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Human adaptation to heat in the context of climate change: A conceptual framework

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ABSTRACT

Climate change is causing serious damage to natural and social systems, as well as having an impact on human health. Among the direct effects of climate change is the rise in global surface temperatures and the increase in the frequency, duration, intensity and severity of heat waves. In addition, understanding of the adaptation process of the exposed population remains limited, posing a challenge in accurately estimating heat-related morbidity and mortality. In this context, this study seeks to establish a conceptual framework that would make it easier to understand and organise knowledge about human adaptation to heat and the factors that may influence this process. An inductive approach based on grounded theory was used, through the analysis of case studies connecting concepts. The proposed conceptual framework is made up of five components (climate change, vulnerability, health risks of heat, axes of inequality and health outcomes), three heat-adaptation domains (physiological, cultural and political), two levels (individual and social), and the pre-existing before a heat event. The application of this conceptual framework facilitates the assistance of decision-makers in planning and implementing effective adaptation measures. Recognizing the importance of addressing heat adaptation as a health problem that calls for political solutions and social changes. Accordingly, this requires a multidisciplinary approach that would foster the participation and collaboration of multiple actors for the purpose of proposing effective measures to address the health impact of the rise in temperature.

1. Introduction

1.1. Background

Human action has already caused a rise in the mean global surface temperature of 1.1 °C above the pre-industrial mean (IPCC, 2023). This phenomenon is leading to a greater frequency and intensity of extreme weather events, something that is, in turn, causing severe damage to natural and social systems and having important effects on human health (Romanello et al., 2022). Among the direct effects of climate change are the rise in global surface temperatures and the increase in the frequency, duration, intensity and severity of heat waves (IPCC, 2022b). The world is facing a climate crisis that affects peace, security and health, among other key dimensions of human life. Adaptation has become more prominent as a worldwide challenge encompassing local, subnational, national, regional, and global aspects. It is now a central focus on both domestic and international political agendas, acknowledged as being equally vital as efforts to mitigate climate change (UNEP, 2022). Climate change will induce tens of millions of people to move within their nations by 2050, seeking to escape the adverse impacts of it. These displacements will originate in less sustainable regions characterised by low water availability and low agricultural productivity, as well as in areas affected by sea-level rise and cyclonic storms. The most impoverished and climate-vulnerable communities will be the most impacted (Rigaud et al., 2018). Although greenhouse gas emissions might be completely eliminated, the climate impacts that are already occurring will continue for some time (European Commission, 2021). Human influence, according to future emission scenarios, will continue to change climate conditions, something that will very likely bring about a rise in sea levels and virtually certain an increase in extreme heat

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(IPCC, 2023). While human beings have a high capacity to adapt to heat (Périard et al., 2016), heat-related mortality has shown a decline in certain countries, such as the United States, Sweden, Spain or Japan. In addition to the demographic and socioeconomic changes themselves, this reduction is attributed to technological, infrastructural, and biophysical adaptations, including the widespread use of air conditioning (Åström et al., 2016; Chung et al., 2018; Davis et al., 2003; Follos et al., 2021). However, our understanding of the adaptation process of the exposed population remains limited, posing a challenge in accurately estimating heat-related morbidity and mortality for projections in the future (Folkerts et al., 2020; Navas-Martín et al., 2024).

Climate and weather conditions have a considerable impact on people's health and wellbeing. Every year, millions of persons die due to environmental factors, which are often aggravated by climate change or its drivers. In fact, climate change acts as a multiplier of global health threats, exacerbating many of the health problems which already confront communities, and disproportionately affect the most vulnerable groups, particularly in low-income countries, by increasing inequalities (UNEP, 2018). Heat waves are associated with an increase in gender-based violence, increasing the risk of femicides, as well as the number of police reports and calls to emergency phones (Sanz-Barbero et al., 2018). In addition, drought is also related to mental health, affecting mood, the incidence of intimate partner violence and the risk of suicide (Padrón-Monedero et al., 2024; Vins et al., 2015). Not only the impact itself, but the climate emergency situation itself causes anxiety, depression, stress, fear, suicidal behavior and even eco-anxiety, among other possible mental health and psychosocial problems (WHO, 2022).

1.2. The concept of adaptation

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as the process of adjustment to actual or expected climate and its effects, with the aim of moderating or avoiding harm or exploiting beneficial opportunities. Whereas in natural systems, adaptation implies an adjustment to the current climate and its effects, the presence of human intervention can facilitate adaptation to the expected climate and its consequences. Similarly, adaptive capacity is defined as the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC, 2022a). From an epidemiological approach, heat adaptation primarily involves population-level responses aimed at mitigating the health impacts of heat-related events, indicating a collective approach rather than individual adjustments (Petkova et al., 2014).

Climate-change adaptation can be implemented by different strategies, such as health and wellbeing, economic and human security, agriculture and subsistence livelihood, infrastructure and built environment, and socio-cultural impacts (Turek-Hankins et al., team). Adaptation in health is developing, executing, overseeing, and assessing strategies, policies, and programs aimed at handling the risks associated with health outcomes relevant to climate change. Therefore, the adaptation strategy aims to mitigate the adverse effects that climate change can impose on the health of individuals, communities, and the health systems themselves. Such adaptation can either occur spontaneously, as the result of unforeseen actions, or can alternatively be planned and specifically targeted at reducing the health impact of climate change. One example of planned adaptation is upgrading health systems to cope with extreme climate events (UNEP, 2018).

1.3. Climate-change adaptation frameworks

A great variety of conceptual and theoretical frameworks address adaptation and climate change, and cover a wide range of issues and aspects. Some authors propose frameworks covering: adaptation of factors that determine vulnerability (Brooks et al., 2005); actions and barriers in adaptation processes (Eisenack and Stecker, 2012); indicators for the natural environment (Pearce-Higgins et al., 2022); equity in adaptation responses (Araos et al., 2021); adaptation of transport infrastructure (Quinn et al., 2018); and how adaptation affects different forms of tourism (Jopp et al., 2010). Other authors have proposed frameworks covering the strategies, evaluation and adaptive capacity of cities and buildings (Araos et al., 2016; Barbosa et al., 2016; Chen et al., 2016; Filho et al., 2019; Kim and Lim, 2016).

However, there are fewer frameworks that specifically address climate change adaptation in the context of health, and even fewer that specifically target heat adaptation. In 2004, the researchers Füssel and Klein drew up a report based on a review of the different conceptual frameworks of adaptation, for evaluating planned adaptations that might affect health in the context of climate change. In their findings, they concluded that there was no single approach to evaluating adaptation policies which was capable of addressing the diversity of health problems. Likewise, no single conceptual framework covered all the relevant issues for evaluating adaptation in respect of human health (Füssel and Klein, 2004). In 2006, the same authors presented a conceptual framework which addresses evaluations of vulnerability to climate change for different purposes, including that of developing adaptation strategies to reduce climate-sensitive risks (Füssel and Klein, 2006).

More recently, Tait and Hanna (2015) proposed a more specific conceptual framework on human adaptation to global warming. Notably, it includes three climate-change adaptation domains (acclimatization, adaptation behaviours and technology) which operate on two levels (personal and social) and within the levels and diverse factors or specific elements that form part of subsystems (Fig. 1). Boeckmann and Zeeb (2016), on the other hand, proposed a framework that is noteworthy for linking two principal concepts, namely climate-change impacts and health outcomes, with seven domains that show variables and content which can be used to measure the achievement of climate justice (Fig. 2). While the first framework only considers three dimensions of adaptation, acclimatization, behaviours and technology, but does not contemplate health outcomes. The second framework encompasses seven dimensions of adaptation but is focused on the evaluation of adaptation from the perspective of justice but does not consider the two levels.

In this context, the information available from epidemiological research on adaptation indicates that the relationship between temperature and mortality is restricted (Navas-Martín et al., 2024). Taking this into account, to guide the conceptual framework, the following research question was posed: How are adaptation and vulnerability to heat linked to adaptation processes in a context that addresses climate change, vulnerability, social inequalities and health? The aim of this study was therefore to establish a conceptual framework on heat adaptation and its relationship with health. This framework could help

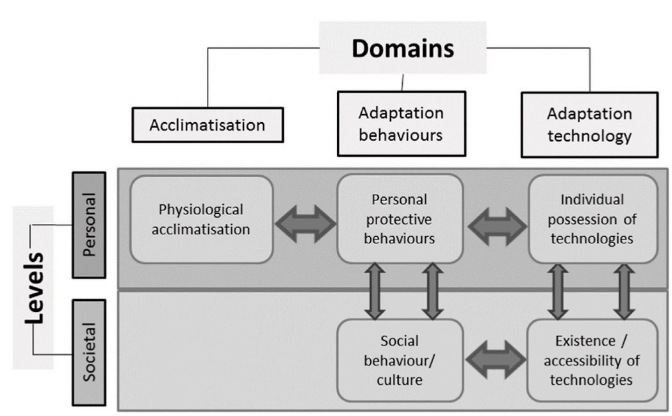

Fig. 1. Conceptual framework on climate change adaptation (Tait and Hanna, 2015).

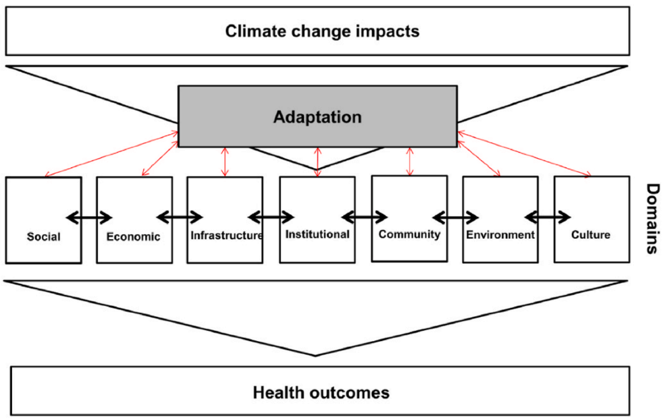

Fig. 2. Theoretical framework for assessing adaptation in terms of climate justice concerns (Boeckmann and Zeeb, 2016).

researchers and policy makers to understand and efficiently organise knowledge (Rocco and Plakhotnik, 2009) of human adaptation to heat and the factors that go to influence this process. This framework will contribute to knowledge on heat adaptation based on research experience on heat-related mortality and morbidity in a specific population. Its results imply the capacity to carry out concrete actions on heat adaptation policies and measures, particularly on health policies aimed at addressing the health impact of heat events. These actions include the development of direct policy action or regulation, the implementation of technical solutions such as architectural improvements, and raising public awareness through awareness campaigns and behavioural changes.

2. Methods

A conceptual framework is an interconnected network or structure of concepts, contributing to a comprehensive undestanding of a specific phenomenon or phenomena. A concept is a idea formed by components that collectively define it. In research, the conceptual framework is not discovered but rather constructed by the researcher, who builds the overall structure and coherence by incorporating borrowed elements or may have originated from their own ideas on your research (Kivunja, 2018; Tamene, 2016). It is carried out through an inductive process in wich small individual pieces (concepts) are linked together with their possible relationships (Imenda, 2017).

To develop the proposed conceptual framework, an inductive approach based on grounded theory was used, through the analysis of case studies. The inductive approach makes it possible to start from scratch as data are collected and analysed until the research result is obtained. One of the methodological references of inductive research is grounded theory (Bryman, 2012; Neuman, 2014), which has evolved over time. Grounded theory is a flexible methodology that facilitates the discovery or construction of a theory, as well as the generation and connection of concepts from qualitative and quantitative data. This allows for the conceptual development of the research (Chun Tie et al., 2019; Holton, 2008). For the interrelationship of the concepts developed in the conceptual framework (Fig. 3), we used findings drawn from our own case studies, bearing in mind that, unlike a theoretical framework which is based on knowledge established by experts, a conceptual framework is developed on the basis of the ideas and thoughts of the researchers themselves (Kivunja, 2018). For this reason, the case selection was purposeful, not random.

Information-rich cases were selected to allow for an in-depth analysis according to the research question (Ebneyamini and Sadeghi Moghadam, 2018). For this purpose, based on the studies carried out by the research group, those cases related to the impact on health due to the effects of high temperatures were selected. They were grouped into two

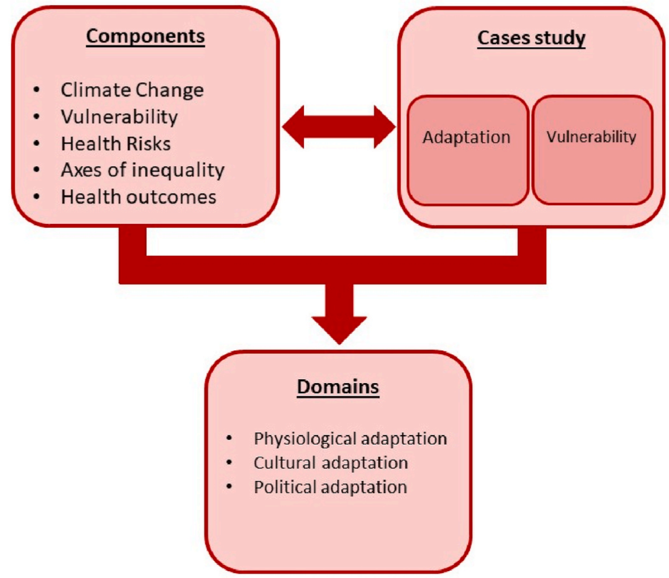

Fig. 3. Diagrammatical overview for the interrelationship of the concepts developed in the conceptual framework.

case study groups to address the study objectives, one related to vulnerability and other capacity to adapt to heat. The case study is used in research to gain a detailed and comprehensive understanding of a complex topic within its real environment. It is widely used in a variety of disciplines, and although its definition may vary, its essential core is based on the imperative of a thorough exploration of an event or phenomenon in its natural context and particularly useful in the construction of new theories (Crowe et al., 2011; Ebneyamini and Sadeghi Moghadam, 2018). Furthermore, in the analysis of the case studies, the cases were categorized (Chun Tie et al., 2019) to relate the concepts of the framework and understand the interrelationships between them. Finally, to connect own ideas with borrowed elements, two relatively recent adaptation frameworks (Boeckmann and Zeeb, 2016; Tait and Hanna, 2015) were used in addition to the principal components. The selection of the frameworks was carried out through a literature review using the Web of Science search engine with the keywords “framework”, “heat”, and “adaptation”, using the Boolean operator AND and filtering between the last 10 years (2013–2023). Subsequently, a screening process was carried out according to the objectives of the study, obtaining the two frameworks.

3. Development of the conceptual framework

The conceptual framework consists of five main components which are interrelated on two levels. Each level includes the pre-existing conditions and respective domains of adaptation (Fig. 4).

3.1. Main components of the conceptual framework

3.1.1. Climate change

Climate change is defined as the change in climate conditions deemed to be caused, directly or indirectly, by human activity, which modifies the composition of the Earth’s atmosphere and is added to the natural climate variations that have been recorded in comparable time periods (UNFCCC, n.d.). Traditionally, there have been two political approaches to this problem: on the one hand, there is adaptation to climate change, which implies adjusting to changing climate conditions; on the other, there is mitigation, which entails limitation of greenhouse gas emissions or the use of carbon sinks (Wang and McCarl, 2011). In the context of the impact of climate change on human health, adaptation and mitigation measures, such as warning systems, serve to reduce the

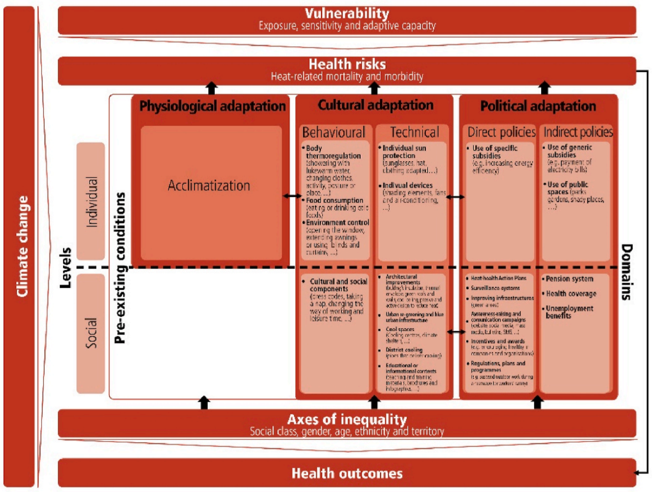

Fig. 4. Conceptual framework of the time trends in human adaptation to heat in the context of climate change. It is defined with 5 main components (climate change, vulnerability, health risks, axes.

morbidity and mortality of a given population (Luyten et al., 2023; Sharifi et al., 2021).

3.1.2. Vulnerability

Vulnerability refers to the level of capacity of a person, group of persons or system to cope with the negative health consequences which climate change may generate. It is determined by exposure, sensitivity and adaptive capacity to risk factors (Füssel and Klein, 2006; Marí-Dell'olmo et al., 2022; Paavola, 2017). Lack of economic resources and access to essential services, such as health, limits people's ability to adapt and respond to the challenges of climate change. Those living in the poorest and most unequal conditions are the most vulnerable to the impacts of climate change (WHO, 2015).

3.1.3. Health risks

Risk, in this context, refers to the possibility of there being negative effects which may endanger human or ecological systems, and whose result or degree of impact cannot be accurately predicted. Risks arise from the combination of the vulnerability of the affected system, prolonged exposure to danger, and the probability of such danger occurring, which is linked to the climate (IPCC, 2022a, 2022b). Climate change involves numerous risks for human health, such as air quality, vector distribution and ecology; nutrient dense diets and food safety; water quality and quantity; heat stress, extreme weather events, floods, storms, wildfires, droughts and other phenomena (Austin et al., 2015; IPCC, 2023; McMichael, 2012; Mojahed et al., 2022).

Heath risks are hazards or threats, which arise due to climate change and affect human health. Such risks can affect health in different ways, including the development or aggravation of respiratory diseases, mental health problems and other adverse effects. When it comes to the health risks posed by extreme temperatures from heat events, these are reflected in the increased mortality and morbidity associated with such situations (IPCC, 2022b; Patz et al., 2005; WHO, 2021b).

3.1.4. Axes of inequality

The axes of inequality that determine the distribution of power in a society and have an impact on health include social class, gender, age, ethnicity or race, and territory (Borrell et al., 2012; Comisión para Reducir las Desigualdades Sociales en Salud en España, 2015). In t he context of climate change, the different axes influence the opportunities that a given individual has to maintain their health in a good state, be in a condition to adapt to climate change and avoid its consequences on their health. People with fewer economic and social resources are the ones who are most exposed to the effects of climate change and face the greatest obstacles to adjusting to and recovering from these effects (Marí-Dell'olmo et al., 2022).

3.1.5. Health outcomes

Health outcomes refer to changes in the health status of an individual, group or population, which are due to a planned intervention or a series of interventions, regardless of whether or not the stated aim of the intervention is to change health status (WHO, 2021a). In the context of climate change, outcomes are determined by health risks, as well as how people are exposed to these risks, their sensitivity to them, and their ability to adapt. These elements, including mode of exposure, sensitivity, and adaptive capacity, combine to determine vulnerability (Paavola, 2017). Although there is difficulty of linking climate change adaptation to health outcomes due to complex interactions, methodological limitations, and incomplete causal understanding in epidemiology (Boeckmann and Zeeb, 2016).

3.2. Levels of the conceptual framework

3.2.1. Individual level

Individual level refers to the perspective of analysis focused on the person (as the basic unit of analysis), taking into account their characteristics and behaviour. In the context of the adaptation process, it refers to the personal conditions that determine this process at a micro level.

3.2.2. Social level

Social level refers to the perspective of analysis focused on persons, considering their interaction and influence in the group context in which they act. In the context of the adaptation process, it refers to the community conditions that determine this process at a macro level.

3.3. Pre-existing conditions

Pre-existing conditions refer to the circumstances or factors that are already present in an individual or population before an event occurs, which in this case means a heat event. At the individual level, in a health context, these are diseases, such as cardiac, pulmonary, renal, psychiatric diseases and acute cerebrovascular accidents, which are present in an individual before a heat event and are thus exacerbated when the event occurs, (Huertas et al., 2021). According to Sánchezí Martinez et al. (Sánchez Martínez, 2019; Sánchez Martinez et al., 2011, 2022), at the social level, there are direct or indirect policies targeting the reduction of vulnerability to heat. Pre-existing conditions can act as a protective factor or risk factor, and several can occur simultaneously.

At an individual level, bearing in mind that vulnerability to extreme heat is determined by each individual's exposure, sensitivity and adaptive capacity, pre-existing conditions may result in some persons being more vulnerable than others to the effects of climate change, experiencing more adverse health outcomes than the rest (Paavola, 2017; Sheridan and Dixon, 2017). Among the various factors that can influence the effects of heat is physical condition or consumption of toxic substances (such as alcohol or drugs), which can modulate the way in which a person experiences the effects of extreme heat (Asghari et al., 2017). At the resource level, having air conditioning or better housing affects exposure to heat (López-Bueno et al., 2020; López-Bueno et al., 2021a,b,c)

At a social level, vulnerability and its effects on health are determined by a community's exposures, sensitivities and adaptive capacity in the face of a threat (Yu et al., 2021). The resources, infrastructure and means available at a community level are also a decisive factor when it comes to adaptation and reducing vulnerability. For instance, the implementation of direct policies, such as heat-health action plans, and indirect policies, such as health coverage, pension plans, or unemployment benefits, can mitigate social vulnerability and its impact on health by modulating the effects of heat (Sánchez Martinez et al., 2011, 2022, 2019). Moreover, various pre-existing factors influence the adaptation to heat, including population acclimatization (Navas-Martín et al., 2022a,b), pollution levels (Culqui et al., 2017; Egea et al., 2023; Linares et al., 2020a,b; Ruiz-Páez et al., 2023), climate conditions (Carmona et al., 2017; López-Bueno et al., 2019; López-Bueno et al., 2021a,b,c), and meteorological factors (Miron et al., 2008; Ruiz-Páez et al., 2023).

3.4. Domains of the conceptual framework

Heat adaptation processes can be approached from different various perspectives, as evidenced by organisations such as the WHO (2015) and national health authorities such as the United Kingdom (Government of United Kingdom, 2023), the United States (The White House, 2023) and Canada (Goverment of Canada, 2023) through resilience to climate change. Regarding adaptation, as there are many definitions and, thus, many different categories, which makes it impossible to have a universal classification (Noble et al., 2015; Smit and Wandel, 2006). Some authors suggest approaching it from the perspective of comfort: these are the classifications of physiological, psychological and behavioural adaptation (Schweiker et al., 2013; Schweiker and Wagner, 2015). Other authors have focused on cultural (Ellen, 2018; Smit and Wandel, 2006), behavioural (Indraganti, 2010; Rijal et al., 2019) or even joint cultural/behavioural adaptation (Araos et al., 2021), as well as adaptive (Biesbroek et al., 2018; Dupuis and Biesbroek, 2013) or institutional policy (Araos et al., 2021; Bellamy, 2019; Noble et al., 2015), among others. Within the proposed conceptual framework, three domains of heat adaptation response are identified: physiological, cultural, and political.

3.4.1. Physiological adaptation (acclimatization)

Physiological adaptation to heat, also known as acclimatization, refers to adjustments made in bodily mechanisms in response to regular exposure to high temperatures, triggering reactions that reduce the adverse impacts of heat stress. Accomplished through increased sweating and skin blood flow reactions, improved fluid balance and cardiovascular stability, a reduced metabolic rate, expansion of plasma volume, and the development of thermal tolerance (Périard et al., 2015). Functional or physiological adaptation is acquired during one's lifetime and is not genetically heritable (Leonard, 2015): 7–14 days are needed to acclimatise, and it is during the first 4–7 days of heat exposure that short-term adaptation occurs (Périard et al., 2016). This type of adaptation, activated to maintain homeostasis and ensure normal biological functioning -such as regulation of body temperature and oxygenation of the blood and tissue in the face of stressful environmental factors (Leonard, 2015)- can lead to short-term acclimatization to heat through frequent exposure, potentially reducing cardiovascular burden and lowering the core temperature response to heat exposure (Charkoudian, 2016).

At an individual level, physical characteristics, such as age, sex, body mass index, health, medication and physical state, significantly influence the efficacy of key thermoregulation functions, such as sweating, cardiac system efficiency, and blood volume regulation. These factors can contribute to the variation in tolerance to heat stress. In particular, it has been observed that both children and older adults have a lower heat tolerance capacity than the rest of the population (Hanna and Tait, 2015; Leonard, 2015; Wickham et al., 2020).

3.4.2. Cultural adaptation

Cultural adaptation is the process of change in response within a given setting or an alteration in the internal factors that affect an entity, such as an organisation, community or company (Denevan, 2010; Smit and Wandel, 2006; Storå, 1994). These cultural factors determine people's support for adaptation measures and their level of motivation to act (Adger et al., 2012). Through learning and teaching, knowledge about adaptation can be transmitted from generation to generation (Leonard, 2015). In adaptive management of the health system, for example, risk assessments clarify local needs or surveys provide information on effectiveness (WHO, 2015). Recent social science studies show that cultural practices which favour adaptation processes can be classified into two categories: behavioural and technical (Smit and Wandel, 2006).

3.4.2.1. Behavioural adaptation. Behavioural adaptation is the adjustment of individual, collective and/or institutional behaviour to reduce society's exposure to climate-related vulnerabilities (Pielke, 1998). Acquired through learning, it is the quickest mechanism and the most flexible for enabling individuals to cope with environmental problems (Hardesty, 1942).

At an individual level, the changes that a person makes consciously or unconsciously to modify their body temperature include a range of actions, such as taking lukewarm showers or changing clothes, activity, posture or place. Additionally, eating or drinking cold foods can contribute to reducing body temperature (Brager and De Dear, 1998; Liu et al., 2012). Similarly, there are passive measures that the individual can adopt in the home, such as opening windows to dissipate the heat, extending awnings, or using blinds and curtains (Alessandrini et al., 2019; Sánchez Martinez et al., 2022; Santamouris et al., 2007). During workdays, it is recommended to take breaks in hot environments (Jay et al., 2021).

At a social level, the change is determined by the cultural and social components of each place: for instance, it may imply changing dress codes adapted to warmer areas, taking a nap during the hottest daylight hours, or modifying the way in which one organises one's work and leisure time (Brager and De Dear, 1998; Liu et al., 2012; Lundgren et al., 2013; Navas-Martín et al., 2022a,b; Weitensfelder and Moshammer, 2020).

3.4.2.2. Technical adaptation. In the broadest sense, technology refers to the use and knowledge of certain tools and techniques, and the way in which their application affects human beings' capacity to adapt to and control their physical and social environment. Thus, the concept may not solely refer to the application of the scientific knowledge, through instruments and industrial processes, such as machines, tools and devices, but may also include more general aspects, such as systems, organisational methods theories, and techniques (Banta, 2009). In the context of climate change, technical adaptation refers to the implementation of these tools and knowledge of technology, to cope with impacts and become more resistant to climate change (Bellamy, 2019). Technical adaptation, thus, may adopt different ways -structural, physical or social-which include educational, informational and behavioral (Bellamy, 2019; Noble et al., 2015).

At an individual level, this would include the use of clothing and accessories with specific features with a particular aim, for instance sun protection, such as sunglasses, hat or clothing purpose-designed and/or adapted to reduce heat (Holmér, 1995; Kearney et al., 2016). In an indoor context, individual shading devices, fans and air-conditioning are usual techniques that may be adjusted to the needs of the person (although fans or air conditioning are usually controlled individually, they can be also used collectively) (Kownacki et al., 2019; Osberghaus and Abeling, 2022).

At a social level, this would cover more complex architectural improvements, such as enhancing the building insulation on the thermal envelope to increase energy efficiency; making use of cool or green roofs and walls, and other elements as part of the building passive design. Also, the selection of the optimal orientation, or the inclusion of solar control devices, and the application of absorbent building materials, for instance, could be a better approach for a shifting climate change scenario where adaptation is needed. Alternatively, achieving indoor hygrothermal comfort may require the implementation of heating, ventilation, and air conditioning systems, along with supplementary elements such as energy exchangers, thermal storage elements, fans, radiant floors and ceilings. However, this approach often leads to increased energy expenses and GHG emissions. This inconvenient may be solved by supplying power, at least in a great extent, with renewable energy sources (Puig, 2021; Sánchez Martinez et al., 2022)

This could also be addressed from the built environment itself (either at a community, neighbourhood, or district scale), with measures such as urban re-greening and the presence of well-managed blue urban infrastructures (Sánchez Martinez et al., 2022), which, among other benefits, serve to mitigate the urban heat island effect (Alvarez et al., 2021; López-Bueno et al., 2020). Furthermore, cooling centres are places purpose-designed to provide temporary relief to people in extreme heat situations, and are usually located in public spaces (Berisha et al., 2017; Nayak et al., 2019). Another potential measure involves converting schools or other public buildings into climate shelters to provide protection during unfavourable situation. These spaces may be used by the community as a place of refuge on hottest days, even outside the school timetable or during weekends (Baró et al., 2022).

A further technical solution is district cooling, which consists of a centralised cooling generation, covering an urban area, and distributed through a pipeline network to buildings added to the grid (Puig, 2021). Lastly, sight should not be lost of the fact that another way of technical adaptation consist of educational training and informative dissemination and engagement, as mentioned above. Environmental education makes it possible to empower and cultivate a public committed to health and the preservation of the environment (Huertas et al., 2021). At a national level, to prevent the impact of heat on society, teaching and training materials, such as brochures and infographics must be created for subsequent distribution and awareness-raising purposes (Sánchez Martinez et al., 2022).

3.4.3. Political adaptation

In general terms, political adaptation refers to the set of actions, decisions and choices made by individuals and organisations, both public and private, at different administrative levels and in different sectors, with the specific purpose of tackling the effects of climate change in policy. The desired results seek to generate a significant impact on groups of actors, geographic areas or sectors vulnerable to the effects of climate change (Biesbroek et al., 2018; Dupuis and Biesbroek, 2013).

There are two types of policies aimed at heat adaptation: direct and indirect (van Staden and Musco, 2010). Direct policies are specific, targeted measures, which are implemented with the aim of reducing the negative effects of extreme heat. In contrast, indirect policies, which are not aimed at promoting adaptation, may nonetheless have a positive impact on the heat adaptation process. While these policies may be specific, e.g., increasing energy efficiency through better climate control systems and thereby increasing the efficacy of air-conditioning, there can also be general policies, such as providing a pension system, health coverage or unemployment benefits, which increase resilience, both overall and specifically to the impacts of climate change.

At a social level, adaptation policies may include: implementation of an early warning system, emergency and heat-health action plans that are activated during a heat wave (Sánchez Martinez et al., 2011, 2022, 2019); monitoring and surveillance systems (Sánchez Martinez et al., 2022); improving infrastructures, such as the creation of green areas, to reduce exposure to heat (García Sánchez et al., 2018; Hrdalo et al., 2015; Mukhamedjanov et al., 2023); conducting awareness-raising campaigns through dissemination and education about the risks of extreme heat; issuing risk warnings via websites, mobile applications, SMS, bulletins, social media and mass media; encouraging healthy actions in companies and organisations through incentives and awards; and drawing up regulations, heat-health action plans and programs to boost actions to combat the effects of heat (EPA, 2023; Puig, 2021; Sánchez Martinez et al., 2022).

At an individual level, this would cover the type of action that a citizen can take in response to a specific policy. Such as the use of subsidies for the payment of electricity bills (Bienvenido-Huertas et al., 2023; Rodriguez-Alvarez et al., 2019), or the use of public space for searching for cool and shady places like parks and gardens.

In the case of these policies, a distinction must be drawn between private adaptation policies, which are implemented as the result of individual initiative and only benefit those who take the decision, and joint adaptation policies, which involve multiple beneficiaries and are implemented by government action (Mendelsohn, 2000). Examples of public policies are improvements to health services, poverty reduction, resource redistribution, education, and heat-wave warning systems (Guo et al., 2018).

3.5. Conceptual framework mechanisms

Climate change is altering health risks, due to the increase in mortality and morbidity caused by increasingly frequent extreme weather phenomena such as heat waves. The influence of such risks on health outcomes is influenced by the population's vulnerability. In the sphere of adaptation, it is axes of inequality, levels and pre-existing conditions that determine adaptive mechanisms.

In Spain, studies conducted by our research group (Table 1 and Table 2) have shown that the relationship between health risks and health outcomes in heat-adaptation terms is determined by axes of inequality, such as gender (Follos et al., 2020; Navas-Martín et al., 2022a,b), age (Navas-Martín et al., 2023a,b) and territory (Díaz et al., 2019; Follos et al., 2021; López-Bueno et al., 2021a,b,c; Navas-Martín et al., 2022a,b; Navas-Martín et al., 2023a,b). In addition to gender (Díaz et al., 2002, 2006; Díaz et al., 2018; López-Bueno et al., 2020) and age (Díaz et al., 2015), the impact on vulnerability to heat is also determined by social class (López-Bueno et al., 2020) and territory (Cuerdo-Vilches et al., 2023; Díaz et al., 2018; Díaz et al., 2015; García-Herrera et al., 2005; Linares et al., 2014; López-Bueno et al., 2022; Miron et al., 2008; Tobias et al., 2012; Tobías et al., 2014).

With respect to the impact of vulnerability, adaptation is determined by pre-existing conditions, not only in terms of environmental variables such as pollution (Díaz et al., 2016; Egea et al., 2023), weather conditions (Montero et al., 2012; Ruiz-Páez et al., 2023) and climate conditions (Carmona et al., 2017; López-Bueno et al., 2021a,b,c), but also in terms of people's physical condition, including diseases preceding a heat episode (Culqui et al., 2017; Linares et al., 2016). Lastly, regarding adaptation domains, the available evidence from epidemiological studies indicates limitations in understanding the temperature-mortality relationship (Navas-Martín et al., 2024). These studies primarily focus on cultural adaptation, particularly technical adaptation, and the protective role of dwellings (López-Bueno et al., 2019; López-Bueno et al., 2019), as well as on direct policy adaptations such as prevention plans (Roldán et al., 2014, 2016).

4. Application of conceptual framework

Climate change is changing the well-known association between heat and health, increasing the exposure and vulnerability of large-sized population groups and the risk of the adverse effects of heat. This modification requires an adaptation effort, not only institutional but also spontaneous, with implementation at both an individual and a group or social level. Adaptation is aimed at reducing vulnerability and the risks of heat, by minimising the adverse health effects. Adaptation, according to the proposed framework, can be categorized into three main domains: physiological (acclimatization), cultural (including behaviours and technologies) and public policies. The relevance of the different dimensions and elements of the conceptual framework is shown in Table 1 for adaptation to heat and in Table 2 for impact on vulnerability to heat.

The proposed conceptual framework serves as a valuable tool for comprehending the interplay among climate change, vulnerability, health risks, axes of inequality, and health outcomes in the heat adaptation process. Social disparities, driven by factors like social class, gender, age, ethnicity, and territory, delineate vulnerability to climate

Table 1
Relationship of the elements of the conceptual framework, local evidence findings and their relevance for heat adaptation through the case studies.

Framework dimension	Specific Framework element	Findings from local evidence	References	Relevance for adaptation
Inequality axes	Age	Population over 65 showed slower acclimatization than general population	Navas-Martín et al. (2023b)	Prevention must assume at best slowest rhythm of acclimatization, specific targeting of the elderly
Inequality axes	Territory	Different territories showed very different rates of adaptation to heat	Navas-Martín et al. (2023a)	Prevention plans must be adapted to climate zones, rely on local epidemiological evidence
Inequality axes	Territory	Urban areas showed higher rates of adaptation to heat than rural areas	Navas-Martín et al. (2022a)	Prevention plans must incorporate the differences in adaptation between urban and rural areas
Inequality axes	Gender	Women showed higher adaptation than men	Navas-Martín et al. (2022b)	Prevention plans must include the gender perspective in order to address gender differences in adaptation
Inequality axes	Territory	Geographical heterogeneities in adaptation	Follos et al. (2021)	Prevention plans must articulate measures at the local level for adaptation
Inequality axes	Territory	Geographical heterogeneities in adaptation	López-Bueno et al., 2021a	Prevention plans must be adapted to heat wave definition threshold temperature at the local level
Inequality axes	Gender	Both genders showed adaptation, although women are more vulnerable to heat.	Follos et al. (2020)	Prevention plans must be evaluated and improved
Political adaptation	Direct	It is important to implement Prevention Health Action Plans	Linares et al. (2020)	Prevention plan must prioritize a health perspective
Inequality axes	Territory	Geographical heterogeneities in adaptation	Díaz et al. (2019)	Prevention plans must articulate measures at the local level for adaptation

change. Emphasizing the necessity for comprehensive and fair policies that prioritize the most vulnerable communities, the framework underscores the physiological, cultural, and political dimensions of adaptation. Pre-existing conditions, encompassing chronic ailments, demographic traits, and socioeconomic elements, emerge as pivotal determinants of both individual and community vulnerability. On an individual scale, these conditions shape the efficacy of physiological heat adaptation, influencing tolerance and responsiveness to extreme conditions. Societally, pre-existing conditions mold cultural adaptation, shaping the ability to instigate behavioral and technological shifts at the community level. This interconnectedness underscores the imperative for policies addressing existing disparities and promoting tailored adaptations at each tier, ensuring both fairness and efficacy in climate health risk management.

5. Discussion

The objective of the proposed conceptual framework is to provide a comprehensive structure for understanding and addressing the relationship between heat adaptation, climate change, vulnerability, health risks, social inequalities and health outcomes. It seeks to establish clear connections between key components, such as pre-existing conditions, individual and societal levels, and the physiological, cultural and political dimensions of heat adaptation. It also aims to guide the development and implementation of inclusive and equitable policies that mitigate disparities and strengthen the capacity of communities, especially the most vulnerable, to cope with the risks associated with climate change. Key findings include the relevance of social inequalities and the pressing need to address heat adaptation from a multidimensional perspective, encompassing physiological, cultural and political aspects. Pre-existing conditions emerge as crucial determinants of vulnerability, both at the individual and societal levels. This finding underlines the need for integrated approaches. It also highlights the importance of inclusive and equitable policies, with a special emphasis on the most vulnerable populations. These findings highlight the urgency of holistic and equitable measures to address the challenges of climate change and ensure effective and equitable adaptation.

In the case of adaptation to heat, our understanding of temperature-mortality relationship is constrained due to limited knowledge from epidemiological studies (Navas-Martín et al., 2024). This conceptual framework aims to improve our understanding of temperature-mortality relationships by taking into consideration local evidence linking heat adaptation to axes of inequality, such as age, territory, and gender. These findings are in line with studies conducted by other researchers, in which differences in heat adaptation have been observed between different cities, age groups and genders (Achebak et al., 2019; Bobb et al., 2014; Chung et al., 2018; Tobías et al., 2021). Similarly, the implementation of heat-health action plans through adaptation policies has been shown to be relevant, as reported by other studies undertaken in different countries, such as Canada (Benmarhnia et al., 2016), Italy (Schifano et al., 2012) and Australia (Nitschke et al., 2016).

When it comes to vulnerability to heat, studies based on local evidence have also found a relationship with axes of inequality such as age, territory and gender. These findings are in line with studies conducted by other researchers, in which differences in heat adaptation were observed between different cities, age groups and genders (Graczyk et al., 2022; Kang et al., 2020; Tong et al., 2014). These differences influence each person's chance of remaining in good health in the face of exposure to the risks of climate change. Likewise, studies which link pre-existing conditions with vulnerability to heat coincide with the findings of other studies on the incidence of environmental factors such as pollution (Yang et al., 2022), climate (Pezza et al., 2012) and weather conditions (Sharma and Mujumdar, 2017), as well as individuals' own health status (Schifano et al., 2009). Lastly, when it comes to evidence pertaining to adaptation domains and cultural policy, this is also supported by other studies which stress the need to implement adaptation policy measures to reduce vulnerability to heat (Boeckmann and Rohn, 2014). Alternatively, implementing technical adaptation measures in homes subject to overheating has shown that dwellings play a crucial role as a protective element against heat (Ramakrishnan et al., 2017).

The adaptation can be said to be the result of a combination of multiple factors. The set of different elements and factors that go to explain the heat adaptation process is known as "heat culture" (Follos et al., 2020; IPCC, 2019; Linares et al., 2020a,b; López-Bueno et al., 2020; Navas-Martín et al., 2022a,b). According to Bobb et al., there is a range of factors that can contribute to a population's adaptation to heat. These include lifestyle changes, a reduction in risk factors, improvements in healthcare services, implementation of early warning systems and public health programs, changes in behaviour such as reducing outdoor exposure on hot days, and improving the built environment through, say, the creation of green areas. Additionally, fostering increased awareness of heat-related risks is of paramount importance (Bobb et al., 2014).

In addition, it is important to highlight other factors that complement and enhance the public's understanding of the heat adaptation process and the measures that can be taken to reduce its negative health effects, such as those identified in the conceptual framework. These factors would allow for the notion of "heat culture" to be extended. Homes play a fundamental role as a protective element against heat, and aspects such as age, state, and restoration and refurbishment of

Table 2
Relationship of the elements of the conceptual framework, local evidence findings and their relevance for heat vulnerability through the case studies.

Framework dimension	Specific Framework element	Findings from local evidence	References	Relevance for adaptation
Inequality axes	Territory	Geographic heterogeneities in the urban heat island (UHI) effect	Cuerdo-Vilches et al. (2023)	Prevention plan must be based on local evidence and consider local factors to determine its impact on health outcomes
Pre-existing conditions	Pollution	Increase in admissions to the emergency for endocrine and metabolic diseases due to ozone and sunlight hours	Egea et al. (2023)	Prevention plan must consider environmental factors based on local epidemiological evidence
Pre-existing conditions	Meteorological	The effect of heat waves on morbidity and mortality depends on the synoptic situation	Ruiz-Páez et al. (2023)	Prevention plan must consider meteorological factors based on local epidemiological evidence
Inequality axes	Territory	Rural areas are less vulnerable to extreme heat than the urban area	López-Bueno et al. (2022)	Prevention plans must incorporate the differences in vulnerability between urban and rural areas
Pre-existing conditions	Climatic	Climatic heterogeneities in the vulnerability to heat wave	López-Bueno et al., 2021b	Prevention plan must consider differences in climate vulnerability to heat waves on local epidemiological evidence
Adaptation policy	Direct	Action plans that consider the different environmental factors affected by heat waves	Linares et al. (2020)	Prevention plans must be integrated into health
Inequality axes	Gender	Women are more vulnerable to heat than men	López-Bueno et al. (2020a)	Prevention plans must include the gender perspective
Inequality axes	Social class	Income level (as a proxy indicator of social class) to explain the different heat impact detected in the districts	López-Bueno et al. (2020b)	Prevention plan must consider differences in vulnerability due to socioeconomic factors
Cultural adaptation	Technical	Housing plays a key role in modulating the impact of heat waves	López-Bueno et al. (2019)	Prevention plans must articulate measures at housing rehabilitation
Adaptation policy	Direct	HHAPs reduces or minimizes heat-related mortality and morbidity	Sánchez Martinez et al. (2019)	Prevention plans must update
Adaptation policy	Direct	Without adaptation measures mortality increases	Sánchez-Martínez et al. (2018a)	Prevention plans must include a long-term perspective in the public health prevention of heat exposure
Inequality axes	Territory	Geographical heterogeneities in vulnerability	Díaz et al. (2018a)	Prevention plans must incorporate the geographical differences in vulnerability
Adaptation policy	Direct	Without adaptation measures mortality increases	Sánchez-Martínez et al. (2018b)	Prevention plans must design as a dynamic, adaptive process from the inception
Inequality axes	Gender	Hospital admissions for respiratory causes due to the impact of heat waves were associated with women	Díaz et al. (2018b)	Prevention plans must include the gender perspective
Pre-existing factors	Diseases	Heat waves were associated with Alzheimer's disease hospital admissions	Culqui et al. (2017)	Prevention plan must consider pre-existing conditions in vulnerability to heat waves on local epidemiological evidence
Pre-existing conditions	Climatic	The use of isoclimatic zones improves the effectiveness of prevention plans in public health	Carmona et al. (2017)	Prevention plan must consider differences in climate vulnerability to heat waves on local epidemiological evidence
Adaptation policy	Direct	Without adaptation measures mortality increases	Roldán et al. (2016)	Prevention plans must include a long-term perspective in the public health prevention of extreme temperatures
Pre-existing factors	Diseases	Heat waves were associated with Parkinson's disease mortality	Linares et al. (2016)	Prevention plan must consider pre-existing conditions in vulnerability to heat waves on local epidemiological evidence
Adaptation policy	Direct	The impact of extremely high temperatures supposes a cost in the hospital load in addition to the loss of human lives	Roldán et al. (2015)	Prevention plans must include an implementation of preventive measures aimed at mitigating the impact of extreme heat on human health and reducing the associated mortality costs
Inequality axes	Territory	Geographical heterogeneities in vulnerability	Linares et al. (2015)	Prevention plans must incorporate the geographical differences in vulnerability
Pre-existing factors	Physical condition	Heat waves are an acute stressor on pregnant women	Linares & Diaz (2015)	Prevention plan must consider pre-existing conditions in vulnerability to heat waves on local epidemiological evidence
Inequality axes	Territory	Geographical heterogeneities in vulnerability	Díaz et al. (2015a)	Prevention plans must incorporate the geographical differences in vulnerability
Inequality axes	Age	Elderly people are more vulnerable to heat	Díaz et al. (2015b)	Prevention plans must include different adaptation measures for each of the vulnerable groups
Inequality axes	Territory	Geographical heterogeneities in vulnerability	Linares et al. (2014)	Prevention plans must incorporate the geographical differences in vulnerability
Inequality axes	Territory	Geographical heterogeneities in vulnerability	Tobías et al. (2014)	Prevention plans must incorporate the geographical differences in vulnerability
Pre-existing conditions	Meteorological	Cyclonic conditions accompanied by low humidity situations are associated with increased mortality from heat waves	Montero et al. (2012)	Prevention plan must consider meteorological factors based on local epidemiological evidence
Inequality axes	Territory	Geographical heterogeneities in vulnerability	Tobias et al. (2012)	Prevention plans must incorporate the geographical differences in vulnerability
Inequality axes	Territory	Geographical heterogeneities in vulnerability	García-Herrera et al. (2010)	Prevention plans must incorporate the geographical differences in vulnerability
Inequality axes	Territory	Geographical heterogeneities in vulnerability	Miron et al. (2008)	Prevention plans must incorporate the geographical differences in vulnerability
Inequality axes	Gender	Gender heterogeneities in vulnerability	Díaz et al. (2006a)	Prevention plans must include the gender perspective
Pre-existing factors	Diseases	Diseases heterogeneities in vulnerability	Díaz et al. (2006b)	Prevention plan must consider pre-existing conditions in vulnerability to heat waves on local epidemiological evidence
Inequality axes	Territory	Geographical heterogeneities in vulnerability	García-Herrera et al. (2005)	Prevention plans must incorporate the geographical differences in vulnerability
Inequality axes	Gender	Older women are more vulnerable to heat than men	Díaz et al. (2002)	Prevention plans must include the gender perspective

dwellings influence the related risk (López-Bueno et al., 2019, 2020; López-Bueno et al., 2021a,b,c; López-Bueno et al., 2021a,b,c; Navas-Martín et al., 2022a,b; Navas-Martín et al., 2023a,b). Furthermore, the use of technical means such as air-conditioning (López-Bueno et al., 2020; Petkova et al., 2014) and the adoption of sun-protection measures, e.g., sunglasses, appropriate clothing or hats, are also key elements in terms of preventing the adverse health effects of heat (Holmér, 1995; Kearney et al., 2016). In the case of older adults, the ability to rely on nearby social networks and interpersonal support is crucial, since living alone during a heat wave becomes a risk factor. Indeed, individuals who engage in greater social interaction have less likelihood of experiencing the negative effects of heat (Lin et al., 2019a, 2019b; López-Bueno et al., 2021a,b,c).

Lastly, environmental education plays a relevant role in fostering concrete knowledge of and heightened awareness about short- and long-term adaptation to extreme climate conditions (Anderson, 2013; Bofferding and Kloser, 2015; Ekpo and Olatunde-Aiyedun, 2019). Taken together, these additional factors enrich the concept of "heat culture" and contribute to a fuller understanding of how to approach and adapt to the effects of heat on health.

The conceptual framework has a series of limitations which should be borne in mind. In the first place, there are few studies that address long-term population heat-adaptation processes. Moreover, there are gaps in research which make it difficult to interrelate certain concepts with the conceptual framework. For instance, when it comes to adaptation, a more in-depth examination is needed of the influence of social class and ethnicity on the axes of inequality, as well as that of adaptation policy, cultural adaptation and pre-existing conditions. Insofar as the impact of vulnerability is concerned, though there is ample evidence available, gaps in research are nonetheless present. These gaps include the need for studies on behavioural adaptation, indirect policies, and studies that give a breakdown of their results by ethnicity.

On the one hand, the implementation of the conceptual framework at the political level may also face certain limitations. Challenges related to logistics and resources, especially in financially constrained settings, could hinder effective policy implementation. Divergent interpretations and prioritization of framework elements among political actors may lead to inconsistent approaches. Political resistance or a lack of commitment to addressing underlying social inequalities could impede policy effectiveness. Additionally, achieving intersectoral coordination and collaboration across government levels may be challenging in fragmented political contexts. On the other hand, societal resistance to change and diverse cultural perspectives might pose challenges to the adoption of recommended adaptation measures. Inequitable access to resources and information could exacerbate existing social disparities, hindering the framework's effectiveness. Therefore, addressing both political and social challenges is crucial for successful implementation, requiring effective governance and active community inclusion and participation. Despite these limitations, the conceptual framework provides a solid basis for application as well as making it possible to identify key elements for future studies.

6. Conclusions

The effects of climate change, specifically the increase in temperature and heat waves, are linked to the associated risks, vulnerability and axes of inequality in the heat adaptation process. Adaptation takes place on two levels or scales, individual and social, and is influenced by preceding personal and community conditions. All this, in turn, has an influence on health outcomes. The proposed conceptual framework will help researchers and policymakers, both to understand and effectively organise knowledge of human capacity to adapt to heat, planning and implementing effective adaptation measures. Likewise, it highlights the fact that the problem of heat adaptation is a health problem which calls for political solutions. Accordingly, this requires a multidisciplinary approach that would foster the participation and collaboration of multiple actors for the purpose of proposing effective measures to address the health impact of the rise in temperature.

Disclaimer

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CRediT authorship contribution statement

Miguel Ángel Navas-Martín: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Teresa Cuerdo-Vilches:** Writing – review & editing, Formal analysis, Data curation. **José Antonio López-Bueno:** Writing – review & editing, Formal analysis, Data curation. **Julio Díaz:** Writing – review & editing, Supervision, Conceptualization. **Cristina Linares:** Writing – review & editing, Supervision, Conceptualization. **Gerardo Sánchez-Martínez:** Writing – review & editing, Supervision, Conceptualization.

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.

Data availability

No data was used for the research described in the article.

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