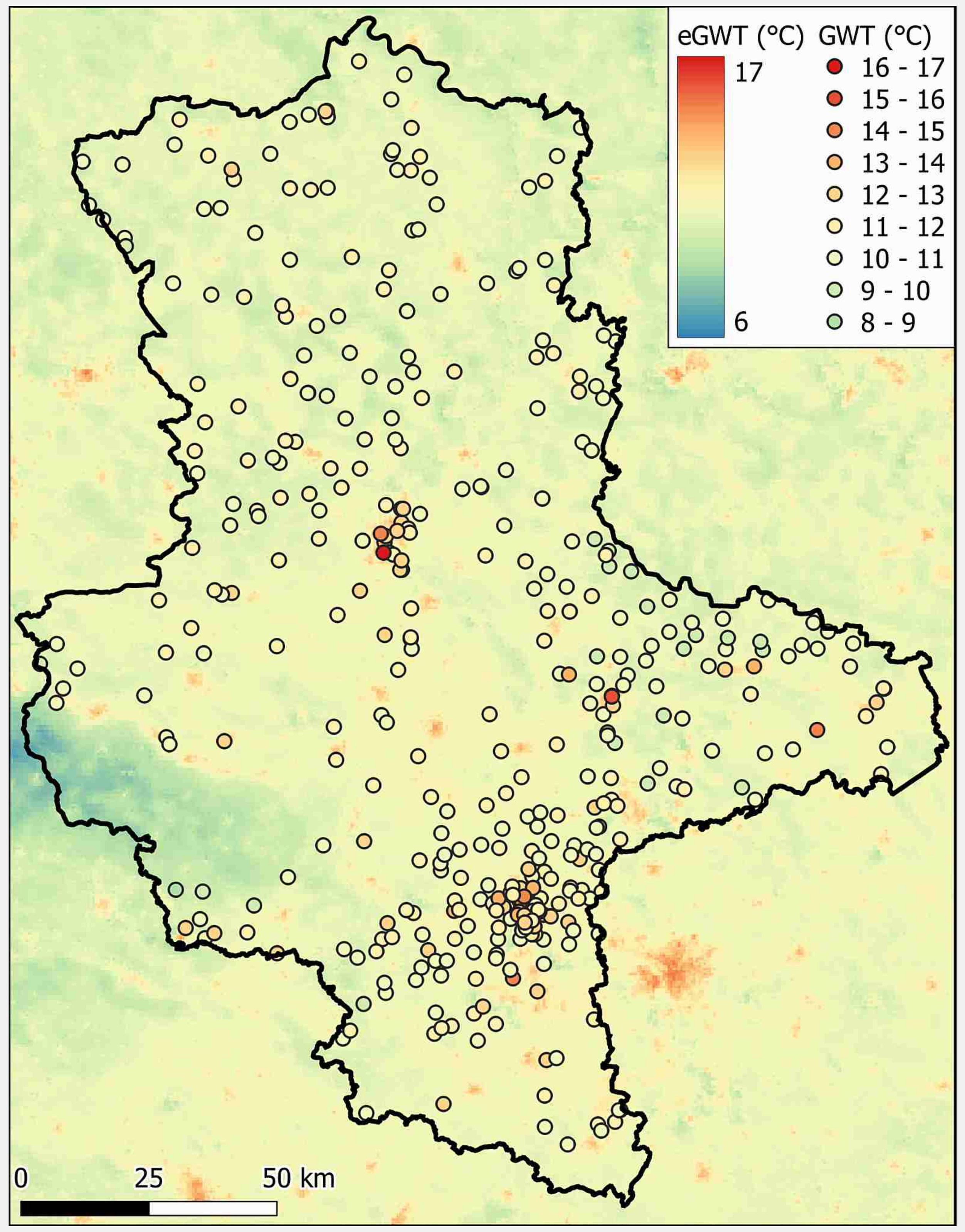
(a) Land Surface Temperature (LST)[1]
(b) Evapotranspiration (ET)[1]
(c) Snow Days (SD)[1]
(d) Building Density (BDR)[2]
(e) CORINE Land Cover (CLC)[3]

Measured data

- **GWT data** from LHW Saxony-Anhalt and own measurements in Magdeburg, Halle, Dessau
- **Selection** of data between:
  - the years **2007** and **2022**
  - **10** and **50 m** depth

(f) **436** out of 1098 **wells** were selected

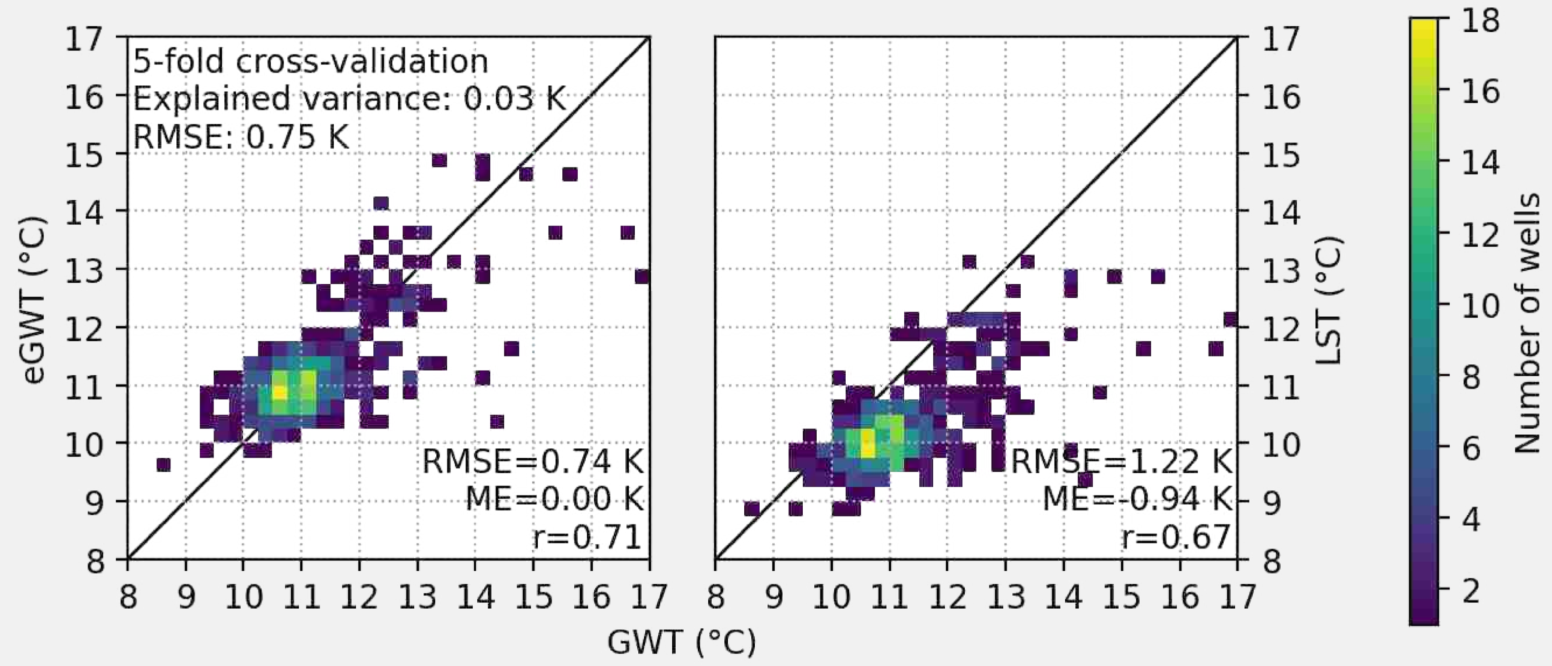
4 GWT distribution map



5 GWT distribution and comparison with eGWT

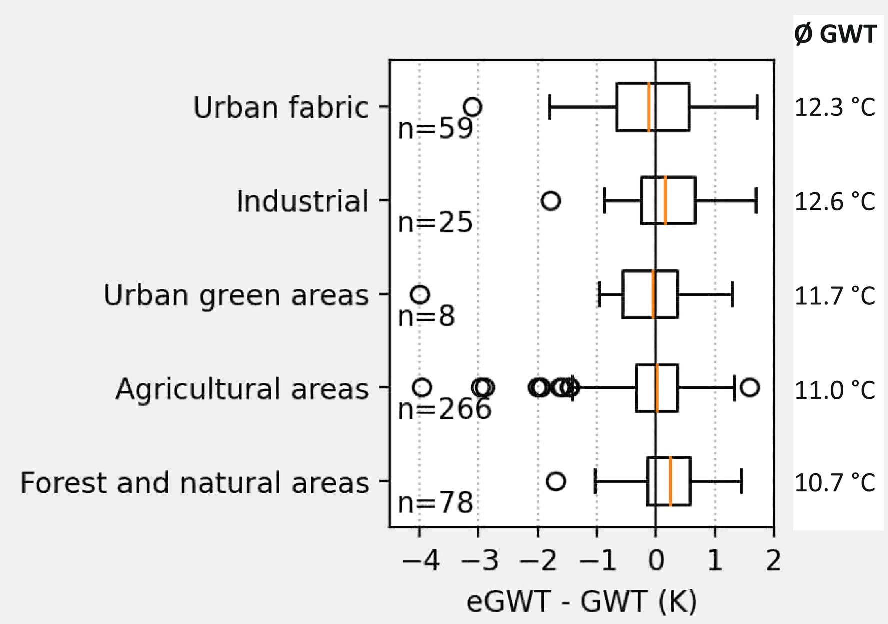
- Mean GWT is 11.2 ± 1 °C
- Min: 8.7 °C (Harz)
- Max: 17 °C (Magdeburg)
- 81% < 12 °C
- Cities warmer than rural areas

Root Mean Square Error (**RMSE**) of the estimation of **0.74 K** is slightly better than in former studies for Cologne[4], Paris[5], and a global dataset[6] (0.86 – 1.4 K).



6 Land cover influence

Model accuracy



Outlier

Location	ΔT (K)	GWT (°C)	eGWT (°C)	CLC-Group	Possible reason
Magdeburg	-4.2	17	12.8	Urban green area	Proximity to medical facility (12 m)
Klöden	-3.9	14.4	10.5	Agricultural area	Proximity to Elbe River (130 m)
Dessau-Roßlau	-3.1	16.6	13.5	Urban fabric	City centre, proximity to building (1 m)
Halle (Saale)	1.5	11.2	12.7	Agricultural area	High LST due to urban location
Halle (Saale)	1.5	12.4	13.9	Urban fabric	Location in city park
Halle (Saale)	1.8	12.3	14.1	Urban fabric	Location in city park

7 Conclusions

Facts

Urban groundwater is **the warmest**, while forests, natural and agricultural areas are **coolest.**

Using remote sensing data for estimating GWT is an **easy** and **reliable alternative** to interpolation.

The applied methodology works best for forests and natural areas. Industrial and urban areas have the **highest errors** due to strong **GWT heterogeneity** in presence of local anthropogenic heat sources.

Numbers

Model results
Mean GWT Saxony-Anhalt
11.2 ± 1 °C
Model accuracy (RMSE)
0.74 K
Resolution
500 m

Geo Berlin 2023

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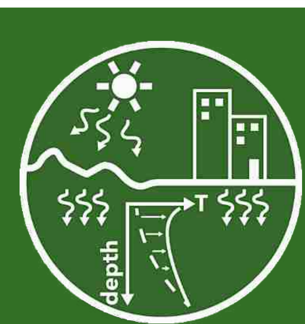
Further information



References

[1] MODIS-LST-V6-Aqua and MODIS-LST-V6-Terra, 2019.
[2] OpenStreetMap, 2023,https://www.openstreetmap.org/copyright.
[3] European Environment Agency, 2023, Copernicus Land Monitoring Service.
[4] Hemmerle, H., Dressel, I., Blum, P., Menberg, K., Benz, S. A., und Bayer, P., 2020, Benefits from Subsurface Urban Heat Islands to Shallow Geothermal Applications–an Example from the City of Cologne, Germany.
[5] Hemmerle, H., Hale, S., Dressel, I., Benz, S. A., Attard, G., Blum, P., und Bayer, P., 2019, Estimation of Groundwater Temperatures in Paris, France: Geofluids, v. 2019.
[6] Benz, S. A., Bayer, P., und Blum, P., 2017a, Global patterns of shallow groundwater temperatures: Environmental Research Letters, v. 12, no. 3, p. 034005.