KlimaNot – Effects of climate change on emergency and acute care: protocol for a mixed-methods study

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Abstract

Background: Due to climate change, the population and healthcare systems face an increasing burden of weather-related health risks. Emergency departments (ED) are one of the first points of contact for acute and emergency care and insights into population health. Previous research has demonstrated that climate change-based weather phenomena have an impact on ED utilization and morbidity. However, research shows inconsistent results for some weather phenomena and disease groups, and no corresponding evidence is yet available for Germany.

Objective: This study aims to investigate the association between climate-related weather conditions and ED utilization and morbidity in Germany. It focuses on identifying particularly vulnerable patient groups, developing indicators for syndromic surveillance, and testing prediction models to support clinical and public health decision-making.

Methods: KlimaNot is a consortium project using a mixed-methods approach. The study comprises several work packages, focusing on health care research, surveillance and prediction. The primary data source for all analyses are ED routine data collected from the AKTIN Emergency Department Data Registry. The dataset contains patient-related, administrative and treatment information on approx. 4,7 million ED visits from up to 43 EDs from the years 2019 to 2023; an extension to 2024 will be requested. The dataset will be linked to environmental data on the basis of the respective ED location. For the health care research work package, specific patient groups will be investigated, with a focus on children, old and multimorbid people. For the old age group, additional data on mobility, fall risk and health-related quality of life will be collected. As further part of the work package, special geographical characteristics will be assed using the hospital Stuttgart as case study. For the surveillance work package, climate change-related indicators, e.g. for heat-sensitive ED visits, will be developed and validated for syndromic public health surveillance. Regarding the prediction work package, machine learning methods are tested to predict expected ED utilization considering different weather constellations. Various strategies and tools for disseminating and visualizing the results will be developed to provide scientific evidence to the public and support clinicians and policy makers in decision making

Results: Retrospective data analyses are ongoing and scheduled for completion by December 31, 2025. The prospective study phase will commence on September 1, 2025, with final results expected by September 1, 2026.

Conclusions: This study will provide the first robust evidence on the impact of climate change–related weather conditions on ED utilization and morbidity in Germany. The findings aim to support early detection, preparedness, and targeted protection strategies for vulnerable populations and inform clinical and public health decision-making. Clinical Trial: The trial is registered in the German Clinical Trials Registry under the registration number DRKS00033214 as of 2024/05/24.

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Abstract

Background

Due to climate change, the population and healthcare systems face an increasing burden of weather-related health risks. Emergency departments (ED) are one of the first points of contact for acute and emergency care and insights into population health. Previous research has demonstrated that climate change-based weather phenomena have an impact on ED utilization and morbidity. However, research shows inconsistent results for some weather phenomena and disease groups, and no corresponding evidence is yet available for Germany.

Objective:

This study aims to investigate the association between climate-related weather conditions and ED utilization and morbidity in Germany. It focuses on identifying particularly vulnerable patient groups, developing indicators for syndromic surveillance, and testing prediction models to support clinical and public health decision-making.

Methods

KlimaNot is a consortium project using a mixed-methods approach. The study comprises several work packages, focusing on health care research, surveillance and prediction. The primary data source for all analyses are ED routine data collected from the AKTIN Emergency Department Data Registry. The dataset contains patient-related, administrative and treatment information on approx. 4,7 million ED visits from up to 43 EDs from the years 2019 to 2023; an extension to 2024 will be requested. The dataset will be linked to environmental data on the basis of the respective ED location. For the health care research work package, specific patient groups will be investigated, with a focus on children, old and multimorbid people. For the old age group, additional data on mobility, fall risk and health-related quality of life will be collected. As further part of the work package, special geographical characteristics will be assed using the hospital Stuttgart as case study. For the surveillance work package, climate change-related indicators, e.g. for heat-sensitive ED visits, will be developed and validated for syndromic public health surveillance. Regarding the prediction work package, machine learning methods are tested to predict expected ED utilization considering different weather constellations. Various strategies and tools for

disseminating and visualizing the results will be developed to provide scientific evidence to the public and support clinicians and policy makers in decision making.

Results:

Retrospective data analyses are ongoing and scheduled for completion by December 31, 2025. The prospective study phase will commence on September 1, 2025, with final results expected by September 1, 2026.

Conclusions:

This study will provide the first robust evidence on the impact of climate change–related weather conditions on ED utilization and morbidity in Germany. The findings aim to support early detection, preparedness, and targeted protection strategies for vulnerable populations and inform clinical and public health decision-making.

Trial registration

The trial was registered in the German Clinical Trials Registry (DRKS) under the registration number DRKS00033214 on May 24, 2024.

Keywords

climate change, emergency department, heat, syndromic surveillance

Introduction

As a result of climate change, there is an expansion of weather-related health risks affecting the population and challenge health system actors. Heat waves can lead to increased mortality [1,2,3,4]. The unusually high summer temperatures in Germany between 2018 and 2020 resulted in a significant number of deaths, with approximately 8,700 heat-related deaths in 2018, 6,900 in 2019, and 3,700 in 2020 [1]. Regarding morbidity, it is already known that individuals afflicted with respiratory disorders, including chronic obstructive pulmonary disease (COPD) and asthma, are susceptible to the adverse effects

of high temperatures [5]. This susceptibility is further exacerbated by environmental pollutants that heighten sensitivity to inflammatory reactions [6,7]. 2021). Cardiovascular diseases such as myocardial infarction and decompensating heart failure [8-10] as well as acute kidney injury resulting from dehydration are associated with high temperatures [11,12]. Furthermore, natural disasters and extreme weather events have been associated with psychological distress, cognitive impairment, and headaches [13,14].

Multimorbid patients, old people, children and adolescents are particularly vulnerable during extreme heat [15-17]. Masselot et al. (2023) examined the impact of extreme temperatures on different age groups in 854 European cities [18]. Their findings emphasize that heat-related health risks increase with age. Specifically, older adults (65 years and above) are more vulnerable to extreme temperatures, experiencing higher relative risks of mortality compared to younger adults. In the United States, it has been shown that extreme heat results in a higher occurrence of ED visits due to heat-related illness, kidney diseases, and mental disorders among both younger and older adults [19]. Bernstein et al. (2022) demonstrated that extreme heat during the warm season has led to a significant increase in ED visits at children's hospitals in the United States. The analysis revealed that high temperatures are associated with a 17% increased risk of all-cause emergency visits. The associations were particularly pronounced for heat-related illnesses such as dehydration and electrolyte disorders (83% increased risk), bacterial enteritis (35% increased risk), and ear infections (30% increased risk). Children with comorbidities, genetic susceptibilities, or those who face adverse social determinants of health are particularly at risk [17]. Thus, the question of how climate change-related weather influences the emergency and acute medical care needs of different socioeconomic groups becomes increasingly important for health care research.

Although there is already extensive evidence on the impact of weather and the environment on population health, the influence of weather-related factors on the utilization of EDs is still not sufficiently understood**.** While there is unambiguous evidence of a positive association between high ambient temperatures and ED visits due to directly heat-sensitive diseases such as dehydration and electrolyte imbalances, there is inconclusive evidence on the relationship between temperature and cardiovascular, renal and respiratory diseases [20-22]. EDs serve as a central element of the German healthcare system and provide crucial insights into current emergency and acute medical care trends. Given the ubiquitous effects of the global-wide climate change and the existing evidence, we hypothesize that climate-

change related weather conditions, such as heatwaves, significantly influence population health and the utilization of EDs in Germany. Moreover, we assume geographical differences and a group-specific impact on children, old and multimorbid patients.

This study protocol describes the design of the project “KlimaNot” for evaluating morbidity and utilization of EDs in Germany using routinely collected ED data and additionally collected prospective data. The study comprises several work packages, focusing on health care research, surveillance and prediction. The overall aim of the project is to assess impacts of climate change-induced weather on population health and ED utilization. For the health care research work package, the whole population as well as specific patient groups will be investigated, with a focus on children and older and multimorbid people. For the group of old people, additional data comprising comprehensive geriatric assessment as well as survey data on socioeconomic setting and health-related quality of life will be collected prospectively in three centers for geriatric medicine. As further part of the health care work package, special geographical characteristics will be assessed using the hospital Stuttgart as case study, which is situated in a basin and valley location. For the surveillance work package, climate change-related indicators, e.g. for heat-sensitive ED visits, will be developed and validated for syndromic public health surveillance. Regarding the prediction work package, machine learning methods are tested to predict expected ED utilization considering different weather constellations. The results of the prediction work package will be made available to the participating EDs in a web application.

Methods

Emergency department data

This research will employ a mixed-methods design, incorporating both retrospective and prospective data. Retrospective data will be sourced from the AKTIN Emergency Department Registry [23] (data usage request 2024-006; 2024-0067). A total of 43 EDs throughout Germany, including clinics of different care levels in cities with different population sizes, provided routine data of all ED visits documented in the respective ED in the years 2019 to 2024. A total of 4.7 million ED visits were submitted by all participating EDs for the study period, with an expected exclusion of 10% of the sample due to missing key data.

This retrospective ED dataset contains patient-specific information on age, sex (male, female, other) and first two digits of the zip code of the patient's place of residence, as well as administrative data on mode of transport to the ED, time of admission and mode of disposition (discharge to home, transfer to other hospital, inpatient admission, death). Furthermore, it contains the following treatment information: ED diagnoses in the form of ICD-10-GM-codes (International Classification of Diseases and Related Health Problems, 10th revision, German Modification) with a labeling of the main ED diagnosis, additional information on diagnosis certainty (secured, suspicion of, condition after or exclusion of diagnose), chief complaint in the form of CEDIS-PCL (Canadian Emergency Department Information System – Presenting Chief Complaints) codes, urgency level coded as MTS (Manchester Triage System) or ESI (Emergency Severity Index), vital parameters, Glasgow Coma Scale (GCS) and isolation status [24-26]. In case of an inpatient admission following the ED visit, inpatient treatment information according to the German social laws regulating the billing of inpatient services (§ 21 Krankenhausentgeltgesetz, KHentG) was added. This information contains the inpatient discharge diagnosis and the inpatient billing code. Multiple ED visits by the same person during the study period cannot be attributed due to data protection requirements.

Additional prospective data on the individual functional level of old patients will be collected at three participating study centers (Department of Geriatric Medicine Aachen, Clinic Barmherzige Brüder Regensburg, University Clinic for Geriatric Medicine Oldenburg). Complementary to the routine comprehensive geriatric assessment implemented in each center, that is assessing the different dimensions of geriatric comorbidity (e.g. mobility, dependency, depression, dementia and frailty), a survey focusing on individual aspects of the current health-related situation will be conducted. For the use case analyzing regional data from Stuttgart, additional information beyond the regular dataset is available for the period 2011 to 2023 with approx. 409.000 cases, enabling longer-term analyses. Compared to the AKTIN Emergency Department Registry, the dataset provides more detailed information on emergency patients and their treatment. In addition to diagnoses and symptoms, treatment times, duration, diagnostics, place of residence, and physician requirements are recorded. This allows for an analysis of not only the emergency presentation but also the diagnostic and therapeutic effort involved.

Environmental data

The retrospective weather and environmental data are collected from freely accessible datasets provided by the German Meteorological Service (Deutscher Wetterdienst, DWD) and the Federal Environment Agency (UBA). The DWD provides data sets comprising hourly and daily aggregated data on air temperature, humidity, wind speed and precipitation. The Federal Environment Agency provides data sets on air quality at an hourly level on ozone (O_3), nitrogen dioxide (NO_2), particulate matter (PM10, PM2.5) and sulphur dioxide (SO_2). For the regular use case Stuttgart, data on global radiation, radiation balance, as well as UV-A and UV-B radiation will also be available. The weather and environmental data of Stuttgart will be sourced from an environmental monitoring station located in the valley basin, approximately 1.3 km from the clinic. In addition, pollen count data will be acquired from the German Pollen Information Service foundation (Polleninformationsdienst, PID). The PID operates various pollen measuring stations in Germany, where the pollen concentration of various allergenic plants and trees is measured and counted on a daily basis. The pollen types with the highest allergic potential for humans will be selected together with experts from the PID.

Data linkage

The linkage between patient data and environmental data is established at the hospital level. For each hospital, the nearest weather station with the smallest air distance is identified, ensuring that there are fewer than 500 missing values within the time interval of 2019–2024. Due to the limited spatial availability and completeness of air quality data, air data are matched solely based on proximity to the hospital, accepting some missing values. Both the weather and air quality data are provided as hourly records, as well as in a summarized format with daily minimum, maximum, and mean values. The spatial granularity is selected to be as fine as possible. However, a finer granularity is not feasible due to data policy restrictions on patient data and the limitations of the environmental measurement grid. Under the assumption that environmental phenomena generally occur on a large scale and that most patients choose the nearest emergency department (ED) in case of an emergency, the linked data provide at least an approximate overview of the environmental influences to which patients were exposed before the onset of their illness. Following scientific best practices and ensuring reproducibility, the Python code used for the data linkage is publicly available on GitHub (https://github.com/timonkl/Klima_NOT). The

pollen stations will be selected in consultation with experts from the PID, considering data completeness as well as proximity to the ED.

Data protection

A scientific advisory board has been established, comprising representatives from medical associations (including the German Interdisciplinary Association for Intensive Care and Emergency Medicine and the German Society for Interdisciplinary Emergency and Acute Medicine), clinical experts specializing in emergency medicine, and a patient representative from the German Coalition for Patient Safety (Aktionsbündnis Patientensicherheit e.V., Berlin). Additional experts from the Federal Office for Citizen Protection and Disaster Support (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe) and the DWD are involved. The purpose of this board is to offer scientific guidance for the project, advocate for the interests of patients, and assist in implementing the outcomes.

Analyses work package health care research I: overall population

The descriptive analysis of the overall population in the KlimaNOT project aims to provide a comprehensive overview of specific variables to characterize the overall cohort and to support the planning of relevant subgroup analyses. This work package will focus on characterizing key aspects of the cohort based on multiple variables, including sociodemographic factors (age, gender), presenting complaints (CEDIS-PCL), initial triage assessment (MTS or ESI), patient referral pathways, hospital stay duration, discharge outcomes, and diagnostic categories (ICD-10). By analyzing these parameters and putting them in relation to environmental data across different EDs, we will gain insights into the distribution and burden of weather-related cases. Understanding the case distribution per ED will help to identify regional differences and potential disparities in ED utilization and morbidity. The descriptive analysis will serve as a baseline for further in-depth investigations within the KlimaNOT project, helping to identify trends, at-risk populations, and potential intervention points to mitigate the health impacts of extreme weather events.

Analyses work package health care research II: children and adolescents

To evaluate the impact of climate change-induced weather variations on pediatric emergency and acute medical care, detailed subgroup analyses will be conducted, stratified by age groups (0–5 years, 6–11 years, and 12–17 years). These analyses will be guided by the findings of a systematic literature review, ensuring that they align with existing evidence on climate-related pediatric health impacts. The primary objective is to explore the spectrum of diseases and health care utilization in pediatric emergency settings in relation to specific climate change-related weather conditions. The disease spectrum will be assessed using three key indicators: the presenting complaints (CEDIS-PCL), ED diagnoses (ICD-10-GM), and inpatient data. Health care utilization will be measured through the number of cases, providing insights into how climate-related factors influence ED visits and hospital admissions. To assess the effects of climate change-related weather conditions on pediatric and adolescent health, logistic regression models will be used with clearly defined and medically relevant outcome variables. Separate models will be developed for heat-related illnesses, respiratory diseases such as acute infections of the upper respiratory tract, and infectious intestinal diseases. Predictor variables will include weather-related exposures such as temperature and humidity, environmental factors such as ozone and particulate matter, as well as sociodemographic information (age, sex). Stratified analyses by age group will allow for the identification of particularly vulnerable subpopulations.

Analyses work package health care research III: old patients

The work package focusses on particular health risks and potential relation to weather conditions in the subgroup of geriatric people (≥ 65 years). A retrospective analysis of all ED visits of old people from 2019-2023 will provide descriptive information on treatment diagnoses, chief complaint, urgency level and admission rate. By linking timely-related weather data to the ED data, more comprehensive analyses to investigate the occurrence of e.g. heat-related diseases or decompensating pulmonary diseases related to humidity will be conducted. In addition, inpatient data (comprising the § 21 data set) will be used to describe specific characteristics of this geriatric cohort utilizing the Hospital Frailty Risk Score [27] and investigate outcomes as length of stay and in-hospital mortality. Secondarily, a prospective study focusing on the subgroup of oldest-old patients (>85 years) will be performed. Therefore, a comprehensive geriatric assessment during inpatient treatment as well as the following assessment instruments will be used: Parker Mobility Score (mobility)

(Parker und Palmer 1993), SF-12 health survey (health-related quality of life) (Ware 2000), and questionnaire on social situation [28]. Each of the instruments is validated, standardized and available in German (Delbaere et al. 2010, Ellert et al. 2004, Parker und Palmer 1993). To gain more comprehensive insights into potential relation between weather conditions and individual deterioration of current health issues, a self-developed questionnaire containing particular items investigating e.g. heat-related problems prior to hospital admission will be used. The development of this questionnaire is part of the project and the choice of items is based on both expert workshops during the project course and existing publications like the interview study of Kemen and colleagues [29]. The data will be collected pseudonymously by study personnel at each center. All emergency inpatient admissions of patients aged ≥ 85 years in the participating EDs in the period from September 1, 2025, to September 30, 2026 will be asked to participate in the study. A follow-up survey six weeks after discharge will provide broader insights by assessing specific geriatric outcomes such as increased level of dependency (e.g. discharge to nursing home) or reduced mobility. Based on the treatment capacities and previous patient population of the participating study centers, an expected total of 281 patients meeting the inclusion criteria during the planned data collection period was estimated. Based on experience from previous geriatric studies, it is assumed that 50% of patients would agree to participate in the study, resulting in an expected case number of 139 patients. Of this total, a drop-out rate of 50% is anticipated for follow-up during the six-week observation period. Informed consent will be obtained in writing by the study centers during treatment. The linkage of ED data, inpatient data, weather data and survey data will generate hypotheses about individual health risks and their relationship to different weather conditions.

Analyses work package health care research IV: regional use case Stuttgart

The aim of this work package is to analyze the influence of climate change-related weather conditions on various illnesses, considering the specific geographical characteristics of the valley basin in Stuttgart. To assess the health effects of climate change-related weather conditions, we will perform multivariate regression analyses linking environmental parameters (e.g., temperature, UV radiation, air pollutants) with ED presentations across disease categories. The study uses a merged dataset combining clinical records and high-resolution environmental data from local measurement stations, considering confounding

factors such as season, weekday, and location (valley vs. elevated areas). Disease diagnoses are categorized into 32 clinically meaningful groups to enable targeted analysis of weather-related health impacts. In addition to linear regression models, we will apply ANOVA and delta-based approaches to evaluate both absolute levels and daily changes of environmental exposures. The results will provide how climate factors impact the prevalence and severity of diseases and their effects on diagnostic and therapeutic resources. Furthermore, the study will assess how weather-related changes influence the demand for medical infrastructure and personnel, enabling better prediction and resource planning for healthcare systems.

Analyses work package surveillance

The surveillance work package focuses on the development and validation of indicators (“syndrome definitions”) for the timely monitoring of climate change-related weather-sensitive emergency admissions for syndromic surveillance on population level. The indicators will be used to identify trends over time and to detect deviations that indicate unusual events in population morbidity and ED utilization. The initial focus is on the development of an indicator monitoring population health during heat events, which has been established in other EU countries for several years [30,31].

To create the syndrome definition, a literature search on ED visits during heat events will be conducted to identify relevant ICD-10-GM- and CEDIS-codes. The feasibility and validity of the created syndrome definitions will then be assessed using the above described retrospective ED data linked with environmental data. We will perform descriptive analysis of the identified cases of the health indicator of interest (e.g. heat-related ED visits) using time series and exposure-outcome-plots to visualize a potential association between the frequency of codes and temperature. Regression analyses will be used to quantify these associations and account for uncertainty. The results will be discussed with clinical experts and the syndrome definition will be adjusted in an iterative process until one indicator is finalized. For internal validation, the time series of the syndrome definition will be compared with temperature time series, and regression analyses will be conducted again to quantify the associations and uncertainty. For external validation, additional data sources, such as heat mortality and heat warnings from the DWD, will be compared with the heat-indicator.

Analyses work package prediction

The goal of this work package is to develop mathematical models using machine learning methods to enable simulation-based analyses, such as weather-dependent predictions. These models will vary in granularity and capture correlations between environmental data and disease-specific demographic factors, such as age and sex. Feature selection will be tailored to different disease types, incorporating demographic characteristics and clinical patient information. Based on this analysis, customized data-driven machine learning models will be developed. Various model types, including Support Vector Machines, Feedforward Neural Networks, and Recurrent Neural Networks, will be explored. These models will be trained and cross-validated using supervised learning on ED data. A literature review will be conducted to identify models that integrate expert knowledge, with a particular focus on time series models incorporating climate data for forecasting ED utilization. An initial approach may involve time series regression with climate variables, allowing for the prediction of seasonal trends. Additionally, daily aggregated environmental data (see section *Data Linkage*) will be incorporated into the modeling process. This dual approach mitigates project risks by combining machine learning as a black-box model with an interpretable time series approach. The integration of both methodologies will enhance insights, particularly in feature selection.

Results

The retrospective analysis of the overall study population has already been completed. However, results will be published separately and are not reported here. The analysis of the impact of specific weather phenomena on pediatric emergency visits will be finalized by October 31, 2025. The retrospective analysis of weather-related health deteriorations in geriatric ED patients will be completed by October 31, 2025. The analysis of data from the multicenter prospective study is scheduled for completion by October 31, 2026. The case study on climate-related health effects in geographically unique settings (e.g., Stuttgart) is expected to conclude by December 31, 2025. The evaluation of the usability of AKTIN data for near real-time public health surveillance in the context of extreme weather events and the implementation of a prototype module for localized application of predictive models will both be finalized by June 30, 2026.

Discussion

This study will provide valuable insights into the impact of climate change-related weather phenomena on emergency and acute care services in Germany. By linking routine data from EDs with environmental data and employing advanced modeling techniques, we aim to improve our understanding of weather-related health risks and enhance planning for these challenges. The findings will offer guidance to health care providers, policymakers, and emergency services on how to better prepare for and respond to the health impacts of climate change.

Strength and Limitations

Our study addresses an urgent global challenge by focusing on health risks associated with climate change and provides much-needed evidence on the effects of weather-related phenomena on ED utilization in Germany. By using routine data, the study reflects real-life clinical conditions and makes efficient use of existing resources. The integration of both retrospective and prospectively collected data allows for a more comprehensive understanding of acute care demands, particularly among vulnerable groups. However, there are also limitations, as the AKTIN registry does not fully represent the entire German hospital landscape, which may limit the generalizability of the findings. In addition, the expected sample size for the prospective geriatric survey is not powered to detect statistically significant effects but is designed to offer exploratory insights into the acute care needs of older adults.

Dissemination

Findings of the study will be made available as oral or poster presentations at scientific conferences and through publications in peer-reviewed journals. In addition, the results of the prediction work package will be made available to the participating EDs in an interactive web application. Using the application, the EDs should be able to estimate what utilization can be expected under the assumption of certain weather constellations.

List of Abbreviations

ANOVA: Analysis of variance, AKTIN: German Emergency Department Data Registry, CEDIS-PCL: Canadian Emergency Department Information System – Presenting Complaint List, COPD: Chronic obstructive pulmonary disease, DUAC: Data Use and Access Committee, DWD: German Meteorological Service (Deutscher Wetterdienst), ED: Emergency department, ESI: Emergency Severity Index, GCS: Glasgow Coma Scale, ICD-10-GM: International Statistical Classification of Diseases and Related Health Problems, 10th Revision – German Modification, MTS: Manchester Triage System, NO_2: Nitrogen dioxide, O_3: Ozone, PID: Polleninformationsdienst, PM10, PM2.5: Particulate matter, SO_2: Sulphur dioxide, UBA: Federal Environment Agency (Umweltbundesamt), UV: Ultraviolet

Declarations

Ethics approval and consent to participate

This study was approved by the leading ethics committee at the Medical Faculty of the University of Magdeburg (29/24 dated March 08, 2024), as well as by the institutional ethic committee at RWTH Aachen (24-333 dated October 10, 2024). The usage of the ED data has been approved by the AKTIN Data Use and Access Committee (DUAC) and is subject to AKTIN's data protection regulations (available online in German under https://aktin.org/notaufnahmeregister/datenschutz/, Data usage request 2024-007; 2024-006). Written informed consent will be obtained from all participants participating in the prospective survey (*work package health care research III: old patients*).

Consent for publication

Not applicable

Availability of data and materials

The emergency department data are managed by the German Emergency Department Data Registry (AKTIN, https://aktin.org/) and are subject to data protection regulations. As such, they are not publicly available but can be requested directly from the registry under applicable conditions. Weather data are publicly accessible via the DWD at https://opendata.dwd.de/. All code used for data processing and analysis is available in our GitHub repository: https://github.com/timonkl/Klima_NOT.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

WS, MP, MS, JU, MKH, JB, TL, CB, SG, TS, FW and RR were involved in the design of the study. Authors KH and MR had the main role in manuscript preparation. Authors KH, MR, MS were responsible for research protocol design, while author KH, MR, and TK has the main role in data collection. First draft of the manuscript was written by KH, MR and MS. All authors critically revised the manuscript, gave final approval of the manuscript and are accountable for the accuracy and integrity of the manuscript.

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Not applicable

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