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Urban heat islands in the subsurface as sustainable source for geothermal energy

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The urban heat island (UHI) is not a phenomenon that solely occurs in the atmosphere with increased air temperatures. We also observe it in the subsurface, and groundwater temperatures in shallow aquifers are strongly influenced by anthropogenic land surface alterations. Widespread thermal anomalies, which are triggered by various processes, such as increased ground surface temperatures (GST) and heat loss from buildings, can be found under many urban areas. With groundwater temperatures elevated by several degrees these aquifers represent large amounts of stored thermal energy. However, to exploit these attractive geothermal reservoirs efficiently and sustainably, the processes, which lead to the profound subsurface urban warming, need to be identified and quantified. In the current study, the spatial extension of the heat anomalies beneath several German cities, such as Berlin, Munich, Karlsruhe and Cologne, is scrutinized by mapping groundwater temperatures in a dense network of observation wells. With the high-resolved spatial distribution of groundwater temperatures, the dominant heat sources and important driving factors can be identified and incorporated into an analytical heat flux model. The annual anthropogenic heat input into the aquifer originating from several heat sources, such as increased GST, basements, sewage networks, district heating networks and reinjections of thermal waste water, is estimated by a Monte Carlo simulation for the cities of Cologne and Karlsruhe. All studied cities exhibit aquifers with significantly elevated temperatures, with the highest temperatures of up to 18°C prevailing in the densely built-up city centers. But also in suburban and industrial areas groundwater temperatures are several degrees above the rural background. The accumulated heat content in the urban aquifers can be estimated based on the thermal ground properties. This content is compared to the annual space heating demand in order to analyze the space heating capacity of the thermal anomalies in the subsurface of the individual cities. The potential heat content of the individual aquifers, which accumulated in the aquifer, could cover the space heating of the studied cities for 1.6-4.5 years. The evaluation of the heat flux processes in Cologne and Karlsruhe shows, that the heat loss from basements and heat input from increased GST are the dominant heat sources, while the other processes are only of minor importance for the regional subsurface warming. However, site-specific heat sources, such as sewage leakages or reinjections of thermal waste water are found to cause pronounced local heat anomalies. The overall annual thermal energy input into the urban aquifer accounts up to 2.4 PJ for the study area in Cologne and 1.5 PJ in Karlsruhe. Thus, nearly 20% of the space heating demand in Karlsruhe could theoretically be covered sustainably by recycling the annual anthropogenic heat input into the urban aquifer.