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Heat adaptation in rural municipalities: A cross-sectional study in the Augsburg district, southern Germany

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ABSTRACT

Extreme heat is an increasing public health challenge, yet heat adaptation in smaller and rural municipalities remains comparatively underexplored. This study assessed municipal heat adaptation, implementation barriers, perceptions of heat-related health impacts, and their relation to regional climate information in the Augsburg district, Southern Germany.

A cross-sectional online survey was conducted among all 46 municipalities in the district between January and March 2025. Forty municipalities responded (87%), and 29 provided complete questionnaires (63% of the sampling frame). Survey data were analyzed primarily descriptively and supplemented by regional climate projections from the GERICS Climate Outlook. Perceived health impacts during the previous and next 10 years were additionally compared using a paired *t*-test and Wilcoxon signed-rank sensitivity analysis.

Fourteen of 29 municipalities (48%) had no assigned responsibility for heat protection. Strategic approaches, including climate analyses and Heat Action Plans, were less established than several infrastructure-based measures. Financial and staffing constraints were among the most frequently reported barriers. Municipalities expected stronger heat-related health impacts over the next 10 years than during the previous decade (mean paired difference 0.655, 95% CI 0.422 to 0.889; $p < 0.0001$), while regional projections indicate increasing heat-related climatic hazards over subsequent decades. Descriptive patterns suggested lower strategic engagement among smaller municipalities. Given the small analytical sample and single-district design, municipality-size patterns should be interpreted as exploratory.

The findings highlight the importance of translating regional climate information into locally applicable adaptation support. Clear responsibilities, accessible guidance, funding support, and capacity building may strengthen climate services and heat adaptation in resource-constrained municipalities.

Practical implications

Extreme heat is becoming an increasingly important challenge for local public health and climate adaptation. Smaller and rural municipalities require particular attention because limited staffing, administrative specialization, and financial resources may constrain their capacity to develop and implement heat adaptation measures (Vetter et al., 2017; Friedrich et al., 2024; Overath and Rösler, 2025). This study examined heat adaptation in 29 municipalities in the Augsburg district, Southern Germany, and considered municipal survey findings alongside regional climate information. The results provide practical insights into how climate information and municipal support structures could be better connected to strengthen local heat adaptation.

Regional climate projections indicate increasing heat-related climatic hazards in the Augsburg district over the coming decades, including increases in hot days, tropical nights, and the duration of heat periods (Pfeifer et al., 2021). Municipal respondents also expected heat-related health impacts to increase over the next 10 years. These findings address different time horizons and should not be interpreted as a direct comparison between perceived and projected risk. Rather, the regional projections provide a longer-term climatic context for municipal adaptation decisions. For climate services, this highlights the importance of

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translating regional climate information into locally relevant and easily accessible information that can support decision-making within municipalities with different levels of administrative capacity (Steynor and Pasquini, 2022; Sillmann et al., 2024; Ministère de la Transition écologique, 2025). Approaches that combine climatic information with local exposure and vulnerability indicators may provide a useful basis for identifying adaptation priorities and supporting evidence-based planning at the municipal level (Rupp et al., 2026).

A central practical challenge concerns the organizational anchoring of heat protection. Fourteen of the 29 municipalities had no clearly assigned primary responsibility for heat protection. Where responsibilities were assigned, mayoral offices and planning and construction departments played prominent roles, while health and social departments were not reported as responsible or additionally involved. This does not necessarily indicate an absence of health or social actors, particularly because smaller municipalities may not have dedicated departments for these functions. Nevertheless, heat adaptation would benefit from clearer responsibilities and stronger links between municipal planning, health, and social expertise (Bolte et al., 2023; Williams et al., 2013; Ochsmann, 2025). Where specialized municipal structures are unavailable, district authorities, public health services, social organizations, or other regional partners could provide complementary expertise (Ochsmann, 2025; Ministère de la Transition écologique, 2025).

The findings also indicate that strategic heat adaptation remains less established than several infrastructure-based activities. Climate analyses and Heat Action Plans (HAPs) were frequently reported as unnecessary, particularly among municipalities with fewer than 10,000 residents. In contrast, green and water-related measures were among the more frequently implemented activities. This suggests that smaller municipalities may benefit from practical planning instruments that build on existing activities without requiring extensive additional administrative structures. Simplified HAP modules, checklists, vulnerability assessment tools, and stepwise implementation guidance could lower practical barriers to more systematic heat adaptation (World Health Organization, 2021; Sieber et al., 2024; Ochsmann, 2025).

Communication and the protection of vulnerable populations represent further areas for development. Residents of senior or nursing facilities, toddlers, and outdoor workers were frequently identified as particularly vulnerable, whereas people with chronic illnesses, pregnant individuals, and people with disabilities were selected less frequently. Recent evidence emphasizes that heat vulnerability extends across population groups and that health impacts depend on individual vulnerability as well as local environmental and adaptive conditions (Winklmayr et al., 2023; Ragettli et al., 2024; Al Ali et al., 2026). Communication with health, care, or educational professionals and consultation with target groups were also often reported as unnecessary in the present survey. Municipal heat adaptation could therefore benefit from stronger involvement of health and social expertise and from communication approaches that explicitly consider the range of populations vulnerable to extreme heat (Winklmayr et al., 2023; Ochsmann, 2025).

Resource limitations are particularly important for implementation. Financial and staffing constraints were among the most frequently reported barriers, while public funding was the most frequently selected potential source of support. These findings are consistent with broader evidence that limited personnel, expertise, and administrative capacity can constrain municipal climate adaptation, particularly in smaller administrations (Häußler and Haupt, 2021; Overath and Rösler, 2025; Eckersley et al., 2025). Providing climate information alone may therefore be insufficient if municipalities lack the personnel or expertise required to translate information into action (Vetter et al., 2017). Climate services for smaller municipalities could combine accessible climate information with practical implementation support, including funding information, standardized templates, technical assistance, and opportunities for capacity building (Ministère de la Transition écologique, 2025).

Intermunicipal and district-level cooperation could complement local capacity. Cooperation with neighboring municipalities was selected as a potential opportunity by 35% of respondents. When asked separately about future cooperation, 31% expressed definite interest and a further 41% responded “maybe”, while 28% responded “no”. These two survey questions measured different aspects of cooperation and should therefore be interpreted separately. Nevertheless, the direct question indicates that a substantial proportion of respondents were at least open to considering cooperation. The reasons for these responses were not assessed. District-coordinated formats could provide opportunities for shared training, expertise, information resources, or technical support without requiring each municipality to develop specialized capacity independently (Ochsmann, 2025; Ministère de la Transition écologique, 2025). Networks and shared capacities have also been identified as potentially relevant for climate adaptation in smaller municipalities (Häußler and Haupt, 2021; Eckersley et al., 2025).

Overall, the findings suggest that effective climate services for smaller municipalities need to extend beyond the provision of climate projections. Regional climate information should be translated into locally understandable and actionable formats and accompanied by organizational and implementation support. Clear responsibilities, practical guidance, accessible funding, health and social expertise, and opportunities to share capacities across municipal and district levels could help municipalities progressively strengthen heat adaptation according to their local conditions and resources. Broader heat health research similarly emphasizes the importance of combining locally appropriate adaptation, vulnerability considerations, communication, and public health protection as heat-related hazards increase (Dube et al., 2025; Al Ali et al., 2026).

1. Introduction

Climate change is intensifying extreme heat across Europe, posing substantial risks to human health, including increased heat-related mortality and exacerbation of cardiopulmonary diseases (Ebi et al., 2021; Winklmayr et al., 2023). Germany experienced one of the highest absolute heat-related mortality burdens in Europe during the summer of 2022 (Ballester et al., 2023). While urban heat islands can amplify thermal exposure, recent evidence shows increased heat-related cardiopulmonary mortality across Germany and indicates that relevant vulnerability factors are present in both urban and rural areas (Zhang et al., 2024). Heat-related health risks are shaped not only by climatic exposure but also by individual, social, and contextual vulnerability, including age, pre-existing health conditions, socioeconomic circumstances, and living or working conditions (Hertig et al., 2023; Ragettli et al., 2024). Rural regions may face additional challenges related to demographic structure, access to services, and occupational outdoor exposure (Li et al., 2017; Bolte et al., 2023; de Schrijver et al., 2023). Although evidence comparing rural and urban populations remains limited and heterogeneous, a systematic review and meta-analysis found no clear evidence that rural populations are less vulnerable to heat-related mortality than urban populations (Li et al., 2017). Recent evidence further highlights occupational heat exposure and limitations in adaptation infrastructure as relevant challenges for rural populations, while regional vulnerabilities and adaptation effectiveness remain comparatively under researched (Dube et al., 2025).

Internationally, several countries have established multilevel frameworks for climate and heat adaptation, such as France's comparatively institutionalized system of heat action planning and coordination across administrative levels (Ochsmann, 2025; Ministère de la Transition écologique, 2025), or community-based approaches in rural India (AIDMI, 2025). However, their transferability to Germany is constrained by different administrative structures. In Germany, municipal responsibilities are divided between local municipalities (Gemeinden), which manage land use, public facilities, and local risk

communication, and district authorities (Landkreise), which coordinate health services and provide technical support. This multilevel arrangement creates particular governance requirements for vertical coordination across administrative levels (Vetter et al., 2017).

Nationally, the strategic framework for heat protection has expanded through recommendations and the 2020 resolution of the Conference of Health Ministers to establish Heat Action Plans (HAPs) nationwide by 2025 (Sieber et al., 2024). The Federal Climate Adaptation Act (KAnG), which entered into force in July 2024, requires federal states to develop adaptation strategies and establishes a framework under which the states determine the public bodies responsible for preparing local climate adaptation concepts based on climate risk analyses. However, municipalities are not legally required to develop HAPs, and concrete obligations depend on evolving state-level regulations (Schink, 2024). Consequently, a persistent implementation gap remains, rooted in long-standing structural challenges in European climate adaptation (Klostermann et al., 2018; Heidrich et al., 2016) and reinforced by current evidence of administrative capacity shortages and unclear responsibilities in German municipalities (Vetter et al., 2017; Ochsmann, 2025; Overath and Rösler, 2025).

Southern Germany is emerging as a climatic hotspot, with projections showing strong increases in hot days, tropical nights, and heatwaves (Kaspar-Ott et al., 2025; Winklmayr et al., 2023; Pfeifer et al., 2021). National surveys offer important insights but often aggregate municipalities into broad categories, obscuring the situation in very small municipalities, which constitute the majority of rural settlements. Moreover, existing research focuses largely on subjective perceptions, leaving limited understanding of how closely local decision-makers' risk assessments align with regional climate projections (Steynor and Pasquini, 2022; Sillmann et al., 2024).

To address these gaps, this study examines rural municipalities in the Augsburg district—a region characterized by demographic aging and predominantly small settlements (see Section 2 for detailed characterization). By combining municipality-level survey data with regional climate information from the GERICS Climate Outlook for the Augsburg district (Pfeifer et al., 2021), we examine the current status of heat adaptation, structural barriers, and municipal perceptions of heat-related health impacts in the context of projected regional changes in heat-related climate hazards.

Specifically, this study addresses the following research questions:

1. RQ1: What are the projected changes in heat-related climate indicators in the Augsburg district under future climate scenarios?
2. RQ2: What is the current status of heat adaptation in rural municipalities in the Augsburg district, Germany, and what are the primary barriers to implementation?
3. RQ3: How do municipal decision makers perceive future heat-related health impacts, and how do these perceptions relate to projected regional heat hazards?
4. RQ4: How do patterns of heat adaptation differ according to municipality size, available resources, and administrative structures?

Conceptually, municipal heat adaptation is understood here as the outcome of interacting climatic hazards, perceived local health impacts, and municipal adaptive capacity. Municipality size is used as an exploratory structural characteristic that may reflect differences in staffing, specialization, and financial resources rather than as an independent causal determinant of adaptation.

2. Methods

2.1. Study design

The study used a cross-sectional design based primarily on a quantitative online survey, supplemented by qualitative responses to selected open-ended questions and regional climate information from the GERICS Climate Outlook.

Quantitative survey data were used to describe municipal perceptions, adaptation measures, organizational structures, and barriers. The qualitative responses were used to contextualize selected quantitative findings, while regional climate projections provided broader climatic context for municipal perceptions of future heat-related health impacts.

2.2. Study area

The study was conducted in the Augsburg district in Southern Germany, which covers an area of approximately 1071 km^2 and has around 260,000 inhabitants. The district is characterized by a predominantly rural settlement structure, with the majority of residents living in small municipalities. In total, 46 municipalities are included, of which most have fewer than 20,000 inhabitants.

The region exhibits a dispersed settlement pattern and demographic aging, alongside limited administrative specialization in smaller municipalities. Despite being classified as an “urbanized district” by the BBSR due to population density, it shows key features of rural contexts, particularly in terms of municipal size structure and administrative capacity (BBSR (Bundesinstitut für Bau-, Stadt u. Raumforschung), 2023) Fig. 1.

The district has a temperate climate. During the 1971 to 2000 reference period, mean annual temperature was 8.2 °C and annual precipitation averaged 871 mm, with the warmest monthly mean temperature occurring in July (17.5 °C). An average of 2.2 sultry days per year was recorded during the reference period; GERICS defines these as days with a water vapor partial pressure above 18.8 hPa, calculated from near surface air temperature and relative humidity (Pfeifer et al., 2021).

2.3. Sample and recruitment

An online questionnaire (see appendix C) was sent to all 46 municipalities in the Augsburg district. A total of 40 municipalities responded (87% response rate), with 29 fully completed questionnaires used for the final analysis (representing a 63% completion rate relative to the total sample frame). While the absolute sample size ($n = 29$) is statistically small, the study followed a census approach by targeting the entire population of municipalities within the district.

Respondents represented different municipal administrative areas, with the Mayor's Office and Planning and Construction being the most frequently reported areas. Responses therefore reflect the assessments of individual municipal representatives and were treated as organizational self-reports rather than independently verified indicators of municipal policy implementation.

2.4. Data collection and statistical analysis

An online survey was used to collect data on heat protection measures, perceived needs, responsibilities, and barriers. The survey was conducted via a platform called SoSci Survey (Leiner, 2024). Invitations and several reminder emails were sent to the municipalities. The data collection period was from January 16 to March 15, 2025.

The questionnaire comprised 20 main questions, predominantly quantitative in nature (e.g., Likert scales, forced-choice items). The quantitative survey data were interpreted alongside regional climate information from the GERICS Climate Outlook for the Augsburg district.

GERICS provides regional climate projections based on multi-model simulations, including indicators such as temperature trends and extreme heat events. Prior to field implementation, the questionnaire underwent a pragmatic pretest with a small convenience sample of colleagues and other individuals. The pretest focused on the comprehensibility and clarity of the questions, questionnaire structure and layout, and the usability of the online survey. Feedback obtained during the pretest was incorporated into the final questionnaire before its

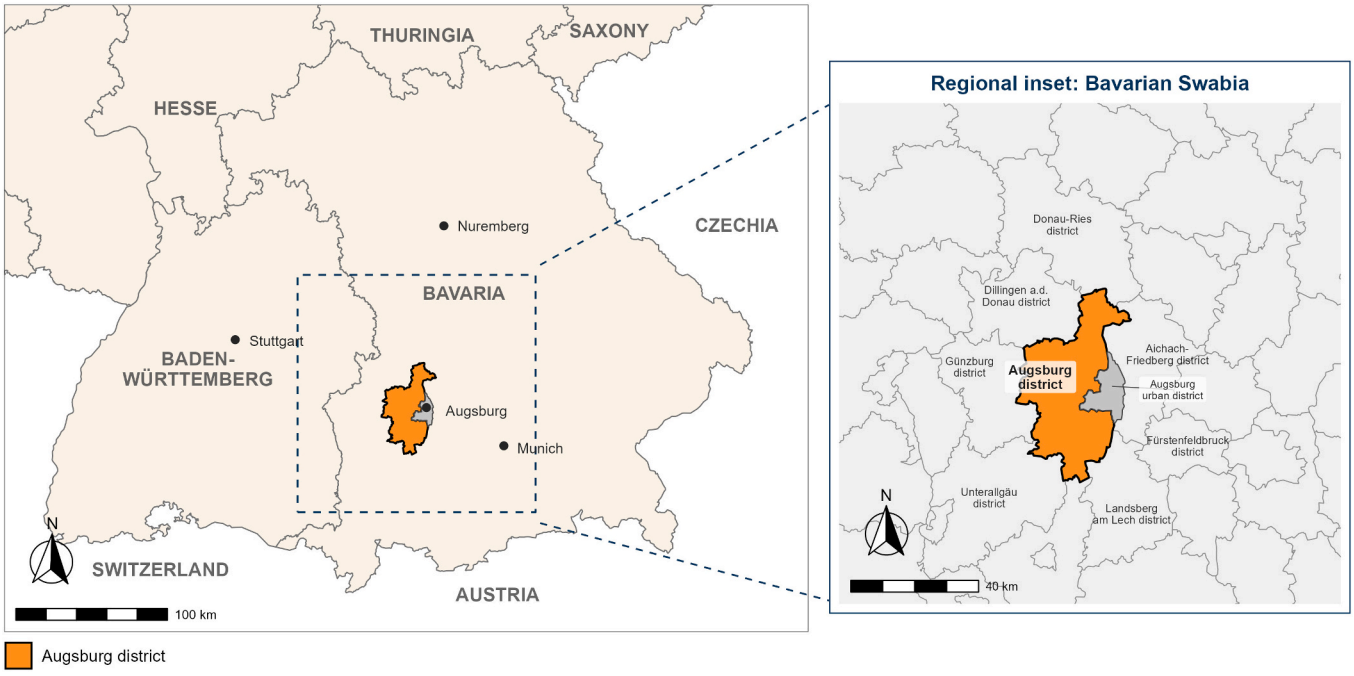


Fig. 1. Study area: Location of the Augsburg district in Southern Germany. Source: Eurostat/GISCO NUTS geometries.

distribution to the municipalities.

Survey data were analyzed primarily using descriptive statistics. Categorical variables are presented as absolute frequencies and percentages, with denominators reported where appropriate. Analyses stratified by municipality size were considered exploratory and descriptive because the four size categories contained 18, 5, 4, and 2 municipalities, respectively. Cross tabulations were used to describe patterns across municipality size categories. Because expected cell counts were frequently below conventional thresholds, chi square test results were not used for statistical inference, and no statistical significance is reported for comparisons between municipality size categories.

One inferential comparison was conducted for respondents' paired assessments of perceived heat-related health impacts during the previous and next 10 years. Responses were coded on a five-point ordinal scale ranging from 1 ("no impact") to 5 ("very strong impact"). A paired *t*-test was used to estimate the mean within respondent difference, defined as the future rating minus the past rating. Given the ordinal response scale and the small sample size, a Wilcoxon signed rank test was additionally conducted as a sensitivity analysis. All tests were two sided, and statistical analyses were performed using SAS Studio 9.4 (SAS Institute Inc., 2025).

Regional climate projections were used to provide medium- and long-term climatic context for municipal perceptions of future heat-related health impacts (RQ3) and were not statistically integrated with the survey data. Climate information was extracted from the published GERICS Climate Outlook for the Augsburg district (Pfeifer et al., 2021); no new analysis of the underlying climate model simulations was performed in the present study. The GERICS Climate Outlook is based on an ensemble of 85 regional climate projections from the EURO-CORDEX initiative and the REKliEs-DE project, comprising 50 simulations for RCP8.5, 17 for RCP4.5, and 18 for RCP2.6. The regional climate simulations have a horizontal resolution of approximately 12 × 12 km. Climate changes for the Augsburg district were calculated by GERICS as area-weighted averages across the model grid cells located within the district. Projected changes are reported relative to the reference period 1971–2000 for two future periods, 2036–2065 and 2069–2098. The ensemble information includes minimum, median, and maximum changes as well as the 20th and 80th percentiles and an assessment of the robustness of projected changes (Pfeifer et al., 2021).

Historical climate conditions were likewise obtained from the GERICS Climate Outlook and are based on the HYRAS v3.0 dataset of the German Meteorological Service (DWD). HYRAS combines station observations interpolated onto a 5 km grid; GERICS calculated spatial averages across the Augsburg district for the climate indicators used in the Climate Outlook (Pfeifer et al., 2021; Rauthe et al., 2013; Razafimaharo et al., 2020).

The GERICS indicators characterize regional climatic hazards and were not interpreted as direct measures of municipality-specific heat-health risk, which may additionally depend on local exposure, vulnerability, and adaptive capacity. The survey and regional climate data address complementary time horizons. Municipal respondents assessed perceived health impacts over the previous and next 10 years, whereas the GERICS projections refer to 2036 to 2065 and 2069 to 2098. The projections were therefore used as medium- and long-term regional climatic context for the shorter-term municipal assessments.

The qualitative component served to provide in-depth interpretation and contextualization of the quantitative findings. It is based on the analysis of a few selectively used open-ended questions in the survey. The response rate for these open questions was generally low. Crucially, only one question yielded substantial qualitative data: the item asking for specific local measures and responsible departments (e.g., green space planning, German: Grünordnung). The analysis of these text responses was performed using Qualitative Content Analysis (QCA), specifically the method of Inductive Category Formation (Kuckartz, 2012; Lamnek and Krell, 2016). This data-driven, bottom-up approach involved iteratively reviewing the text, generating codes, and refining them into a robust set of Fields of Action (German: Handlungsbereiche), which are presented in Table 2. The inductive QCA ensured that the resulting categories were empirically grounded in the diverse responses of the municipal administrators. Given the limited number of qualitative responses, the qualitative findings are used to contextualize and illustrate quantitative patterns rather than to generate standalone analytical claims.

2.5. Ethical aspects

The need for ethics committee approval was assessed prior to data collection in consultation with the academic supervisor, and formal ethics committee approval was considered not to be required for this organizational survey. Participation was voluntary and based on informed consent. The questionnaire primarily collected information about municipal structures, responsibilities, perceptions, and adaptation activities. Respondents could optionally provide their name and contact details for follow-up purposes. Any contact information provided was handled confidentially and was not used for the analysis. Survey data were treated confidentially throughout the study.

2.6. Defining "rural areas"

Definitions of "rural" in Germany vary considerably across institutions. According to the settlement-structural district types used by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), rurality is defined primarily through population density and settlement structure. Within this classification system, the Augsburg district is categorized as an urbanized district, reflecting its comparatively high population density despite the fact that 72% of its residents live in municipalities with fewer than 20,000 inhabitants (BBSR, 2023).

In contrast, the Thünen Institute uses a multidimensional rurality index combining structural and socioeconomic indicators. According to this typology, Augsburg is categorized as "rather rural/good socioeconomic situation" (Küpper, 2016).

Approach for this study:

The two municipalities in the ≥20,000-resident category were included in the municipality-size analysis for completeness but were not considered rural municipalities under the operational definition applied in this study. This is consistent with the population thresholds of the BBSR Stadt- und Gemeindetyp classification, in which municipalities with 20,000 to fewer than 100,000 residents are generally classified as medium-sized towns (BBSR (Bundesinstitut für Bau-, Stadt u. Raumforschung), 2023).

2.7. Operationalization of municipality size

Municipality size was used as a descriptive stratification variable to examine whether patterns in heat adaptation differed across municipalities of different population sizes. Given the small and highly unequal numbers of municipalities within the four size categories, these comparisons were intended to identify descriptive patterns rather than to estimate or test municipality size effects.

The following four disjoint size classes were established for the sample classification, based on resident population:

Small: < 5000 residents.

Medium: 5000 to 9999 residents.

Mid-sized: 10,000 to 19,999 residents.

Large: 20,000 residents or more.

This classification structure is congruent with the established categories used by the Federal Statistical Office (Destatis) and the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) (Arbeitsgruppe Regionale Standards, 2019; BBSR (Bundesinstitut für Bau-, Stadt u. Raumforschung), 2023).

In the BBSR typology, municipalities with fewer than 5000 residents and without a basic central-place function are classified as rural municipalities (German: Landgemeinden), whereas municipalities with 5000 to fewer than 20,000 residents are generally classified as small towns (German: Kleinstädte). In local government research, this range is further differentiated into Small Towns (5000 to 9999) and Larger Small Towns (10,000 to 19,999), reflecting variations in administrative capabilities and central functions (Milbert and Fina, 2021). The differentiation applied in this study reflects this scholarly sub-categorization. The 20,000 resident threshold typically marks the administrative transition to a Medium-Sized Town (German: Mittelstadt) (BBSR, 2023). These larger entities are qualitatively distinct from Small Towns, particularly regarding their central place function and administrative sophistication (Milbert and Fina, 2021).

3. Results

3.1. Climate analysis and projection

3.1.1. Historical climate of the Augsburg District

The Augsburg district is situated in a temperate climate zone. Between 1971 and 2000, the average annual temperature was 8.2 °C, with the coldest monthly average in January with −0.9 °C and the warmest in July with 17.5 °C. Over the same period, the average annual precipitation was 871.0 mm, with the lowest monthly rainfall in February (46.1 mm) and the highest in June (108.4 mm).

A comparison of two 30-year periods, from 1951 to 1980 and 1986–2015, shows an average increase of about 0.9 °C in the annual mean temperature. For average annual precipitation, there was a mean increase of 32.8 mm per year; however, this change is not statistically significant (Pfeifer et al., 2021).

3.1.2. Projected climate changes compared with the historical reference period

Future climate projections for the Augsburg district are based on Representative Concentration Pathways (RCPs), which represent different trajectories of future greenhouse gas concentrations and are used to project the corresponding climate changes. The GERICS Climate Outlook considers three scenarios: RCP2.6, representing a low emission pathway with strong mitigation, RCP4.5, representing an intermediate emission pathway, and RCP8.5, representing a high-emission pathway with continued growth in greenhouse gas emissions. In the following, RCP8.5 is presented as a high-emission scenario to illustrate the upper range of projected heat-related climate changes (Pfeifer et al., 2021).

The GERICS projections indicate increases in several temperature-related heat indicators in the Augsburg district across all three scenarios, although the magnitude of change differs between scenarios and projection periods. For the mid-century period (2036 to 2065), relative to the reference period 1971 to 2000, the RCP8.5 ensemble projects an increase in annual mean temperature of 1.4 to 3.2 °C, with a median increase of 2.0 °C. Hot days are projected to increase by 0.5 to 26.8 days per year (median: 4.9 days), tropical nights by 0 to 22.9 days per year (median: 0.7 days), and the maximum duration of heat periods by 0.4 to 8.4 days (median: 1.7 days) (Pfeifer et al., 2021).

For the end-of-century period (2069 to 2098), projected changes are larger under the high-emission RCP8.5 scenario. Annual mean temperature is projected to increase by 2.7 to 5.5 °C (median: 3.6 °C), hot days by 2.7 to 61.0 days per year (median: 13.9 days), tropical nights by 0 to 54.7 days per year (median: 5.0 days), and the maximum duration of heat periods by 1.4 to 24.6 days (median: 3.5 days), relative to 1971 to 2000 (Pfeifer et al., 2021). These values represent the range and median of the available RCP8.5 model ensemble rather than a single expected future outcome.

Across the GERICS assessment, the direction of change in temperature-related indicators is considered robust. GERICS defines a robust increase as one in which at least two thirds of the simulations indicate an increase and at least half indicate a statistically significant increase. The underlying projections constitute an ensemble of opportunity, meaning that the available simulations do not necessarily capture the full range of possible future climate changes and that the ensembles for the three RCP scenarios differ in size and model composition (Pfeifer et al., 2021).

3.2. Primary results of the survey

3.2.1. Survey sample composition

Table 1 given the small and unequal group sizes, all comparisons by municipality size are presented descriptively. The two municipalities in the ≥20,000 resident category were retained in these comparisons for completeness but do not meet the operational definition of rural municipalities applied in this study.

3.2.2. Municipal heat protection actors

Municipal heat protection responsibilities were assessed based on respondents' own administrative areas, the unit reported as primarily responsible for heat protection, and other involved departments. The survey was intended to be completed by a person responsible for or involved in heat protection within the municipality.

3.2.3. Respondent's own department

Respondents most frequently identified the Mayor's Office as their own administrative area, with 17 mentions, including 15 direct selections and two responses coded from the "Other" category. Planning and Construction was reported six times and was represented across several municipality size categories. Climate Protection/Energy Efficiency was reported by one respondent. Health and Social Affairs were not reported as respondents' own administrative areas.

3.2.4. Primary responsibility

Fourteen of the 29 municipalities (48.3%) reported that no primary responsibility for heat protection had been assigned. Among the 15 municipalities reporting an assigned responsibility, the Mayor's Office and Planning and Construction were the most frequently identified administrative areas (Fig. 2). Health and Social Affairs were not reported as primarily responsible for heat protection.

3.2.5. Other involved departments

Among additional departments involved in heat protection, Planning and Construction was reported eight times and the Mayor's Office five times. Environmental departments were reported twice and Public Security/Public Order once. Administrative management was reported once. Health and Social Affairs were not reported as additionally involved departments. No additional external stakeholders were named.

3.2.6. Perceived importance of heat protection

This section assessed the perceived general importance of heat protection and its relevance for the respondent's own municipality.

Overall, 17 of 29 respondents (58.6%) rated heat protection as important or very important. The distribution of general importance and perceived local relevance differed descriptively across municipality size categories (Fig. 3). Given the small numbers in the larger size categories, these subgroup differences are not interpreted inferentially.

3.2.7. Perceived health impact of summer heat: Past vs. future

This item assessed perceived health impacts of summer heat over the past 10 years and expectations for the next 10 years (scale 1–5).

Past heat-related health impacts were predominantly rated as minor or moderate, while future ratings shifted toward moderate and strong impacts (Fig. 4). None of the 29 municipalities expected no health impact during the next 10 years. Nine respondents (31.0%) expected a minor impact, ten (34.5%) a moderate impact, and ten (34.5%) a strong impact.

Across all municipalities, perceived heat-related health impacts were rated higher for the next 10 years than for the previous 10 years. A Wilcoxon signed-rank test indicated a significant increase in perceived future impacts ($S = 76.5$, $p < 0.0001$). A paired *t*-test yielded a consistent result, with a mean paired difference (future minus past) of 0.655 points (95% CI: 0.422 to 0.889; $t(28) = 5.75$, $p < 0.0001$). The median within-municipality difference was one response category (IQR 0 to 1), and no municipality rated future impacts lower than past impacts.

Table 1
Municipality Size Distribution in the Survey Sample.

classification of municipalities by size	Percentage	Number of Municipalities
Small (<5000 residents)	62.1%	18
Medium (5000–9999 residents)	17.2%	5
Mid-sized (10,000–19,999 residents)	13.8%	4
Large (≥20,000 residents)	6.9%	2
Total		**29**

Source: authors' survey data.

Table 2
Identified operational areas where heat stress is considered. Source: authors' survey data.

Category	n (abs.)	Share (%)	Exemplary Coding (Keywords)
Urban & Land-Use Planning	7	30.4%	Land-use planning, urban development, designation of new building areas, outdoor area design (planning focus)
Structural & Civil Engineering	6	26.1%	Road construction, structural engineering, thermal protection.
Climate Adaptation & Shading	4	17.4%	Shade sails, tree preservation/ planting, playground shading, air conditioning.
Administration & Infrastructure	3	13.0%	Staff resources; building administration; public facilities (administrative management)
Statutory Law & Regulation	3	13.0%	Local statutes (setback distances & sealing regulations), green space regulation.
Total	**23**	**100%**	

3.2.8. Discussion in local politics and administration and consideration in various operational areas

Of the 28 municipalities with valid responses, 11 (39.3%) reported that heat and health was discussed in local politics and administration, while 17 (60.7%) reported that it was not. By municipality size, discussion was reported by 6/17 (35.3%) municipalities with fewer than 5000 residents, 1/5 (20.0%) with 5000 to 9999 residents, 3/4 (75.0%) with 10,000 to 19,999 residents, and 1/2 (50.0%) with at least 20,000 residents.

Heat stress was reported as being considered in one or more operational areas by 12/28 municipalities (42.9%). This included 8/17 (47.1%) municipalities with fewer than 5000 residents, 2/5 (40.0%) with 5000 to 9999 residents, 1/4 (25.0%) with 10,000 to 19,999 residents, and 1/2 (50.0%) with at least 20,000 residents.

The qualitative analysis yielded 23 coding units, which were assigned to five fields of action (Table 2). Urban and Land Use Planning accounted for seven coding units (30.4%), followed by Structural and Civil Engineering with six (26.1%), Climate Adaptation and Shading with four (17.4%), and Administration and Infrastructure and Statutory Law and Regulation with three each (13.0%).

3.2.9. Key findings on vulnerable groups

Among the 29 municipalities, residents of senior or nursing facilities were the most frequently identified vulnerable group (24/29, 82.8%), followed by toddlers in daycare or kindergarten (23/29, 79.3%) and outdoor workers (19/29, 65.5%). School children and adolescents were selected by 17/29 municipalities (58.6%). People with chronic illnesses were selected by 13/29 (44.8%), pregnant individuals by 12/29 (41.4%), and people with disabilities by 11/29 (37.9%). Children and adolescents in sports clubs were selected least frequently (5/29, 17.2%). No respondent selected the "Other" category. The distribution of identified vulnerable groups is shown in Fig. 5.

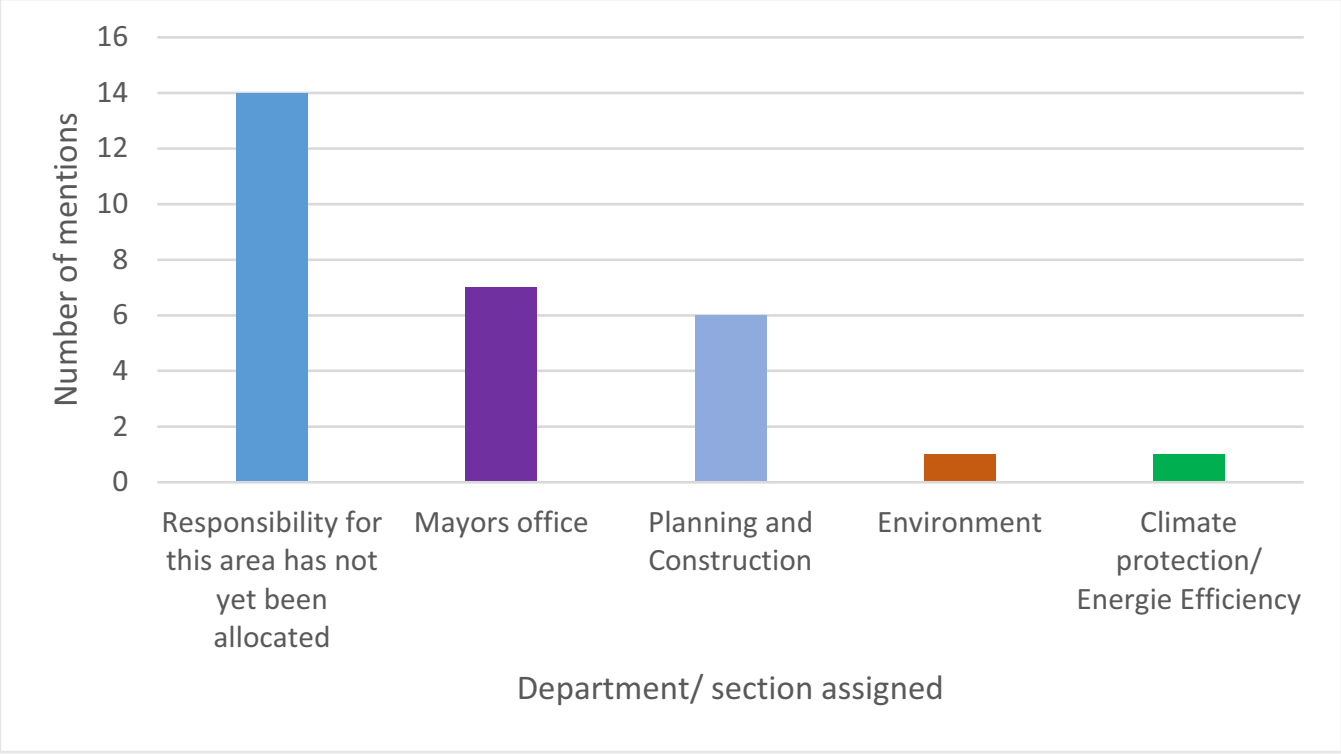


Fig. 2. Assigned departments: primary responsibility (total: 29 municipalities). Source: authors' survey data.

3.2.10. Status of heat protection measures

Strategic analyses and planning instruments showed comparatively limited implementation. For climate analyses, 14/18 (77.8%) municipalities with fewer than 5000 residents and 4/5 (80.0%) municipalities with 5000 to 9999 residents reported no need. Among municipalities with 10,000 to 19,999 residents, 2/4 reported no need, one had initiated first steps, and one had already conducted an analysis; among the two municipalities with at least 20,000 residents (included in the municipality-size comparison but not classified as rural under the study definition), one reported no need and one had initiated first steps. A similar descriptive pattern was observed for HAPs, with "no need" reported more frequently among the municipalities with <5000 residents, whereas responses in the larger categories more often indicated an existing need or planning activity. Impact and vulnerability analyses showed a more heterogeneous distribution across size categories. By contrast, an assessment of municipal action needs was considered necessary by 17/29 municipalities (58.6%), and 9/29 (31.0%) reported no need. All five municipalities with 5000 to 9999 residents reported a need for such an assessment. A need for a catalogue of measures was also frequently reported among municipalities with 5000 to 19,999 residents, while 10/18 (55.6%) of municipalities with fewer than 5000 residents reported no need.

Information and communication measures showed varying levels of perceived need and implementation. Eleven of 29 municipalities (37.9%) reported no need for an information or warning system; such systems had already been implemented by 2/18 municipalities with fewer than 5000 residents and 1/4 municipalities with 10,000 to 19,999 residents. Communication with health, care, or educational professionals was less frequently identified as necessary: 15/29 municipalities (51.7%) reported no need for communication with professional staff in preparation for heat events, and 14/29 (48.3%) reported no need for such communication during heat events. Similarly, 16/29 municipalities (55.2%) reported no need for consultation with target groups or stakeholders. In contrast, population-oriented communication measures, including public awareness before heat events and communication during heat events, were more frequently reported as needed or already under development.

Several infrastructure and spatial planning measures were already implemented in parts of the sample, whereas implementation of strategic planning instruments was less frequently reported. The preservation or creation of green spaces, water bodies, and evaporation surfaces had the highest reported implementation rate among these measures, with 11/29 municipalities (37.9%) reporting that the measure had already been implemented and only 2/29 (6.9%) reporting no need. Nine of the 18 municipalities with fewer than 5000 residents reported that this measure had already been implemented. Shaded areas and the reduction of impervious surfaces were also reported at different stages of need, planning, and implementation across the sample. In contrast, promotion of green roofs was considered unnecessary by 17/29 municipalities (58.6%). For heat protection concepts in public buildings, 9/29 municipalities (31.0%) had initiated first steps and 5/29 (17.2%) reported no need. Urban or village development concepts were reported at different stages of implementation, whereas responses regarding regional development concepts were more mixed.

Measures providing direct relief in public spaces during heat events were less consistently established. Thirteen of 29 municipalities (44.8%) reported no need for access to cool public buildings, including 10/18 municipalities with fewer than 5000 residents. Eleven of 29 municipalities (37.9%) reported no need for public drinking water dispensers. Neither of the two municipalities with at least 20,000 residents reported "no need" for either of these measures. Responses concerning public water features were distributed across perceived need, planning, initial steps, and implementation; six of the 27 municipalities with fewer than 20,000 residents reported that public water features had already been implemented.

One additional measure was reported in the open response field: "citizens' own responsibility."

3.2.11. Perceived barriers to heat protection and perceived potential

The reported barriers covered resource constraints, knowledge-

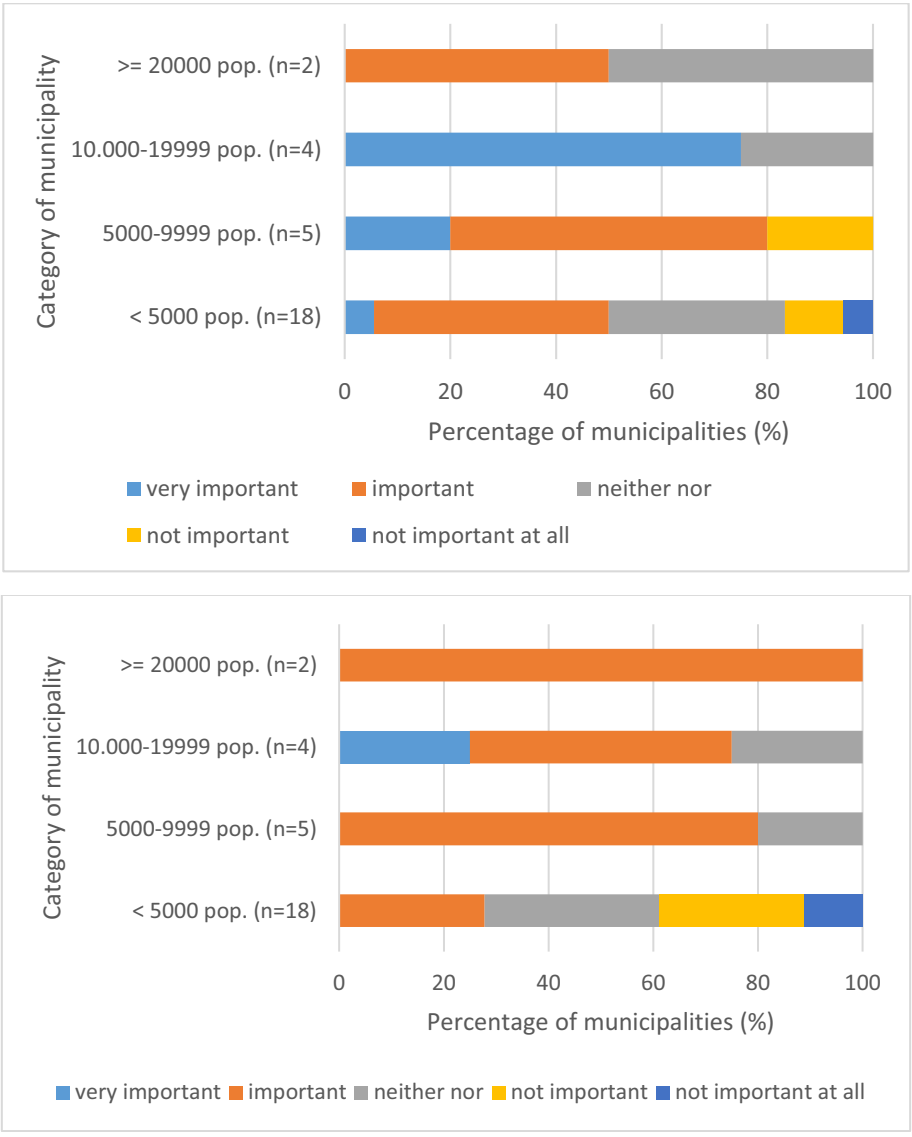


Fig. 3. (a) General Importance of heat protection measures: percentage within municipality category. Source: authors' survey data. (b) Relevance of heat protection measures for Own Municipality: percentage within municipality category. Source: authors' survey data.

related challenges, and administrative or implementation-related obstacles (Fig. 6a). The most frequently selected barriers were financial and staffing constraints, demonstrating the particular relevance of available resources for municipal heat adaptation. Shortages of qualified personnel were also reported, alongside barriers related to knowledge about future impacts and possible measures. Additional barriers concerned the availability of practical guidance, administrative responsibilities, acceptance, and planning related uncertainties. Individual barriers are presented separately in Fig. 6a because they represent distinct implementation challenges and correspond to different potential support needs.

Among the potential opportunities for strengthening heat protection, application for public funding was the most frequently selected option (17/29, 58.6%). Cooperation with neighboring municipalities and employee training were each selected by 10/29 municipalities (34.5%), while funding from research projects was selected by 5/29 (17.2%) (Fig. 6b).

3.2.12. *Municipal willingness to cooperate on heat protection*

When asked directly about interest in future cooperation with neighboring municipalities, nine municipalities (31.0%) responded "yes", 12 (41.4%) responded "maybe", and eight (27.6%) responded "no". Responses varied descriptively across municipality size categories. Among the two municipalities with at least 20,000 residents, both respondents selected "maybe".

3.3. *Municipal perceptions in the context of regional heat projections*

Municipal assessments showed a clear tendency toward stronger expected heat-related health impacts over the next 10 years compared with the previous decade. Thus, respondents generally anticipated an increasing health burden from summer heat, although the expected level of impact varied across municipalities. Regional climate projections also indicate increasing heat-related climatic hazards in the Augsburg district over the medium and long term, including increases in hot days, tropical nights, and the maximum duration of heat periods (Pfeifer et al., 2021).

The survey and climate projections address different components and time horizons. Municipal respondents assessed perceived health impacts over the next 10 years, whereas the GERICS Climate Outlook provides projections of climatic hazards for 2036 to 2065 and 2069 to 2098 at the district level.

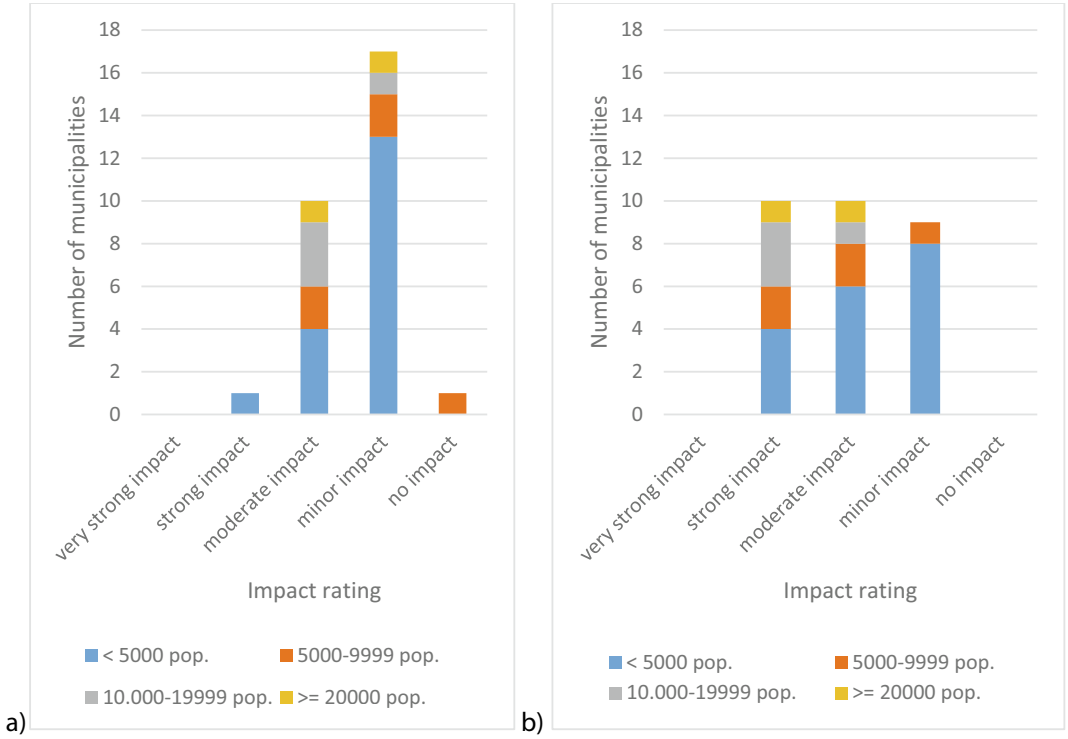


Fig. 4. (a) Perceived health impact of summer heat in the past 10 years, (b) Perceived health impact of summer heat in the next 10 years (absolute numbers, $n = 29$). Source: authors' survey data.

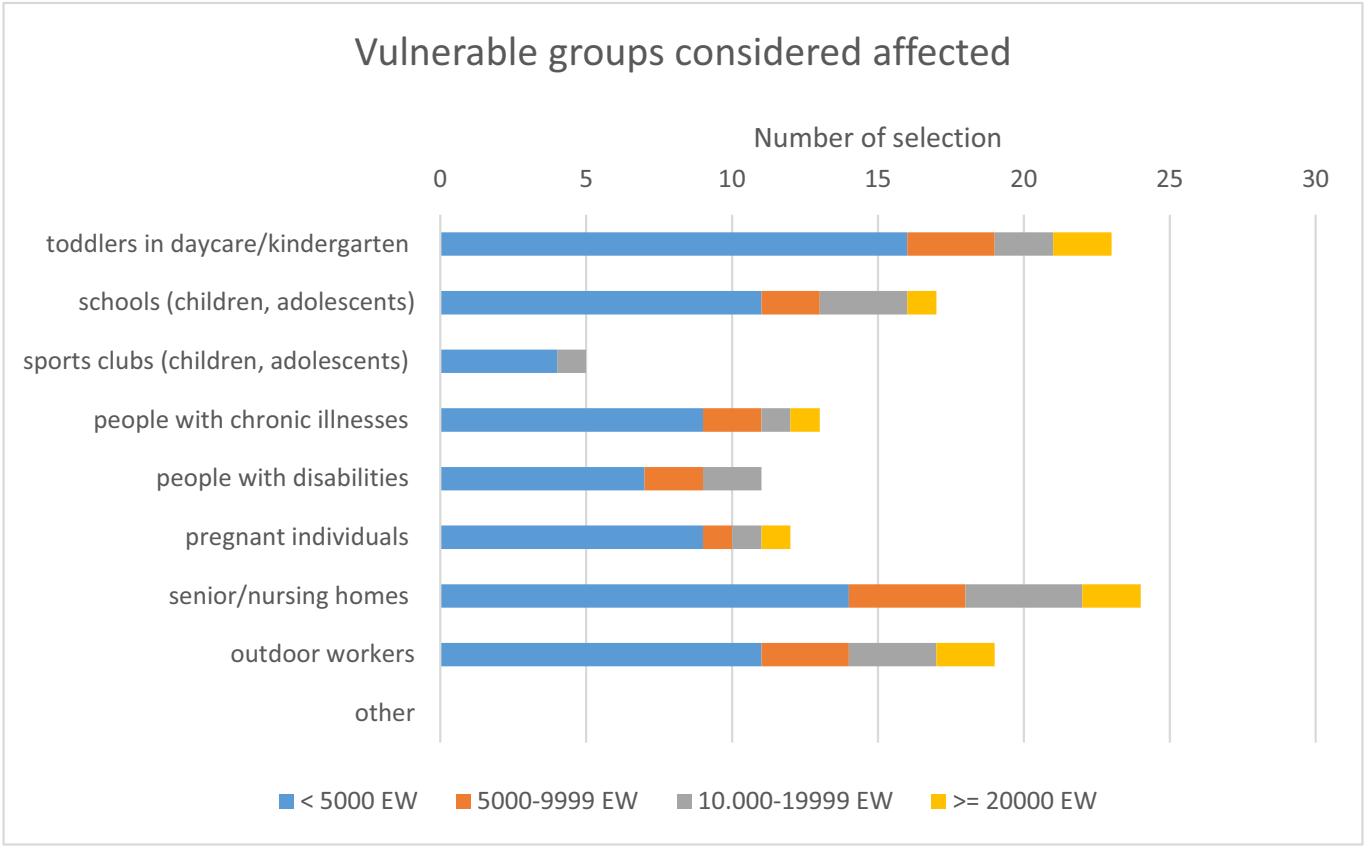


Fig. 5. Key vulnerable populations among municipalities. Source: authors' survey data.

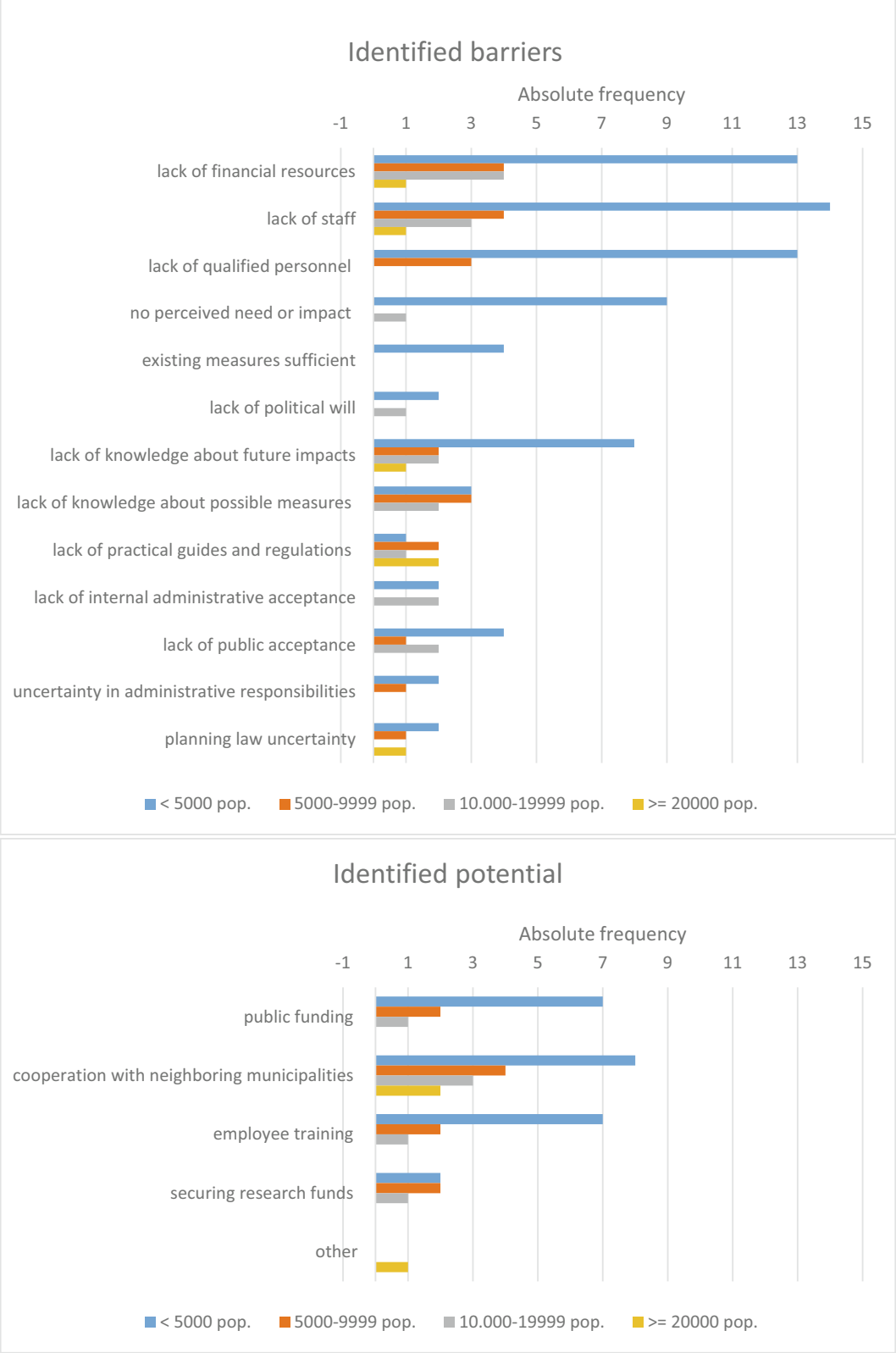


Fig. 6. (a) Perceived barriers to heat protection efforts, (b) perceived potential for heat protection efforts ($n = 29$). Source: authors' survey data.

4. Discussion

4.1. Interpretation of findings and comparison with literature

The findings addressing RQ1 show a continued increase in heat-related climatic hazards in the Augsburg district. Across the scenarios considered by GERICS, temperature-related indicators show increasing heat exposure, although the magnitude of change differs according to emission scenario and projection period. Under the high-emission RCP8.5 scenario, the median projected increase in annual mean

temperature is 2.0 °C for 2036 to 2065 and 3.6 °C for 2069 to 2098 relative to 1971 to 2000. The projections also indicate increases in hot days, tropical nights, and the maximum duration of heat periods (Pfeifer et al., 2021).

These projections characterize the regional climatic hazard rather than municipality-specific heat health risk. Local health consequences may additionally depend on exposure, population vulnerability, the built environment, and adaptive capacity. Moreover, the spatial resolution and district-level aggregation of the GERICS projections do not permit conclusions regarding small-scale climatic differences between individual municipalities. The climate projections should therefore be interpreted as regional context for municipal heat adaptation rather than as evidence of identical heat health risk across the district.

The projected increase in heat-related hazards is nevertheless relevant for local public health planning. Heat exposure is associated with substantial health impacts, including increased mortality and morbidity (Winklmayr et al., 2023). A recent global systematic review and meta-analysis found that extreme heat events were associated with increased all-cause mortality, while also demonstrating considerable variation between geographical and population contexts (Al Ali et al., 2026). Health effects are therefore not determined by climatic hazard alone but also by local exposure, vulnerability, and adaptive conditions. Evidence from Germany further indicates that heat-related health impacts are not restricted to densely populated urban environments (Zhang et al., 2024). This supports the relevance of heat adaptation planning in rural and smaller municipalities as well as in cities.

With respect to RQ2, the survey identified substantial gaps in the organization and implementation of municipal heat adaptation. Nearly half of the surveyed municipalities had not assigned primary responsibility for heat protection, while reported responsibilities were concentrated mainly in mayoral offices and planning and construction departments. This organizational pattern is consistent with previous research on German municipalities, which has identified unclear responsibilities and insufficient institutional anchoring as important barriers to climate and heat adaptation (Vetter et al., 2017; Ochsmann, 2025).

Strategic instruments such as HAPs, climate analyses, and vulnerability assessments were also limited, whereas individual infrastructural measures, including green spaces and shading, were more frequently reported. A similar tension between strategic heat action planning and more established spatial or infrastructure-based climate adaptation measures has been described in German municipalities (Ochsmann, 2025). Observational evidence from Switzerland showed a stronger temporal decline in heat-related all-cause mortality in a region where cantonal heat health action plans had been implemented than in regions without such plans (Ragettli et al., 2024).

Resource constraints represented another prominent finding. Financial and staffing limitations were among the most frequently reported barriers, consistent with previous evidence that limited personnel, administrative capacity, and unclear responsibilities can impede local climate adaptation in Germany (Vetter et al., 2017; Friedrich et al., 2024; Overath and Rösler, 2025). In small administrations in particular, climate adaptation competes with numerous other municipal responsibilities, potentially restricting the capacity to initiate more complex activities such as vulnerability assessments, strategic planning, or the acquisition of external funding. This interpretation is consistent with previous work on climate adaptation capacity in smaller municipalities (Häußler and Haupt, 2021; Eckersley et al., 2025).

Health and social departments were not reported as being involved in heat adaptation by respondents in this survey. This finding should not be interpreted as evidence that health or social actors are entirely absent from heat-related activities, particularly because smaller municipalities may not have dedicated departments for these functions. Nevertheless, the pattern is relevant because heat adaptation requires consideration of health-related vulnerability and vulnerable population groups. Previous research similarly emphasizes the importance of integrating health considerations into climate adaptation planning (Williams et al., 2013; Bolte et al., 2023; Ochsmann, 2025).

The survey also revealed differences in the recognition of vulnerable groups. Young children and residents of senior or nursing facilities were frequently identified, whereas some clinically or socially vulnerable groups were mentioned less often. This is relevant because heat vulnerability is not restricted to age alone. Recent evidence identifies elevated heat-related mortality among older adults and individuals with specific pre-existing conditions, while socioeconomic position, education, and social circumstances may further modify vulnerability (Ragettli et al., 2024; Al Ali et al., 2026). However, because the present survey did not investigate why particular groups were selected less frequently, these differences should not be interpreted as evidence that they are deliberately overlooked. Rather, the findings suggest an opportunity to strengthen awareness of the full range of populations that may require protection during periods of extreme heat.

Regarding RQ3, municipalities generally expected heat-related health impacts to increase in the future. The paired analysis showed that respondents rated health impacts for the next 10 years higher than those experienced during the previous 10 years, and this finding was consistent in both the paired *t*-test and the Wilcoxon signed rank sensitivity analysis. Nevertheless, the level of expected future impact remained heterogeneous: 31.0% anticipated a minor impact, 34.5% a moderate impact, and 34.5% a strong impact.

These perceptions need to be interpreted in relation to the different time horizons represented in the study. The municipal survey addressed expected health impacts over the next 10 years, whereas the GERICS projections characterize climatic changes for 2036 to 2065 and 2069 to 2098. The climate projections therefore provide medium- and long-term contextual evidence rather than a temporally matched measure against which the municipal responses can be directly evaluated. Consequently, the present study does not establish that municipalities objectively underestimate their heat health risk. Rather, it shows that relatively moderate short-term health impact assessments coexist with regional projections of increasingly pronounced heat-related climatic hazards over subsequent decades.

One possible interpretation is that the translation of regional climate information into local risk perception and adaptation decisions remains challenging. Previous research has shown that the availability of climate information alone does not necessarily result in local adaptation action and that climate risks may be perceived as temporally or geographically distant (van der Linden, 2015; McDonald et al., 2015; Rossow et al., 2025). Psychological distance may therefore provide one possible conceptual explanation for the observed pattern, but this mechanism was not measured in the present study. Recent work from Germany further highlights the importance of translating climate information into locally actionable planning tools. For example, Rupp et al. (2026) developed a transferable heat risk index that combines climatic conditions with exposure and social vulnerability information to identify spatial heat-risk patterns and support the prioritization of adaptation measures. Such approaches may help bridge the gap between regional climate information and local decision-making by identifying locations and population groups requiring particular attention in heat adaptation planning.

The rural context is also relevant when interpreting these findings. Although urban populations can experience additional thermal exposure through the urban heat island effect, heat-related health impacts are not exclusively an urban issue. Recent German evidence found higher heat exposure in urban districts but a similar mortality response to a given weekly mean temperature across different district types (an der Heiden et al., 2025). Studies from Germany have also demonstrated relevant heat-related mortality across urban and rural settings (Gabriel and Endlicher, 2011; Zhang et al., 2024). Earlier international evidence similarly found no clear indication that rural populations are generally less vulnerable to heat-related mortality than urban populations, although estimates varied substantially between settings (Li et al.,

2017). Broader heat health research additionally identifies occupational heat exposure and limitations in adaptation infrastructure as relevant challenges for rural populations (Dube et al., 2025). Taken together, this evidence reinforces the importance of locally appropriate heat adaptation strategies and cautions against viewing heat-related health risks primarily as an urban concern.

Finally, the findings related to RQ4 suggest descriptive differences in adaptation activities across municipality size categories. In the present sample, smaller municipalities more frequently reported limited strategic engagement for several measures, while some planning and implementation activities were more frequently reported in the larger municipality categories. However, these findings must be interpreted in light of the highly unequal group sizes of 18, 5, 4, and 2 municipalities. They therefore represent exploratory descriptive patterns and do not establish municipality size as an independent determinant of adaptation progress. Because the municipality-size comparison included two municipalities with ≥20,000 residents, these findings should be interpreted as comparisons across municipality-size categories rather than exclusively among municipalities meeting the study's operational definition of rurality.

A plausible interpretation is that some of the observed differences reflect administrative capacity and specialization rather than population size itself. Smaller municipalities often operate with fewer specialized personnel and may rely more strongly on generalist administrative structures. Previous studies similarly identify personnel capacity, institutional specialization, and administrative resources as important conditions for local climate adaptation (Vetter et al., 2017; Häußler and Haupt, 2021; Overath and Rösler, 2025; Eckersley et al., 2025). Municipality size may therefore function partly as an indicator of broader differences in administrative capacity, but this mechanism could not be tested with the present sample.

The findings also suggest that smaller municipalities should not simply be considered less willing to adapt. Financial resources and staffing were among the most frequently reported barriers across the sample, indicating that limited implementation may reflect structural constraints rather than a lack of interest alone (Vetter et al., 2017). This distinction is important for policy because measures designed for larger administrations may be difficult to implement in municipalities with limited personnel and technical capacity. The need for more systematic adaptation identified in the present survey is consistent with the broader heat health literature, in which early warning systems, heat action planning, vulnerability assessment, and infrastructure-based cooling measures represent central components of heat adaptation (Ragettli et al., 2024; Dube et al., 2025).

Intermunicipal cooperation presents a more nuanced picture. Cooperation with neighboring municipalities was selected as a potential opportunity by 34.5% of respondents. However, when municipalities were asked directly about their interest in future cooperation, 31.0% expressed definite interest and a further 41.4% responded “maybe”. This suggests that although cooperation was not among the most frequently selected general opportunities, many municipalities were at least open to considering it when asked directly. The reasons for this difference were not assessed in the survey and require further investigation.

4.2. Strengths and limitations

A major strength of this study is the broad coverage of the sampling frame: 40 of 46 municipalities responded to the survey (87%), and 29 municipalities provided complete questionnaires for analysis (63% of all municipalities in the district). This is higher than the average reported for comparable municipal surveys (cf. Friedrich et al., 2024; LGL, Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit, 2023) and provides a substantial empirical basis for describing heat adaptation within the study district.

However, several limitations must be considered. A selection bias cannot be ruled out, as municipalities already engaged in climate protection may have been more motivated to participate. Second, while the high level of regional representation allows for a detailed contextual analysis, the small absolute number of cases ($n = 29$) and the specific focus on a single district limit the statistical generalizability to all German rural areas, particularly those in structurally weak or remote regions. Furthermore, the reliance on self-reported data carries a risk of social desirability bias, and the timing of the survey in winter may have affected the perceived urgency of heat as an acute risk.

The cross-sectional design does not allow causal conclusions regarding the relationship between municipality characteristics and adaptation activities. In addition, survey responses were provided by individual municipal representatives and may therefore be affected by informant-specific knowledge or perceptions. Reported measures and organizational structures were not independently verified against municipal documents or administrative records.

In addition, comparisons across municipality size categories were limited by highly unequal group sizes ($n = 18$, 5, 4, and 2). Particularly for the larger municipality categories, percentages may be influenced by individual responses. Municipality-size-specific findings should therefore be interpreted as descriptive patterns and not as evidence of statistically established size effects.

4.3. Generalizability

The findings may be informative for other districts with similar settlement structures, administrative conditions, and heat adaptation challenges, particularly in Southern Germany. However, transferability to other regions depends on differences in governance structures, socioeconomic conditions, climate exposure, and municipal resources.

The Augsburg district should therefore be considered an illustrative regional case for predominantly rural municipalities and small towns rather than a statistically representative case for rural municipalities in Germany.

Several of the structural challenges observed in this study are consistent with findings from broader German research. Limited staffing, financial resources, administrative capacity, and access to specialized expertise have also been identified as barriers to municipal climate adaptation in national and regional studies (Friedrich et al., 2024; (LGL, Bayerisches Landesamt für Gesundheit und Lebensmittelsicherheit, 2023); Overath and Rösler, 2025). Research on smaller and medium-sized municipalities further emphasizes the importance of administrative capacity, institutional specialization, and intermunicipal or regional networks for local climate adaptation (Häußler and Haupt, 2021; Eckersley et al., 2025). This consistency suggests that some of the challenges identified in the Augsburg district may also be relevant in other municipalities facing similar structural conditions.

At the same time, rural heat adaptation is strongly context dependent. Previous research from rural and remote settings has demonstrated that local institutional structures, population vulnerability, access to services, and available adaptation resources can shape both heat-related challenges and the capacity to respond (Williams et al., 2013; Williams et al., 2017; de Schrijver et al., 2023; Dewi et al., 2024). The findings of the present study should therefore not be generalized directly to rural municipalities in other regions or countries. Comparative studies across multiple districts and different governance contexts are needed to determine which of the observed patterns are specific to the Augsburg district and which may be transferable to other rural settings.

4.4. Recommendations

The following recommendations (See Table 3) derive from challenges identified in the survey and from adaptation approaches discussed in the literature. They should be regarded as potential strategies rather than measures whose effectiveness was evaluated in the present study.

Table 3
Suggested Implications Based on the Survey Findings. Source: authors' survey data.

Identified Challenge	Evidence from Study	Recommendation	Responsible Level
Lack of assigned responsibility	14 of 29 municipalities had no designated heat-protection lead; responsibility concentrated in mayor's office.	Establish a clear, formalized responsibility for heat adaptation; create a coordination unit or designate an existing officer.	Municipality
Limited reported involvement of health and social competencies	Health and social departments were not reported as respondents' own departments, primary leads, or additionally involved departments.	Integrate regional health authorities, social services, or NGOs into municipal heat planning; formal cooperation agreements.	Municipality & District
Low perceived need for strategic tools (HAP, climate analysis, vulnerability assessment)	Municipalities with <5000 residents frequently reported "no need" for analyses or plans.	Provide simplified templates, checklists, and context-specific HAP modules, with minimum guidance standards developed at district or state level.	District & State
Limited administrative capacity (staff, expertise)	Financial and staffing constraints were among the most frequently reported barriers.	Offer shared district-level services (e.g., climate officer, GIS support, grant application desk); regional capacity pooling.	District
Translation of regional climate information into local risk awareness	Municipal perceptions refer to the next 10 years, while regional projections indicate increasing heat-related hazards over subsequent decades.	Develop localized, easy-to-read climate briefs; targeted awareness campaigns; annual district-level heat risk report.	District & Climate Services
Lack of practical guidance	Lack of practical guidance, such as regulations or guidelines, was reported as an implementation barrier.	Provide practical, stepwise guidance and standardized templates adapted to the needs of smaller municipalities.	State & Climate Services
Uncertainty regarding intermunicipal cooperation	Cooperation was selected as a potential by 34.5%; direct interest was 31.0% yes, 41.4% maybe, and 27.6% no.	Facilitate low-threshold, district-coordinated opportunities for intermunicipal cooperation, such as joint training or shared information resources.	District
Insufficient communication structures	Communication with professional staff and consultation with target groups were frequently reported as unnecessary.	Develop low-threshold, multi-channel communication approaches adapted to local structures and target groups.	Municipality
Uneven recognition of vulnerable groups	Chronic illness, disability, pregnancy recognized by <50%.	Provide training on vulnerability profiles; partner with health sector to ensure inclusive heat planning.	Municipality & District
Incomplete implementation of heat-adaptation measures in public spaces	Green and water-related measures were relatively common, while shading, drinking water points, and cooling spaces were less consistently implemented.	Strengthen green and blue infrastructure (trees, shading structures, water features) to reduce thermal load in public spaces	Municipality & District
Limited heat-relief infrastructure	44.8% reported no need for access to cool public buildings and 37.9% reported no need for public drinking water dispensers.	Expand accessible cooling spaces, drinking water stations and shaded public areas to protect residents during extreme heat	Municipality

5. Conclusion

This study provides insight into the current status of heat adaptation in municipalities in the Augsburg district and highlights several organizational and structural challenges. Nearly half of the participating municipalities had no clearly assigned responsibility for heat protection, while strategic approaches such as climate analyses and HAPs were less established than individual infrastructural measures. Limited financial and human resources emerged as major barriers to implementation.

Municipal respondents expected heat-related health impacts to increase over the next 10 years. At the same time, regional climate projections indicate a continuing increase in heat-related climatic hazards over the medium and long term. Because the survey and climate projections address different time horizons and different aspects of heat-related risk, these findings should be interpreted as complementary rather than as a direct comparison of perceived and projected risk.

Descriptive differences were observed across municipality size categories, with smaller municipalities in this sample reporting lower levels of strategic engagement for several adaptation measures. However, the small and unequal group sizes do not allow municipality size to be identified as an independent determinant of adaptation progress. The findings instead point to the potential importance of administrative capacity, including staffing, expertise, financial resources, and clearly defined responsibilities.

Strengthening heat adaptation in smaller municipalities may therefore require practical guidance, accessible funding mechanisms, clearer organizational responsibilities, and opportunities to share expertise across municipal and district levels. Greater involvement of health and social expertise may also support the identification and protection of vulnerable population groups. Future research should examine the decision-making processes underlying municipal adaptation, include larger and more diverse regional samples, and evaluate how different governance and support approaches affect the implementation and effectiveness of heat adaptation measures.

Overall, this study contributes local empirical evidence to the still limited research on heat adaptation in predominantly rural municipalities and smaller local administrations.

and emphasizes the importance of considering administrative capacity alongside regional climate information when developing locally appropriate heat adaptation strategies.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the author used Google Gemini and Microsoft Copilot in order to optimize the language (style and grammar) and to assist with the translation of specific text passages. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

CRediT authorship contribution statement

Mona Claesson: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Elke Hertig:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cliser.2026.100751.

Data availability

Data will be made available on request.

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Glossary

Administrative Capacity: The human, financial and organizational resources available within a municipality to plan, implement and sustain climate-adaptation measures. Limited capacity is a central barrier in small rural communities.

Climate Projections: Model-based estimates of future climate conditions derived from emission scenarios. They provide quantitative expectations of changes in temperature, precipitation and extreme events and are essential for local adaptation planning.

Climate Services: User-specific climate information, tools and products, such as projections, risk maps or adaptation guidance, intended to support evidence-based decision-making and strengthen adaptive capacity across sectors.

GIS Support: Assistance using Geographic Information Systems to map and analyze spatial data. In heat adaptation, this includes identifying heat hotspots, vulnerable locations and land-use patterns to support evidence-based municipal planning.

Heat Action Plan (HAP): A structured framework outlining preventive, preparedness and emergency measures to reduce heat-related health impacts. HAPs typically include communication strategies, identification of vulnerable groups and concrete operational procedures.

Representative Concentration Pathways (RCPs): Standardized greenhouse-gas concentration trajectories used in climate modelling. They represent different futures, ranging from strong mitigation (RCP2.6) to high-emission scenarios (RCP8.5).

Urban Heat Island (UHI): A phenomenon where urban areas experience higher temperatures than surrounding rural areas due to dense built structures, reduced vegetation and anthropogenic heat emissions, especially affecting nighttime cooling.

Vulnerability (Heat Vulnerability): The susceptibility of individuals or populations to heat impacts, determined by exposure, sensitivity (e.g., age, health status) and adaptive capacity.

Vulnerability Assessment: A systematic evaluation of who is at risk, why, and to what degree. It integrates climatic, demographic, health and infrastructural factors to guide local adaptation planning.