# Exploring the link between socio-economic and physical structure in cities to inform heat adaptation options: the case of Stuttgart

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***Abstract*—Heat stress is recognised among the key risks in the context of climate and societal changes. This study aims to explore the link between socio-economic and spatial factors contributing to the effects of extreme heat events in the city of Stuttgart. The paper presents some findings of the Citizens' Survey 2021 in the city of Stuttgart on some key variables such as experience with heat stress and access to green spaces. The analysis further gives special emphasis to relationships between these variables and socio-economic factors e.g. income levels with heat-related adaptation options. The survey data was analyzed using Statistical Package for Social Sciences (SPSS) and then exported to ArcGIS pro and linked with geographical data (shapefiles) of the city districts. The study provides new insights into the spatial variability of heat experience as well as the socio-economic profile that needs to be targeted for future heat adaptation planning in the city.**

***Keywords—human vulnerability, heat stress adaptation, Stuttgart, heat waves***

## I. INTRODUCTION

The urban environment interconnects the earth's climate system with our society, culture, and economy. Within urban planning, such interactions between climate-related hazards, their modification through urban forms and settlement structures, as well as the social structure within different city parts need to be well understood. This is vital for informing future climate change mitigation and adaptation policies. Admittedly, adaptation to the effects of climate change is representing key principles and simultaneously challenges for spatial planning.

Among diverse climate-related hazards, heat stress is exacerbated by the globally rising temperatures and also affected by the local climate, physical and socio-economic factors; this can pose a significant risk to human health and affect daily activitiesBesides the physical and spatial factors such as land-use, building height and density [1-3], a number of studies have been dedicated to the importance of socio-economic factors in forming urban structures and their contribution to intensifying the urban heat-related effects in European countries and worldwide [1, 4-7]. Some examples of these factors that increase human susceptibility to heat include age [8-10], existing health issues [11-13] and income level [14] [15]. Other factors such as the density of and access to green spaces [16], and access to information via media [10, 17] have been also mentioned as the determinants of coping and adaptive capacities to heat. The extent to which extreme heat events pose a risk to different city parts and population groups depends not only on their intensity and frequency of occurrence, but also on the susceptibility as well as the adaptability and coping capacity of the communities [18].

The city of Stuttgart is the capital of the state of Baden-Wuerttemberg situated in south-western Germany. It has a population of about 634,830 (2019) [19]. Stuttgart is spread across several hills, valleys (e.g., the valley of River Neckar), and green areas. These topographical characteristics together with the Black Forest in the West and the Swabian Alb in the South influence its local climate. The complex terrain has a significant influence on all climatic elements like radiation, air temperature and wind, resulting in large climatic distinctions within the city area [20]. Despite the green belts and several parks, these topographical characteristics together with the densely populated and heavily industrialised areas contributed to an intense urban heat island, in particular in the central areas [31]. The number of summer days in Stuttgart with temperatures above 25 °C more than doubled from 40 (1987) to 87 (2020); and the number of heat days above 30 °C in 2020 was 25 days while in the 90s, it was about 10 days [21].

This paper aims to explore the link between some socio-economic and spatial factors in the context of heat stress in the city of Stuttgart. Some findings of the Stuttgart Citizens' Survey 2021 on how and where different groups experience heat stress, and where are the hot spots regarding access to green spaces are presented. Furthermore, the role of economic factors e.g. income level in implementing adaptation measures was explored. Accordingly, the study examines the following research questions:

– How is the spatial variability of heat experience in the city of Stuttgart?

- What are the linkages among spatial characteristics (e.g., location and access to green spaces), heat experience, and future adaptation options?
- How socio-economic factors (e.g., income) may contribute to the implementation of adaptation options (e.g. relocation to a heat-adapted living environment)?

## II. Methods and Data

### A. Citizen survey in Stuttgart

As mentioned, this study links the data from the Stuttgart Citizens' Survey 2021 (Bürgerumfrage 2021) and administrative shapefile at the city district (Stadtteile) level to evaluate some heat-related determinants. The Statistical Office of Stuttgart has been producing the Stuttgart Citizens' Survey every two years since 1995. An identical survey number is used for this purpose, which also serves as access authorization to the online questionnaire. According to an agreement, the University of Stuttgart-institute of Spatial and Regional Planning (IREUS) has incorporated seven questions to explore heat vulnerability and adaptation options of the citizens in Stuttgart.

To explore the socio-economic data and its linkage with heat stress-related variables e.g., risk perception, buildings and open spaces, and adaptation measures, IREUS has conducted an analysis in the Landeshauptstadt Stuttgart- Statistisches Amt to ensure the data protection issues and only aggregated data is further used.

### B. Data analysis:

Initially, the data was analyzed in Statistical Package for Social Sciences (SPSS) to aggregate information from individual household level to city districts. Thereafter, descriptive statistic (cross tabulation) is used to assess the factors mentioned in the last section. For example, information on income levels was crossed with adaptation to heat stress and presented in form of bar charts. The tables generated in SPSS for the selected factors were then exported to ArcGIS pro and linked with geographical data (shapefiles) of the city district. The selected information from each factor was then mapped to analyze the spatial differences at the district level (Stadtteile) in terms of the experience of heat stress, access to green spaces and moving to heat adapted neighbourhood as an adaptation option to heat stress.

## III. Results

This section shows the analysis of experience with heat stress and adaptation measures that people have implemented along with their linkages with vulnerable populations and access to green spaces.

The results show that a higher proportion of households living in the central parts of the city experience stronger heat stress compared to those living in the outskirts of the city (see figure 1A). The inner-city parts namely Stuttgart-West (e.g. the districts Hölderlinplatz and Feuersee), Stuttgart-East (e.g. the district Stöckach), the city center/Stuttgrat-Mitte (e.g. the districts Kernerviertel and Dobel), Bad Cannstatt (e.g. the districts Winterhaldeand and Seelberg), as well as Zuffenhausen (e.g. the districts Zuffenhausen-Mitte and Zuffenhausen-Hohenstein) are mainly among those where people experience stronger heat stress. These parts of the city are characterized by dense built-up areas with closed perimeter residential structures (e.g., multifamily row building blocks) which allow limited air circulation. In addition, households living in the central parts of the city reported limited availability of green spaces within a 300-meter radius of their residence. For example, between 40-60% of households living in city parts namely Stuttgart-West (e.g. the districts Hölderlinplatz and Rosenberg), Stuttgart-East (e.g. the district Stöckach), the city center/Stuttgrat-Mitte (e.g. the districts Rathaus and Dobel), Bad Cannstatt (e.g. the districts Winterhaldeand and Seelberg), as well as Zuffenhausen (e.g. the district Zuffenhausen-Mitte) reported that there are not sufficient green spaces within a 300-meter radius of their residence (see figure 1B) while it is vice versa for those living around the central part with sufficient and better access to green areas. It is interesting to see that most of the households reporting insufficiency of greenspaces have also experienced stronger heat stress.

Stuttgart-West is an example of a district with high/very high levels of heat experience. The key factors contributing to this include the building structure (typically Blocks), very high population density in Stuttgart (a population of about 52,470) and insufficient green spaces which partially also can be measured by remote sensing data. This can be also supported by local climate studies e.g. [20] that say Stuttgart-West is the most thermally stressed area in Stuttgart because of the high building density in the valley floor which causes local streams to be blocked and mostly don’t reach the inner district.

In terms of adaptation measures e.g., moving to heat adapted living environment, a higher proportion of households living in outer parts of the city have implemented this adaptation option (see figure 1C). On the contrary, only a few households living in the central parts of the city implemented this measure. Our analysis further depicted that implementation of this adaptation measure has a strong link – among other factors – with the income levels of households. Figure 1D. show that households having higher incomes (more than 4,000 euros per month) moved to heat adapted environment and the majority of high-income households reside in the outer parts of the city.

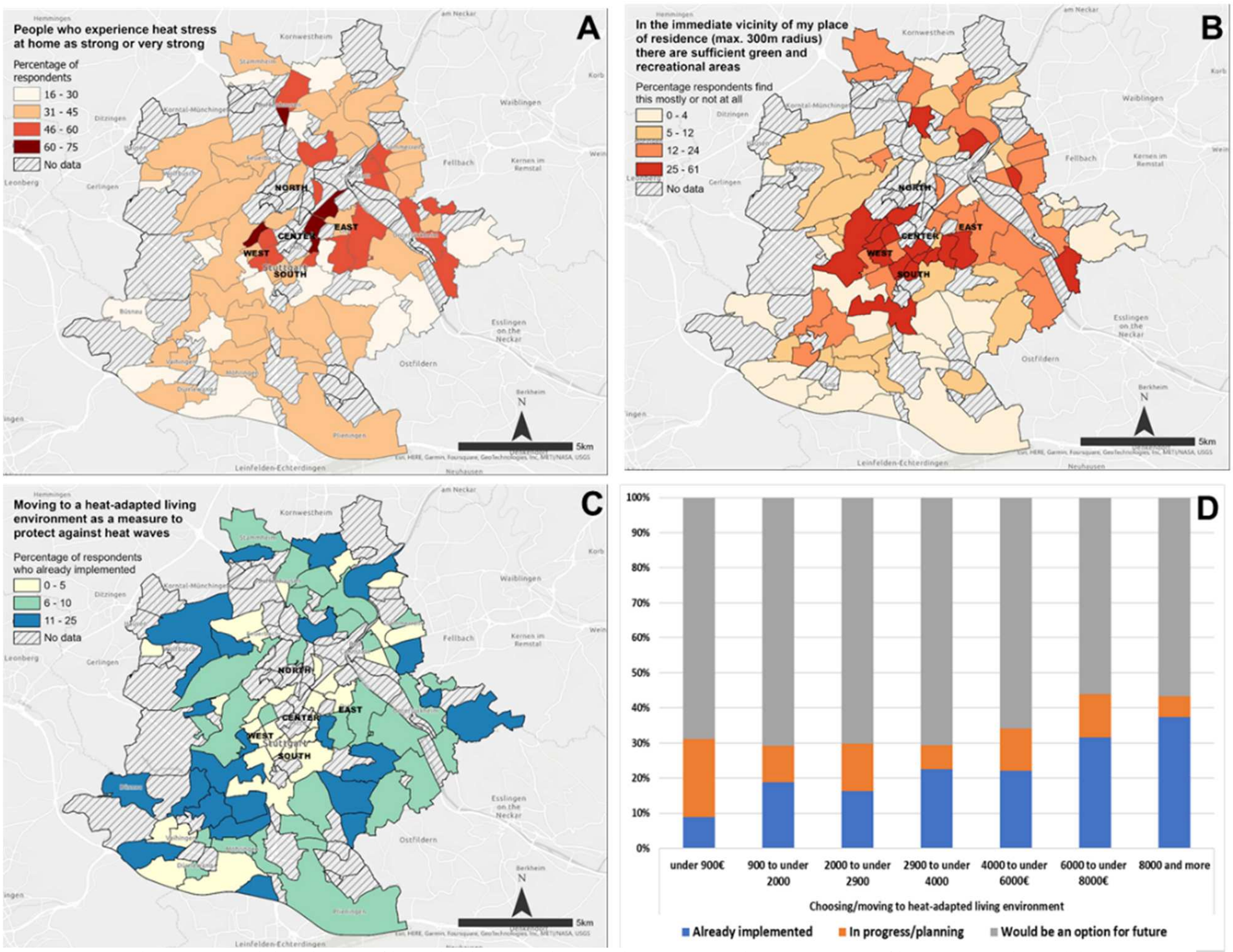


*Figure 1: Map showing spatial distribution of households in city districts that represent their experience of heat stress at home (A), access to green spaces in their immediate vicinity (B), moving to heat adapted living environment as an adaptation measure against heat (C); as well as a bar chart showing relationship of income with response of households in relation to moving heat adapted living environment. Source of the data: the Landeshauptstadt Stuttgart- Statistisches Amt; Source of the background map: Esri, HERE, Germin, Foursquare, Geotechnologies, Inc, METI/NASA, USGS*

## IV. Discussion and Conclusion

The analysis of different topics of heat stress and its linkages with spatial factors like access to green spaces and economic factors like income provided interesting insights. It is evident from the results that heat stress differs spatially within the administrative boundary of the city. People residing in and around the central part of the city or parts where building density is higher, and people live in multistory row housing structures experience stronger heat stress. This indicates the higher exposure to heat stress in residential buildings in the central and more densely built-up areas. [22] in the case of Berlin also found that residential buildings (particularly those categorized as multistory row housing) with higher density in the inner city were affected by heat. Similarly, high-density areas in the Philippines also experience higher heat stress [23].

Better access to green spaces is also a factor that could reduce the heat stress of residents of Stuttgart. Our analysis clearly indicates that households having insufficient access to green areas experience stronger heat stress. [24] maintained that green spaces could reduce thermal stress. Moreover, outdoor vegetation limits heat in and around buildings and lowers heat stress [24]. Thus, access to green spaces could be crucial in limiting heat stress to an urban population.

In terms of adaptation, we found that several households reported moving to heat-adapted living environments. These households mainly belong to the outer parts of the city which has higher access to green areas (e.g., parks and forest) (see figure 1B). In Australia, extreme heat is found to be an important reason for migration to cooler areas, particularly for older people [25]. In addition, there are economic factors associated with it, for example, income which is found to play an important role. With regard to moving costs, it is even more expensive choosing residential areas in Stuttgart that are more adapted to heat e.g., areas equipped with sufficient fresh air ventilation, green space and constructed with material that is effective against heat. Thus, people with higher income have the capacity to afford such adaptation options. Several studies have underscored the importance of economic factors for adaptation [6, 26-29]. [30] also indicate that low-income groups have rather low adaptive capacities due to socio-demographic factors and experience disproportionately high temperatures and limited access to refuge from extreme heat. All of the above, along with the results of the present study, point towards the need need to cost-effective and affordable adaptation options to heat stress that can easily be accepted and adopted by low-income population groups.

Climate adaptation measures such as a sensible green belt policy, safeguarding vital fresh air corridors, and roof greening have been implemented in the city of Stuttgart [31]. Besides the structural interventions, other adaptation actions to reduce human susceptibility also play a vital role . These may include enhancing heat warning systems, heat protection measures during the day and night at home and workplace, and changes in commuting patterns. Future research is needed to link the socio-economic profile of Stuttgart with the city structure types and building typologies to better inform the future heat adaptation planning in the city. For this purpose, remote sensing data also plays an important role to determine spatial parameters of the city that also influence and measure the heat island effect, such as built-up density and green space ratio.

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