Exploring the interactions between vulnerability, resilience and adaptation to extreme temperatures

Ana Raquel Nunes (raquel.nunes@warwick.ac.uk)
University of Warwick Warwick Medical School

Research Article

Keywords: Vulnerability, Resilience, Adaptation, Extreme temperatures, Extreme events, Climate change

Posted Date: March 3rd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-259270/v1

Version of Record: A version of this preprint was published at Natural Hazards on July 19th, 2021. See the published version at https://doi.org/10.1007/s11069-021-04919-y.

Abstract

Proposed ways of improving adaptation to climate change have most often been supported by narrowly framed and separate analysis. This article investigates how different levels of vulnerability and resilience interplay with adaptation to extreme temperatures, what is the nature of these relationships and whether lower vulnerability and higher resilience contribute to increased adaptation. This article explores the governance implications of a project that, unlike other brings together vulnerability, resilience and adaptation assessments. The project has made significant advances in addressing the current deficit integrated assessments for shaping governance propositions. Such propositions argue that the diverse levels of vulnerability and resilience convey important bases for (1) targeting at-risk older individuals; (2) developing vulnerability reduction actions; (3) resilience building actions; and (4) understanding 'success cases' and learn from them for developing appropriate policy measures. Taken together, these propositions offer a social, psychological and health framework not simply for governing extreme temperatures but for governing responses to climate change at large.

1. Introduction And Literature Review

In recent years the impacts of climate and temperature on human health and wellbeing have been receiving increased attention. Both the Intergovernmental Panel for Climate Change (IPCC) and the World Health Organization (WHO) have reaffirmed that weather, climate and climate variability negatively affect human health (IPCC, 2018; WHO, 2013). Significant human vulnerability to extreme events has resulted in increased impacts on mortality and morbidity (Anderson et al., 2019; Guo et al., 2018). Older people are considered to be particularly vulnerable to extreme temperatures (Tong and Ebi, 2019). Within this age group, health status, sex, marital status, living arrangements and social factors are some of the key determinants of risk (Hajat et al., 2007). Despite this, the health impacts of extreme temperatures are preventable and avoidable (Haines and Ebi, 2019; Tong et al., 2016; Astrom et al., 2011) and can be mitigated through strategies aiming at reducing vulnerability, increasing resilience and improving adaptation (Bellamy, 2019; Keim, 2008) but there are still numerous constraints on implementing solutions (Bellamy, 2019). To achieve this, some argue that we need to better understand the factors shaping both vulnerability and resilience, as well as the factors underpinning adaptation decisions and actions (Atteridge and Remling, 2018; Bankoff, 2019; Curtis and Oven, 2012).

It has been argued that interdisciplinary research is needed (Tong and Ebi, 2019; Tong et al., 2016) and according to Watts and colleagues (2015) and McMichael and colleagues (2006) a more holistic line of research should address the implications of climate change in regards to the determinants of health and reducing health inequalities (Watts et al., 2018; Marmot, 2010). But despite growing scientific interest and attention, few interdisciplinary scientists have examined how vulnerability, resilience and adaptation interact. This article adopts a case study approach to explore interactions between vulnerability, resilience and adaptation, examining extreme heat and extreme cold temperatures. This article aims to understand why individuals respond to extreme temperatures the way they do allows a clear understanding of what underpins their decisions and focus on what is needed for adaptation actions that minimise impacts. The

ultimate goal is to understand how this influences impacts and outcomes, and its potential to change policy and practice.

1.1 Vulnerability

The concept of vulnerability has been widely used across disciplines such as psychology, economics, engineering, sociology, anthropology, disaster management, environment and health (McDowell et al., 2016; Gaillard, 2010). Unsurprisingly, there are many ways in which vulnerability is understood and used. This multiplicity of considerations has allowed vulnerability to become a highly contested concept where no single definition exists. Most of the conceptualisations and uses of vulnerability refer to a general, rather than a specified event or situation. As a result, Wisner and colleagues (2004) have expressed apprehension regarding the indiscriminate use of the concept of vulnerability, whilst Moser (2011) and Adger (2006) state that one of the advantages of these numerous conceptualizations is that vulnerability can be used in many different ways, settings and fields.

The different conceptualisations of vulnerability have led to the development of various methods to measure it (McDowell et al., 2016; Gaillard, 2010). One of the approaches to quantitatively measure current vulnerability is the development of indices using a composite index approach. The concept of assets and the five asset model (human, financial, physical, place-based, social assets) play an important role in the process of operationalising human vulnerability. Access to assets can thus be seen as the root causes of vulnerability (Moser, 2011), being associated to lack of assets in the sense that the bigger and the more diverse the asset portfolio the less vulnerable individuals are. Despite this, the role of assets in reducing vulnerability still needs to be further understood through exploring the relationships with resilience and adaptation (Ungar, 2018; Ebi et al., 2018; Romero-Lankao et al., 2012).

1.2 Resilience

The resilience of individuals is modified by events such as extreme temperatures, thus the need for improvements in planning and policy in order to increase resilience in the short, medium and longer terms (IPCC, 2018). Ebi and colleagues (2018) and Walker and colleagues (2004) emphasize the importance of access to assets, institutions and governance within the many factors shaping resilience, which can impact on the empowerment and agency of individuals. Resilience has been found to be associated with individuals and the characteristics where they live (Ungar, 2018; Brown and Westaway, 2011). This includes assets which are considered to influence the impacts of threats and stressors. Curtis and Oven (2012) have called for a better understanding of the factors and processes contributing to human resilience as research has shown that reducing individual vulnerability (e.g. increase access to assets) may increase their resilience. Opportunities to increase resilience have been proposed and include the development and implementation of programmes aiming at reducing vulnerability (Mc Dowell et al., 2016; Keim, 2008). Despite this, there is a lack of evidence on human resilience to climate change in general and extreme temperatures in particular (IPCC, 2018).

As a result of the diverse disciplinary roots of resilience many approaches have been taken to measure it (Bankoff, 2019; Leichenko, 2011). Lorenz (2013) makes direct links between the construct of resilience and health by giving special attention to salutogenesis and Sense of Coherence construct (Antonovsky, 1996) as it focuses on the factors (e.g. resources, assets) that make someone resilient (Wilkinson, 2005). Almedom (2008) asserts that these changes represent a significant development that allows connections between resilience and the sense of coherence which is the central construct of salutogenesis (Wiesmann et al., 2009). The use of the Sense of Coherence scale to assess human resilience is gaining more interest from researchers and is considered to be an accepted measure of individual resilience (e.g. Kimhi, 2014). The Sense of Coherence has links with assets having been used to measure resilience (Almedom et al., 2007; Glandon et al., 2008). As such it has been used to better understand general and specified resilience to different threats (i.e. war, natural disasters) (e.g. Glandon et al., 2008; Almedom et al., 2007).

1.3. Adaptation

Human adaptation has been taking place ever since individuals evolved to deal with their environments (Atteridge and Remling, 2018; Beall et al., 2012). Additionally, climate change is expected to increase the need for individuals to adapt (Haines et al., 2019; Watts et al., 2018). Entangled in the definitions of adaptation is the fact that it entails several decisions on the actions to implement (Atteridge and Remling, 2018; Bellamy, 2019; Adger et al., 2005). Research on extreme temperatures has been mostly limited to the impacts on human health through mortality and morbidity studies, resulting in an incomplete understanding of how individuals adapt and the factors influencing adaptation (Anderson et al., 2019; Ebi et al., 2018; Fuller and Bulkeley, 2013).

Brown and Westaway (2011) made links between resources or assets and agency, with assets and access to assets as being what determines adaptation (Atteridge and Remling, 2018). Adaptation research often takes into account an assets approach to vulnerability by focusing on the range of strategies individuals and households in the developing world adopt to respond to a threat through the use of assets (Birkmann et al., 2010). Furthermore, Adger (2003) asserts that access to assets determines individuals' ability to adapt.

The way in which people adapt depends on many factors such as social, cultural and financial (Tong and Ebi, 2019; Tod et al., 2012), perceptions of heat and cold (Ebi et al., 2018; Wolf et al., 2010) as well as on past experiences of extreme temperatures (Fuller and Bulkeley, 2013) which may create opportunities as well as limits to adaptation. The IPCC (2018) asserts that adaptation assessments are deemed necessary for the identification of adaptation needs and options aimed at the reduction of the negative impacts of climate change to human health.

1.4. Links between vulnerability, resilience and adaptation

This article brings together diverse conceptualisations and focus on the dynamic factors that shape vulnerability, resilience and adaptation by focusing on vulnerability and resilience as baseline

characteristics of individuals (general vulnerability and resilience) influenced by external events such as extreme temperatures (specified vulnerability, resilience and adaptation).

The underpinning processes of how individuals adapt are still relatively unclear, and the breadth of work addressing the links between vulnerability, resilience and adaptation reflects a body of complementary research rather than an integrated understanding of how they are connected. Despite a growing need for a collective agenda, consideration needs to be placed on how the three concepts are defined and operationalised in relation to each other (Bulkeley and Tuts, 2013).

Vulnerability, resilience and adaptation have emerged and evolved from diverse research arenas, and as a result, a growing number of studies have explored the theoretical connections between these three concepts (Ebi et al., 2018; Miller et al., 2010; Turner, 2010). Despite this, studies operationalising this relationship are still few. This article builds on existing knowledge, theories and approaches to build a novel theoretical and analytical multiconceptual approach.

Brooks (2003) argues that vulnerability is influenced by adaptations that occurred in the past as well as current availability of potential options for adaptation, and relying on assets. Furthermore, Moser (2011) offers an asset-focused framework for understanding climate change rooted in previous work on asset vulnerability and asset adaptation. Resilience thinking can also provide the tools for analysing and improving adaptation (Bankoff, 2019; Ungar, 2018; Bulkeley and Tuts, 2013). Nelson and colleagues (2007) assert that improving adaptation may also include vulnerability reduction and increase resilience. Despite all this, Leickenko and Silva (2014) argue that not enough is known regarding how resilience is shaped and call for more research on the characteristics or factors that allow individuals to adapt.

According to Miller and colleagues (2010), vulnerability and resilience embody allied approaches to understand adaptation, whilst Nelson and colleagues (2007) provide additional insights stressing that improvements in adaptation may be due to vulnerability reduction and increased resilience. Furthermore, an individual can have high resilience and at the same time be considered vulnerable (Miller et al., 2010). That is why some authors argue it is crucial that translation of theory into practice and policy occurs so that research targets those individuals most impacted by threats, as in most cases they are left out (Ebi et al., 2018; Miller et al., 2010; Vogel et al., 2007). This also calls for the use of mixed approaches in vulnerability and resilience research using both quantitative and qualitative methods, offering a holistic methodological view on both concepts (Miller et al., 2010).

In summary, assets are used in this project as a basis for defining the scope for assessing general and specified (i.e. extreme temperatures) vulnerability and for opening up avenues for exploring general and specified (i.e. extreme temperatures) resilience and adaptation. Definitions of the four key concepts explored in this article were developed and are presented in Table 1, aiming at providing a guide in terms of the theoretical and operationalization of such concepts.

Table 1 Definitions of concepts in this project.

Concept	Definition in this project
Asset	Human, financial, physical, place-based and social factors or characteristics directly or indirectly available to individuals in anticipating or responding to threats.
Vulnerability	The degree of susceptibility to harm determined by the availability of assets.
Resilience	The ability or capacity to actively access, mobilise and use the available assets to positively adapt. Is a function of: 1) ability to make sense of threats; 2) assets availability, access and use; 3) the perception of the ability to cope and act.
Adaptation	Action, response, strategy, or behaviour individuals implement in pre-emption or response to threats.

The project has separately reported on the *adaptation* (Nunes, 2018), *vulnerability* (Nunes, 2020a) and *resilience* (Nunes, 2020b) strands. This article focuses on examining the broader and unique *implications* of the project as a whole, *analysing* previously unexamined interactions, *synthesising* the complete set of data, *reflecting* on the findings, and for the first time *developing* a framework for linking vulnerability, resilience and adaptation. It begins by giving an overview of vulnerability and resilience and subsequently how these shape adaptation, before then offering and discussing propositions for policy and practice drawn from its findings. The article concludes by summarizing its contributions and posing several key recommendations for future research and policy.

2. Methods

The methods used in this project are explained more fully in Nunes (2018, 2020a and 2020b), but understanding the context in which the implications of the project will be integrated and discussed demands the provision of an overview here.

2.1. Study site

The city of Lisbon in Portugal is selected to investigate the interactions between general and specified vulnerability, resilience and adaptation to extreme temperatures. Portugal is a country with a mild Mediterranean climate but with significant changes in the frequency of temperature extremes resulting in severe impacts on human health (Rodrigues et al., 2020; Lucio et al., 2010). In spite of a series of major extreme temperature events and human health impacts in recent years there is a dearth of impact assessments associated with a dearth of mitigation and adaptation strategies at both national and local levels (Rodrigues et al., 2020; Carvalho et al., 2014; Lucio et al., 2010). Lisbon is Portugal's capital and largest city, and has warm temperate climate with dry and hot summers, and mild winters (Kottek et al., 2006). Lisbon is a suitable location for this study due to the high health impacts observed especially on the older population (Rodrigues et al., 2019; Casimiro et al., 2006).

2.2. Data collection

A mixed methods research design was used during summer and winter months in three phases. These comprised general quantitative structured interviews (Phase 1), heat-related qualitative semi-

structured interviews (Phase 2) and cold-related qualitative semi-structured interviews (Phase 3). Participants were selected using the following inclusion criteria: age 65 years or over; living independently in the city of Lisbon. The sampling uses a mix of non-probability sampling techniques and includes a strategy to approach participants with diverse characteristics (e.g. sex, marital status, education level, financial and health status). The sample size was decided after ensuring theoretical saturation (Bryman, 2012). Informed consent was obtained for a total of 52 participants that participated in all phases of research, recruited from several organizations through gatekeepers. All interviews were audio-recorded, quantitative data was transferred MS Excel and qualitative transcripts transferred to QSR NVivo software.

2.3. Measures included in the study

2.3.1. Vulnerability

Vulnerability is assessed though measuring access to and availability of five different types of assets (human, financial, physical, place-based, social). The quantitative structured interviews (Phase 1) examine participants' asset portfolio for developing the General Vulnerability Index (GVI) using a composite index approach (e.g. Hahn et al., 2009). The GVI varies between 0 (lowest vulnerability) and 1 (highest vulnerability) with a cut-off point of 0.5 (, see Nunes 2020a). Qualitative semi-structured interviews convey a more specific understanding of participants' vulnerability to extreme temperatures (Phases 2 and 3). Thematic analysis (King and Horrocks, 2010) was undertaken to assess specified vulnerability to extreme temperatures, i.e. heat- (HRV) and cold-related vulnerability (CRV). HRV and CRV were assessed by defining 'high' assets vulnerability for each of the five types of assets, which determined that participants with at least three 'high' assets vulnerability are considered to have high specified vulnerability (see Nunes, 2020a).

2.3.2. Resilience

Resilience is assessed through using the sense of coherence (SOC) approach and the theory of salutogenesis. The Orientation to Life Questionnaire (SOC-13 scale) is used to access general resilience and ultimately for calculating the General Resilience Index (GRI). A novel contribution of this project is the development of the GRI using the SOC-13 scale building on Antonovsky's (1987) work and on resilience composite indices approaches (e.g. Cutter et al., 2008). The SOC-13 scale has been deployed in psychology to capture individual resilience in different settings and threats (Kimhi, 2014; Kimhi et al., 2010; Glandon et al., 2008). It has thirteen items that measure three components: comprehensibility (cognitive dimension – sense making), manageability (instrumental or behavioural dimension – perception of availability of assets) and meaningfulness (motivational dimension – aspiration to action) (Antonovsky, 1993). The response format was a typical Likert scale 7-point agreement basis. Qualitative semi-structured interviews convey a specific understanding of participants' resilience to extreme temperatures. Specified resilience to extreme temperatures were assessed by coding the data according to the three dimensions of resilience as 'high' or 'low' using thematic analysis (Braun and Clarke, 2006) (see Nunes, 2020b).

2.3.3. Adaptation

The study captured and assessed adaptation to extreme temperatures through response to open-ended questions that explored assets and their role in behaviours and responses to such events. Results were thematically coded (Braun and Clarke, 2006) with the identification of themes and sub-themes of dominant groupings of adaptation in relation to assets that included positive and negative valenced responses – *human assets* – independence and control, return to the nest, illiteracy and health illiteracy, chronic illness not frailty; *financial assets* – managing competing expenses and still struggling, savings should be savings, thrifty and proud; *physical assets* – lack of insulation, lacking cooling and heating devices; *place-based assets* – indoor versus outdoor spaces; work the land, ward level activities, Heatwave/Cold Weather Plan, what Plan?; *social assets* – 'I'm connected … to my family', 'I feel supported but never ask for help', 'I socialise but not as much as I should' (see Nunes, 2018).

2.3.4. Relationship between vulnerability, resilience and adaptation

Structured and semi-structured interview data (Phases 1-3) are used as the bases for the combined findings and, vulnerability and resilience matrices. Both quantitative and qualitative vulnerability and resilience findings (Nunes, 2020a; Nunes 2020b) showed a great diversity of vulnerability and resilience amongst participants. The analysis undertaken here is intended to understand how vulnerability and resilience interact with each other by developing 2x2 matrices. Participants are positioned in each matrix taking into account their levels of combined vulnerability and resilience, using both quantitative and qualitative data. The development of the matrices started by defining the variables axis (y axis: vulnerability; x axis: resilience) and characterizing the four quadrants: 1) low vulnerability & low resilience (bottom-left quadrant) representing participants with access to assets but with low ability to act; 2) high vulnerability & low resilience (top-left quadrant) representing the most threatened participants, with lack of assets and low ability to act; 3) high vulnerability & high resilience (top-right quadrant), representing those with lack of assets but with high ability to act, and; 4) low vulnerability & high resilience (bottom-right quadrant), with access to assets and high ability to act, representing the strongest participants and the 'success cases' from which to learn for developing appropriate policy measures (Fig. 1).

3. Results

3.1. Integrating vulnerability, resilience and adaptation findings

The findings on vulnerability, resilience and adaptation arising from the project are described more fully in Nunes (2018, 2020a, 2020b), but it is in this article that their interactions and implications for understanding how they are shaped, and subsequently how this may influence underpinning adaptation decisions are synthesised and discussed. To this end, it will be necessary to briefly elucidate the project's main findings.

Table 2 presents a summary of the key findings and outlines the combined main findings of this research (Nunes, 2016; Nunes, 2018; Nunes, 2020a; Nunes 2020b). Participants in this research showed a

variety of levels of both vulnerability and resilience as well as adaptation. Such findings allowed examining the constraints and barriers to adaptation associated with such diversity for understanding the roots and solutions for reducing vulnerability, enhancing resilience and improving adaptation.

Table 2 Summary of research findings and combined main findings

	Vulnerability	Resilience	Adaptation
Research findings	Overall greater general vulnerability derives from lack of financial, followed by physical, social, human and place-based assets. Specified vulnerability was found to be much higher than general vulnerability. Heat-related vulnerability was slightly higher than cold-related vulnerability, and both were much higher than general vulnerability. (Nunes 2020a)	Overall high general resilience, greater meaningfulness, followed by manageability and comprehensibility dimensions. Overall high heat-related resilience, with higher comprehensibility followed by meaningfulness and manageability. Overall low cold-related resilience with high comprehensibility followed by lower meaningfulness and manageability. (Nunes 2020b)	Participants engaged in a variety of adaptation actions. Adaptation is determined by vulnerability and resilience. Engaging in adaptation actions requires adequate information on health risks and impacts of extreme temperatures, in order to identify asset needs and availability for assessing appropriate adaptation options. Adaptation constraints and limits associated with high levels of vulnerability and reduced resilience. Opportunities for enhancing adaptation responses exist and relate to reducing vulnerability and building resilience. (Nunes (2018)
Combined main findings	Diverse combinations of vulnerability-resilience-adaptation actions. Numerous barriers to resilience and adaptation were found to be related to individual and place characteristics. The levels of vulnerability and resilience convey important arguments for: targeting at-risk older individuals (high vulnerability & low resilience); developing vulnerability reduction actions (high vulnerability & high resilience); resilience building actions (low vulnerability & low resilience), and; understanding 'success cases' (low vulnerability & high resilience), as well as learn from them to develop appropriate policy measures. Generally, planned adaptation options were implemented by low vulnerability & high resilience participants, whilst autonomous adaptation options were more common within other participants. Links between vulnerability-resilience-adaptation with social justice, equity and austerity, especially to whether participants or trusted ones have the scope to reduce their vulnerability (assets portfolio) and enhance resilience for adaptation.		

3.2. Developing vulnerability and resilience matrices

3.2.1. General vulnerability and resilience matrices

Each participant was positioned in the vulnerability-resilience matrices according to their individual overall indices values (GVI and GRI) (see Supplementary material A).

The combined GVI and GRI matrices are presented in Fig. 2a) to f). General resilience values are constant and characteristic to each participant throughout, but vulnerability values change. The great majority of participants fall into the two high resilience quadrants (top- and bottom-right quadrants) revealing that most participants despite their levels of vulnerability both low or high showed high levels of resilience. These participants revealed an overall orientation expressing feelings of confidence in their lives. Analysis of the relative position participants take in the overall matrix (Fig. 2a) shows that the majority of participants are in the 'low vulnerability & high resilience' group (54.9%) and 13.7% fall into the 'high vulnerability & low resilience' group. The matrices also show that around 12% to 14% of all participants are part of the 'high vulnerability & low resilience' group for indicators such as, human assets (13.7%), financial assets (13.7%), social assets (11.8%), (Fig. 2b), c) and g), respectively). The percentage of participants falling into the high physical and high place-based assets vulnerability & low resilience is smaller (5.9%; 5.9%, respectively) (Fig. 2d) and e), respectively). These findings suggest that the 'high vulnerability & low resilience' group of participants are characterised to a larger extent in terms of human assets, followed by financial assets and social assets vulnerability in their lives in addition to low resilience. Furthermore, in addition to the lack of assets these participants with low resilience struggle to make sense of their lives, and/or perceive they do not have the assets needed and/or lack the motivation to act using the scarce assets available. High resilience participants (bottom- and top-right quadrants), independently of their vulnerability are confident they can confront any threat or stressor and/or perceive they have assets available and/or are motivated to act as best as they can.

This research provided evidence that the great majority of participants fell into the high general resilience group revealing, despite their levels of general vulnerability (low or high), an overall capacity to access the assets available to them, making sense of threats, having feelings of confidence in their lives and ability to act (i.e. high resilience) (Fig. 3). The analysis also showed that participants with 'high vulnerability & low resilience' faced greater restrictions due to lack of human assets, financial assets, social assets, and to a lower extent lack of physical and place-based assets (Fig. 2b) to f)).

Overall, assets were found to be a key determinant of vulnerability and resilience. Vulnerability was found not to be a key determinant of resilience (Fig. 4), as participants showed diverse combined levels of vulnerability and resilience.

3.2.2. Heat-related vulnerability and resilience matrices

The findings presented here result from the coding and categorisation of heat-related qualitative interviews data. Here, the aim is to bring to life individual participants' characteristics and the factors shaping their vulnerability and resilience to heat, and ultimately, adaptation to heat. Each participant represents a unique combination of vulnerability and resilience that are not fully evident when looking at

the whole sample dataset. Supplementary material B presents a summary of participants' heat-related vulnerability and resilience.

A review of all heat-related participants' transcripts was undertaken to characterize their vulnerability and resilience characteristics and map each participant on a vulnerability-resilience matrix. Fig. 5 was developed according to individual characteristics and provides a qualitative snapshot of vulnerability and resilience at a defined point in time (i.e. interview). The order of participants within each quadrant does not reflect different levels of vulnerability or resilience.

Fig. 5a) to f) presents the combined vulnerability and resilience findings where resilience features of each participant are constant throughout and vulnerability features change. Participants' distribution within the matrix is not uniform and the biggest proportion fall into three of the four quadrants of the matrix. In Fig. 5a) of all participants the worse-off (36.5%) fall into the 'high vulnerability & low resilience' quadrant (top-left) and are the most threatened from suffering the impacts of heat as they lack assets, have lower understanding and/or awareness of what causes the impacts, and/or lack the knowledge of which assets are available and how to use them, and/or lack the motivation to act in order to deal with the threat heat poses to health. 'High vulnerability & high resilience' participants (38.5%) (top-right quadrant) lack assets but manage to make sense of the problem and/or use the assets available to them and/or are motivated to act upon. Better-off participants (23.1%) are situated in the 'low vulnerability & high resilience' quadrant (bottom-right) and overall have the assets and/or the understanding and/or motivation to act in order to reduce the health impacts of heat. Only one participant (1.9%) is located in the 'low vulnerability & low resilience' quadrant (bottom-left) which means that despite having assets needed to respond to heat, this participant lacks the understanding, and/or uses of the assets available to him ineffectively and/or lacks motivation to act. Regarding the asset-related vulnerability-resilience matrices (Fig. 3b) to f)) participants' positions change to a certain extent. A higher number of participants show high physical assets vulnerability and low resilience (38.5%), and a lower number is included in the high place-based assets and low resilience group (23.1%). Thus, a higher number of participants are most threatened by the combination of having problems with temperature in the home during very hot weather and/or inability to keep the home cool and/or not being able to keep themselves cool in the home during very hot weather and/or not using of cooling devices (high physical assets vulnerability) and low resilience; and a lower number of participants reveal being most threatened by the combination of not being aware of the Heatwave Plan and/or had no interest on it (high place-based vulnerability) and low resilience regarding heat.

3.2.3. Cold-related vulnerability and resilience matrices

The findings presented here result from the analysis of qualitative cold-related vulnerability and resilience interviews (Nunes, 2020a; Nunes, 2020b). Supplementary material C presents a summary of participants' cold-related vulnerability and resilience.

The mapping of participants on a vulnerability-resilience matrix was developed following a review of all participants' qualitative interviews and is a qualitative illustration accounting unique individual features in a defined space and time (see Fig. 6a) to f)).

Participants' distribution within the cold-related vulnerability-resilience matrix is not identical and the biggest proportion falls into three of the four quadrants of the matrix. In Fig. 6a) the majority of participants (52.2%) fall into the 'high vulnerability & low resilience' quadrant (top-left) and are the most threatened from suffering the health impacts of cold as they lack the assets, have lower understanding and/or awareness of what causes the impacts, and/or lack the knowledge of which assets and how to use the assets available, and/or lack the motivation to act in order to deal with the threat cold poses to health. 'High vulnerability & high resilience' participants (21.7%) (top-right quadrant) lack assets but manage to make sense of the problem and/or use the assets available to them and/or are motivated to act upon. Better-off participants (26.1%) are situated in the 'low vulnerability & high resilience' quadrant (bottom-right) and overall have the assets and/or the understanding and/or motivation to act in order to reduce the health impacts of cold. No participant is located in the 'low vulnerability & low resilience' quadrant (bottom-left). Regarding the asset-related vulnerability-resilience matrices (Fig. 6b) to f)) participants' positions change to a certain degree. A higher number of participants show high human assets vulnerability and low resilience (46.2%), and a lower number is included in the high place-based assets and low resilience group (34.6%). Thus, a higher number of research participants reveal being most threatened by the combination of having health problems during very cold weather and/or physical health limitations during very cold weather (high human assets vulnerability) and low resilience, and a lower number of participants reveal being most threatened by the combination of not being aware of the Cold Weather Plan and/or had no interest on it (high place-based vulnerability) and low resilience regarding cold.

In summary, participants' combined vulnerability and resilience to heat and cold reveals that more participants are included in the overall 'high vulnerability & low resilience' quadrant in extreme cold (46.2%) than in extreme heat (36.5%) (Fig. 5a and 6a). These findings unravel higher concerns regarding the ability of these participants to respond to extreme cold. An equal number of participants reveal overall 'low vulnerability & high resilience' (23.1%) to both heat and cold, where all participants kept their position in the matrices, except one participant (BM). This participant saw his vulnerability increase (BM) and his position was occupied by another participant (ZF) who saw her vulnerability decrease (ZF). Most participants kept their positions in the matrices (e.g. BBF, OM) but some saw their vulnerability increase (e.g. BM) and their resilience decrease (e.g. GGF, BM) regarding cold. Despite this, a small number of participants saw their vulnerability decrease (e.g. ZF) and their resilience increase (e.g. KM). Comparatively, regarding the asset-related matrices for both heat and cold (Fig. 5 and 6b) to f)), there is a consistent higher proportion of participants falling into the 'high vulnerability & low resilience' quadrant regarding cold in all types of assets.

3.2.4. Integrating vulnerability, resilience and adaptation to extreme temperatures

Having developed the vulnerability and resilience matrices presented above, this section integrates these findings with adaptation. Participants' adaptation to extreme temperatures is varied and intricate with many diverse features, however, recognisable differences in participants' adaptation can be drawn from participants' location within the vulnerability-resilience matrices.

The findings on vulnerability to extreme temperatures showed it was primarily shaped by individual characteristics and the places where participants lived (e.g. housing, neighbourhood) (i.e. assets). In addition, an array of adaptation strategies to deal with extreme temperatures were used by research participants. Despite this, they found constraints and limits to adaptation mainly resulting from their high vulnerability and low resilience (Table 2). Furthermore, participants also found opportunities to improve their responses to extreme temperatures which implied increasing their asset portfolio for reducing their vulnerability and increasing their resilience.

This research found that the distribution of participants within the extreme heat vulnerability-resilience matrix is not uniform: a high percentage of participants had overall heat-related 'high vulnerability & low resilience' (Fig. 7 modified from Fig. 5a)); these are considered to be the most threatened by extreme heat as: a) they lack assets (high vulnerability) and; b) they have limited understanding and/or; c) feel they are limited in the assets needed to respond and/or; d) they lack the motivation to act (low resilience).

The biggest proportion of participants were characterised by 'high vulnerability & low resilience' (52.2%) to extreme cold (Fig. 8 modified from Fig. 6a)); these are at high risk from extreme cold as they lack assets, have limited understanding and/or perceive they lack assets to adequately respond and/or lack the motivation to act.

Overall, assets were found to be a key determinant of vulnerability, resilience and adaptation. Vulnerability was found not to be a key determinant of resilience, which is mostly influenced by an understanding of the challenges posed by threats and feeling motivated to act, thus being a key determinant of adaptation (Fig. 9).

Participants who revealed comparatively *lower levels of vulnerability and higher levels of resilience* to extreme temperatures compared to others demonstrated to be able to better respond. Reasons for this comprise having more diverse and greater assets portfolio readily available to use, and being more likely to define extreme temperatures as non-stressors, non-problematic and believing one can adapt to the demands they pose. Based on the overall sample findings, planned adaptations seem to be a feature more frequently observed in participants with lower vulnerability and greater resilience. Their strategies and responses are based on previous experiences, present impact and envisioning future extreme temperatures stresses and impacts to their health. Their adaptations to both heat and cold were extensive and diverse as they were seen as threats and dependent on their health status.

Participants demonstrating relatively *higher levels of vulnerability and lower levels of resilience* to extreme temperatures compared to others were more likely to reveal narrow and limited strategies and responses. Extreme temperatures were more likely to be seen as universal but not individual threats to health. These participants either did not see themselves needing to engage in planned adaptations as in their view what they already did was deemed enough, or felt they were not able or did not know what and how to engage in additional strategies or responses to be able to deal with the threats these events posed, both now and in the future.

Those participants who revealed somewhat *greater vulnerability and resilience* to extreme temperatures compared to others, felt hope that their responses enabled them to actively deal with the threats these events pose to them. They were not able to engage in planned adaptations due to limits to their asset portfolio but if in provision of enough and the right amount of assets would be likely to initiate planned adaptations as they understood the threat and were motivated to act, and this would be the case for both heat and cold.

Demonstrating relatively *lower vulnerability and resilience* to extreme temperatures was uncommon in the research sample. These participants were more likely to be anxious and at the same time show apathy towards acting in the face of the threats of extreme temperatures, they felt confused and lacking the ability to act. Adapting was found to be focused on emotional features of not being able to manage the anxiety, feeling hopeless, almost as paralysed and overwhelmed to deal with the stress arising from these events. Such participants despite having the assets available to deal with these events see them as stressors, as burdens and assume that they cannot adapt to the demands they pose.

It was found that not only vulnerability influences and impacts on the possibility, willingness and motivation to act (resilience), but that it plays a crucial role in determining how individuals make sense of the threat posed by extreme temperatures, how they perceive the assets available to them to deal with the threat and the motivation to act, and ultimately, adapt. Those participants that revealed greater and extended adaptation relatively to others were those with lower vulnerability and higher resilience. Justifications for this include having more assets available to use, perceiving the threat in an ordered way, feeling that the assets available are adequate and having the motivation to act (bottom-right quadrants). Despite this, other participants with higher vulnerability and higher resilience showed that not having as many assets available did not constrain their orientation to endure; they felt confident that they were able to act and engaged in adaptations with the assets available to them (top-right quadrants). Participants with high vulnerability and low resilience were somewhat most at risk from the impacts of extreme temperatures, as the assets available to them are limited and their confidence and motivation is low making it extremely difficult to them to understand the threat and internally find it worth investing which in practice meant that their adaptations were also restricted (top-left quadrants). Based on the vulnerability-resilience matrices, there were also participants with low vulnerability and low resilience. Their assets availability was high but their orientation and confidence to deal with the threats posed to them, the perception of assets available and their motivation to act was very low which seemed to

compromise their adaptations, meaning that not much strategies were put in action (bottom-left quadrants).

3.2.5. Individual portraits

So far this article has presented individual participants' analysis and positioning in relation to general, heat- and cold-related vulnerability and resilience, as well as providing an approach to integrating adaptation to heat and cold. In this section, more details on the individual characteristics of participants are brought to light by presenting portraits of particular participants as an illustration of their vulnerability and resilience characteristics and adaptation responses to extreme temperatures. The portraits developed aim to illustrate and 'bring to life' certain features of the participants, with the goal of showcasing rich and interesting sketches of how vulnerability, resilience and adaptation to heat and cold materialize revealing different spheres of participants' lives. The six portraits were chosen from all participants taking into account their relative positions in both heat- and cold-related vulnerability-resilience matrices but do not represent fixed typologies of characteristics of participants in the same position of the matrices, thus they are not intended to represent the vulnerability-resilience quadrant they are part of.

Participants' levels of vulnerability and resilience are intrinsically linked to the ways in which they adapt. Less vulnerable participants are in a better position to have high resilience and better adapt to heat. Despite this, some exceptions were found in this research, where low vulnerability does not predict high resilience revealing that not all older individuals with the necessary assets have the willingness and motivation to act/adapt, and due to this face important barriers and limits to adaptation. Similarly, having high vulnerability did not define levels of resilience in this research. A high number of participants were defined as having high vulnerability but with distinguished levels of resilience. Again, not having the necessary assets to deal with heat was not a predictor of the willingness and motivation to act/adapt. A range of diverse factors besides assets are influencing participants' resilience and adaptation behaviours, as discussed above, and can be better understood by looking at six portraits of participants.

The individual portraits of participants (see Supplementary material D) recognise the individuality of participants' circumstances. There is significant individual variability and distinctiveness in vulnerability, resilience and adaptation circumstances between participants which is lost when looking at the whole sample data. The data contains great diversity of vulnerability and resilience combinations, and adaptation strategies which help in the understanding and need for development of person-centred strategies and actions for reducing vulnerability, increasing resilience and improving adaptation to extreme temperatures.

4. Discussion

The results demonstrate that the levels of combined vulnerability and resilience differ between older individuals. It was found that vulnerability is not to be a key determinant of resilience, and both vulnerability and resilience were found to be key determinants of adaptation. Altogether these results

suggest particular approaches for reducing vulnerability and increasing resilience with implications for improved adaptation.

4.1. General vulnerability and resilience

Relationships between assets and vulnerability have been explored in sociology for four decades (Moser, 2011; Chambers, 2006; Sen, 1981) with an emphasis on the role of inequitable access to assets as sources of vulnerability (Sen, 1999; 1981). In the disasters literature, access to assets is seen as an important factor in understanding vulnerability (Bankoff, 2019; Birkmann et al., 2010). The health literature has also started to show growing interest in understanding the contributing factors to vulnerability, including assets (Watts et al., 2018; Marmot, 2010; Morgan and Ziglio, 2007). Despite this, few interdisciplinary studies have been implemented for understanding the role of assets in shaping vulnerability (Ebi et al., 2018; Fussel, 2007). As a result, the work in this article draws from these existing literatures and introduces a novel interdisciplinary and empirical perspective to understanding the role assets play in shaping vulnerability.

The relationship between resilience and assets has been to date less studied; in the disaster and human development literatures, some authors have highlighted the influence between the resilience of individuals and the places where they live (Ungar, 2018; Romero-Lankao et al., 2012; Brown and Westaway, 2011; Luthar et al., 2000). In examining this relationship, the results of this article show a strong link between access to assets and resilience, which has also been highlighted by the Royal Society (2014). In contrast, however, findings of studies relating vulnerability to resilience have been diverse and less clear cut, with some authors asserting that reducing vulnerability is essential for increasing resilience (Bankoff, 2019; Keim, 2008). However, this research has found that being more vulnerable does not imply being less resilient. Some aspects of vulnerability do affect one dimension of resilience (manageability) but vulnerability is not a key determinant of resilience. These findings emerge from this research because it has used a different approach focusing on broad aspects of vulnerability and resilience, and used particular metrics to elicit these (i.e. GVI and GRI).

4.2. Vulnerability, resilience and adaptation to extreme temperatures

Few have been the empirical studies investigating the relationships between the concepts of vulnerability, resilience and adaptation to extreme temperatures (Bankoff, 2019; Ebi et al., 2018; Deschenes, 2013), having mainly focused on one of the concepts in isolation or on combinations of two concepts (i.e. assets and vulnerability, vulnerability and adaptation, resilience and adaptation). A growing number of studies from diverse disciplines have explored the theoretical links between these concepts (Bankoff, 2019; Ebi et al., 2018; Miller et al., 2010; Turner, 2010; Berkes, 2007; Nelson et al., 2007; Vogel et al., 2007). The literature indicates that different types of assets are key determinants of vulnerability to extreme temperatures. As an example, in their work on heatwaves and adaptation, Wolf and colleagues (2010) found that social assets (i.e. social capital) influence older individual's adaptation and assert that social assets may enhance resilience. Research undertaken by Wilhelmi and Hayden (2010) for example has suggested that adaptation to extreme heat can reduce vulnerability and as a result reduce the health

impacts of extreme heat. In addition, the IPCC (2018) has asserted that reductions in vulnerability will result in improved adaptation, as well as increasing resilience, whilst at the same time increasing assets.

This research agrees with the literature, on the role access and availability of assets play in adaptation to extreme temperatures. However, this research has found that vulnerability is not a key determinant of resilience. This is based on the finding that assets have an important role in one of resilience dimensions (manageability) but not in the other two dimensions (comprehensibility and meaningfulness); and in fact participants revealed diverse levels of combined vulnerability-resilience. Furthermore, the work in this article is in agreement with the literature asserting that older individual's resilience is an enabler for adaptation (Ebi et al., 2018; Ungar, 2018; Conlon et al., 2011; Hansen et al., 2011).

Thus, this research contributes to a better understanding of human general and specified vulnerability and resilience, as well as adaptation to extreme temperatures by building an integrated framework. This research has highlighted the role assets play in shaping human vulnerability, resilience and adaptation. Access to and availability of assets determine the vulnerability, resilience and adaptation of older individuals. This research also found that vulnerability is not a determinant of resilience, as older individuals showed great diversity of combined vulnerability and resilience. Whilst vulnerability is determined directly by access to and availability of assets, resilience is determined by the ability to make sense of the threat extreme heat and cold pose (comprehensibility dimension), the motivation to act and respond (meaningfulness dimension) and the perception that assets are available for one to use to respond to the threat extreme heat and cold pose (manageability dimension). As a result, individuals may be vulnerable and at the same time resilient to extreme temperatures. However, adaptation is determined by both vulnerability and resilience. This article challenges previous theoretical perspectives, suggesting that increasing assets is essential to reduce vulnerability, increase resilience and improve adaptation.

The work in this article also highlights the importance of undertaking more integrated studies and assessments of vulnerability, resilience and adaptation, which builds upon the more singularly focussed analyses of vulnerability, resilience and adaptation found in most research to date.

An important contribution of this article is also in the similarities of the relationships between assets, vulnerability, resilience and adaptation to extreme heat and extreme cold found in this empirical research; these suggest some common lessons regarding these two expressions of extreme temperatures can be derived from this work.

5. Conclusions

This article has integrated and discussed the results of combined general and specified vulnerability, resilience and adaptation to extreme temperatures. The approach taken in presenting a combined analysis is novel and a contribution to knowledge in the sense that it allows an integrated discussion of the roots and drivers of vulnerability and resilience for understanding adaptation to heat and cold. Participants revealed diverse combinations of vulnerability-resilience and adaptation actions. First,

participants revealing comparatively lower levels of vulnerability and higher levels of resilience presented better ways of responding to both heat and cold. Second, participants comparatively demonstrating relatively higher levels of vulnerability and lower levels of resilience were more likely to reveal narrow and limited strategies and responses to both heat and cold. Third, participants revealing somewhat higher vulnerability and resilience felt hope that they would be able to actively respond to heat and cold, despite not having all the assets needed to do that. Fourth, participants demonstrating relatively low vulnerability and resilience were uncommon in this study, and were more likely to be anxious and at the same time show apathy towards acting.

The levels of vulnerability and resilience convey important bases for: targeting at-risk older individuals (high vulnerability & low resilience); developing vulnerability reduction actions (high vulnerability & high resilience); resilience building actions (low vulnerability & low resilience), and; understanding 'success cases' (low vulnerability & high resilience) and learn from them for developing appropriate policy measures. Generally, planned adaptation options were implemented by low vulnerability & high resilience participants, whilst autonomous adaptation options were more common within other participants. Participants also commented on the links between vulnerability, resilience and adaptation with social justice, equity and austerity, especially to whether participants or trusted ones have the scope to reduce their vulnerability (assets portfolio), enhance resilience (comprehensibility, manageability and meaningfulness) and improve adaptation.

Declarations

Funding: This work was supported by the Fundação para a Ciência e a Tecnologia from the Portuguese Ministry for Science, Technology and Higher Education [grant number SFRH/BD/68936/2010].

Conflicts of interest/Competing interests: None.

Availability of data and material: Further data available as Electronic Supplementary Material.

Code availability: Not applicable.

Author contributions: Sole author, Conceptualization, Funding acquisition, Methodology, Investigation, Sample processing, Data analysis, Writing - Original Draft, Writing - Review & Editing.

Ethics approval: Ethical approval was obtained was obtained from the University of East Anglia, Faculty of Medicine and Health Sciences Research Ethics Committee (Reference 2011/2012–30) and from Universidade de Lisboa, Instituto de Ciências Sociais Ethical Committee.

Consent to participate: Written informed consent was obtained for all participants in the research.

Consent for publication: Author consents publication.

References

Adger, W. (2003). Social capital, collective action, and adaptation to climate change. *Economic Geography*, 79(4), pp.387-404.

Adger, W. (2006). Vulnerability. *Global Environmental Change*, 16(3), pp.268-281.

Adger, N., Arnell, N. and Tompkins, E. (2005). Successful adaptation to climate change across scales. *Global Environmental Change*, 15(2), pp.77-86.

Almedom, A. (2008). Resilience research and policy/practice discourse in health, social, behavioral, and environmental sciences over the last ten years. *African Health Sciences*, 8(3).

Almedom, A., Tesfamichael, B., Saeed Mohammed, Z., Mascie-Taylor, C. and Alemu, Z. (2007). Use of 'Sense of Coherence (SOC)' scale to measure resilience in Eritrea: Interrogating both the data and the scale. *Journal of Biosocial Science*, 39(01), pp.91-107.

Anderson, G., Barnes, E., Bell M., Dominici, F. (2019). The future of climate epidemiology: opportunities for advancing health research in the context of climate change. *Am. J. Epidemiol.*, 188 (5), pp.866-872.

Antonovsky, A. (1987). *Unraveling the mystery of health*. 1st ed. San Francisco: Jossey-Bass.

Antonovsky, A. (1993). The structure and properties of the sense of coherence scale. *Social Science & Medicine*, 36(6), pp.725-733.

Antonovsky, A. (1996). The salutogenic model as a theory to guide health promotion. *Health Promotion International*, 11(1), pp.11-18.

Astrom, D., Bertil, F. and Joacim, R. (2011). Heatwave impact on morbidity and mortality in the elderly population: a review of recent studies. *Maturitas*, 69(2), pp.99-105.

Atteridge, A., Remling, E. (2018). Is Adaptation Reducing Vulnerability or Redistributing It? *Wiley Interdisciplinary Reviews: Climate Change*. pp. e500.

Bankoff, G. (2019). Remaking the world in our own image: Vulnerability resilience and adaptation as historical discourses. *Disasters* 43(2): 221–239.

Beall, C., Jablonski, N.G., Steegmann, A.T. Jr. (2012). Human adaptation to climate: temperature, ultraviolet radiation and altitude. Chapter 6, pp 177-250. In Human Biology: An Evolutionary and Biocultural Perspective, Second Edition. Edited by Sara Stinson, Barry Bogin, Dennis O'Rourke. Wiley-Blackwell. John Wiley & Sons Inc.

Bellamy, R. (2019). Social readiness of adaptation technologies. *Wiley Interdisciplinary Reviews: Climate Change*, 10(6), e623.

Berkes, F. (2007). Understanding uncertainty and reducing vulnerability: lessons from resilience thinking. *Natural Hazards*, 41(2), pp.283-295.

Birkmann, J., Buckle, P; Jäger, J., Pelling, M., Setiadi, N., Garschagen, M., Fernando, N. and Kropp, J. (2010). Extreme Events and Disasters: A Window of Opportunity for Change? – Analysis of Changes, Formal and Informal Responses After Mega Disasters, *Natural Hazards*, 55(3), pp.637-655.

Braun, V., and V. Clarke, 2006: Using thematic analysis in psychology. Qual. Res. Psychol., 3, 77–101.

Brooks, N. (2003). Vulnerability, risk and adaptation: A conceptual framework. *Tyndall Centre for Climate Change Research Working Paper*, 38, pp.1-16.

Brown, K. and Westaway, E. (2011). Agency, capacity, and resilience to environmental change: lessons from human development, well-being, and disasters. *Annual Review of Environment and Resources*, 36, pp.321-342.

Bulkeley, H. and Tuts, R. (2013). Understanding urban vulnerability, adaptation and resilience in the context of climate change. *Local Environment*, 18(6), pp.646-662.

Bryman, A. (2012). *Social research methods*. 1st ed. Oxford: Oxford University Press.

Carvalho, A., Schmidt, L., Santos, F. and Delicado, A. (2014). Climate change research and policy in Portugal. *Wiley Interdisciplinary Reviews: Climate Change*, 5(2), pp.199-217.

Casimiro, E., Calheiros, J., Santos, F. and Kovats, S. (2006). National assessment of human health effects of climate change in Portugal: approach and key findings. *Environmental Health Perspectives*, pp.1950-1956.

Chambers, R. (2006). *Vulnerability, Cooing and Policy (Editorial Introduction)*. Institute of Development Studies Bulletin, 37 (4).

Conlon, K., Rajkovich, N., White-Newsome, J., Larsen, L. and O'Neill, M. (2011). Preventing cold-related morbidity and mortality in a changing climate. *Maturitas*, 69(3), pp.197-202.

Curtis, S. and Oven, K. (2012). Geographies of health and climate change. *Progress in Human Geography*, 36(5), pp.654-666.

Deschenes, O. (2013). Temperature, human health, and adaptation: A review of the empirical literature. *Energy Economics,* http://dx.doi.org/10.1016/j.eneco.2013.10.013.

Ebi, K., Boyer, C., Bowen, K., *et al.,* (2018). Monitoring and evaluation indicators for climate change-related health impacts, risks, adaptation, and resilience. *Int. J. Environ. Res. Public Health*, 15 (9), pp. E1943.

Fuller, S. and Bulkeley, H. (2013). Changing countries, changing climates: achieving thermal comfort through adaptation in everyday activities. *Area*, 45(1), pp.63-69.

Fussel, H. (2007). Vulnerability: a generally applicable conceptual framework for climate change research. *Global Environmental Change*, 17(2), pp.155-167.

Gaillard, J. (2010). Vulnerability, capacity and resilience: perspectives for climate and development policy. *Journal of International Development*, 22(2), pp.218-232.

Glandon, D., Muller, J. and Almedom, A. (2008). Resilience in Post-Katrina New Orleans, Louisiana: A Preliminary Study. *African Health Sciences*, 8(3).

Guo, Y., Gasparrini. A., Li, S., *et al.,* (2018). Quantifying excess deaths related to heatwaves under climate change scenarios: a multicountry time series modelling study. *PLoS Med.*, 15 (7), e1002629.

Haines, A. and Ebi, K. (2019). The imperative for climate action to protect health. *N. Engl. J. Med.*, 380, pp. 263-273

Hajat, S., Kovats, R. and Lachowycz, K. (2007). Heat-related and cold-related deaths in England and Wales: who is at risk?. *Occupational and Environmental Medicine*, 64(2), pp.93-100.

Hahn, M., Riederer, A. and Foster, S. (2009). The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. *Global Environmental Change*, 19(1), pp.74-88.

Hansen, A., Bi, P., Nitschke, M., Pisaniello, D., Newbury, J. and Kitson, A. (2011). Perceptions of heat-susceptibility in older people: Barriers to adaptation. *International Journal of Environmental Research and Public Health*, 8(12), pp.4714-4728.

Intergovernmental Panel on Climate Change (IPCC) (2018). **Global Warming of 1.5 °C.** http://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf, Accessed 12th Feb 2021

Keim, M. (2008). Building human resilience: the role of public health preparedness and response as an adaptation to climate change. *American Journal of Preventive Medicine*, 35(5), pp.508-516.

Kimhi, S. (2014). Levels of resilience: Associations among individual, community and national resilience. *Journal of Health Psychology*, pp.1-7. DOI:10.1177/1359105314524009

Kimhi, S., Eshel, Y., Zysberg, L., Hantman, S., Enosh, G. (2010). Sense of coherence and socio-demographic characteristics predicting posttraumatic stress symptoms and recovery in the aftermath of the Second Lebanon War. *Anxiety, Stress, and Coping*, 23(2), pp139-152.

King, N. and Horrocks, C. (2010). *Interviews in qualitative research*. 1st ed. Los Angeles: SAGE.

Kottek, M., Grieser, J., Beck, C., Rudolf, B. and Rubel, F. (2006). World map of the Koppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, 15(3), pp.259-263.

Leichenko, R. (2011). Climate change and urban resilience. *Current Opinion in Environmental Sustainability*, 3(3), pp.164-168.

Lorenz, D. (2013). The diversity of resilience: contributions from a social science perspective. *Natural Hazards*, 67(1), pp.7-24.

Lucio, P., Silva, A. and Serrano, A. (2010). Changes in occurrences of temperature extremes in continental Portugal: a stochastic approach. *Meteorological Applications*, 17(4), pp.404-418.

Luthar, S., Cicchetti, D. and Becker, B. (2000). The construct of resilience: A critical evaluation and guidelines for future work. *Child Development*, 71(3), pp.543-562.

Marmot, M. (2010). *Fair society, healthy lives*. 1st ed. [London]: Marmot Review.

McDowell, G., Ford, J., & Jones, J. (2016). Community-level climate change vulnerability research: Trends, progress, and future directions. *Environmental Research Letters*, 11(3), 33001.

McMichael, A., Woodruff, R. and Hales, S. (2006). Climate change and human health: present and future risks. *The Lancet*, 367(9513), pp.859-869.

Miller, F., Osbahr, H., Boyd, E., Thomalla, F., Bharwani, S., Ziervogel, G., Walker, B., Birkmann, J., van der Leeuw, S., Rockstrom, J. and others, (2010). Resilience and vulnerability: complementary or conflicting concepts. *Ecology and Society*, 15(3), p.11.

Morgan, A. and Ziglio, E. (2007). Revitalising the evidence base for public health: an assets model. *Promotion & Education*, 14(2 suppl), pp.17-22.

Moser, C. (2011). A conceptual and operational framework for pro-poor asset adaptation to urban climate change. In *Cities and Climate Change: Responding to an Urgent Agenda*. 1st ed. Washington DC: World Bank Publications, p.225.

Nelson, D., Adger, W. and Brown, K. (2007). Adaptation to environmental change: contributions of a resilience framework. *Annual review of Environment and Resources*, 32(1), p.395.

Nunes, A. R., 2016. Assets for health: linking vulnerability, resilience and adaptation to climate change. Tyndall Centre for Climate Change Research Working Paper, 163: 1-41.

Nunes, A. R., 2018. The contribution of assets to adaptation to extreme temperatures among older adults. PLOS ONE, 13, e0208121.

Nunes, A. R., 2020a. General and specified vulnerability to extreme temperatures among older adults. Int. J. Environ. Health Res., 30(5), 515–532.

Nunes, A. R., 2020b. Determinants of general and specified resilience to extreme temperatures. Weather, Climate and Society, 12(4), 913-928.

Rodrigues, M.; Santana, P.; Rocha, A. (2020). Portuguese Metropolitan areas under climate change: who is at risk? *Atmosphere*, 11(2), 159.

Rodrigues, M.; Santana, P.; Rocha, A. (2019). Effects of extreme temperatures on cerebrovascular mortality in Lisbon: A distributed lag non-linear model. *Int. J. Biometerol.*, *63*, 549–559.

Romero-Lankao, P., Qin, H. and Dickinson, K. (2012). Urban vulnerability to temperature-related hazards: A meta-analysis and meta-knowledge approach. *Global Environmental Change*, 22(3), pp.670-683.

Royal Society (2014). Resilience to extreme weather. The Royal Society Science Policy Centre report 02/14. Issued November 2014, DES3400.

Sen, A. (1981). *Poverty and Famines: An Essay on Entitlement and Deprivation*. Oxford: Clarendon Press.

Sen, A. (1999). *Development as freedom*. 1st ed. New York: Knopf.

Tod, A., Lusambili, A., Homer, C., Abbott, J., Cooke, J., Stocks, A. and McDaid, K. (2012). Understanding factors influencing vulnerable older people keeping warm and well in winter: a qualitative study using social marketing techniques. *BMJ*, 2(4).

Tong, S., Ebi, K. (2019). Preventing and mitigating health risks of climate change. *Environmental Research*, 174, pp. 9–13.

Tong, S., Confalonieri, U., Ebi, K., *et al.* (2016). Managing and mitigating the health risks of climate change - calling for the evidence-informed policy and action. *Environ. Health Perspect.*, 124, pp. A176-A179.

Turner II, B.L. (2010). Vulnerability and resilience: coalescing or paralleling approaches for sustainability science?.*Global Environmental Change*, 20(4), pp.570-576.

Ungar, M. (2018). Systemic resilience: Principles and processes for a science of change in contexts of adversity. *Ecology & Society*, 23 (4):34

Vogel, C., Moser, S., Kasperson, R. and Dabelko, G. (2007). Linking vulnerability, adaptation, and resilience science to practice: Pathways, players, and partnerships. *Global Environmental Change*, 17(3), pp.349-364.

Walker, B., Holling, C.S., Carpenter, S.R. and Kinzig, A. (2004). Resilience, adaptability and transformation in socio-ecological systems. *Ecology and Society*, 9(2), 5.

Watts, N., Adger, W.N., Agnolucci, P., *et al.,* (2015). Health and climate change: policy responses to protect public health. *Lancet*, 386, pp. 1861-1914.

Watts, N., Amann, M., Ayeb-Karlsson S., *et al.* (2018). The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. *Lancet*, 391, pp. 581-630.

Wiesmann, U., Niehorster, G. and Hannich, H. (2009). Subjective health in old age from a salutogenic perspective. *British Journal of Health Psychology*, 14(4), pp.767-787.

Wilhelmi, O. and Hayden, M. (2010). Connecting people and place: a new framework for reducing urban vulnerability to extreme heat. *Environmental Research Letters*, 5(1), p.014021.

Wilkinson R (2005). *The Impact of Inequality: How to Make Sick Societies Healthier.* London, Routledge.

Wisner, B., P. Blaikie, T. Cannon, and I. Davis (2004). *At Risk: Natural Hazards, People's Vulnerability and Disasters* (2nd edition). New York: Routledge.

Wolf, J., Adger, W., Lorenzoni, I., Abrahamson, V. and Raine, R. (2010). Social capital, individual responses to heatwaves and climate change adaptation: An empirical study of two UK cities. *Global Environmental Change*, 20(1), pp.44-52.

World Health Organization (WHO), (2013). Protecting Health from Climate Change: Vulnerability and Adaptation Assessment. WHO, Geneva/Switzerland.

Figures

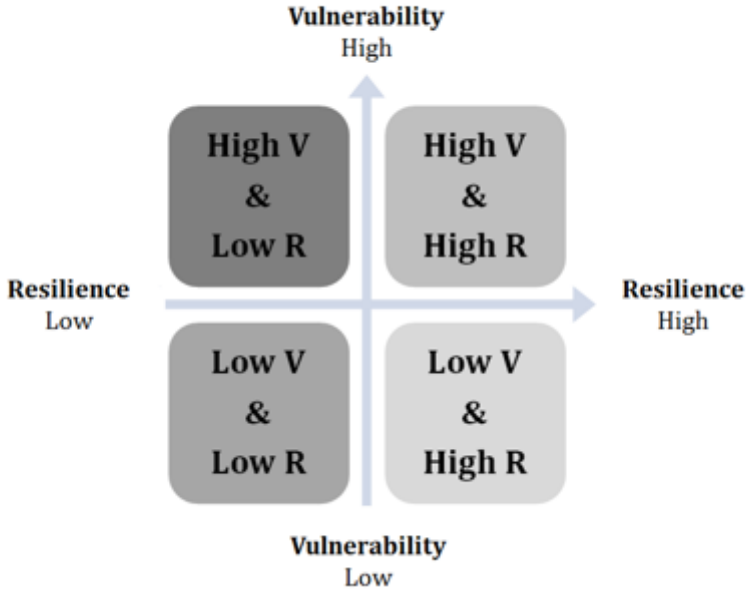

Figure 1

Representation of the vulnerability-resilience matrix. Legend: V – vulnerability; R – resilience.

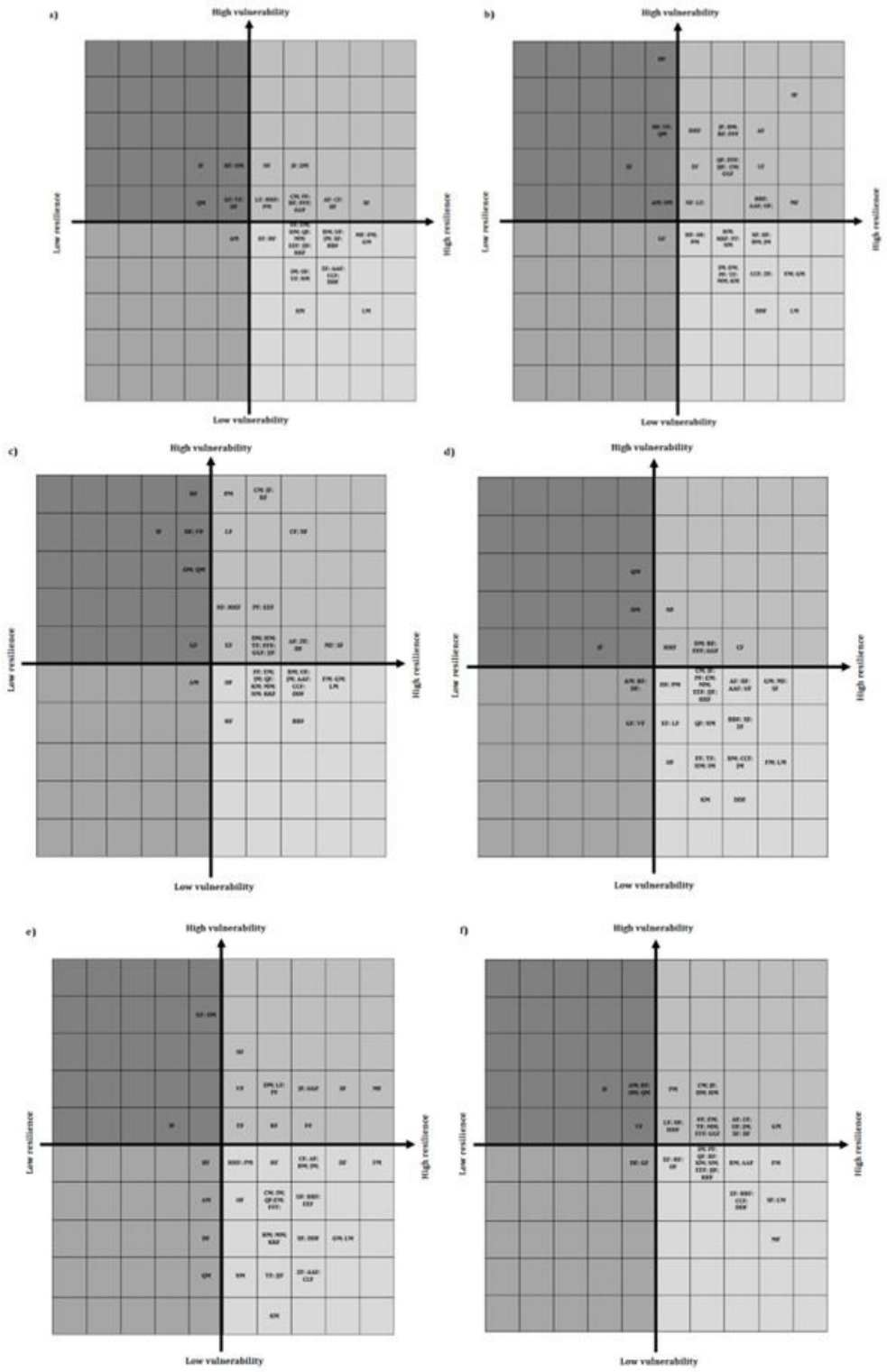

Figure 2

General vulnerability (GVI) and general resilience (GRI) matrices. Legend: a) GVI & GRI; b) human capital vulnerability & GRI. c) financial assets vulnerability & GRI; d) physical assets vulnerability & GRI. e) place-based assets vulnerability & GRI; f) social assets vulnerability & GRI.

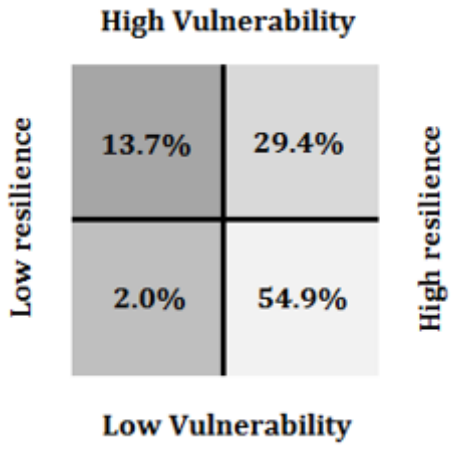

Figure 3

Percentage of participants in each overall general vulnerability & general resilience quadrant (modified from Fig. 2a))

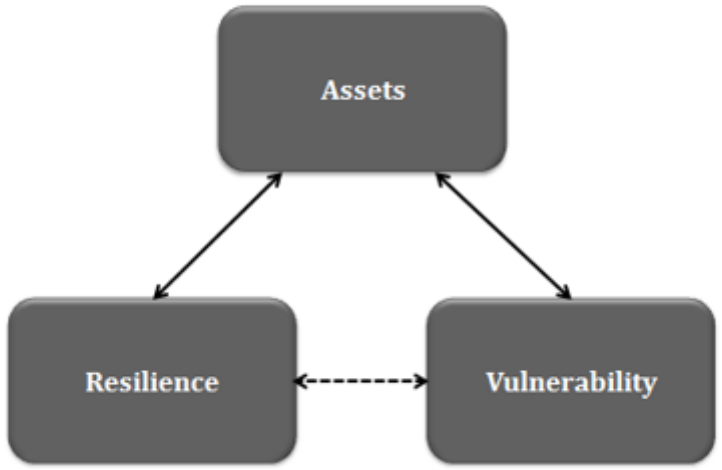

Figure 4

Relationship between general assets, vulnerability and resilience. Legend: full arrows represent key determinant relationships; dotted arrow represents a non-key determinant.

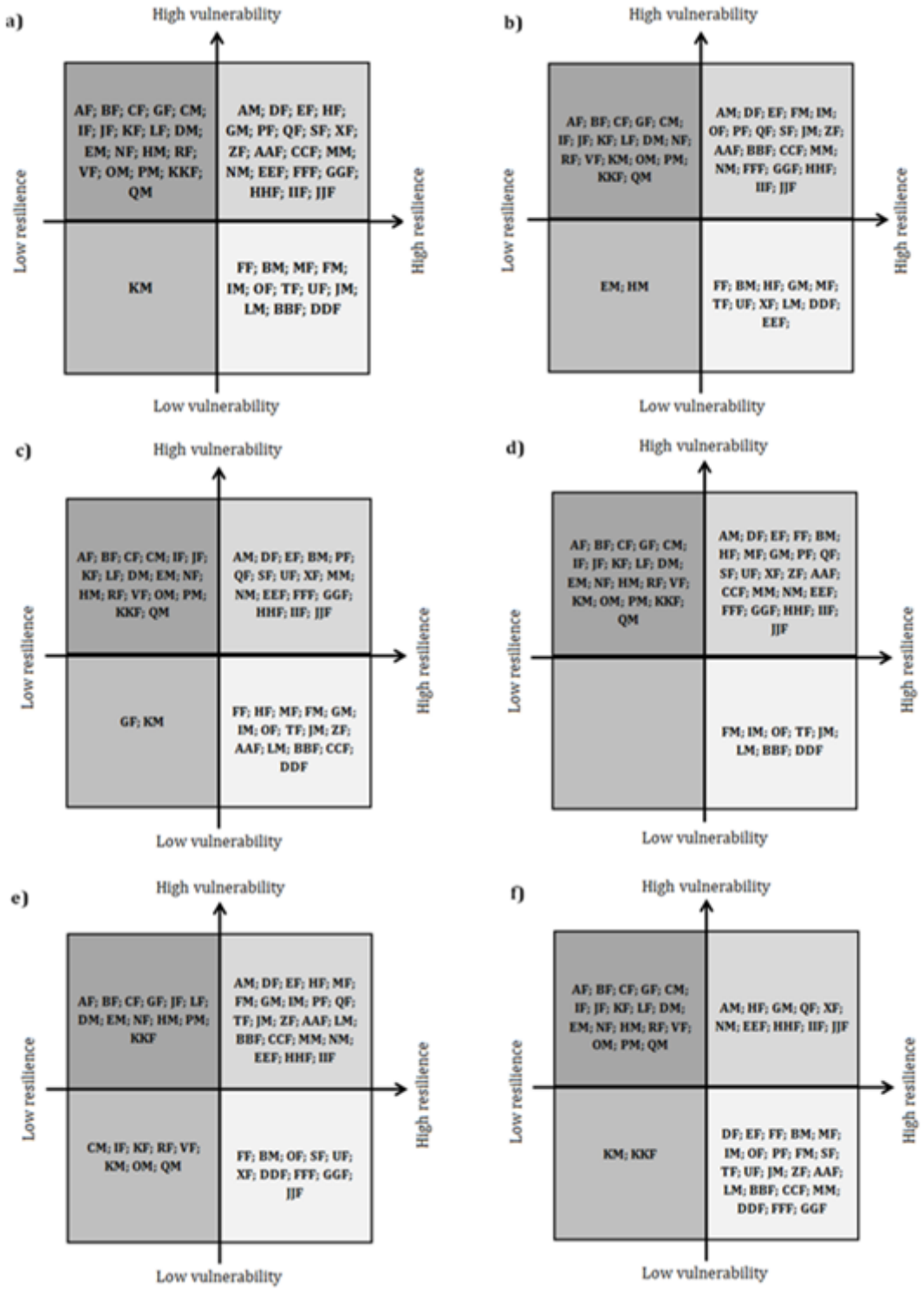

Figure 5

Heat-related vulnerability- resilience matrices Legend: a) Overall vulnerability & overall resilience; b) human capital vulnerability & overall resilience; c) financial assets vulnerability & overall resilience; d) physical assets vulnerability & overall resilience; e) place-based assets vulnerability & overall resilience; f) social assets vulnerability & overall resilience. Note: Participants' position inside each vulnerability-resilience quadrant of the matrix does not reflect different levels of combined vulnerability and resilience.

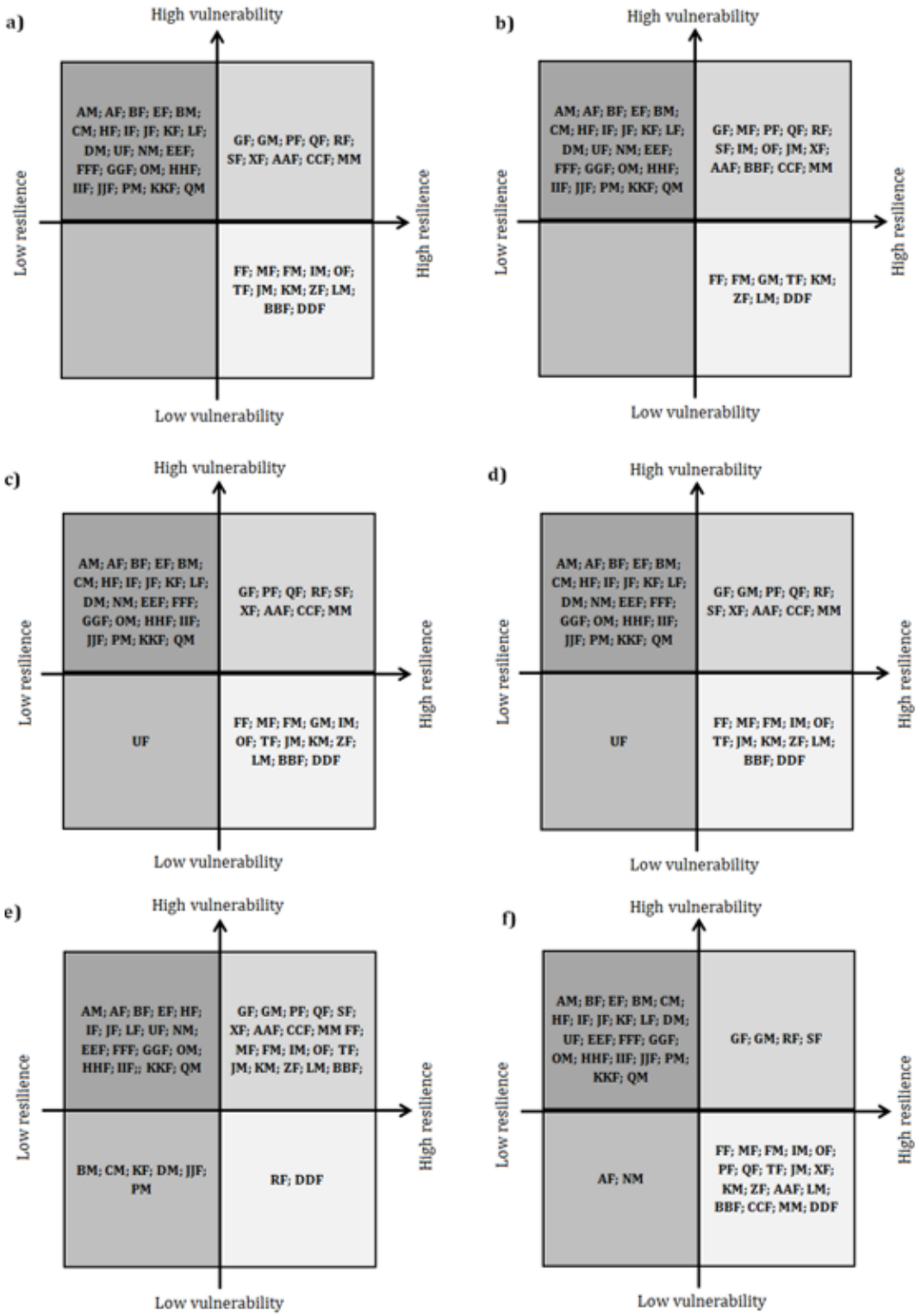

Figure 6

Cold-related vulnerability- resilience matrices Legend: a) Overall vulnerability & overall resilience; b) human capital vulnerability & overall resilience; c) financial assets vulnerability & overall resilience; d) physical assets vulnerability & overall resilience; e) place-based assets vulnerability & overall resilience; f) social assets vulnerability & overall resilience. Note: Participants position inside each vulnerability-resilience quadrant of the matrix does not reflect different levels of combined vulnerability and resilience.

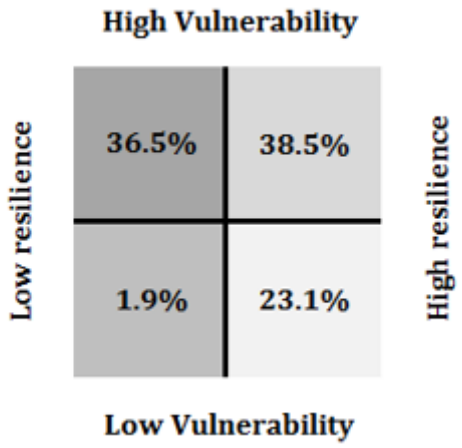

Figure 7

Percentage of participants in each heat-related vulnerability & resilience quadrant (modified from Fig. 5a))

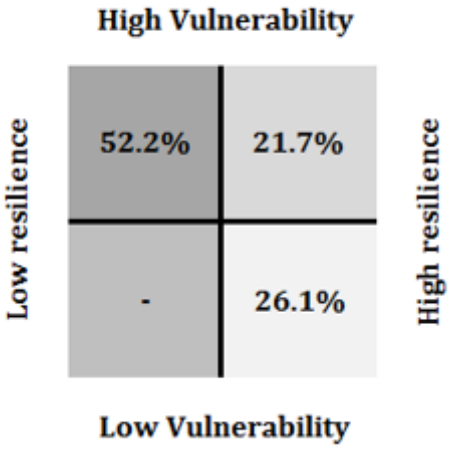

Figure 8

Percentage of participants in each cold-related vulnerability & resilience quadrant (modified from Fig. 6a))

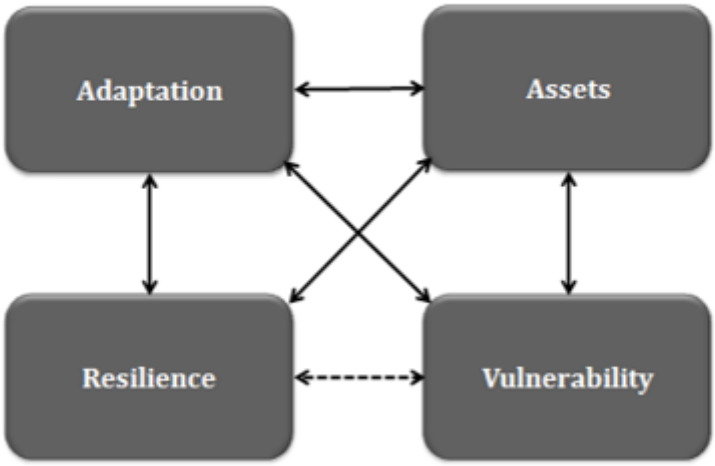

Figure 9

Relationship between specified assets, vulnerability, resilience and adaptation. Legend: straight arrow represents being a key determinant and dotted arrow represents not being a key determinant.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplimentaryMaterialA.docx
- SupplimentaryMaterialB.docx
- SupplimentaryMaterialC.docx
- SupplementaryMaterialD.docx