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Urban heat islands in the subsurface of German cities

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In the subsurface of many cities there are widespread and persistent thermal anomalies (subsurface urban heat islands) that result in a warming of urban aquifers. The reasons for this heating are manifold. Possible heat sources are basements of buildings, leakage of sewage systems, buried district heating networks, re-injection of cooling water and solar irradiation on paved surfaces. In the current study, the reported groundwater temperatures in several German cities, such as Berlin, Munich, Cologne and Karlsruhe, are compared. Available data sets are supplemented by temperature measurements and depth profiles in observation wells. Trend analyses are conducted with time series of groundwater temperatures, and three-dimensional groundwater temperature maps are provided. In all investigated cities, pronounced positive temperature anomalies are present. The distribution of groundwater temperatures appears to be spatially and temporally highly variable. Apparently, the increased heat input into the urban subsurface is controlled by very local and site-specific parameters. In the long-run, the superposition of various heat sources results in an extensive temperature increase. In many cases, the maximum temperature elevation is found close to the city centre. Regional groundwater temperature differences between the city centre and the rural background are up to 5 °C, with local hot spots of even more pronounced anomalies. Particular heat sources, like cooling water injections or case-specific underground constructions, can cause local temperatures > 20°C in the subsurface. Examination of the long-term variations in isotherm maps shows that temperatures have increased by about 1°C in the city, as well as in the rural background areas over the last decades. This increase could be reproduced with trend analysis of temperature data gathered from several groundwater wells. Comparison between groundwater and air temperatures in Karlsruhe, for example, also indicates a spatial correlation between the urban heat island effect in the subsurface and in the atmosphere.