UNIVERSIDADE DE COIMBRA

Ricardo Jorge Meireles Almendra

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CUSTOS SOCIAIS E ECONÓMICOS DO EXCESSO DE MORTALIDADE E DE MORBILIDADE DURANTE O INVERNO

Tese no âmbito do Doutoramento em Geografia orientada pela Professora Doutora Ana Paula Santana Rodrigues e e co-orientada pelo Doutor João Viljoen de Vasconcelos, apresentada ao Departamento de Geografia e Turismo da Faculdade de Letras da Universidade de Coimbra.

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Ao abrigo do Art.º 8º do Decreto-Lei nº 388/70, fazem parte desta dissertação as seguintes publicações:

I – Almendra, R., Santana, P., Freire, E., Vasconcelos, J., 2016. Seasonal mortality patterns and regional contrasts in Portugal. Bull. Geogr. 32, 7–18. https://doi.org/10.1515/bog-2016-0011

II – Almendra, R., Santana, P., Vasconcelos, J., 2017. Evidence of social deprivation on the spatial patterns of excess winter mortality. Int. J. Public Health 62, 849–856. https://doi.org/10.1007/s00038-017-0964-7

III – Almendra, R., Perelman, J., Vasconcelos, J., Santana, P., Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case. Int. J. Biometeorol. 63, 873-883. 10.1007/s00484-019-01700-6

IV –Almendra, R., Santana, P., Mitsakou, C., Heaviside, C., Samoli, E., Rodopoulou, S., Katsouyanni, K., Vardoulakis, S. Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London. Implications for health promotion. *Submetido* a 15 de Outubro de 2018.

V – Almendra, R., Loureiro, A., Silva, G., Vasconcelos, J., Santana, P., 2019. Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon. Sci. Total Environ. 647, 127–133. https://doi.org/10.1016/j.scitotenv.2018.07.337

VI – Almendra, R., Santana, P., Vasconcelos, J., Silva, G., Gonçalves, F., Ambrizzi, T., 2017. The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal. Int. J. Biometeorol. 61, 325–333. https://doi.org/10.1007/s00484-016-1214-z

Ao longo desta dissertação, colaborei decisivamente na conceção dos objetivos e hipóteses em estudo, na seleção dos métodos de análise de dados, na sua aplicação e na interpretação dos resultados dos artigos. Sou o autor responsável dos artigos submetidos, tendo redigido a versão inicial de todos os manuscritos e colaborado ativamente na preparação das suas versões finais. Também foi da minha responsabilidade a resposta aos revisores.

A investigação que origina esta dissertação foi realizada no Centro de Estudos de Geografia e Ordenamento do Território, na Faculdade de Letras da Universidade de Coimbra, no Núcleo de Apoio à Pesquisa – MUDANÇAS CLIMÁTICAS da Universidade de São Paulo e no *Environmental Change Department of Public Health England*, sob orientação da Professora Doutora Ana Paula Santana Rodrigues e co-orientação do Doutor João Viljoen de Vasconcelos.

Foi financiada pela Fundação para a Ciência e a Tecnologia, através da atribuição de uma bolsa de doutoramento individual SFRH/BD/92568/297 2013 ao abrigo do FSE e do programa de financiamento POCH.

Agradecimentos

Em primeiro lugar devo uma palavra de apreço e agradecimento aos meus orientadores. À Professora Paula Santana agradeço ter-me direcionado para o doutoramento numa fase de muitas incertezas, as condições de investigação ímpares proporcionadas, os conselhos oportunos e os incentivos constantes que fui recebendo e se revelaram fundamentais nas diferentes fases da investigação.

Ao João Vasconcelos agradeço todo o tempo aplicado na minha formação académica, a confiança depositada na realização deste doutoramento e a *palavra* bem-disposta que sempre teve.

À Professora Elisabete Freire agradeço ter proporcionado as condições para dar os primeiros passos neste projeto e acompanhado a minha introdução a esta temática.

Ao grupo de investigação ClimaHabs agradeço os momentos de boa disposição contagiante e o ambiente de aprendizagem que me foi proporcionado.

Ao Professor Tércio Ambrizzi e ao Professor Fábio Gonçalves que me receberam no Incline, Núcleo de Apoio à Pesquisa – MUDANÇAS CLIMÁTICAS da Universidade de São Paulo, e incentivaram a iniciar-me em métodos que me pareciam inalcançáveis.

To the researchers, that briefly received me at Environmental Change Department of Public Health England. I would like to thank Sotiris Vardoulakis, Christina Mitsakou, Sani Dimitroulopoulou, Clare Heaviside for all the patience to discuss methods, results, data even long after the internship.

Ao Professor Giovani Silva agradeço pelas infindáveis horas que lhe roubei, pelas dúvidas fora de horas e pelo modo paciente como sempre me tentou ensinar.

Ao Professor Julian Perelman agradeço a visão crítica e partilha de conhecimento em temas dos quais pouco sabia.

Ao Centro de Estudos de Geografia e Ordenamento do Território agradeço as condições de trabalho que me proporcionaram.

Ao *pessoal residente* do Grupo de Investigação em Geografia da Saúde, a quem foi passando, e aos que passando acabaram por ficar, um muito obrigado pela partilha de ensinamentos, de experiências, por me *aturar* e pela boa disposição com que se encaram as dificuldades!

Resumo

O excesso de mortalidade e morbilidade durante o inverno é um fenómeno comum aos países europeus apresentando, no entanto, importantes desigualdades espaciais. Evidência científica refere que a sazonalidade da mortalidade advém dos impactos de temperaturas adversas na saúde. É, no entanto, nos países do Sul da Europa, onde os invernos são mais amenos, que se verificam os maiores valores de mortalidade em excesso no Inverno. Destacar ainda que, em comparação com os restantes países mediterrâneos, os impactos do frio são superiores em Portugal.

A vulnerabilidade ao frio resulta de um vasto conjunto de fatores biológicos, epidemiológicos, socioeconómicos e comportamentais e traduz-se em impactos significativos para a saúde, sendo fundamental medir as variações sazonais das doenças e compreender os fatores que explicam a desigualdade espacial da vulnerabilidade ao frio.

Esta dissertação tem como objetivo geral analisar e quantificar o impacto das variações sazonais de mortalidade e morbilidade e caracterizar os fatores que contribuem para o aumento da vulnerabilidade ao frio em Portugal, através da: i) identificação das causas de morte com maior variação sazonal e dos seus padrões geográficos; ii) avaliação das condições socioeconómicas que contribuem para um aumento da vulnerabilidade ao frio; iii) quantificação dos custos sociais e económicos (no SNS) do excesso de mortalidade e morbilidade no inverno; iv) avaliação do impacto de fatores meteorológicos na mortalidade e morbilidade; v) identificação de medidas de minimização ou de mitigação dos efeitos do frio na saúde.

Para responder aos objetivos propostos foram recolhidos e utilizados dados secundários a diversas escalas (Administração Regional de Saúde e NUT III, município e para a Área Metropolitana de Lisboa) relativos a resultados em saúde, condições socioeconómicas, condições meteorológicas e de qualidade do ar. Com estes dados foram calculadas medidas de sazonalidade como o excesso de mortalidade e de morbilidade no inverno e os óbitos atribuíveis ao frio e foram aplicados métodos de análise de padrões espaciais e de séries temporais.

A aplicação destes métodos permitiu verificar que as doenças do aparelho circulatório e respiratório apresentam a maior variação sazonal e são responsáveis pela maioria do excesso de mortalidade no inverno. Esta variação é mais importante nos municípios do interior do país e está estatisticamente associada com as condições habitacionais e socioeconómicas da área de residência. As consequências da vulnerabilidade ao frio sazonal (no inverno) são graves e traduzem-se em importantes custos sociais e económicos, tendo-se estimado (em 2009-12): i) 87 anos de vida potencialmente perdidos em excesso no inverno por 100.000 habitantes; ii) decréscimos de um ano na esperança média de vida; iii) custos acrescidos para o Serviço Nacional de Saúde com internamentos hospitalares em excesso em cerca de 4,4%. Estimou-se que na Área Metropolitana de Lisboa a mortalidade aumenta significativamente quando a temperatura do ar é inferior a 16,5ºC e que 5,7% dos óbitos foram estatisticamente associados ao impacto do frio.

O excesso de mortalidade e morbilidade no inverno e a mortalidade associada ao frio podem ser evitáveis, ou pelo menos minimizados, através de intervenções de base territorial e direcionadas aos determinantes sociais e económicos da saúde. Os resultados apresentados podem constituir importantes contributos para o desenvolvimento de intervenções mais eficazes.

PALAVRAS-CHAVE: vulnerabilidade ao frio, excesso de mortalidade no inverno, excesso de morbilidade no inverno, determinantes ambientais da saúde

Abstract

Although excess winter mortality and morbidity are common in European countries, important spatial inequalities can be found. Scientific evidence indicates that mortality seasonality results from the impact of harmful temperatures. However, in southern European countries, where winters are milder, excess winter mortality and morbidity burden is greater. In comparison with other Mediterranean countries, cold related health impacts are higher in Portugal.

Vulnerability to cold is influenced by a vast number of biological, epidemiologic, socioeconomic and behavioral factors that result in significant health impacts. Therefore, it is fundamental to measure seasonal variations of disease and to understand the factors that may be responsible for the spatial inequalities of vulnerability to cold.

This dissertations main objective is to analyze and quantify the impact of the mortality and morbidity seasonal variations and to characterize the factors contributing to vulnerability to cold in Portugal, by: i) identifying mortality causes with higher seasonal variations and its geographical patterns; ii) assessing the socioeconomic conditions that contribute to vulnerability to cold; iii) quantifying social and economic costs (of the National Health Service) attributable to excess winter mortality and morbidity; iv) assessing the impact of meteorological factors on mortality and morbidity; v) identifying measures to minimize the effects of cold on health.

To address the presented objectives primary and secondary data at several scales (regional: Regional Health Administration and NUT III; local: municipality and Lisbon Metropolitan Area) were collected. Data collected refers to health outcomes, socioeconomic conditions, meteorological conditions and air quality. Measures of seasonality such as excess winter mortality and morbidity, and cold related mortality were calculated; spatial analysis and time series methods were applied.

Diseases of the circulatory and respiratory system were identified as the causes of death with higher seasonal variation and higher excess winter mortality. The seasonal mortality increase is more important in the municipalities of the inland and is statistically associated with the housing and socioeconomic conditions of the place of residence. The consequences of the vulnerability to seasonal cold weather (during winter) are severe and result in important social and economic costs, which was estimated to account for: i) 87 potential years of life lost per 100,000 inhabitants; ii) life expectancy decreases of one year; iii) added costs to the National Health Service of near 4.4% with excess winter hospital admissions in 2009-12. Further, it was estimated that in Lisbon mortality increases significantly when air temperature is lower than 16.5 ºC and that 5.7% of deaths are due to cold.

Excess winter mortality and morbidity and cold related mortality can be avoided, or at least minimized, by adequate interventions directed towards the social determinants of health. The results presented in this dissertation may be an important contribution for the development of further effective interventions.

KEYWORDS: vulnerability to cold, excess winter mortality, excess winter morbidity, environmentl determinants of health.

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Lista de abreviaturas

AF: *Attributable Fraction*

ARS: Administração Regional de Saúde

CID: Classificação Internacional de Doenças e Problemas Relacionados à Saúde

DGS: Direção-Geral da Saúde

DLNM: *Distributed Lag Non-linear Models*

EMI: Excesso de Mortalidade no Inverno

INE: Instituto Nacional de Estatística

NICE: *National Institute for health and Clinical Excellence*

NUT: Nomenclatura de Unidade Territorial

OMS: Organização Mundial de Saúde

RR: Risco Relativo

SIAM: *Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures*

SNS: Serviço Nacional de Saúde

Introdução

A presente dissertação centra-se na investigação dos determinantes da doença em Portugal Continental. Mais especificamente, parte da avaliação das variações sazonais de mortalidade e morbilidade para destacar o papel do ambiente térmico, concretamente da exposição a baixas temperaturas, na saúde humana e caracterizar os fatores que contribuem para o aumento da vulnerabilidade ao frio.

Considerando a complexa relação entre os fatores em análise, esta temática tem a geografia como ponto de partida integrando-se, também, nos domínios da epidemiologia, da saúde pública, do ordenamento do território e das ciências do ambiente.

A literatura revela a presença de um padrão sazonal da doença ao longo do ano que é comum à maioria dos países europeus. Na maioria das causas de morte, este padrão pode ser descrito através de uma linha em forma de "U" em que a mortalidade é superior nos meses de inverno, no início e do final do ano. A este aumento sazonal da mortalidade durante os meses de inverno, comparativamente aos restantes meses do ano, foi atribuída a designação de Excesso de Mortalidade no inverno (EMI).

Fowler et al. (2015) estimam que na Europa, entre 2002 e 2011, o número de óbitos em excesso no inverno ascenda a valores superiores a 2 milhões; Asher et al. (2012) referem que para cada morte em excesso haverá cerca de 8 internamentos hospitalares e 32 admissões em ambulatório. A magnitude do EMI tem contribuído para que este problema de saúde pública tenha vindo a ser destacada em vários países.

Apesar do aumento da mortalidade registada no inverno ser comum na Europa, é nos países do Sul da Europa, com climas temperados mediterrâneos, que os óbitos associados ao frio são superiores (Analitis et al., 2008; Gasparrini et al., 2015). Esta aparente contradição, descrita por Healy (2003) como paradoxo do EMI, sugere que haverá um conjunto de condicionantes não climáticas a influenciarem o padrão de mortalidade sazonal. Evidência científica refere que desigualdades socioeconómicas podem estar na origem da heterogeneidade espacial que se verifica nos impactos do frio na saúde (Healy, 2003; Rudge & Gilchrist, 2005; Vasconcelos et al., 2011; Hales et al., 2012; Fowler et al., 2015; Marí-Dell'Olmo et al., 2018).

Os efeitos da exposição a temperaturas abaixo do ótimo biológico no corpo humano (Nichelmann, 1983) são vários e em última instância, podem conduzir à morte. Estas consequências do frio justificam o EMI, no entanto são as condições de contexto e os comportamentos dos indivíduos que explicam os diferentes níveis de exposição ao frio (Gemmell et al., 2000).

Portugal destaca-se pela elevada dimensão que este problema de saúde pública atinge, sendo frequentemente referido como o país da Europa com maior EMI (Keatinge, 1997; Healy, 2003; Fowler et al., 2015). No entanto, esta não tem sido considerada uma questão prioritária para as autoridades de saúde e de proteção civil (Monteiro et al., 2013). A identificação das condições que favorecem o aumento da mortalidade durante os meses de inverno poderá ser um importante passo para a definição de medidas e ações capazes de minimizar o impacto do frio na saúde.

Assim, o objetivo deste trabalho é analisar e quantificar o impacto das variações sazonais de mortalidade e morbilidade e caracterizar os fatores que contribuem para o aumento da vulnerabilidade ao frio em Portugal através da: i) identificação das causas de morte com maior variação sazonal e dos seus padrões geográficos; ii) avaliação das condições socioeconómicas que contribuem para um aumento da vulnerabilidade ao frio; iii) quantificação dos custos sociais e económicos (no SNS) do excesso de mortalidade e morbilidade no inverno; iv) avaliação do impacto de fatores meteorológicos na mortalidade e morbilidade; v) identificação de medidas de minimização ou de mitigação dos efeitos do frio na saúde.

A presente dissertação organiza-se em cinco capítulos: i) Estado da arte; ii) Objetivos; iii) Dados e opções metodológicas; iv) Resultados; v) Discussão e conclusões.

Os primeiros três capítulos apresentam o estado da arte, os objetivos e o enquadramento conceptual e metodológico.

O capítulo relativo aos Resultados incluiu os seis artigos científicos que se enquadram no âmbito desta dissertação e que visam responder aos objetivos propostos (figura 1): I - *Seasonal mortality patterns and regional contrasts in Portugal*; II - *Evidence of social deprivation on the spatial patterns of excess winter mortality*; III - *Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case*; IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London*; V - *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon*; VI - *The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal*.

O capítulo relativo à discussão dos resultados e conclusões descreve e sistematiza os resultados dos artigos.

Espera-se que a presente dissertação possa contribuir para uma melhor avaliação da vulnerabilidade ao frio e para o desenvolvimento de medidas mais adequadas de mitigação dos efeitos do frio na saúde mais adequadas, em Portugal.

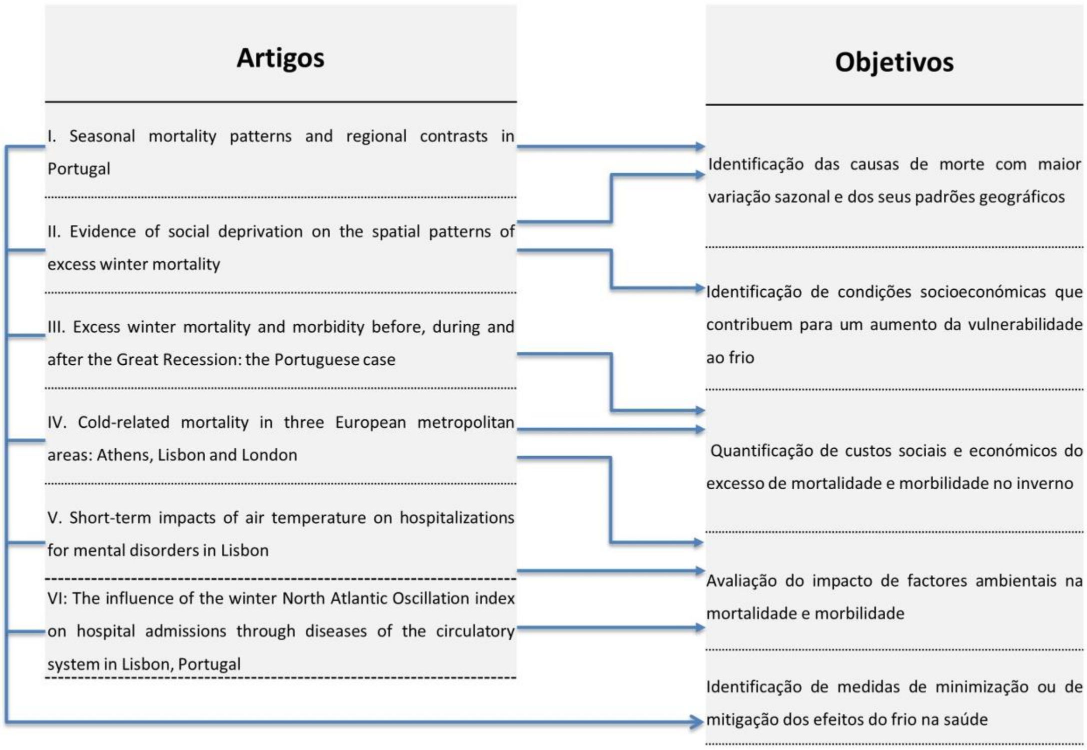

Figura 1. Representação esquemática da correspondência entre artigos objetivos.

1. Estado da arte

1.1 Introdução ao capítulo

Esta secção apresenta o estado da arte, enquadrando tematicamente a dissertação, os conceitos chave e os trabalhos que foram considerados relevantes para a análise da vulnerabilidade ao frio em Portugal.

Começa por sistematizar os *determinantes em saúde*, enquanto fatores com influência no estado de saúde do indivíduo, destacando as condições do ambiente natural e ecossistema global.

De seguida são descritas as respostas fisiológicas do corpo humano quando exposto a temperaturas adversas e as consequências que essa exposição tem no Ser Humano.

As condições de vulnerabilidade ao frio são apresentadas, sendo descrito o modo como a exposição a temperaturas baixas é influenciada por fatores epidemiológicos, socioeconómicos e comportamentais, e os impactos da desigual distribuição destes fatores.

São, posteriormente, descritos os padrões sazonais das doenças, como resultado da influência da exposição ao frio e das condições de vulnerabilidade ao frio.

O capítulo termina com a identificação de planos, ações e medidas, estudadas ou implementadas em diferentes países, com potencial de minimizar o impacto da exposição ao frio.

1.2 Determinantes da saúde

O conceito de saúde promovido pela Organização Mundial de Saúde (OMS), na década de 40 do século XX, considera *saúde* como um estado de completo bem-estar físico, mental e social e não somente como a ausência de doença (WHO, 1948), encontrando-se associado a um conjunto de fatores comportamentais, biológicos, socioeconómicos e ambientais (Dahlgren & Whitehead, 1991; Marmot, 2005; Santana, 2005, 2014; Mackenbach et al., 2008; Nogueira, 2008). Este conjunto abrangente de condicionantes com impacto na saúde é designado pela OMS, no seu site, como determinantes em saúde: "*The social determinants of health are the conditions in which people are born, grow, work, live, and age, and the wider set of forces and systems shaping the conditions of daily life.*" (World Health Organization, 2018).

O estudo da relação entre as condições ambientais e a saúde humana tem vindo a ser desenvolvido desde a antiguidade (Nogueira, 2008). Os trabalhos de Hipócrates, nos séculos III e IV a.C., são frequentemente referidos como um dos primeiros exemplos da perspetiva ecológica da saúde e da doença, nos quais são destacadas as possíveis causas naturais da doença (condições atmosféricas, climáticas, de dieta e de estilos de vida, por exemplo) (Kessel, 2006; Gaspar, 2007; Nogueira, 2008).

O termo ambiente refere-se ao espaço vivido, externo ao indivíduo e inclui elementos do ambiente natural (condições climáticas, solo, água), do ambiente construído (condições de habitação, sistemas de transporte, uso do solo) e do ambiente socioeconómico (interações sociais e culturais, dinâmicas económicas) (Barton & Grant, 2006; Nogueira, 2008; Maantay & McLafferty, 2011).

O modo como se interpreta a interação entre o Ser Humano e as condições do ambiente onde está inserido, da escala local à escala global, tem evoluído ao longo das últimas décadas (Reis et al., 2015). Atualmente reconhece-se que a saúde e a doença não são apenas o produto das características biológicas, genéticas ou do acesso e utilização de serviços de saúde, mas resultam também de uma complexa interação de um conjunto de fatores contextuais e de opções individuais e de estilos de vida (Marmot, 2008; Braveman et al., 2011; Santana, 2014). Esta perspetiva ecológica da saúde engloba o indivíduo, os seus ambientes e as relações de interdependência entre eles (Hancock et al., 1999; McLaren & Hawe, 2005; Santana, 2014).

Destaca-se, portanto, a importância das diversas circunstâncias em que as pessoas vivem, trabalham e envelhecem, com influência, positiva ou negativa, no seu estado de saúde físico e mental (Santana, 2005; Nogueira, 2008; Hoffmann et al., 2014; Loureiro et al., 2015b). Marmot (2005) refere a importância de intervir nos determinantes socioeconómicos, não apenas para melhorar as condições de saúde, mas também para combater as desigualdades injustas em saúde. Uma vez que a desigual distribuição dos determinantes em saúde se traduz em resultados heterogéneos em saúde, onde, por exemplo, locais caracterizados por maiores níveis de privação socioeconómica tendem a apresentar piores resultados em saúde (Nogueira, 2010).

Vários modelos têm sido desenvolvidos para descrever e sintetizar o sistema complexo de fatores que condicionam a saúde humana (Graham & White, 2016). Um dos mais divulgados e utilizados é proposto por Dahlgren e Whitehead (1991), e posteriormente adaptado por Barton e Grant (2006), onde a saúde surge como o resultado de um conjunto de múltiplos fatores interligados, organizados em diferentes camadas, de acordo com a sua abrangência, onde se incluem as características biológicas do indivíduo e os seus estilos de vida, as redes sociais e envolvimento na comunidade, as condições de trabalho e de vida, as condições socioeconómicas, culturais, do ambiente construído e natural e o ecossistema global (figura 2).

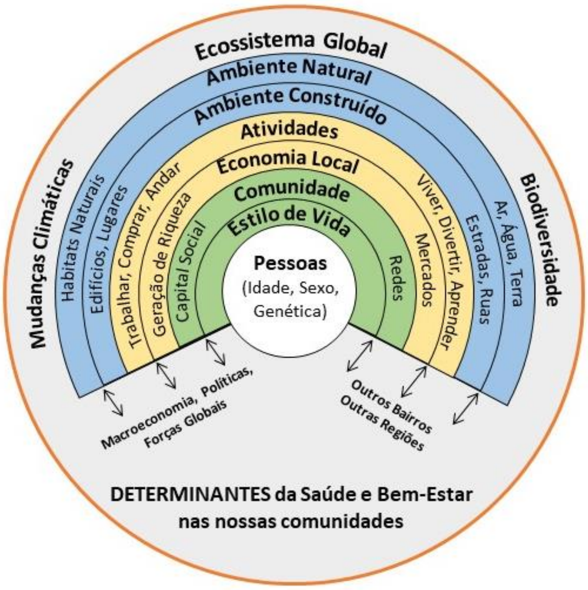

Figura 2. Determinantes sociais da saúde.

Fonte: Adaptado de Santana, P. (2014) e Barton e Grant, 2006.

De seguida serão apresentados alguns exemplos de determinantes em saúde relativos às várias camadas do modelo proposto por Barton e Grant (2006) com influência direta ou indireta na saúde da população (Barton, 2017). Será atribuído particular destaque a alguns fatores do ambiente natural e do ecossistema global.

Estilos de vida

Aspetos relacionados com os estilos de vida, como o consumo excessivo de álcool, tabagismo, sedentarismo, dieta desajustada, foram associados a maior prevalência de diabetes, hipertensão, obesidade, maior risco de acidente coronário, pior saúde mental, entre outros (Bize et al., 2007; Santana et al., 2009; Klijs et al., 2011; Mendes et al., 2013; Loureiro et al., 2015a; Minghelli et al., 2015; Santana, 2015; Alves et al., 2016). Os estilos de vida são, por sua vez, significativamente influenciados pelas condições do ambiente urbano como o acesso a espaços verdes, por exemplo (Santana et al., 2009; Chum & O'Campo, 2015; Barton, 2017).

Comunidade

Características da comunidade, influenciadas por intervenções no ambiente físico (Barton, 2017), dos quais se destacam o capital social, as interações sociais, o sentimento de pertença, podem contribuir para evitar sentimentos de isolamento e solidão, sendo fatores importantes para que a população possa alcançar boa saúde mental (Araya et al., 2006; Santana et al., 2007; Nogueira, 2008; Loureiro et al., 2015a).

Economia local

Dinâmicas relacionadas com a economia local, de que são exemplos a ausência ou reduzida oferta de emprego, baixos rendimentos ou privação material, têm impactos na saúde e bem-estar dos indivíduos, tendo sido associadas a aumentos significativos da mortalidade prematura e evitável (Lynch, 2000; Santana, 2005; Nogueira, 2007, 2010; Borrell et al., 2014; Hoffmann et al., 2014; Santana et al., 2015a).

Atividades

Padrões da atividade humana relacionados com a fruição do espaço público ou a realização das atividades do dia-a-dia são os responsáveis pela dinâmica dos espaços urbanos; a disponibilidade, quantidade e acessibilidade de atividades sociais, recreativas ou económicas são descritos como tendo significativos impactos na saúde, afetando o bem-estar e a qualidade de vida das populações (Barton, 2017).

Ambiente construído

Segundo Barton (2017) a dimensão relativa ao ambiente construído é a que poderá ser influenciada diretamente pelos agentes de planeamento do território. Características do ambiente construído, como a proximidade a espaços verdes, a disponibilidade de serviços, a segurança, as condições de habitação, têm vindo a ser avaliadas na sua relação, direta ou indireta, com a mortalidade e a morbilidade (Macintyre et al., 2002; McCary & O'Connell, 2005; Santana et al., 2007, 2009; Leal et al., 2008; Curl & Kearns, 2015; Santana, 2015; Mitsakou et al., 2018).

Ambiente natural e ecossistema global

O ambiente natural (solo, ar, água, habitat, etc.) e o ecossistema global (clima, biodiversidade, etc.), referem-se a condições que são geralmente partilhadas pelos elementos de uma comunidade (Nogueira, 2008; Santana, 2014) e têm influência nos níveis apresentados anteriormente.

As intervenções, tendo em vista a melhoria do estado de saúde da população, relativas a esta camada do modelo, visam frequentemente estratégias e medidas de adaptação a condições do ambiente natural e do ecossistema global, e às suas alterações previstas (Barton, 2017).

Fatores do ecossistema global como as alterações climáticas ou os padrões de circulação da atmosfera têm importantes impactos indiretos na saúde humana (Alcoforado, 1991; Casimiro et al., 2006; Almendra et al., 2017; Majeed & Moore, 2018).

Alcoforado e Andrade (2007: 104) referem que "*os principais domínios climáticos com impacto biometeorológico no espaço urbano são o ambiente térmico, a qualidade do ar, o ruido e os efeitos mecânicos do vento*". As consequências da exposição a temperaturas adversas (ao frio e ao calor) na saúde têm vindo a ser exploradas por um vasto número de autores, tendo sido encontradas associações estatísticas entre a temperatura e, por exemplo, as doenças cardiovasculares (Eurowinter, 1997; Braga et al., 2002; Ana Monteiro et al., 2013b), respiratórias (Braga et al., 2002; Carson et al., 2006; Ana Monteiro et al., 2013b), mentais (Page et al., 2007; Almendra et al., 2019) e a diabetes (Li et al., 2014).

A exposição a poluentes do ar ($PM_{2.5}$, PM_{10}, NO, NO_2, SO_2, O_3, por exemplo) tem vindo a ser associada ao risco acrescido de doenças respiratórias, cardiovasculares, tumores malignos, doenças da pele, irritação da pele e dos olhos (Ana Monteiro et al., 2013b; Dimakopoulou et al., 2014; Lam et al., 2016; Raaschou-Nielsen et al., 2016).

Outros fatores meteorológicos têm sido também considerados elementos de risco para a saúde humana. Lam et al. (2016) verificaram que valores elevados de humidade, durante a estação quente, e valores baixos de humidade, durante a estação fria, estão associados ao aumento significativo de internamentos por episódios de asma. Verificou-se uma associação positiva estatisticamente significativa entre a ocorrência de precipitação e as doenças parasitárias (Casimiro et al., 2006; Nogueira, 2007; Clements et al., 2009); simultaneamente, a ocorrência de precipitação poderá ter consequências positivas para a saúde, uma vez que contribui para a "limpeza" dos poluentes da atmosfera (Laakso et al., 2003). A rápida descida da pressão atmosférica foi associada ao aumento da probabilidade de ataque cardíaco (Houck et al., 2005).

Nos últimos anos, em virtude dos padrões (observados e previstos) das alterações climáticas, tem-se verificado um renovado interesse pelos impactos das condições meteorológicas na saúde (Analitis et al., 2008). Destacam-se as consequências da exposição a temperaturas adversas, enquanto um problema de saúde pública (Analitis et al., 2014; Gasparrini et al., 2015; Marí-Dell'Olmo et al., 2018), que se traduzem em impactos fortes no presente e que, de acordo com as previsões atuais, não parecem vir a diminuir no futuro (Hajat et al., 2014; Vardoulakis et al., 2014).

1.3 Resposta fisiológica do corpo humano a temperaturas adversas

O balanço térmico do corpo humano é descrito como uma equação entre a energia produzida pelo organismo, a energia recebida, armazenada e aquela que é dissipada (Freire, 1996; Jessen, 2001; Parsons, 2014). A função metabólica do corpo fornece energia, que é responsável pelo funcionamento do corpo, havendo ainda um contributo energético proveniente do movimento físico, dos fluxos de calor convectivo e latente, dos fluxos térmicos resultantes da inspiração do ar, dos fluxos resultantes da transpiração, e ainda, do calor armazenado pela massa corporal; a perda de calor dá-se através da pele por convecção, radiação, evaporação e através da respiração, por convecção e evaporação (Freire, 1996; Höppe, 1999; Vasconcelos, 2012; Parsons, 2014).

Acima de determinada temperatura, observa-se o aumento do fluxo de sangue em direção à epiderme, aumentando a libertação de calor para o exterior do corpo humano (figura 3) (Basu, 2009); este processo é maximizado pela transpiração, contribuindo, a evaporação, para o arrefecimento superficial (Foster et al., 1976). Simultaneamente, verifica-se o aumento do ritmo cardíaco e respiratório, a diminuição da pressão arterial e o aumento da viscosidade do sangue

(Keatinge et al., 1986). Segundo Gasparrini et al. (2017), os mecanismos fisiológicos que conduzem à mortalidade associada ao calor ainda não são totalmente compreendidos e, provavelmente, variam entre as diversas causas de morte.

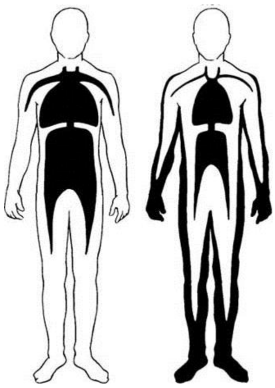

Figura 3. Esquema da distribuição do volume sanguíneo no corpo humano perante a exposição ao frio (à esquerda) e ao calor (à direita).

Fonte: Adaptado de Rowell (2011: 986).

Segundo Keatinge (2002), a exposição ao frio desencadeia diversas respostas: i) redução do fluxo sanguíneo na pele, o que reduz a transferência de calor para a epiderme e a sua perda; ii) sobrecarga de sangue nos órgãos centrais, sendo o excesso eliminado principalmente através da função renal, com espoliação de sódio e água; iii) aumento da concentração de elementos sanguíneos como glóbulos vermelhos e brancos, plaquetas, colesterol e fibrinogénio; iv) aumento da viscosidade do sangue e da pressão arterial. Estes processos aumentam a probabilidade de o sangue coagular, principalmente em idosos. O frio induz, também, a broncoconstrição e limita a função mucociliar, entre outras reações imuno-inflamatórias, aumentando o risco de infeções respiratórias (Eccles, 2002). Estas reações fisiológicas podem sentir-se várias semanas após a exposição (Gasparrini et al., 2017).

A associação estatística entre temperatura e mortalidade tem sido modelada em diversos estudos (Curriero et al., 2002; Analitis et al., 2008; Iñiguez et al., 2010; Hajat et al., 2014; Gasparrini et al., 2015), sendo geralmente descrita de modo não linear, através de uma curva em forma de U, V ou J, em que a mortalidade tende a aumentar a partir de um ponto central, à medida que a temperatura se desvia desse ponto (Kunst et al., 1993; Ballester et al., 1997).

O ponto intermédio, em que a mortalidade atinge o valor mais reduzido, é considerado como representativo do intervalo de temperaturas em que o organismo está sujeito a menor stress térmico, sendo também referido como *optimum* biológico (Nichelmann, 1983). A exposição do corpo humano a temperaturas fora desse intervalo de valores tem consequências fisiológicas que, em alguns casos, podem resultar em morte.

Na Europa, a maior parte dos óbitos associados a temperaturas adversas são devidos ao frio (Braga et al., 2002; Rau, 2004; Hajat et al., 2014). Mesmo considerando as projeções de aquecimento global, Vardoulakis et al. (2014) estimam que tanto no Reino Unido, como na Austrália, a mortalidade associada ao frio continuará a ser superior à atribuível ao calor (figura 4).

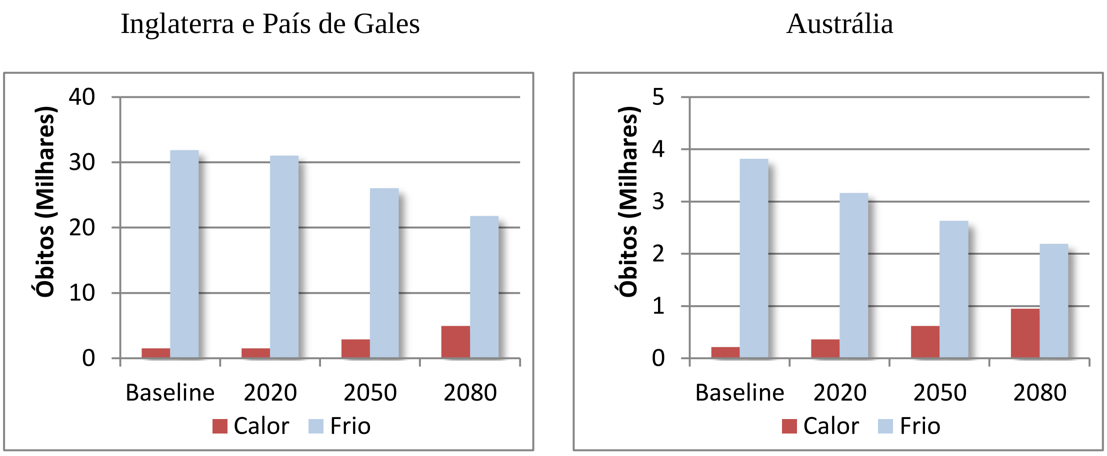

Figura 4. Estimativa e projeção do número de óbitos atribuíveis ao calor e ao frio em Inglaterra e País de Gales e na Austrália (estimativa relativa a cinco cidades Australianas).

Fonte: Adaptado de Vardoulakis et al. (2014: 1288).

1.4 Condições de vulnerabilidade ao frio

Considera-se, frequentemente, que os fatores do ambiente natural, com destaque para as condições meteorológicas, são partilhados por todos os habitantes de uma região (Nogueira, 2008; Santana, 2014), afetando-os, no entanto, de forma desigual (World Health Organization Regional Office for Europe, 2010; Almendra et al., 2017). O estudo comparativo dos impactos do frio na saúde em várias regiões, com diferentes condições socioeconómicas e climáticas, pode contribuir para a identificação de fatores de risco e, nesse sentido, para o planeamento de intervenções em saúde pública (Keatinge, 1997; Healy, 2003; Analitis et al., 2008; Vasconcelos et al., 2013; de' Donato et al., 2015; Marí-Dell'Olmo et al., 2018).

Nos últimos anos, alguns estudos analisaram o impacto de temperaturas adversas na saúde, comparando diversas cidades (Keatinge, 1997; Analitis et al., 2008; Gasparrini et al., 2015, 2017). Apesar das diferenças metodológicas entre estes estudos, os resultados obtidos destacam um aspeto comum: desigualdades geográficas no impacto do frio na mortalidade. Verificando-se que nas cidades com invernos mais amenos as consequências da exposição a temperaturas baixas são, tendencialmente mais graves do que nos locais onde os invernos são mais frios (Eurowinter, 1997; Analitis et al., 2008). O caso concreto da Europa confirma esta tendência, sendo a as consequências do frio na saúde mais severas nos países do Sul da Europa (Healy, 2003; Fowler et al., 2015).

A heterogeneidade espacial da vulnerabilidade ao frio sugere que a relação entre temperatura e saúde não deve ser explicada apenas por alterações de oscilações térmicas (Healy, 2003; Davie et al., 2007; Almendra et al., 2017). A vulnerabilidade resulta da complexa interação de fatores epidemiológicos, biológicos, socioeconómicos, comportamentais, sociais e das estratégias de adaptação aos efeitos do frio, que podem exacerbar a exposição ao frio ou as suas consequências (Medina-Ramón & Schwartz, 2007; Andrade et al., 2011; Hales et al., 2012; Cunha, 2013; Alcoforado et al., 2015; Rodopoulou et al., 2015; Marí-Dell'Olmo et al., 2018).

A mortalidade associada ao frio é geralmente superior nos grupos etários mais envelhecidos (Hajat et al., 2014). Segundo Carter et al. (2016), com o aumento da idade há uma progressiva deterioração do estado de saúde, perda de resiliência psicológica, adoção de estilos de vida menos saudáveis e uma tendência para o isolamento social. O Eurowinter Group (1997) refere que em países relativamente quentes os idosos reportam frequentemente comportamentos desadequados durante o inverno, quando seria necessário minimizar a exposição ao frio (não vestem roupas adequadas ao frio e não permanecem dentro de casa em períodos de frio intenso), que potencialmente resultam numa maior exposição ao frio.

Maheswaran et al. (2004), num estudo realizado no Reino Unido, identificaram que o excesso de mortalidade e morbilidade no inverno por doenças do aparelho respiratório é superior nas mulheres. Os resultados obtidos por Barnett (2005), num estudo comparativo entre 21 países, confirmam esta tendência, verificando que em períodos de maior frio as mulheres apresentam um risco acrescido de acidente coronário comparativamente aos homens.

Condições de privação socioeconómica são frequentemente associadas a maior exposição ao frio (simultaneamente no interior das habitações e na rua) e a consequências mais graves dessa exposição. A influência das condições socioeconómicas nos óbitos associados ao frio, ou na mortalidade em excesso no inverno, é suportada por evidência científica (Healy, 2003; Hajat et al., 2006; Hales et al., 2012), incluindo trabalhos realizados em Portugal (Monteiro et al., 2013; Alcoforado et al., 2015; Almendra et al., 2017), no entanto, há estudos que evidenciam não existir associação estatística entre a privação e a vulnerabilidade ao frio (Lawlor et al., 2000; Maheswaran et al., 2004; Davie et al., 2007).

Num estudo realizado na Nova Zelândia, Hales et al. (2012) referem que o rendimento é um fator de risco, sendo os indivíduos com menores rendimentos os que apresentavam maior probabilidade de morrer no inverno (13% maior probabilidade que os indivíduos com maiores rendimentos). Segundo o mesmo estudo, as desigualdades no acesso a cuidados de saúde podem constituir-se como mediadores na associação entre rendimento e o excesso de mortalidade no inverno. Healy (2003) também identificou uma associação positiva entre baixo rendimento e excesso de mortalidade no inverno, num estudo que inclui 14 países da União Europeia.

Vários aspetos das condições de habitação têm sido referidos como fatores fundamentais para explicar a vulnerabilidade ao frio (Marmot Review Team, 2011): a qualidade geral da habitação (Mitchell et al., 2002); baixas temperaturas interiores (Critchley et al., 2007); aquecimento central inexistente ou insatisfatório (Aylin et al., 2001; Heyman et al., 2005; Vasconcelos et al., 2011); mau isolamento térmico (Healy, 2003; Heyman et al., 2005).

A incapacidade de manter a casa a uma temperatura adequada, devido a limitações económicas, é designada como Pobreza Energética (*Fuel Poverty*). Segundo Boardman (2013), pode dever-se a três fatores: i) consumo excessivo de energia; ii) baixo rendimento familiar; e iii) necessidade de racionamento energético para diminuir os gastos. Viver em habitações frias sem capacidade de as aquecer, devido a pobreza energética, tem sido associado a acrescidos riscos para a saúde física e mental e a impactos negativos no bem-estar social (Anderson et al., 2012). Condições socioeconómicas como o isolamento social ou a baixo rendimento estão associadas à pobreza energética e podem também contribuir para o agravamento do estado de saúde (Marmot Review Team 2011).

Indivíduos com menores níveis de educação têm vindo a ser caracterizados como mais vulneráveis a temperaturas baixas (O'Neill et al., 2003), porque o nível educacional pode ser um preditor de baixo rendimento e influenciar o acesso a condições de habitação adequadas (por exemplo, aquecimento central, isolamento térmico) (Marmot Review Team, 2011; Marí-Dell'Olmo et al., 2018).

Situações contextuais, como a recessão económica sentida em Portugal de 2009 a 2014 (de acordo com a definição técnica de recessão de dois trimestres de crescimento negativo por ano) que afetou significativamente as estruturas sociais e económicas, podem, consequentemente, agravar o padrão de mortalidade sazonal (Benmarhnia et al., 2014; Perelman et al., 2015).

A gripe sazonal desempenha um papel relevante na relação entre temperatura e a mortalidade ou morbilidade em excesso (Conlon et al., 2011; Phu Pin et al., 2012; Fowler et al., 2015; Vestergaard et al., 2017). Segundo Vestergaard et al. (2017), o excesso de mortalidade registado na Europa, no inverno de 2016/17, deveu-se à circulação generalizada do vírus da gripe A(H3N2) várias semanas antes do que se verificou nos invernos dos anos anteriores (sendo este o vírus mais frequentemente associado ao aumento de mortalidade nos idosos). O estudo desenvolvido por Ballester et al. (2016) comparando 16 países Europeus, refere que Portugal e Holanda são os países onde a correlação entre a gripe sazonal e a mortalidade no inverno é menor, sugerindo menores impactos da gripe sazonal no excesso de mortalidade no inverno.

Fatores comportamentais podem funcionar como mediadores e moderadores na relação entre temperaturas adversas e saúde (Telfar Barnard et al., 2008; Tanner et al., 2013), por exemplo: a exposição ao frio é influenciada pela utilização de sistemas de aquecimento na habitação e de roupa adequada e pela permanência desnecessária ao frio em ambiente exterior. A fragilidade biológica a temperaturas adversas é potenciada pelo consumo de tabaco, consumo excessivo de álcool, inatividade física ou sedentarismo (Eurowinter, 1997; Aylin et al., 2001; Donaldson et al., 2001; Marmot Review Team, 2011; Vasconcelos et al., 2011; Barnett et al., 2013; Hajat & Gasparrini, 2016; Nunes, 2018).

A figura 5 propõe uma representação esquemática da interação entre os determinantes em saúde e três elementos de vulnerabilidade (exposição, sensibilidade e adaptação) de acordo com o sugerido por Crimmins et al. (2016). Este esquema sintetiza alguns determinantes em saúde associados a elementos de vulnerabilidade, onde maior exposição, maior sensibilidade e menor capacidade de adaptação se traduzem em acréscimo de vulnerabilidade ao frio e é sugerida a potencial sequência de relações entre os fatores climáticos e os resultados em saúde.

Em suma, verifica-se: i) exposição diferenciada - determinados indivíduos, ou grupos de indivíduos, estão mais expostos; ii) consequências díspares da exposição - a conjugação de vários fatores (fragilidade biológica e social, por exemplo) pode traduzir-se em impactos com consequências mais graves para determinados grupos; e iii) capacidade de adaptação - determinados indivíduos poderão ter menor capacidade de adaptação e reação às adversidades (iliteracia, baixo rendimento, por exemplo), e consequentemente, os efeitos para a sua saúde poderão manifestar-se de forma mais grave.

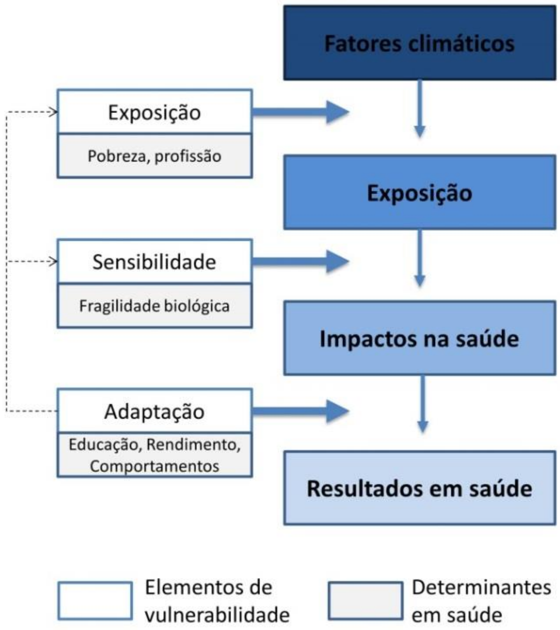

Figura 5. Representação esquemática da interação entre os determinantes em saúde e elementos de vulnerabilidade ao frio.

Fonte: Adaptado de Crimmins et al. (2016: 251).

1.5 Padrões sazonais da doença

Atualmente, a distribuição mensal ao longo do ano da maioria das doenças, medida através de internamentos ou óbitos, apresenta um padrão típico, caracterizando-se, tendencialmente, por um pico nos meses de inverno.

Segundo Rau (2004), é a partir do século XIX que é possível reconstituir os padrões sazonais de mortalidade com base em dados coletados, verificando-se um padrão bimodal com um pico associado ao frio e outro ao calor. McKeown e Record (1962) referem que, no inicio do século XIX, em consequência de más condições sanitárias alguns países europeus apresentavam picos de mortalidade durante a estação quente, em virtude de surtos epidémicos de doenças como a cólera.

No início do século XX, a maioria dos países europeus apresentava já um padrão sazonal de mortalidade semelhante ao atual. Rau (2004), referindo-se a Alain Bideau et al. (1988), indicam que a diminuição dos picos de mortalidade associados ao calor está relacionada com a melhoria das condições de higiene, que contribuíram para a quase total irradicação das doenças intestinais, e que se constituíam como a maior causa para o excesso de mortalidade no verão.

Alcoforado et al. (2015) referem que, em Lisboa, durante a primeira metade do século XIX, o pico de mortalidade verificava-se nos meses de Verão; após 1940, estabelece-se o padrão de sazonalidade atual, marcado por aumentos de mortalidade durante os meses de inverno.

Segundo Mercer (2003), na Europa registam-se anualmente cerca de 250 mil mortes em excesso no inverno, representando este valor apenas uma fração do problema. Yang et al. (2015) identificaram um comportamento sazonal da mortalidade que se traduz num aumento significativo de anos de vida potencialmente perdidos, em várias cidades da China. No Reino Unido, foi estimado que para cada morte em excesso serão contabilizados cerca de 8 internamentos hospitalares e 32 admissões em ambulatório (Asher et al., 2012), estimando-se que os custos do impacto do frio na saúde, para o Serviço Nacional de Saúde do reino Unido, rondem 1,5 mil milhões de Libras, faltando ainda contabilizar as perdas económicas devido a ausências laborais.

O aumento da mortalidade durante o inverno não se verifica de forma homogénea em todas as causas de morte; os óbitos por doenças do aparelho respiratório e circulatório registam variações sazonais superiores (Rau, 2004; Wilkinson, 2004; Almendra et al., 2016). Este padrão foi também observado em Portugal (quadro 1), verificando-se um aumento sazonal nas doenças do aparelho respiratório, sendo, no entanto, mais elevado o número de óbitos em excesso nas doenças do aparelho circulatório. Causas como o suicídio ou a hipotermia não influenciam este padrão sazonal de forma decisiva (Rau, 2004). Se por um lado a mortalidade por hipotermia é residual, as causas externas, onde se encontra o suicídio, apresentam um padrão oposto, com tendência para aumentar durante os meses de verão (Almendra et al., 2016, 2019).

Apesar das dificuldades em comparar a mortalidade associada ao frio entre regiões distintas, devido às disparidades nos padrões de mortalidade, estruturas etárias e flutuações espaciais do vírus da gripe sazonal (Eurowinter, 1997), Portugal tem vindo a ser descrito como o país da Europa com valores maiores de excesso de mortalidade no inverno (figura 6) (Healy, 2003; Fowler et al., 2015). Milner et al. (2014) referem que padrões sazonais de mortalidade, caracterizados pelo aumento dos óbitos durante o inverno, são indicativos da vulnerabilidade aos efeitos do frio.

Quadro 1. Rácio de mortalidade entre inverno e verão em Portugal, por grande grupo de causa de morte.

Causas de morte (CID 10)	Rácio inverno /verão
Todas as causas de morte	1,32
Doenças infeciosas e parasitárias	1,07
Tumores (neoplasmas) malignos	1,05
Doenças do sangue e dos órgãos hematopoéticos e alguns transtornos imunitários	1,22
Doenças endócrinas, nutricionais e metabólicas	1,41
Transtornos mentais e comportamentais	1,29
Doenças do sistema nervoso e dos órgãos dos sentidos	1,36
Doenças do aparelho circulatório	1,46
Doenças do aparelho respiratório	1,76
Doenças do aparelho digestivo	1,21
Doenças do sistema osteomuscular/ tecido conjuntivo	1,35
Doenças do aparelho geniturinário	1,32
Causas externas de lesão e envenenamento	0,96

Fonte: Adaptado de Almendra et al.(2016).

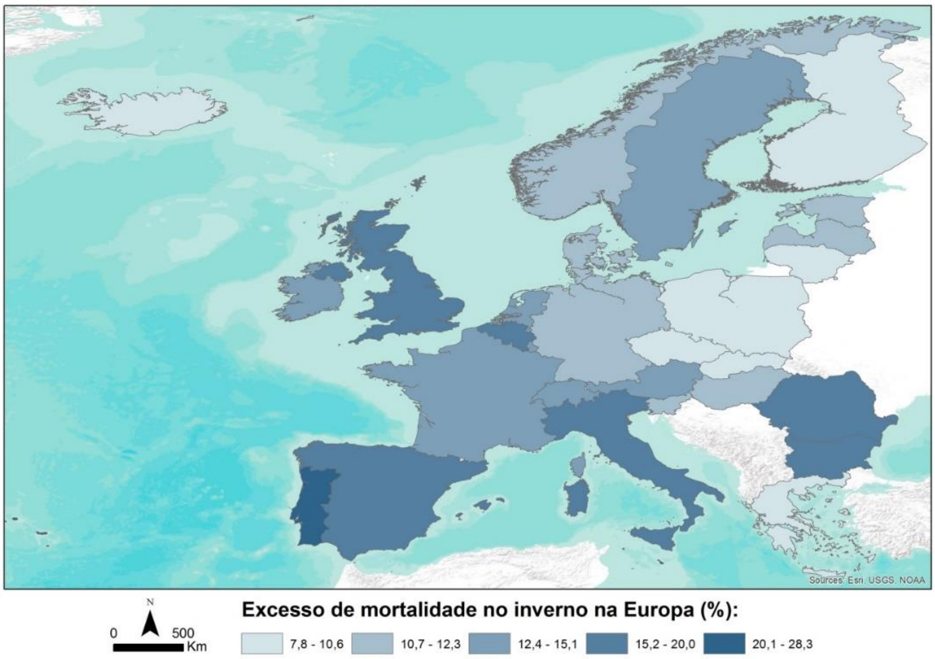

Figura 6. Excesso de mortalidade no inverno na Europa.

Fonte: Adaptado de Fowler et al. (2015).

1.6 Medidas de minimização ou de mitigação dos efeitos do frio na saúde

Tem-se vindo a desenvolver um amplo debate científico sobre possíveis ações e medidas de minimização dos efeitos do frio na saúde, de forma a reduzir os óbitos associados ao frio e a mortalidade e morbilidade em excesso no inverno.

De acordo com McMichael et al. (2006), os processos adaptativos ao frio de ordem fisiológica, comportamental e cultural desempenham um papel significativo na redução da vulnerabilidade a temperaturas adversas, sendo que os efeitos destes processos poderão ser mais relevantes do que os impactos de um sistema de alerta. Christidis et al. (2010) destacam medidas de adaptação como o incentivo à eficiência energética dos edifícios, a promoção de estilos de vida saudáveis, o apoio à instalação de sistemas de aquecimento mais eficientes e a redução da tarifa elétrica (quadro 2).

Quadro 2. Exemplo de estratégias de adaptação ao frio ao nível do indivíduo, edifício e bairro.

Escala	Estratégias de adaptação
Indivíduo	Incentivo ao exercício físico Implementação de normas legais sobre uniforme e roupa de trabalho em atividades desenvolvidas no exterior
Edifício	Climatização das habitações (isolamento eficaz, redução de infiltrações, janelas mais eficientes, eficiência energética) Implementação de programas de assistência energética direcionados a grupos vulneráveis
Bairro	Escolha de vegetação urbana adequada Aplicação de *Solar Envelope* standards para maximizar a exposição ao sol Implementação de sistemas urbanos de distribuição de calor

Fonte: Adaptado de Conlon et al. (2011).

Os resultados apresentados por Gasparrini et al. (2015) sugerem que a mortalidade associada a baixas temperaturas é superior em períodos de frio moderado do que em períodos de frio extremo, sugerindo a necessidade de planeamento de medidas e ações preventivas e adaptativas ao longo do ano. No Reino Unido, o *Cold Weather Plan for England* de 2012-13 manifesta já esta preocupação (Public Health England, 2017a), que tem vindo a ser reforçada nas edições seguintes do plano (Public Health England, 2017b, 2017a).

O planeamento e consequente implementação de ações concretas de prevenção antes do inverno podem ter consequências cruciais na redução da mortalidade e morbilidade associadas ao frio (NICE, 2015a). São exemplos disso as ações voltadas para a redução da exposição ao frio (dentro das habitações, no trabalho, na rua), a promoção de atividade física ou o controle da transmissão do vírus da gripe sazonal (Arbuthnott et al., 2018). Ballester et al. (2016) destacam ainda o impacto resultante da implementação de sistemas de alerta meteorológico e da disponibilidade de cuidados de saúde adequados (e convenientemente preparados) na redução da vulnerabilidade ao frio.

A monitorização e avaliação da implementação destes planos, e dos seus impactos, são tarefas complexas. Destaque para a abrangência dos parâmetros analisados no modelo sugerido por Chalabi et al. (2016) que permite avaliar o custo-efetividade do *Cold Weather Plan for England* (figura 7). Este modelo inclui: i) o peso da doença atribuível ao frio antes da implementação do Plano (em termos de óbitos e de internamentos) (contabilizado no painel A); ii) o grau de implementação do Plano (avaliado no Painel B), iii) a estimativa dos ganhos potenciais associados à diminuição da mortalidade e morbilidade evitada com a implementação do Plano (presentes no painel C). Os resultados desta avaliação, em termos de custo-efetividade, sugerem terem sido alcançados impactos positivos com a implementação deste Plano.

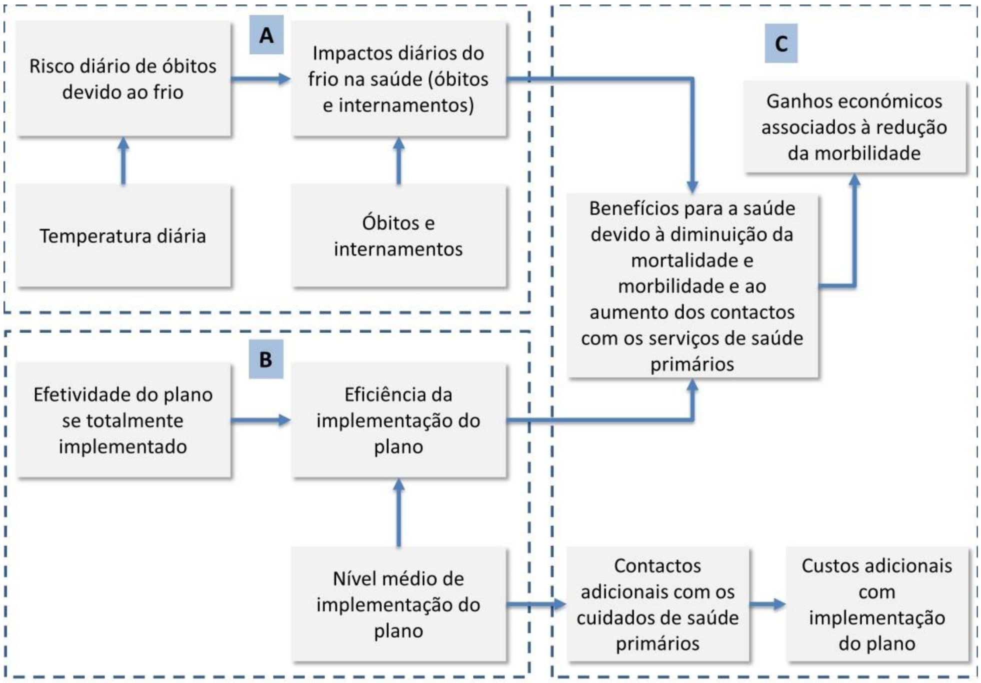

Figura 7. Modelo para análise de custo-efetividade do *Cold Weather Plan for England*.

Fonte: Adaptado de Chalabi et al. (2016).

Evidência científica destaca a importância que as condições de habitação têm no excesso de mortalidade no inverno, tendo sido identificadas associações estatísticas entre a vulnerabilidade ao frio e a pobreza energética, habitações frias, com humidade ou fungos (Heyman et al., 2005; Critchley et al., 2007; Braubach & Fairburn, 2010; Marmot Review Team, 2011; Anderson et al., 2012; Tanner et al., 2013). Neste sentido, no Reino Unido, a maioria das intervenções com o objetivo de reduzir os impactos do frio na saúde estão relacionas com a melhoria das condições de habitação e com o combate à pobreza energética (NICE, 2015b).

Armstrong et al. (2018) realizaram um estudo com o objetivo de avaliar o impacto na saúde das ações de melhoria da eficiência energética nas habitações (diminuição da exposição ao frio através de isolamento de paredes, sótão, instalação de vidros duplos, melhoria dos sistemas de aquecimento, instalação de sistema de isolamento de portas, por exemplo). Um dos resultados apresentados destaca que, em média, as intervenções aplicadas efetuadas nas habitações entre 2002 e 2007 resultaram no aumento da temperatura interior em apenas 0,1ºC; apesar da melhoria das condições térmicas ter sido limitada, traduziu-se numa diminuição da mortalidade associada ao frio em cerca de 300 óbitos por ano. No mesmo estudo, os autores recomendam que, para maximizar os resultados, as intervenções devem ser direcionadas aos edifícios com eficiência energética inferior à média.

Na Nova Zelândia, Grimes et al. (2011), avaliaram um programa nacional que disponibilizava subsídios para melhorar o isolamento das habitações e introduzir formas de aquecimento sustentáveis, do ponto de vista ambiental. Os benefícios provenientes da implementação deste programa surgiram através da diminuição dos consumos energéticos e da redução da emissão de poluentes, decréscimo dos gastos em internamentos hospitalares e consumo de medicamentos e, ainda, na diminuição da mortalidade.

Em Portugal, a Direção-Geral da Saúde (DGS) elabora, desde 2015 o Plano de Contingência Saúde Sazonal – Módulo Inverno (em 2015, chamava-se: *Plano de Contingência para Temperaturas Extremas Adversas - Módulo de Inverno*; em 2016: *Saúde Sazonal: Inverno e Saúde - Plano de Contingência para Temperaturas Extremas Adversas*). Ressalvar que a DGS (2018: 5) refere que "promove a implementação, desde 2004, de Planos de Contingência com o objetivo de minimizar os potenciais efeitos do frio extremo na saúde da população".

O Plano de Contingência Saúde Sazonal – Módulo Inverno é ativado entre outubro e abril e tem como finalidade "prevenir e minimizar os efeitos negativos do frio extremo e das infeções respiratórias, nomeadamente da gripe, na saúde da população em geral e dos grupos de risco em particular" (DGS, 2018: 6), está organizado em três eixos: i) informação; ii) prevenção, contenção e controlo; e iii) comunicação.

Em termos de medidas de prevenção dos efeitos do frio, o Plano dá grande ênfase à vacinação contra a gripe sazonal e outras infeções, refere com relativa consistência a necessidade de transmissão de informação adequada à população e a promoção da literacia, todavia apresenta um défice de medidas relativas à diminuição da exposição ao frio. No âmbito do controlo da exposição ao frio refere a necessidade de implementação de medidas de climatização em estruturas residenciais para pessoas idosas e indica que a comunicação com a população deve incluir recomendações sobre vestuário e alimentos adequados. De referir que segundo Nunes (2018), num estudo realizado em Lisboa, indivíduos com menor literacia não recebem a informação necessária sobre os comportamentos adequados a ter durante períodos de frio, referindo ainda que os participantes no estudo prefeririam receber informação através de canais personalizados (médico de família, por exemplo) do que através de meios de comunicação gerais.

Seria ainda importante avaliar de modo consistente o impacto que este plano e outras medidas, como a tarifa social energética, tiveram, e estão a ter, no conforto térmico das famílias beneficiadas e na diminuição dos efeitos negativos do frio na saúde humana.

2. Objetivos

A vulnerabilidade ao frio resulta de um vasto conjunto de fatores biológicos, epidemiológicos, socioeconómicos e comportamentais e traduz-se em doença e morte que poderiam ser evitadas. Apesar das previsões climáticas apontarem para um aquecimento global, estudos anteriores indicam que o frio continuará a ter fortes impactos na saúde (mortalidade), superiores aos do calor. É, portanto, fundamental medir as variações sazonais das doenças e compreender os fatores que contribuem para a explicação das desigualdades espaciais da vulnerabilidade ao frio.

O presente trabalho tem como objetivo geral analisar e quantificar o impacto das variações sazonais da mortalidade e da morbilidade e caracterizar os fatores que contribuem para o aumento da vulnerabilidade ao frio em Portugal, através da:

1. Identificação das causas de morte com maior variação sazonal e dos seus padrões geográficos;
2. Avaliação das condições socioeconómicas que contribuem para um aumento da vulnerabilidade ao frio;
3. Quantificação dos custos sociais e económicos (no SNS) do excesso de mortalidade e morbilidade no inverno;
4. Avaliação do impacto de fatores meteorológicos na mortalidade e morbilidade;
5. Identificação de medidas de minimização ou de mitigação dos efeitos do frio na saúde.

3. Dados e opções metodológicas

3.1 Introdução ao capítulo

Este capítulo descreve genericamente os dados e as opções metodológicas que foram adotadas para responder aos objetivos propostos, tendo em atenção o estado da arte dos conhecimentos no domínio em estudo. Inicialmente, são indicados métodos de recolha e seleção bibliográfica e os dados recolhidos.

Segue-se a apresentação das medidas de sazonalidade utilizadas nos três primeiros Artigos: I. *Seasonal mortality patterns and regional contrasts in Portugal*, II. *Evidence of social deprivation on the spatial patterns of excess winter mortality* e III. *Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case.*

Na secção relativa à análise dos padrões espaciais é apresentada a metodologia utilizada para avaliar a associação entre condições socioeconómicas e o excesso de mortalidade no inverno (Artigo II. *Evidence of social deprivation on the spatial patterns of excess winter mortality*).

Posteriormente, são descritos os métodos de análise de séries temporais de dados ambientais utilizados para avaliar o impacto de fatores meteorológicos (temperatura e Oscilação do Atlântico Norte) na mortalidade e morbilidade presentes nos Artigos: IV. *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London*; V. *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon;* e VI. *The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal*.

O capítulo de dados e opções metodológicas termina com a apresentação e justificação das escalas de análises selecionadas.

Informação detalhada pode ser encontrada na secção de dados e métodos dos artigos presentes nesta dissertação.

3.2 Processo de revisão da literatura

A consulta da literatura que acompanhou o processo de elaboração desta dissertação, e dos artigos científicos que a constituem, encontra-se sintetizada no capítulo de revisão do estado da arte. Deu-se especial atenção a documentos de cariz científico (artigos, livros, relatórios, por exemplo), escritos em Português, Inglês, ou Espanhol, presentes em bases de dados internacionais (Pubmed, ScienceDirect, Biblioteca do Conhecimento online, entre outros). Os termos de pesquisa utilizados incluíram: *excess winter mortality*; *excess winter morbidity*; cold *related mortality; cold weather plan; vulnerability; cold weather vulnerability; temperature-related mortality; attributable mortality fraction; burden of cold; seasonal mortality; seasonality; seasonal burden disease; health determinants; cold exposure; DLNM.*

Este processo de pesquisa permitiu recolher um número vasto de textos relativos aos determinantes em saúde, à resposta fisiológica do corpo humano a temperaturas adversas, às condições de vulnerabilidade ao frio, aos padrões sazonais da doença, às medidas de mitigação dos impactos do frio, aos métodos de análise de dados espaciais, aos métodos de análise de séries temporais em Geografia da Saúde, entre outros.

Foram ainda identificados relatórios de diversas instituições com informação relevante para o desenvolvimento do tema da dissertação (por exemplo: OMS, NICE, *Public Health England*, DGS).

Destaca-se a importância que a investigação científica desenvolvida no Reino Unido teve no desenvolvimento desta dissertação. Este facto deve-se, em grande parte, há já longa tradição de estudos sobre o impacto do frio na saúde, a aplicação de programas de contingência e à avaliação desses programas.

3.3 Dados

Para analisar e quantificar o impacto das variações sazonais da mortalidade e da morbilidade e caracterizar os fatores que contribuem para o aumento da vulnerabilidade ao frio em Portugal, foram recolhidos e utilizados dados secundários relativos a resultados em saúde (internamentos hospitalares e óbitos), condições socioeconómicas e condições meteorológicas e de qualidade do ar.

De modo semelhante ao verificado em vários trabalhos de investigação em Geografia da Saúde foram utilizados resultados em saúde de mortalidade (óbitos) e de morbilidade (internamentos hospitalares) (Santana, 2005, 2014; Dummer, 2008; Nogueira, 2008; Monteiro et al., 2012; Hoffmann et al., 2014; Santana et al., 2015b; Rosenberg, 2016). Nos artigos apresentados nesta dissertação são efetuados diferentes agrupamentos de causas de morte e de internamento, de acordo com o objetivo do estudo e com as limitações inerentes à disponibilidade dos dados (necessidade de agrupar causas de morte para evitar os constrangimentos associados aos pequenos números, por exemplo) (quadro 3).

Quadro 3. Causas de morte e de internamento hospitalar e fontes de informação utilizadas.

Dimensão		**Causas de morte e internamento (Classificação Internacional de Doenças)**	**Período**	**Fonte**
Resultado em saúde	Internamentos hospitalares	Todas as causas, exceto causas externas de lesão e envenenamento e Complicações da gravidez, parto e puerpério (CID 9: 001-629; 760-799)	2009-16	Administração Central do Sistema de Saúde
		Perturbações mentais (CID 9: 291-293; 295-298; 300; 3071; 3074; 3075; 3078; 303-305; 308-309; 311; 316; E95)	2008-14	Administração Central do Sistema de Saúde
	Óbitos	Todas as causas de morte (CID 10: A00-Y89)	2009-16	Instituto Nacional de Estatística
		Doenças infeciosas e parasitárias (CID 10: A00-B99)	2000-09	Instituto Nacional de Estatística
		Tumores (neoplasmas) malignos (CID10: C00-C97)	2000-09	Instituto Nacional de Estatística
		Doenças do sangue e dos órgãos hematopoéticos e alguns transtornos imunitários (CID10: D50-D89)	2000-09	Instituto Nacional de Estatística
		Doenças endócrinas, nutricionais e metabólicas (CID10: E00-E89)	2000-09	Instituto Nacional de Estatística
		Transtornos mentais e comportamentais (CID10: F00-F99)	2000-09	Instituto Nacional de Estatística
		Doenças do sistema nervoso e dos órgãos dos sentidos (CID10: G00-H95)	2000-09	Instituto Nacional de Estatística

Dimensão		Causas de morte e internamento (Classificação Internacional de Doenças)	Período	Fonte
		Doenças do aparelho circulatório (CID10: I00-I99)	2000-11	Instituto Nacional de Estatística
		Doenças do aparelho respiratório (CID10: J00-J99)	2000-09	Instituto Nacional de Estatística
		Doenças do aparelho digestivo (CID10: K00-K92)	2000-09	Instituto Nacional de Estatística
		Doenças do sistema osteomuscular/ tecido conjuntivo (CID10: M00-M99)	2000-09	Instituto Nacional de Estatística
		Doenças do aparelho geniturinário (CID10:N00-N99)	2000-09	Instituto Nacional de Estatística
		Causas externas de lesão e envenenamento (CID10: V01-Y89)	2000-09	Instituto Nacional de Estatística

CID: Classificação Internacional de Doenças (versão 9: CID 9 e versão 10: CID 10).

Os indicadores socioeconómicos selecionados foram utilizados para descrever condições que potencialmente contribuem para o aumento da vulnerabilidade ao frio (condições de habitação, envelhecimento, educação, por exemplo). Este conjunto de indicadores é, simultaneamente, o resultado da revisão da literatura efetuada ao longo do programa doutoral, da disponibilidade de dados e das análises de sensibilidade realizadas durante o desenvolvimento do Artigo II - *Evidence of social deprivation on the spatial patterns of excess winter mortality* (quadro 4).

Na avaliação do impacto de fatores ambientais na mortalidade e na morbilidade foram recolhidos indicadores meteorológicos, de qualidade do ar e representativos do padrão de circulação atmosférica. Detalhes sobre a recolha destes indicadores, nomeadamente as estações selecionadas, podem ser consultados na secção de dados e métodos dos Artigos IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London*, V - *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon* e VI - *The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal* (quadro 5).

Quadro 4. Indicadores socioeconómicos e fontes de informação utilizadas.

Dimensão	Dados / Indicadores (unidade)	Período	Fonte
Habitação e edificado	Proporção de edifícios de residência habitual construídos até 1960 (%)	2011	Instituto Nacional de Estatística
	Proporção de alojamentos sem sistema de aquecimento (%)	2011	Instituto Nacional de Estatística
	Proporção de alojamentos familiares com aquecimento central (%)	2011	*Eurohealthy data platform*
	Proporção de edifícios com estrutura de alvenaria, pedra solta ou adobe (%)	2011	Instituto Nacional de Estatística
Emprego e ocupação laboral	Taxa de desemprego (%)	2011	Instituto Nacional de Estatística
	Proporção de trabalhadores manuais (%)	2011	Instituto Nacional de Estatística
Educação	Proporção de população residente com 15 e mais anos sem ensino secundário (%)	2011	Instituto Nacional de Estatística
	Proporção de população que completou pelo menos o ensino secundário (%)	2011	*Eurohealthy data platform*
Demografia	Densidade populacional (hab./km^2)	2011	*Eurohealthy data platform*
	Índice de envelhecimento (N.º)	2011	*Eurohealthy data platform*

Quadro 5. Indicadores meteorológicos e de qualidade do ar e fontes de informação utilizadas.

Dimensão	Dados / Indicadores (unidade)	Período	Fonte
Indicadores meteorológicos	Temperatura média diária (ºC)	2002-14	*National Oceanic and Atmospheric Administration*
	Humidade relativa média diária (%)	2002-14	*National Oceanic and Atmospheric Administration*
	Velocidade do vento média diária (m/s)	2003-12	*National Oceanic and Atmospheric Administration*
	Precipitação diária (mm)	2002-12	*National Oceanic and Atmospheric Administration*
	Índice da Oscilação do Atlântico Norte diário (N.º)	2003-12	*National Oceanic and Atmospheric Administration*
Indicadores de qualidade do ar	PM_{10} médio horária (µg/m^3)	2008-14	Agência Portuguesa do Ambiente
	$PM_{2.5}$ médio horária (µg/m^3)	2003-12	Agência Portuguesa do Ambiente

Dimensão	Dados / Indicadores (unidade)	Período	Fonte
	CO médio horária ($\mu g/m^3$)	2003-12	Agência Portuguesa do Ambiente
	O_3 médio horária ($\mu g/m^3$)	2008-14	Agência Portuguesa do Ambiente
	NO_2 médio horária ($\mu g/m^3$)	2003-12	Agência Portuguesa do Ambiente
	NO médio horária ($\mu g/m^3$)	2003-12	Agência Portuguesa do Ambiente
	SO_2 médio horária ($\mu g/m^3$)	2003-12	Agência Portuguesa do Ambiente

3.4 Escalas de análise

Condicionantes relativas à disponibilidade e às características dos dados têm implicações nas escalas temporais e espaciais de análise (Nogueira, 2008). Simultaneamente, a seleção da escala de análise deve ter em conta que *"os modelos de avaliação e de cartografia da exposição de pessoas, do valor dos bens e da vulnerabilidade social … dependem muito da escala da análise"* (Cunha, 2013: 159). O quadro 6 apresenta as escalas espaciais, temporais e períodos de análise utilizados nos artigos desenvolvidos no âmbito desta dissertação.

O Artigo I - *Seasonal mortality patterns and regional contrasts in Portugal* analisa os padrões sazonais de diversas causas de mortalidade (doenças infeciosas e parasitárias, tumores malignos, doenças do sangue e dos órgãos hematopoéticos e alguns transtornos imunitários, doenças endócrinas, nutricionais e metabólicas, transtornos mentais e comportamentais, doenças do sistema nervoso e dos órgãos dos sentidos, doenças do aparelho circulatório, doenças do aparelho respiratório, doenças do aparelho digestivo, doenças do sistema osteomuscular/tecido conjuntivo, doenças do aparelho geniturinário e causas externas de lesão e envenenamento) à escala da NUT III para o país com uma década de dados mensais (2000-2009); o Artigo II - *Evidence of social deprivation on the spatial patterns of excess winter mortality* avalia o padrão espacial do excesso de mortalidade por doenças do aparelho circulatório no inverno, no Continente, à escala do concelho, também agrupando dados de 10 anos (2002-2011), e analisa a relação entre o excesso de mortalidade e a privação sociomaterial; o Artigo III - *Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case* estima os custos económicos e sociais do excesso de mortalidade e morbilidade no inverno para o Continente à escala da

Administração Regional de Saúde (ARS), comparando o período da recessão económica (2009-2012) com o período antecedente (2005-2008) e posterior (2013-2016).

Os Artigos IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London*, V - *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon* e VI - *The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal* avaliam o impacto de fatores ambientais na mortalidade e morbilidade na NUT III Área Metropolitana de Lisboa (aquando da realização do Artigo V, estava ainda em vigor a versão de 2002 das unidades territoriais, tendo sido analisada a NUT III Grande Lisboa). A análise, e mensuração, dos efeitos de temperaturas adversas na saúde são frequentemente realizadas à escala da cidade, devido à necessidade de avaliar a associação entre dados diários de um resultado em saúde (agrupados em divisões administrativas) e de temperatura (medidos por estações meteorológicas). O Artigo V analisa dados diários de 7 anos, enquanto nos Artigos IV e VI são utilizados dados diários de 10 anos.

Quadro 6. Escala espacial, temporal e períodos de análise utilizados.

Artigo	**Escala espacial**	**Período de análise**	**Escala temporal**
Artigo I - *Seasonal mortality patterns and regional contrasts in Portugal*	Portugal / NUT III	2000-09	Dados agrupados (10 anos)
Artigo II - *Evidence of social deprivation on the spatial patterns of excess winter mortality*	Continente / Concelho	2002-11	Dados agrupados (10 anos)
Artigo III - *Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case*	Continente / Administração Regional de Saúde	2009-16	Dados agrupados em 3 períodos de 4 anos
Artigo IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London. Implications for health promotion*	Área Metropolitana de Lisboa	2002-12	Dados diários
Artigo V - *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon*	Área Metropolitana de Lisboa	2008-14	Dados diários
Artigo VI - *The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon*	Área Metropolitana de Lisboa	2003-12	Dados diários

3.5 Métodos

3.5.1 Medidas de sazonalidade

As variações sazonais de mortalidade e morbilidade foram avaliadas utilizando as medidas EMI e o Índice de EMI, apresentadas por Johnson e Griffiths (2003); estas medidas têm sido utilizadas por outros investigadores (Healy, 2003; Fowler et al., 2015; Liddell et al., 2016, por exemplo) e instituições (Instituto Nacional de Estatísticas do Reino Unido).

De acordo com Johnson e Griffiths (2003), o excesso de mortalidade corresponde ao aumento de óbitos que ocorre no período de inverno (dezembro, janeiro, fevereiro e março), relativamente aos que seriam esperados tendo em conta o padrão anual de mortalidade do período de não inverno (meses de abril a novembro) (figura 8). Ou seja, o EMI é calculado através da comparação do número de óbitos registados no inverno com o número de mortes no período não inverno:

$$EMI = \text{óbitos entre dezembro e março} - \frac{\text{óbitos entre abril e novembro}}{2}$$

(Office for National Statistics, 2017)

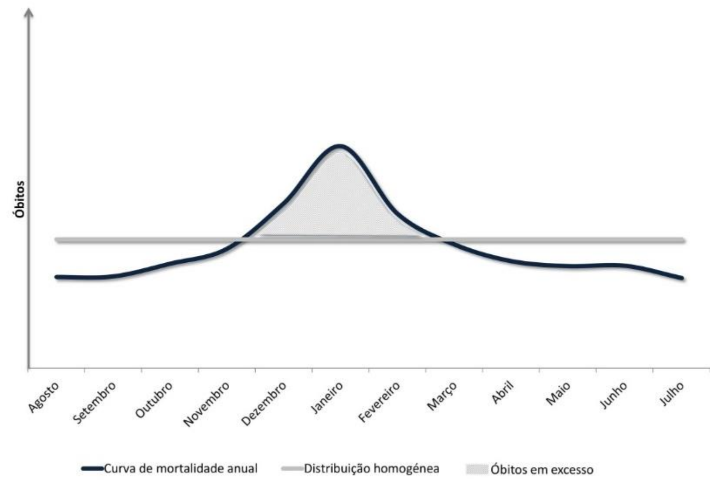

Figura 8. Representação esquemática da curva de mortalidade anual (por todas as causas) e dos óbitos em excesso no inverno.

Fonte: Elaboração própria.

O Índice de EMI mede o aumento da mortalidade no período de inverno, através do aumento percentual do número de óbitos em excesso no inverno comparativamente com a média do período não inverno:

$$\text{Índice de } EMI = \frac{EMI}{\text{óbitos entre abril e novembro} \ / \ 2} \times 100$$

(Office for National Statistics, 2017)

O cálculo de intervalos de confiança complementa a avaliação desta medida:

$$IC = \text{Índice de } EMI \ \pm 1.96 \sqrt{\frac{\text{Índice de } EMI}{EMI}}$$

(Office for National Statistics, 2017)

A estimativa do número de óbitos em excesso no inverno é influenciada pelas características demográficas dos residentes de cada unidade territorial. Territórios com população mais envelhecida são mais vulneráveis aos efeitos do frio e, por isso, tendem a apresentar maior mortalidade em excesso no inverno (Fowler et al., 2015). Para além da influência das características demográficas, verifica-se que os óbitos em excesso no inverno estão associados ao padrão de mortalidade dos territórios, uma vez que o volume de excesso de óbitos será, em parte, uma consequência da magnitude da mortalidade registada em cada região (Almendra et al., 2016). Em sentido oposto, o Índice de EMI mede a variação sazonal da mortalidade, não sendo influenciado pela dimensão populacional ou pelo volume de mortalidade registado em cada região (Office for National Statistics, 2017).

A partir do número de óbitos em excesso no inverno foram calculados diversos indicadores: Taxa de mortalidade em excesso, Taxa de mortalidade padronizada em excesso, Anos de vida potencialmente perdidos em excesso e Esperança de vida sem óbitos em excesso (detalhes sobre o cálculo destes indicadores estão presentes nos Artigos I - *Seasonal mortality patterns and regional contrasts in Portugal*, II - *Evidence of social deprivation on the spatial patterns of excess winter mortality* e principalmente III - *Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case*). O cálculo destes indicadores permite ultrapassar as limitações associadas à dimensão populacional de cada unidade administrativa, possibilitando, desse modo, a comparação entre territórios.

Foram aplicados os mesmos procedimentos metodológicos à morbilidade hospitalar para estimar o número de internamentos em excesso e avaliar o padrão sazonal da morbilidade. A estimativa do excesso de internamentos permitiu o cálculo da Taxa de internamentos padronizada em excesso e uma estimativa dos custos do SNS com estes internamentos (quadro 7).

Quadro 7. Indicadores calculados nos Artigos I, II, III e IV.

Artigo	**Indicadores calculados**
Artigo I - *Seasonal mortality patterns and regional contrasts in Portugal*	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por todas as causas de morte
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por doenças infeciosas e parasitárias
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por tumores malignos
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por doenças do sangue e dos órgãos hematopoéticos e alguns transtornos imunitários
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por doenças endócrinas, nutricionais e metabólicas
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por transtornos mentais e comportamentais
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por doenças do sistema nervoso e dos órgãos dos sentidos
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por doenças do aparelho circulatório
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por doenças do aparelho respiratório
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por doenças do aparelho digestivo
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por doenças do sistema osteomuscular/ tecido conjuntivo
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por doenças do aparelho geniturinário
	Taxa de mortalidade em excesso no inverno e índice de excesso de mortalidade por causas externas de lesão e envenenamento
Artigo II - *Evidence of social deprivation on the spatial patterns of excess winter mortality*	Taxa de mortalidade em excesso no inverno por doenças do aparelho circulatório
	Razão de mortalidade em excesso no inverno por doenças do aparelho circulatório
Artigo III - *Excess winter mortality and*	Taxa de mortalidade padronizada em excesso no inverno e índice de excesso de mortalidade por todas as causas de morte

Artigo	Indicadores calculados
morbidity before, during and after the Great Recession: the Portuguese case	Taxa de internamentos padronizada em excesso no inverno e índice de excesso de internamentos por todas as causas exceto causas externas de lesão e envenenamento e Complicações da gravidez, parto e puerpério
	Anos de vida potencialmente perdidos em excesso no inverno
	Esperança de vida sem óbitos em excesso no inverno
	Custos em internamentos em excesso no inverno
Artigo IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London. Implications for health promotion*	Taxa de mortalidade por óbitos atribuíveis ao frio

3.5.2 Modelos bayesianos espaciais de EMI (associação estatística com ambiente social e económico)

Para analisar a associação entre às condições socioeconómicas e o EMI foram utilizados modelos de regressão ecológica (Artigo II - *Evidence of social deprivation on the spatial patterns of excess winter mortality*), tendo sido analisada a associação estatística entre dois índices que representam os determinantes do ambiente social e económico (Índice de privação material e o Índice de privação habitacional), considerados como variáveis independentes, e o rácio de EMI por doenças do aparelho circulatório (variável dependente). Foram, assim, utilizados modelos condicionais auto-regressivos como distribuição *a priori* para efeito espacial aleatório (Santana et al., 2015a).

De modo semelhante ao efetuado por Goerre et al. (2007), Kysely et al. (2009) ou Vasconcelos et al. (2013), por exemplo, optou-se por analisar este grupo de causas de morte devido à forte associação estatística entre a exposição ao frio e as doenças do aparelho circulatório; associação suportada pela reação biológica do corpo humano à exposição ao frio. Vários investigadores têm vindo a optar por utilizar metodologias semelhantes para avaliar a associação estatística entre variáveis com forte componente espacial (Nogueira & Santana, 2005; Nogueira, 2010; Santana et al., 2015a).

Devido à instabilidade associada aos pequenos números, são frequentemente encontrados, em municípios com menor população, valores extremos de óbitos em excesso (observados e estimados[1]), traduzindo-se em resultados que poderão não corresponder à magnitude do problema em análise. Para ultrapassar esta limitação e obter resultados mais estáveis, foi aplicado um modelo hierárquico Bayesiano, como o proposto por Besag et al. (1991):

$$O_i \sim Poisson\ E_i \theta_i$$

$$log\ (\theta_i) = \alpha + S_i + H_i$$

(Santana et al., 2015b)

Onde, para cada unidade *i*, O_i representa os casos observados, E_i os casos esperados, θ_i o risco relativo, $\propto$ a ordenada na origem, S_i *o* efeito espacial aleatório e H_i os efeitos heterogéneos não espaciais (Santana et al., 2015b).

A utilização desta metodologia considera, simultaneamente, o efeito aleatório espacialmente não estruturado e o efeito aleatório espacialmente estruturado de cada unidade territorial. Tratando-se de um modelo condicional autorregressivo, o valor de cada unidade resulta da população residente em cada unidade, da taxa observada na unidade em causa e da taxa observada nas unidades territoriais vizinhas (Johnelle Sparks et al., 2013). Esta conjugação de fatores permite identificar unidades com taxas anormalmente instáveis e corrigir essa instabilidade através da influência dos seus vizinhos (figura 9).

As condições socioeconómicas foram medidas através da construção de dois índices de privação, seguindo o método proposto por Carstairs e Morris (1990), tendo sido avaliadas as dimensões habitacional e material. O Índice de privação habitacional representa o resultado da aplicação da normalização de variáveis, através do Z-score, que indicam condições desfavoráveis de habitação: i) a proporção de edifícios de residência habitual construídos até 1960; ii) a proporção de alojamentos sem sistema de aquecimento; e iii) a proporção de edifícios com estrutura de alvenaria, pedra solta ou adobe. O Índice de privação material utiliza a mesma metodologia e inclui: i) a taxa de desemprego; ii) a proporção de trabalhadores manuais (grupos 6-9 da classificação internacional de profissões); e iii) a proporção de população residente com 15 e mais anos sem ensino secundário.

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[1] *Vide* secção de métodos no Artigo II - *Evidence of social deprivation on the spatial patterns of excess winter mortality* sobre o cálculo do rácio de EMI e sobre o cálculo do número estimado de óbitos em excesso

Detalhes metodológicos sobre os modelos estatísticos utilizados para avaliar as associações entre o Rácio suavizado de EMI e os índices e privação podem ser encontrados no Artigo II - *Evidence of social deprivation on the spatial patterns of excess winter mortality*.

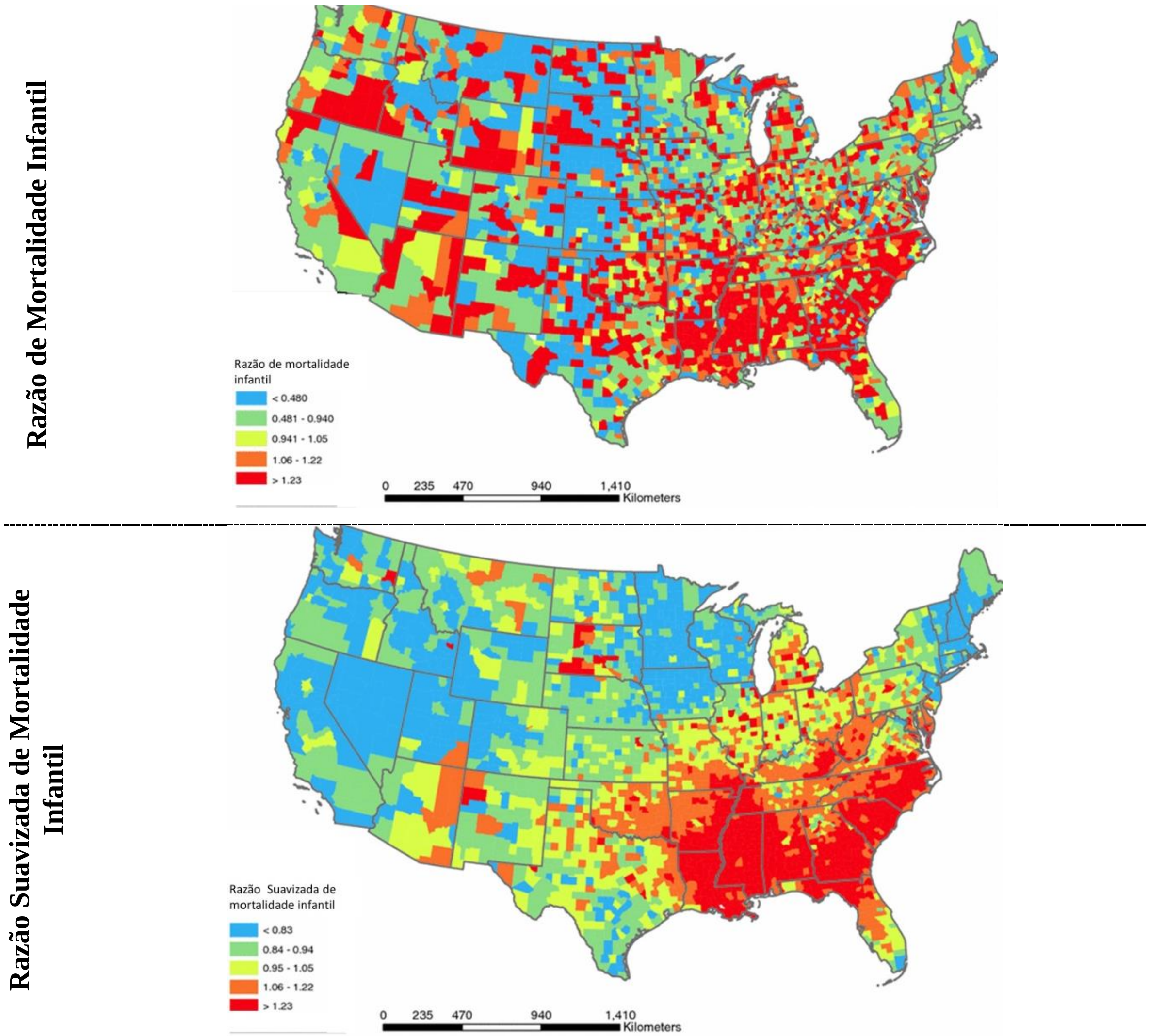

Figura 9. Exemplo de suavização espacial bayeseana.

Fonte: Adaptado de Johnelle Sparks et al. (2013).

3.5.3 Análise de séries temporais da mortalidade e morbilidade (associação estatística com variáveis do ambiente natural)

Foram utilizados métodos de análise de séries temporais de dados ambientais para avaliar o impacto da temperatura (Artigos IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London* e V - *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon*) e dos padrões da Oscilação do Atlântico Norte na mortalidade e morbilidade (VI - *The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon*).

Esta tipologia de métodos é frequentemente utilizada para estudar a associação entre resultados em saúde e condições ambientais, como a temperatura ou poluentes atmosféricos (Armstrong, 2006). São vários os exemplos de trabalhos científicos, com destaque para autores portugueses (Ana Monteiro et al., 2013b; Burkart et al., 2013; Nogueira & Mateus, 2013; Vasconcelos et al., 2013; Bras et al., 2014) e europeus (Analitis et al., 2006; Vardoulakis & Heaviside, 2012; Rodopoulou et al., 2015; Gasparrini et al., 2017), que utilizam regressões de séries temporais para concretizarem objetivos semelhantes aos apresentados neste trabalho.

Nos Artigos IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London* e V - *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon* são utilizados modelos não lineares com desfasamento (*Distributed Lag Linear and Non-Linear Models*). A sua aplicação permitiu a identificação de limiares de temperatura, mínima e máxima, a partir do qual se regista um aumento significativo da mortalidade ou morbilidade, assumindo uma relação não linear com efeitos desfasados no tempo (Gasparrini, 2016). Apesar da sua complexidade, a aplicação deste tipo de modelos tem vindo a ser cada vez mais comum nos últimos anos, como por exemplo Gasparrini et al. (2017) ou Antunes et al. (2017).

A identificação do limiar mínimo de temperatura é uma etapa fundamental para o cálculo da *Population Attributable Fraction* e, através deste método, estimar o número de óbitos atribuível ao frio (Artigo IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London. Implications for health promotion*). A *Population Attributable Fraction* é uma medida epidemiológica, frequentemente utilizada em saúde pública para medir o impacto da exposição a determinadas condições, ou fatores adversos; representa a fração de óbitos (ou outro caso adverso) que pode ser atribuída a condições de exposição específicas (Hanley, 2001). No caso concreto do Artigo IV foi aplicada a seguinte equação para calcular a *Attributable Fraction* (AF):

$$AF = \frac{RR^{\Delta T} - 1}{RR^{\Delta T}}$$

(Steenland & Armstrong, 2006)

Onde ΔT corresponde à temperatura média diária abaixo do limiar térmico e RR corresponde ao risco relativo de mortalidade por cada grau de decréscimo da temperatura.

Apesar de ser conhecido o efeito acumulado que diversos determinantes do ambiente natural têm na saúde, a sua avaliação é complexa, sendo frequentemente utilizados métodos que incluem processos de mediação (Morello-Frosch et al., 2011; Sexton, 2012; Solomon et al., 2016).

Para compreender melhor a relação entre o frio e a morbilidade, o Artigo VI aplica modelos de mediação causal (*causal mediation analysis*). Esta opção metodológica permite analisar o possível efeito indireto da variável *X* na variável *Y* através de *M* (figura 10). Neste Artigo são avaliados os possíveis efeitos indiretos do padrão espacial da Oscilação do Atlântico Norte (*X*) nos internamentos hospitalares (*Y*) através de medidas de conforto térmico e de poluentes atmosféricos (CO, $PM_{2.5}$, O_3, NO, NO_2, SO_2, ou $PM_{10,}$), enquanto mediadores (*M*).

A avaliação de possíveis efeitos indiretos tornou-se bastante comum em vários campos da ciência, com destaque na saúde pública, na epidemiologia ou nas ciências sociais, porque permite quantificar relações causais[2] específicas (Lange et al., 2017).

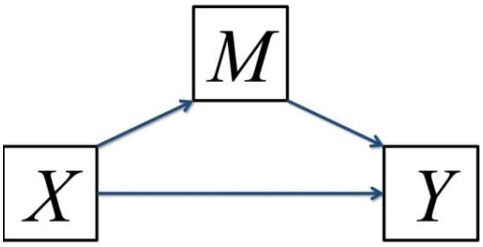

Figura 10. Representação esquemática de um modelo de modelação causal simples.

Fonte: Adaptado de Lange et al. (2017).

[2]O termo “causal” é utilizado aqui em sentido estrito, reportando-se à terminologia relativa ao método em causa (Lange et al., 2017).

4. Resultados

4.1 Introdução ao capítulo

Este capítulo contém as seis publicações que fazem parte desta dissertação.

Os Artigos I - *Seasonal mortality patterns and regional contrasts*, II - *Evidence of social deprivation on the spatial patterns of excess winter mortality* e III - *Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case* respondem aos primeiros três objetivos desta dissertação identificando: i) as causas de morte com maior variabilidade sazonal (Artigo I) e os padrões espaciais do excesso de mortalidade e de internamento no inverno (Artigo I, II e III); ii) as condições socioeconómicas associadas ao excesso de mortalidade no inverno (Artigo II); e iii) apresentando estimativas de custos sociais e económicos do excesso de mortalidade e de internamento no inverno (Artigo III e IV) (figura 11).

Os Artigos IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London*, V - *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon* e VI - *The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal*. Respondem ao quarto objetivo avaliando o impacto das condições meteorológicas na saúde, o número de mortes atribuíveis ao frio (*cold related deaths*) em três áreas metropolitanas europeias (Artigo IV), os efeitos da temperatura na saúde mental (Artigo V) e a influência da Oscilação do Atlântico Norte nas doenças do aparelho circulatório (Artigo VI), apresentando uma alteração na escala de análise (Área Metropolitana de Lisboa)

O objetivo 5 inclui a identificação de minimização ou de mitigação dos efeitos do frio na saúde, sendo tratado na discussão dos resultados dos 6 artigos que constituem os resultados desta dissertação.

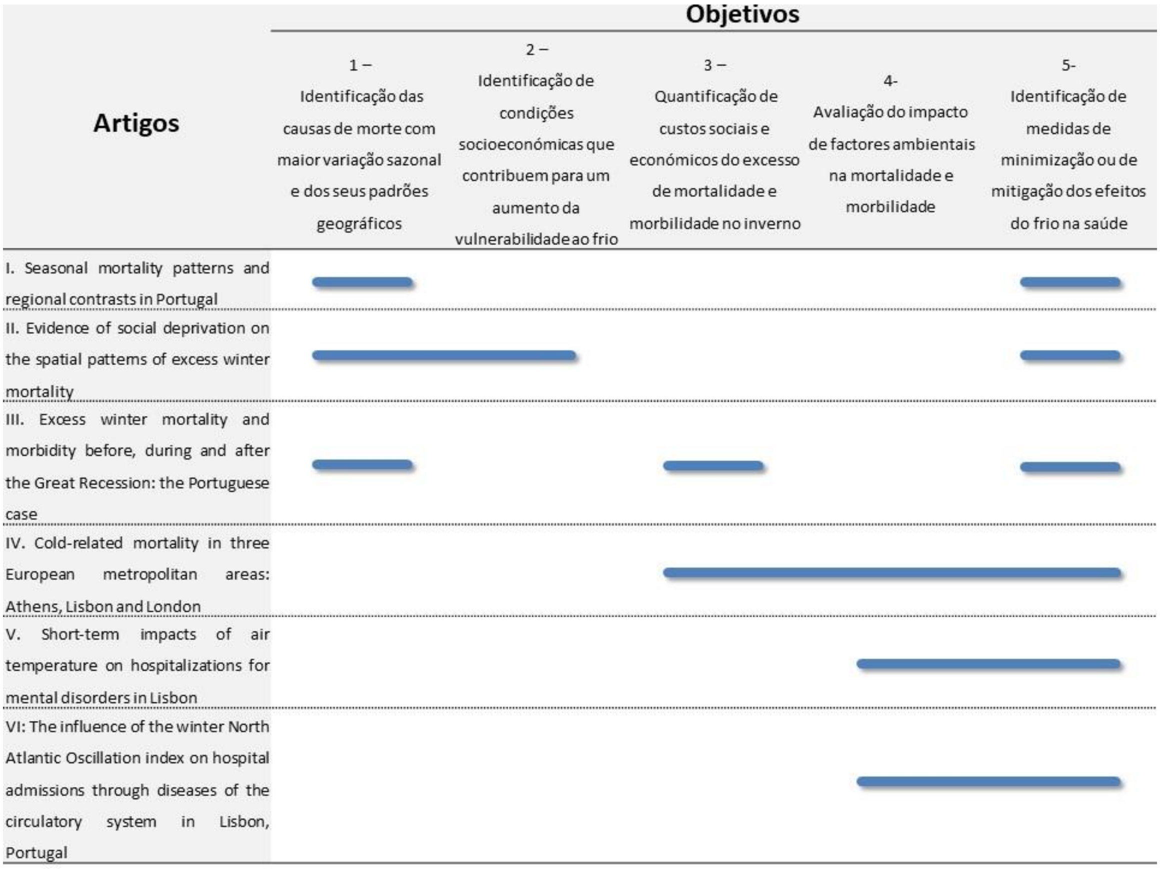

Figura 11. Representação esquemática da organização dos artigos e correspondência com os objetivos da dissertação

4.2 Artigo I - Seasonal mortality patterns and regional contrasts in Portugal

Bulletin of Geography. Socio–economic Series / No. 32 (2016): 7–17

ISSN 1732–4254 quarterly

BULLETIN OF GEOGRAPHY. SOCIO–ECONOMIC SERIES
journal homepages:
http://www.bulletinofgeography.umk.pl/
http://wydawnictwoumk.pl/czasopisma/index.php/BGSS/index
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Seasonal mortality patterns and regional contrasts in Portugal

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How to cite:
Almendra, R., Santana, P., Freire, E. and Vasconcelos, J., 2016: Seasonal mortality patterns and regional contrasts in Portugal. In: Szymańska, D. and Chodkowska-Miszczuk, J. editors, *Bulletin of Geography. Socio-economic Series*, No. 32, Toruń: Nicolaus Copernicus University, pp. 7–18. DOI: http://dx.doi.org/10.1515/bog-2016-0011

Abstract. The main aim of this study is to identify the geographical seasonal mortality patterns in Portugal and, for the first time, to assess the relationship between seasonal and overall mortality. Monthly data from the Portuguese mortality database (2000-2009) by major cause of death were analysed and standardized to 30 days with adjustments for leap years. The chi-square goodness-of-fit test was used to compare the observed monthly deaths with deaths that could be expected if mortality were randomly distributed throughout the year. The seasonal burden was measured using the excess winter deaths (EWD) rate and the seasonal impact of winter on mortality was assessed through the EWD Index. The regions were clustered according to the overall mortality rate and the seasonal impact: 1–low seasonality and high values of overall mortality; 2–high seasonality and high values of overall mortality; 3–low values of seasonality and low overall mortality; 4–high seasonality and low overall mortality. Significant seasonal mortality increases were found in all causes of death. There were 86,000 EWDs, mostly through circulatory and respiratory diseases. 73% of the population lives in regions with high winter vulnerability to respiratory mortality and 60% in regions with high winter vulnerability to circulatory mortality. This study reinforces the idea that vulnerability to cold weather may play an important role in the public health in Portugal. This knowledge may be used to construct a set of regulations or policies designed to implement better health planning procedures and more effective warning systems.

Article details:
Received: 20 May 2014
Revised: 10 December 2015
Accepted: 22 February 2016

Key words:
winter mortality,
seasonal mortality,
respiratory diseases,
circulatory diseases,
Portugal.

Contents:

1. Introduction

The relationship between health and environment has long been studied, and there are no doubts that exposure to extreme temperatures increases the risk of morbidity and mortality (Bhaskaran et al., 2009; Kunst et al., 1991). However, the question of how ambient temperature influences health continues to be debated.

In Europe there is an apparent paradox regarding the geographical seasonal mortality pattern, as countries with mild winters have higher Excess Winter Death (EWD) rates than those with much colder climates (Eurowinter Group, 1997; Healy, 2003; Rau, 2006). This paradox suggests that seasonal mortality may be more associated with poor protection against cold weather than with the direct influence of harsh winter weather conditions (Aylin et al., 2001; Gemmell et al., 2000; Hajat et al., 2007; Vasconcelos et al., 2013).

The uneven distribution of environmental risk factors is also the result of inequalities in other social health determinants such as income, social status, employment and education, but also non-economic aspects such as gender, age or ethnicity. Therefore, seasonal mortality results more directly from socioeconomic and behavioral factors than from low temperatures. Considering this relationship, it is believed that, at least, some of the cold-related deaths can be avoided (Davie et al., 2007; McKee, 1989; Wilkinson et al., 2004).

Portugal is often described as the most vulnerable country to winter weather conditions in Europe (Healy, 2003), however, the seasonal burden is still overlooked and has not yet been systematically quantified or used to set any public policy. As a consequence, the influence of winter weather conditions in Portugal is generally underrated compared to the influence of summer heat.

According to Donaldson and Keatinge (1997), excess winter mortality decreased 17% from 1977 to 1994 in England; this trend is attributed to better general medical care and to the improvements in socioeconomic conditions that result in better adaptation to cold weather.

It would be expected that similar results could be found in Portugal as a consequence of the improvements experienced in the socioeconomic conditions until 2009. However, in a study analysing the trends of seasonal mortality due to diseases of the circulatory system in Portugal since 1990, Almendra et al (2015) did not find a significant reduction of excess winter mortality. In Portugal, being exposed to cold weather conditions seems to be accepted as an inevitable environmental consequence (Vasconcelos et al., 2011). Therefore, and as cold weather is still highly neglected, there are no policies to mitigate its effects nor there any systematic actions to identify the impact of cold weather upon health.

It is therefore of fundamental importance to understand the role of cold as a trigger factor for several diseases, and to assess the vulnerability to winter weather conditions in Portugal, in order to provide the necessary expertise to the stakeholders (e.g. urban planners, health and social protection authorities). The main aim of this paper is to identify the geographical seasonal mortality patterns in Portugal and to assess the relationship between seasonal and overall mortality.

2. Data and methods

This study uses monthly data from the Portuguese mortality database from 2000 until 2009. Cause-specific mortality was clustered according to the European shortlist causes of death (Classification of Diseases 10th revision): Infectious and parasitic Diseases (A00-B99); Malignant neoplasms (C00-C97); Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism (D50-D89); Endocrine, nutritional and metabolic diseases (E00-E89); Mental and behavioural disorders (F01-F99); Diseases of the nervous system and sense organs (G00-H95); Diseases of the circulatory system (I00-I99); Diseases of the respiratory system (J00-J99); Diseases of the digestive system (K00-K92); Diseases of the musculoskeletal system and connective tissue (M00-M99); Diseases of the genitourinary system (N00-N99); External causes of morbidity and mortality (V01-Y89). Deaths by month were standardized to 30-days with adjustment for leap years and analysed by region (NUT III) and country.

The chi-square goodness-of-fit test was used to compare the observed monthly deaths with deaths that could be expected if mortality were randomly distributed throughout the year (Alcorn et al., 2013). A winter/summer ratio was applied to assess the differences between summer and winter mortality: the ratio was calculated by dividing the number of winter deaths (December to March) by the number of deaths during summer (June to September).

The number of EWD and the EWD index were calculated according to Johnson and Griffiths (2003) in order to quantify the winter mortality burden. The number of EWD was calculated by comparing the number of deaths in winter months (December to March) with the average number in non-winter months (the previous August to November and the following April to July). The seasonal impact of winter was assessed through the EWD Index which was used to determine if the number of deaths during winter was higher than expected, when compared to the rest of the year. Thus, the EWD number is the amount of winter deaths that occurs above the average of the non-winter months of the year, while the EWD index is the proportion of the winter mortality increases.

To identify the regions where the impact of seasonal cold weather, as a trigger factor, was more pronounced, the *all-year* mortality rate (hereinafter referred to as overall mortality) and the seasonal impact were compared with the country average value. Following this process, four categories were established: 1 – high overall mortality and low seasonality; 2 – high overall mortality and high seasonality; 3 – low overall mortality and low values of seasonality; 4 – low overall mortality and high seasonality (Fig. 1). For instance, one region with higher overall mortality than the country average and with higher EWD index than the country average would be clustered in the second group of regions.

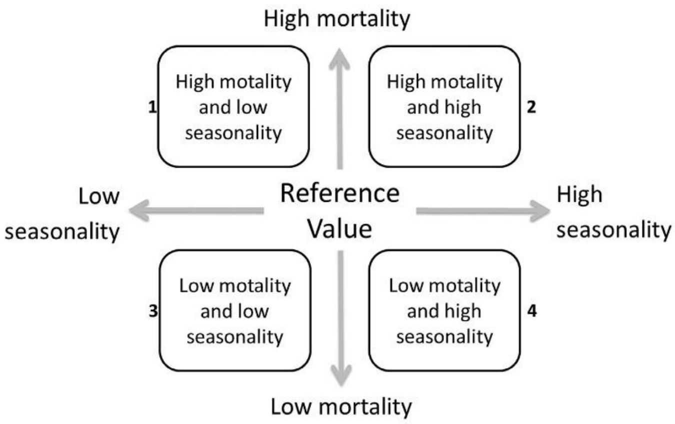

Fig. 1. Classification according to the overall and seasonal mortality
Source: Own elaboration

3. Results

3.1. Seasonal mortality in Portugal

All main causes of death had significant monthly variations (p<0.005), and the group All causes had significant seasonal increase in every year of the decade (p<0.001) (Table 1).

According to the winter/summer ratio, the winter mortality increased in all causes of death, except for the external causes. The respiratory (winter/summer ratio: 1.76) and circulatory (winter/summer ratio: 1.46) diseases showed a higher seasonality having the highest differences between winter and summer. The external causes had a slight summer increase (winter/summer ratio: 0.96), and the malignant neoplasms had a very low winter increase (winter/summer ratio: 1.05).

Attending to all causes of death, there were 85,952 EWD (8% of all mortality). The respiratory (18,116) and circulatory diseases (39,972) were the main responsible causes of death for this toll, representing about 70% of all excess winter mortality.

The mortality for all causes increased 27% in winter; again, the highest increase was among the respiratory (64%) and circulatory (37%) diseases, although the endocrine, nutritional and metabolic diseases and the nervous system diseases had winter increases over 30%.

Table 1. Seasonal mortality by cause (2000-09)

Cause of death (ICD 10)	Number of deaths	Chi-Square Goodness-of-Fit Test	Winter / / summer	EWD	EWDI (%) (95% CI)
All causes	1,053,425	*p<0.005*	1,32	85,952.4	27.2 (26.7; 27.7)
Certain infectious and parasitic D.	23,356	*p<0.,005*	1,07	581.6	7.8 (4.9; 10.8)
Malignant neoplasms	227,522	*p<0.005*	1,05	3,080.3	4.2 (3,3; 5.1)
D. of the blood and blood-forming organs and certain disorders involving the immune mechanism	2,719	*p<0.005*	1,22	160.1	19.1 (10.2; 28.9)
Endocrine, nutritional and metabolic D.	48,821	*p<0.005*	1.41	4,950.3	34.6 (32.1;37)
Mental and behavioural disorders	4,278	*p<0.005*	1.29	322.9	24.9, (17.4;33)
D. of the nervous system	23,283	*p<0.005*	1.36	2,188.3	31.8 (28.3;35.3)
D. of the circulatory system	372,157	*p<0.005*	1.46	39,971.9	36.9 (36;37.8)
D. of the respiratory system	104,295	*p<0.005*	1.76	18,115.6	64.4 (62.4;66.5)
D. of the digestive system	45,178	*p<0.005*	1.21	2,533.5	18.2 (15.9;20.5)
D. of the musculoskeletal system and connective tissue	2,513	*p<0.005*	1.35	221.4	29.6 (19.5;40.5)
D. of the genitourinary system	24,346	*p<0.005*	1.32	2,148.8	29.6 (26.3;33)
External causes of morbidity and mortality	49,427	*p<0.005*	0.96	-	-

Source: Own elaboration based on data from the Statistics Portugal

3.2. Regional patterns of mortality due to diseases of the circulatory and respiratory systems and all causes

Regional mortality patterns can be identified in Portugal, both in mortality by all causes and in mortality due to diseases of the circulatory and respiratory systems; inland regions tend to have higher overall mortality rates than regions near the coast line (Fig. 2).

3.3. Regional patterns of excess winter mortality

Winter mortality increases were recorded throughout the country, however, the seasonal burden varied remarkably across regions and by cause of death.

The EWD rate through circulatory diseases varied from 248 to 742 deaths per million inhabitants, the highest results were in the inland and southern regions, while the lowest were recorded in the coastal areas. The winter burden due to respiratory diseases ranged from 122 to 399 deaths per million inhabitants, the northern and inland regions tended to have higher EWD rates (Fig. 3).

The EWD index due to diseases of the respiratory system varied from 42% to 91%, the worst results were registered in the North and inland regions. Regarding the circulatory diseases, the EWD index ranged from 21% to 48%, the regions in the central part of the country tended to have lower results, even though a clear pattern was not identified (Fig. 4).

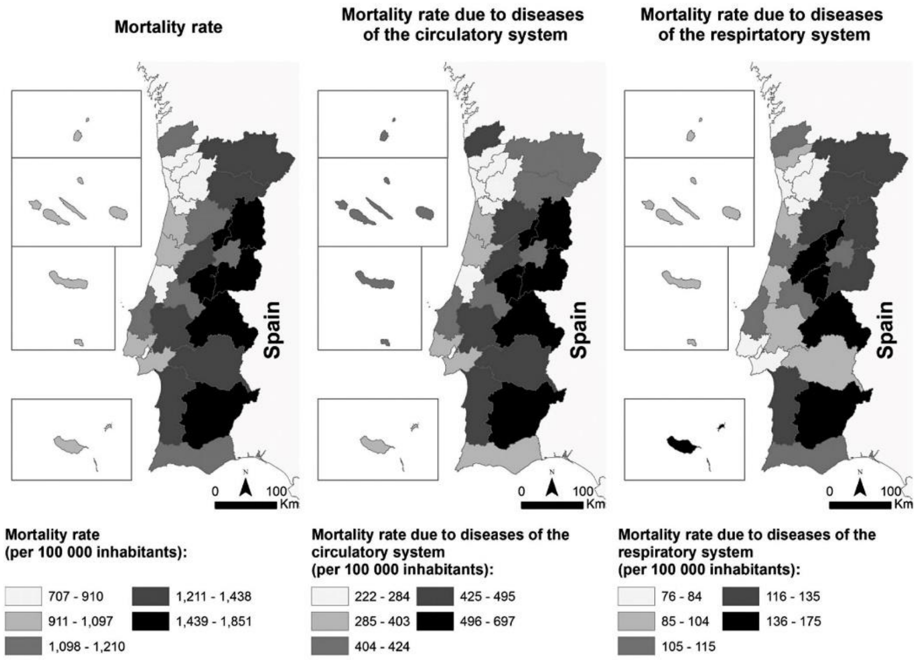

Fig. 2. Mortality rates due to diseases of the circulatory and respiratory systems and all causes

Source: Own elaboration based on data from the Statistics Portugal

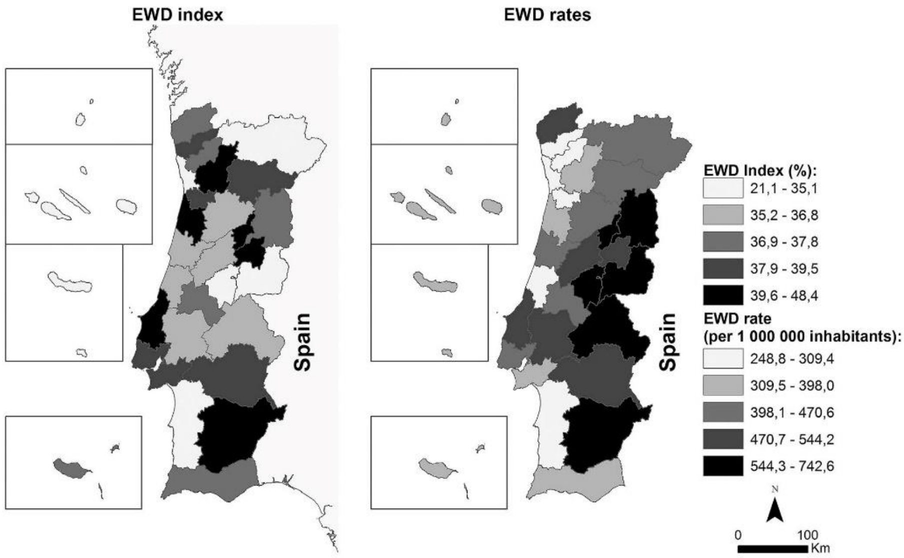

Fig. 3. Diseases of the circulatory system

Source: Own elaboration based on data from the Statistics Portugal

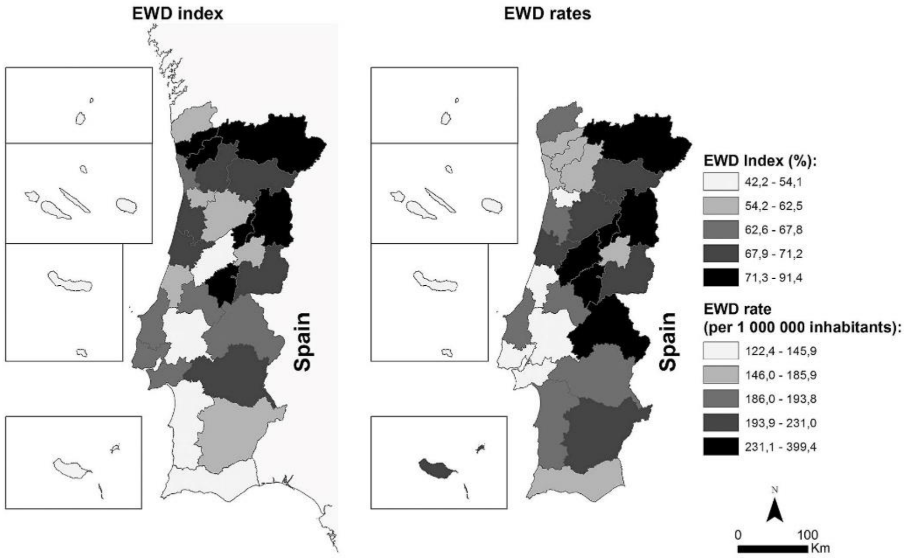

Fig. 4. Diseases of the respiratory system

Source: Own elaboration based on data from the Statistics Portugal

3.4. Relationship between seasonal mortality and overall mortality

Most of the regions classified as being prone to both high mortality and seasonality were inland regions (Fig. 5). It was found that about 34% of the country population lives in regions with high mortality and high seasonality due to circulatory diseases, and about 22% due to respiratory diseases (Table 2). On the contrary, only about 20% of the population lives in regions with low mortality and seasonality vulnerability to the circulatory diseases and 5% of respiratory diseases. Furthermore, most of the population lives in regions with high seasonality and low cause-related mortality (25.5% due to circulatory and 52.9% due to respiratory diseases).

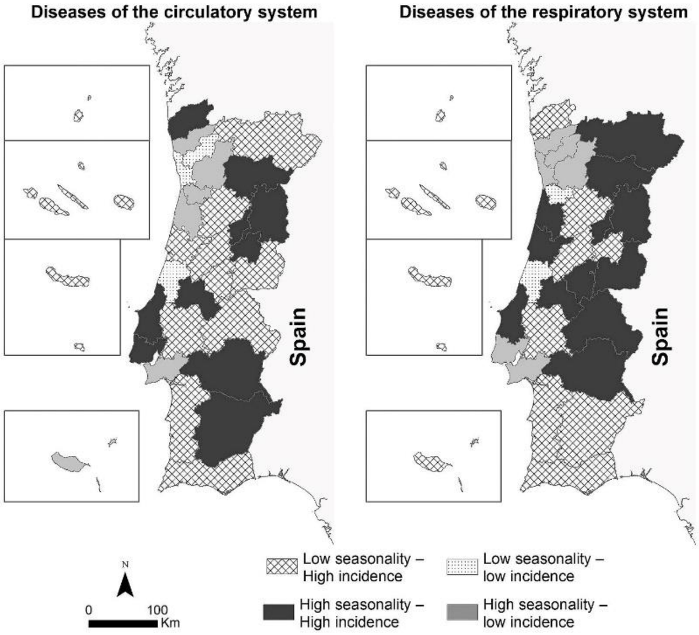

Fig. 5. Classification according to overall and seasonal mortality

Source: Own elaboration based on data from the Statistics Portuga

Table 2. Proportion of population living and number of regions in each vulnerability class

Seasonality | incidence	Circulatory		Respiratory	
	population	regions	population	regions
+ | +	34.1%	10	21.5%	12
+ | -	25.5%	6	52.9%	6
- |+	20.8%	3	20.3%	10
- | -	19.6%	11	5.3%	2
Total	100%	30	100%	30

Source: Own elaboration based on data from the Statistics Portugal

4. Discussion

Seasonal patterns of mortality and morbidity are a well-known phenomenon in many regions and countries worldwide (Burkart et al., 2011)which to a certain extent can be considered as mid-to long-term influences of meteorological conditions. In addition to atmospheric effects, the seasonal pattern of mortality is shaped by non-atmospheric determinants such as environmental conditions or socioeconomic status. Understanding the influence of season and other factors is essential when seeking to implement effective public health measures. The pressures of climate change make an understanding of the interdependencies between season, climate and health especially Portugal has a seasonal mortality pattern similar to other European countries which is marked by a winter increase (Rau, 2006). In Portugal, since 2000 to 2009, about 86000 excess winter deaths were recorded (accounting for a seasonal increase of 27%). Portugal has the worst results in Europe, with even higher excess winter mortality than the other Mediterranean countries (Eurowinter Group, 1997; Healy, 2003; Rau, 2006) age structure, and influenza epidemics confound comparisons of cold-related increases in mortality between regions with different climates. The Eurowinter study aimed to assess whether increases in mortality per 1 degree C fall in temperature differ in various European regions and to relate any differences to usual winter climate and measures to protect against cold. Percentage increases in deaths per day per 1 degree C fall in temperature below 18 degrees C (indices of cold-related mortality.

Although the seasonal mortality pattern is related to weather conditions, there are several non-atmospheric factors, such as cultural, behavioral and socio-economic aspects that play a major role in explaining the winter increase in mortality (Healy, 2003; Rau, 2006). Surprisingly, countries with mild winters face higher excess winter mortality than those with harsh weather conditions (Eurowinter Group, 1997). It is acknowledged that in these countries there is a better adaptation to cold, both physiological and social (Hajat et al., 2007); people living in colder climates are less vulnerable to cold, they wear warmer clothes and know how to protect themselves better (Burkart et al., 2011)which to a certain extent can be considered as mid-to long-term influences of meteorological conditions. In addition to atmospheric effects, the seasonal pattern of mortality is shaped by non-atmospheric determinants such as environmental conditions or socioeconomic status. Understanding the influence of season and other factors is essential when seeking to implement effective public health measures. The pressures of climate change make an understanding of the interdependencies between season, climate and health especially important. Thus, it means that at least part of the excess winter death could be avoidable, and so the seasonal mortality increase should be considered an important public health issue.

In Portugal, the winter mortality peak results mainly from the winter increases of respiratory and circulatory diseases (together they represent 70% of all EWM). The respiratory diseases had the strongest seasonal increase, but, as they are not the main cause of death, the highest EWD toll was in the circulatory system diseases. This pattern was also found in other European countries such as France (Boulay et al., 1999), the Netherlands (Kunst et al., 1991), Spain (Ballester-Díez et al., 1997), England (Lawlor et al., 2000)and if this were so preventive interventions could be directed at populations in these areas. The association between deprivation and excess winter mortality has not been adequately investigated in the past. The aim of this study was to look at the association between excess winter mortality and socio-economic deprivation, so that policy decisions to reduce this excess mortality could be appropriately directed. Super Profile groups derived from the 1991 Census were used as a measure of socio-economic status. The age-standardized excess winter death index (EWDI, New Zealand (Davie et al., 2007), Denmark (Rau, 2006), among others. In fact, the exposure to cold causes several biomedical reactions in the human body; it can lead to vasoconstriction or haemoconcentration, which increases the risk of death due to a circulatory system disease (Eurowinter Group, 1997; Keatinge, 2002). The winter mortality increases through respiratory diseases are generally attributed to the adverse effects of cold on the immune system's resistance to infections and to the fact that low temperatures assist survival of bacteria in droplets (Eurowinter Group, 1997). The several biological factors are inter-related, there is a relationship between respiratory infection and myocardial infarction or strokes (Clayton et al., 2011).

The seasonality (expressed by the EWD index) and the winter burden (expressed by the EWD rate) have different geographical patterns in Portugal. In regions with low overall mortality, the EWD rate will always be small, but, as the EWD index varies according to the distribution of death over the year, it is not influenced by the overall mortality. The spatial patterns of the EWD rate and the overall mortality rate have a strong positive association. This association may suggest that the determinants of the disease can also be important variables to explain the geographical pattern of the EWD rate. Unhealthy behaviours (e.g. alcohol consumption, smoking, sedentary habits, stress, diet), socioeconomic conditions (e.g. poor housing, low education, low income) and biological characteristics (e.g. sex, age) are often described as increasing the risk of disease. Therefore, the role of cold weather, as a trigger factor for several diseases, is more important within the more vulnerable population groups.

The seasonal patterns are more difficult to explain; it is obvious that temperature and thermal comfort are two very different parameters, being the last more important to explain the winter seasonal increase. The exposure to cold is strongly related to socioeconomic factors and behavior (Gemmell et al., 2000) but the extent of how these factors contribute to the seasonal mortality is unclear (Davie et al., 2007); Healy (Healy, 2003) documented the consequences of poverty, deprivation and fuel poverty on the increase of cold exposure; Aylin et al. (2001) stressed the importance of using central heating; similarly, Ballester (2003) pointed the improvements in housing conditions as a significant protective measure; also Goodwin (2000) highlighted the adoption of adequate behaviors and appropriate clothing to protect from cold.

To identify the regions where it is critical to intervene, the EWD index and the overall mortality should be addressed together. Only by combining them it is possible to identify the appropriate measures and policies to mitigate this public health issue. The expected health gains from the application of protective measures and policies designed to tackle the impacts of cold weather are greater in regions with high mortality and seasonality (where the exposure to cold weather is an important trigger factor), and where intervention is a priority. The regions with high mortality and low seasonality should be monitored carefully, because as the vulnerability to the disease is higher; even a small increase in the vulnerability to cold weather could have a strong impact on the number of EWD. The regions with low seasonality are somehow protected from seasonal factors, but since Portugal is a country with the highest seasonal increase in Europe, this assumption of low seasonality must be put into perspective (table 3).

Table 3. Synthesis table

Mortality| Seasonality	Relation between seasonality and mortality
+ | +	High mortality and seasonality. The risk factors of the disease and the seasonality are combined. The cold is an important trigger factor
- | +	Low mortality and high seasonality. There is high vulnerability to seasonal risk factors but some level of protection from the disease. The impact of cold as a trigger factor is less important because of the lower incidence.
+ | -	High mortality and low seasonality. High vulnerability to the disease, but the winter increase is not higher. However, as the incidence is higher, one small increase in cold exposure can represent an important seasonal burden
- | -	Low mortality and low seasonality. This combination suggests that there seems to be some protection from the risk factors of the disease and seasonality.

Explanation: "+" - overall mortality and/or seasonality higher than the country level; "–" - overall mortality and/or seasonality lower than the country level

Source: Own elaboration

Limitations of the study

This study has some limitations. The access to monthly mortality data was only possible without age disaggregation, thus not allowing for the calculation of standardized indexes. Therefore, these results are not controlled for differences in age distributions.

5. Conclusion

This research has studied the seasonal mortality patterns in Portugal. There were important winter increases in mortality, mainly in circulatory and respiratory diseases. Important regional differences were observed in the EWD rate and index (inland regions tend to have higher EWD rate and EWD index). The amount of EWD is related to the determinants of the disease, but the seasonality is not fully explained by those factors. These results highlight the seasonal burden and the vulnerability to cold as an important determinant of health in Portugal, where winter weather conditions are generally underrated compared to summer heat.

EWD can be successfully prevented, or at least decreased, through proper policies and interventions. Cold-related policies, aiming to reduce the exposure to cold weather conditions, should be considered in environmental health programs and should be part of health promoting policies. In some countries, such as Scotland and the UK, exposure to cold weather has been acknowledged as a public health priority and policies were set to improve housing conditions and combat fuel poverty. In Portugal similar measures could also contribute to decreasing the number of EWD; however, further research is still needed to better understand the regional disparities and the ways in which socioeconomic conditions influence the vulnerability to cold weather.

Acknowledgements

The authors would like to thank the referees for their very helpful comments. This research was developed within the framework of the "CLIMAHABS" and "Geography of health status – An application of a Population Health Index in the last 20 Years – GeoHealthS projects funded by FCT (Fundação para a Ciência e Tecnologia).

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4.3 Artigo II - Evidence of social deprivation on the spatial patterns of excess winter mortality

Int J Public Health (2017) 62:849–856
DOI 10.1007/s00038-017-0964-7

ORIGINAL ARTICLE

Evidence of social deprivation on the spatial patterns of excess winter mortality

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Received: 19 May 2016 / Revised: 20 February 2017 / Accepted: 22 February 2017 / Published online: 30 March 2017

Abstract
Objectives The aims of this study are to identify the patterns of excess winter mortality (due to diseases of the circulatory system) and to analyse the association between the excess winter deaths (EWD) and socio-economic deprivation in Portugal.
Methods The number of EWD in 2002–2011 was estimated by comparing the number of deaths in winter months with the average number in non-winter months. The EWD ratio of each municipality was calculated by following the indirect standardization method and then compared with two deprivation indexes (socio-material and housing deprivation index) through ecological regression models.
Results This study found that: (1) the EWD ratio showed considerable asymmetry in its geography; (2) there are significant positive associations between the EWD ratio and both deprivation indexes; and (3) at the higher level of deprivation, housing conditions have a stronger association with EWD than socio-material conditions.
Conclusions The significant association between two deprivation dimensions (socio-material and housing deprivation) and EWDs suggests that EWD geographical pattern is influenced by deprivation.

Keywords Excess winter deaths · Socio-economic deprivation · Environmental vulnerability

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Introduction

In recent decades, social determinants of health have emerged as key aspects to understanding population health (Mahamoud et al. 2013). It is believed that community health and well-being are the result of several socio-economic factors that influence the conditions in which people live, grow, work, and interact with others (Santana 2002; Marmot et al. 2008; Monteiro et al. 2012).

The same is valid for the field of environmental health, where socio-economic conditions influence the level at which people are exposed to environmental risk factors. The uneven exposure to harmful environmental conditions often results from inequities in social health determinants, such as income, social status, housing conditions, employment, and education, or from biological aspects, such as gender, age, and ethnicity (World Health Organization 2010).

A clear example of a health problem that results from the exposure to environmental risk factors and that is ultimately associated with the inequity of social health determinants is the seasonal variation of mortality.

The seasonal variation is 'driven' by the effect of temperature on human health (Gemmell et al. 2000). According to Analitis et al. (2008), in a study analyzing the effect of cold temperatures conducted in 15 European cities, decrease of 1 °C in air temperature was associated with a 1.35% increase in the daily number of total natural deaths.

The influence of cold weather in the human health clearly triggers the seasonal mortality patterns and, however, is the population's ability (or lack of it) to protect themselves against low temperatures that determines one's vulnerability to cold weather (Gemmell et al. 2000). Healy (2003) studied the conditions that enhance the vulnerability to cold winter weather in Europe and was able to

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establish a relationship between socio-economic conditions and excess winter mortality. In Europe, higher excess winter mortality rates are generally found in countries with less severe winter climates, where there should be less potential for cold strain and cold-related mortality. This pattern is usually referred as the "paradox of excess winter mortality". Portugal has the highest seasonal variation in mortality, which, according to the same study, may be related to socio-economic factors, such as poor housing conditions, poverty, income, inequality, deprivation, and fuel poverty.

Much debate still remains around the determinants of excess mortality during cold weather and how to avoid it (The Marmot Review Team 2011). Despite Healy's (2003) strong findings when performing cross-country comparisons, several other studies did not find evidence suggesting that excess winter mortality increases with socio-economic deprivation, at either the individual or small area level (Lawlor et al. 2000; Aylin et al. 2001; Maheswaran et al. 2004; Davie et al. 2007).

The winter increase in mortality varies considerably among countries, and even between regions of the same country, reflecting the complexity of the interactions between people, their biological, social and cultural characteristics, behaviour, and other determinants of health status (Carson et al. 2006; Hajat et al. 2007; Hales et al. 2012).

Regardless of this complexity, it is believed that most temperature-related deaths are theoretically avoidable (Carson et al. 2006; Davie et al. 2007), and not an environmental inevitability. The built environment is a potential modifiable factor that affects one's vulnerability to harmful temperatures (Hales et al. 2012), and effective building insulation and proper heating systems can contribute to reducing one's exposure to adverse temperatures (Braubach and Fairburn 2010). Cold housing and fuel poverty are recognized determinants of excess winter mortality characterized by a social gradient: lower income families are more likely to be at risk (Rudge and Gilchrist 2007; The Marmot Review Team 2011). Appropriate behavioral attitudes against cold exposure, both indoor (e.g., use of indoor heating) as well as outdoor (e.g., use of adequate clothing), can play an important role in tackling the issue of vulnerability to cold weather conditions (Vasconcelos et al. 2011; Fowler et al. 2015).

The human body reacts when exposed to cold weather, increasing the likelihood of thrombosis and blood clotting (Pell and Cobbe 1999). When exposed to cold temperatures, the human body reduces its blood flow to the peripheral parts of the body and overloads the central organs, which increases blood viscosity by around 20% and the concentration of red cells, white cells, platelets, cholesterol, and fibrinogen by around 10% (Keatinge 2002).

Most excess winter deaths are caused by cardiovascular, cerebrovascular, and respiratory diseases, and if all the circulatory diseases are combined together, they represent about two-thirds of all excess winter mortality (Rau 2006; Almendra et al. 2016a). Different causes of death, such as cancer or suicide, show a different pattern and have a lower winter increase (Gemmell et al. 2000) or an increase in spring months (Woo et al. 2012), respectively.

Portugal is still described as the country with the highest excess winter mortality in Europe (Almendra et al. 2012; Fowler et al. 2015) and despite the improvements in living conditions and health care which have led to significant health gains over the last 20 years (e.g., life expectancy, infant mortality, and premature mortality), cold weather vulnerability, and excess winter mortality is not showing any signs of decrease (Nogueira et al. 2006; Alcoforado et al. 2015; Almendra et al. 2015, 2016b).

The social determinants of health regarding the excess winter mortality are still not fully studied and may be the key to tackling avoidable mortality associated with the exposure to cold weather. Thus, the aims of this study are to identify excess winter mortality patterns (due to diseases of the circulatory system) and to assess the possible association between the EWD ratio and socio-material and housing deprivation indexes in Portugal.

Methods

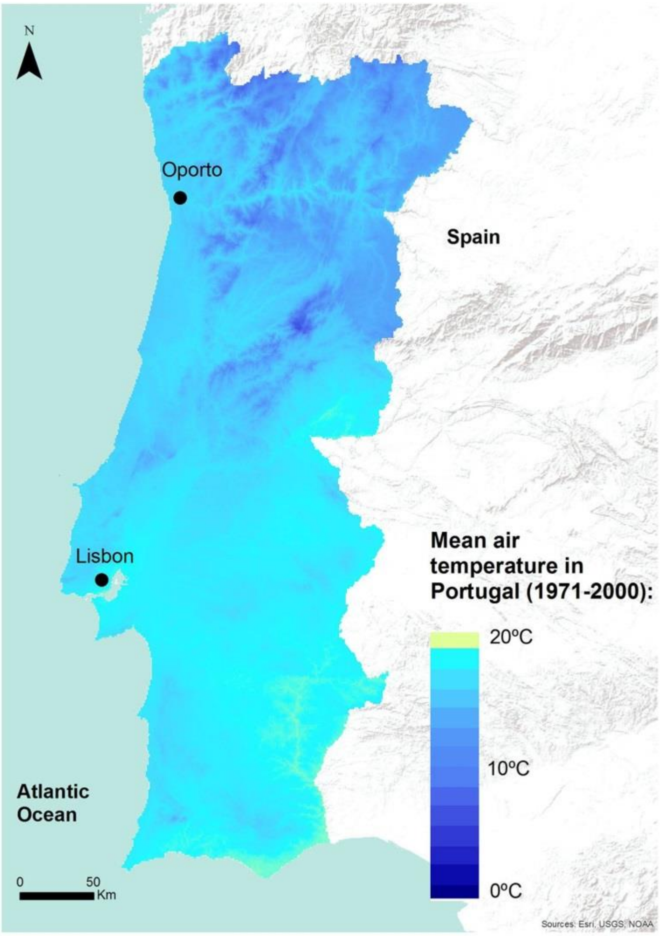
Mainland Portugal (hereafter referred to as Portugal) is located in Western Europe and, according to the Köppen–Geiger classification, has a typical Mediterranean climate with mild, wet winters and warm, and dry summers (Csa in the South and Csb in the North). Average yearly temperatures tend to be higher in the southeast and lower in the north and centre (Fig. 1).

Portugal consists of 278 municipalities. According to the 2011 census, Portugal has nearly 10 million inhabitants with an average population density of 113 hab/km^2 (it varies between 5 and 7363 hab/km^2). Lisbon and Oporto are the two most populous cities; the metropolitan areas together account for nearly 4.5 million inhabitants.

Excess winter deaths ratio

To estimate the number of EWD in Portugal due to diseases of the circulatory system (ICD 10: I00-I99), monthly death from 2002 until 2011 was used (available from Statistics Portugal). EWD were computed using the standardized monthly deaths (Davie et al. 2007) and then following the method proposed by Johnson and Griffiths (2003), which compares the number of deaths in winter months (December–March) with the average number in non-winter months (the previous August–November and the following April–July):

Fig. 1 Annual average mean temperature in Portugal, 1971–2001 (normal climate data are provided via the climate web portal of the Portuguese Meteorological Institute's web map service)



$$\text{EWD} = \text{Winter deaths} - \frac{\text{Non-winter deaths}}{2}$$

Once the number of EWD was found, the EWD ratio was calculated for each municipality following the indirect standardization method (Naing 2000). The "expected" number of deaths was estimated by applying the Portuguese EWD rate to the resident population of each municipality (available at the national statistics office). The EWD ratio results from the division of the number of observed deaths by the number of expected deaths. Municipalities with an EWD ratio of 100 have the same number of EWDs as Portugal; values above 100 imply higher EWDs than expected, and the opposite for values below 100.

Deprivation indexes

To assess the conditions that may affect the vulnerability to cold weather, two deprivation indexes were calculated for 2011: socio-material deprivation index and housing deprivation index. The first includes (1) unemployment rate, (2) proportion of workers with manual occupations-groups 6–9 of the European Union variant of International Standard Classification of Occupations, and (3) proportion of resident population with 15 and more years under upper secondary education level. Housing deprivation index, includes: (1) the proportion of conventional dwellings of usual residence constructed until 1960; (2) proportion of housing units without a central heating system; and (3) proportion of buildings whose structure is of mortared masonry walls, adobe, earth, timber, or metal.

The deprivation indexes were constructed according to the Carstairs and Morris method (Carstairs and Morris 1990), where the indicators forming each index were standardized (through the z-score method) to have a weighted mean of 0 and a variance of 1 and aligned in order that higher values represent more deprivation. The scores are summed up to form the composite deprivation index, where higher values mean higher deprivation, and 0 represents the average of all municipalities.

Statistical analysis

Excess winter deaths (observed and estimates) are dependent on population size; thus, municipalities with low population tend to present high variance of results. To overcome this feature, the hierarchical Bayesian model proposed by Besag et al. (1991) was used. This process provides smoothed EWD ratio (sEWDR) and the probability of higher risk (sEWDR significantly higher than Portugal). This method has already been successfully used in previous ecologic studies (Mari-Dell'Olmo et al. 2015; Santana et al. 2015a, b).

The statistical association between the sEWDR and the deprivation indexes (categorized into quintiles) was tested through ecological regression models, assigning an intrinsic conditional autoregressive prior distribution to the spatial effect, while the heterogeneous effect was represented using independent normal distributions (Santana et al. 2015a). A half-normal distribution was assigned to the standard deviations and a vague prior distribution was assigned to the explanatory variables. INLA library (version 3.0.1) and the R statistical package (version R.2.15.2) were used to perform these tests (Santana et al. 2015a).

To evaluate the relative risk (RR), deprivation indexes were categorized into quintiles, and the RR estimates were then obtained based on their posterior means, along with the corresponding 95% credible intervals (CI).

Results

In the 10 years studied, 350,000 deaths due to circulatory system diseases were recorded, corresponding to 35% of all mortality in Portugal. On average, there were 35,412 deaths in the winter months, 27% more than in non-winter months (25,809).

There is an uneven distribution of the excess winter mortality across the country with a strong geographical pattern: municipalities located in the coastal area tend to have lower ratios of excess winter deaths than the inland regions (Fig. 2). Two-thirds of the municipalities have sEWD ratio above 100 and the probability of having more excess winter mortality than Portugal is higher ($\geq$0.80) in 164 (60%) municipalities.

Different patterns were found between the socio-material and housing deprivation index ($R^2=0.1$; $p=0.3$; p value <0.05) (Fig. 3). The socio-material deprivation index has a pattern characterized by better conditions in the central and southern coastal municipalities and worse conditions in the municipalities located in the Northwest and Southeast. The housing deprivation index has a different geography: housing conditions tend to be worse in southern municipalities than in the northern ones.

A significant positive association between excess winter mortality and the deprivation indexes (both socio-material and housing) was found (Fig. 4). Municipalities with higher deprivation have higher RR of excess winter mortality: the Q5 of socio-material deprivation has 71% (CI 45–100%) higher probability of having higher excess winter mortality and the Q5 for housing deprivation has 82% (CI 50–119%).

Discussion

This study aimed to identify excess winter mortality patterns through diseases of the circulatory system and to assess the relationship between EWD and socio-material and housing deprivation indexes at the municipality level in Portugal (2002–2011). This research found that: (1) the sEWD ratio through diseases of the circulatory system showed considerable asymmetry in its geography; (2) there are significant positive associations between the sEWD ratio and socio-economic deprivation indexes (both socio-material and housing deprivation indexes); and (3) at the higher level of deprivation, housing conditions have stronger association with EWD than socio-material conditions.

The sEWD ratio varies between 39.3 (municipalities with fewer than half the EWDs than the national average) and 343.1 (municipalities with three times more EWDs than the national average) and tend to be lower for the coastal and northern municipalities. If temperature were the only factor responsible for excess winter mortality, lower values would be expected in the southern municipalities. International studies have also found important regional disparities that cannot be explained only by temperature, suggesting the importance of social health determinants to explain regional contrasts (Eurowinter Group 1997; Healy

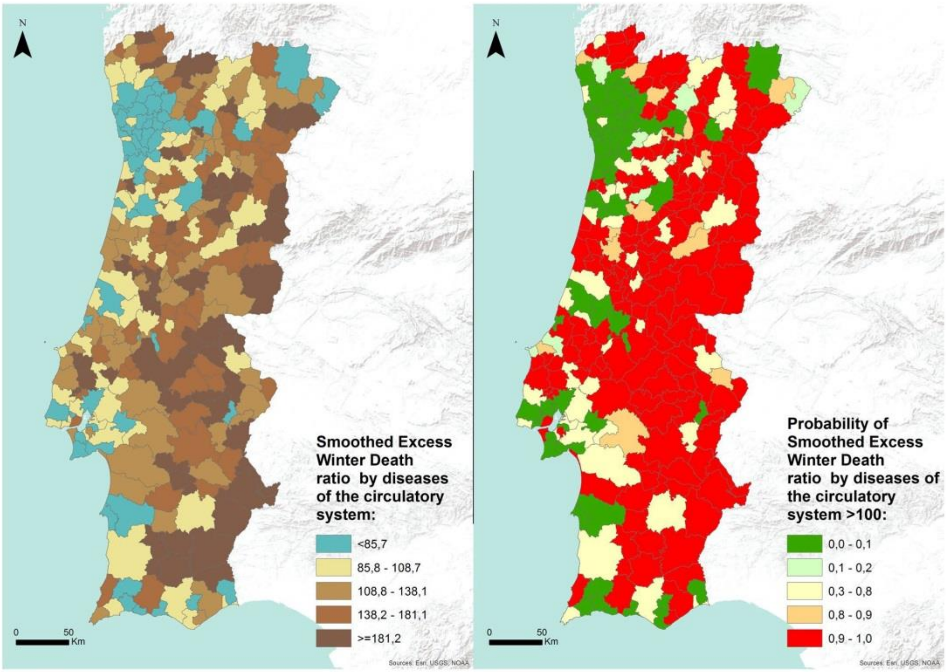


Fig. 2 Smoothed excess winter death ratio by diseases of the circulatory system and probability of smoothed excess winter death ratio higher than 100 in Portugal, 2002–2011

2003; Davie et al. 2007; Analitis et al. 2008; Fowler et al. 2015).

Higher levels of socio-material and housing deprivation levels are significantly associated with higher excess winter mortality. The association found between the socio-material and housing deprivation indexes and excess winter mortality was expected (Healy 2003; Hales et al. 2012), although not always found. At the small area level, several studies did not find relationship between socio-economic deprivation and excess winter mortality (Lawlor et al. 2000; Aylin et al. 2001; Maheswaran et al. 2004; Davie et al. 2007).

At the lower deprivation quintiles (Q2, Q3), socio-material conditions show a stronger association to excess winter mortality than the housing conditions. At the higher level of deprivation (Q5), housing conditions have a stronger association to EWD. This result can be related to the poor housing conditions found in Portugal, where 22% of the population lives in housing with leaking roofs or damp walls, floors or foundations, or with rot in window frames or floors (the European average is 15%) (Rybowska and Schneider 2011), and where 89% of the dwellings do not have central heating and 12% do not have any kind of heating system whatsoever (Statistics Portugal 2016).

Poor housing conditions (e.g., houses with poor insulation, leaking roofs) are often the cause of thermal discomfort, since more effort, energy, and money are required to provide the house with a satisfactory heating regime (Rudge and Gilchrist 2005; Marmot et al. 2008). Households in fuel poverty are defined as those spending more than 10% of their income on heating to maintain an appropriate indoor temperature (The Marmot Review Team 2011). Fuel poverty is driven by three main factors: (1) household income; (2) the current cost of energy; and (3) the energy efficiency of the home. Often, the more deprived groups face these three main factors simultaneously, increasing their exposure to cold temperatures and, therefore, increasing their vulnerability (Howieson and Hogan 2005; Marmot and Bell 2012).

The perception of risk is known to be influenced by complex psychological, socio-economic, and cultural processes (Bickerstaff 2004), and this notion is of particular importance when analyzing cold-related health impacts in

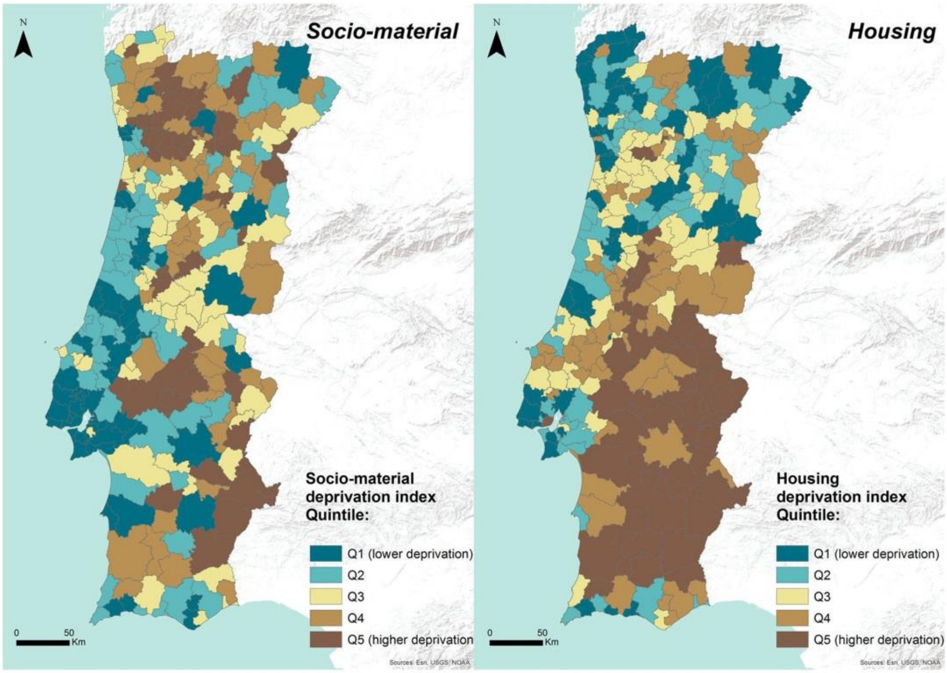


Fig. 3 Socio-material and housing deprivation index in Portugal, 2011

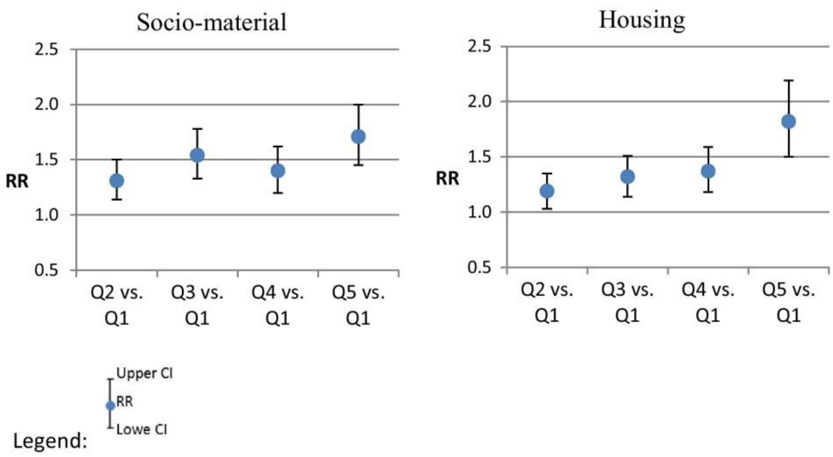


Fig. 4 Excess winter death rate ratios between the first deprivation index quintile and the others deprivation quintiles in Portugal

a country often described by its warm summers and mild winters and where the media mostly focus on heat-related health effects. Vasconcelos et al. (2011), in a study conducted in Portugal on in-patients with acute coronary syndrome, mentioned that 26% of the patients only had one heating device and half of them did not use it in the previous winter. These results simultaneously demonstrate the difficulty in obtaining proper heating and the lack of awareness as to the effects of exposure to the cold.

EWDs are an easy way to measure the outcome of cold exposure (Howieson and Hogan 2005), although it masks important social costs (e.g., cost of prescriptions, medical consultations and absenteeism, and energy waste).

Strengths and limitations

One of the aims of this study was to find possible relationships between socio-economic conditions and the risk of EWD for the first time in Portugal. The results obtained are important contributions which have increased our understanding of vulnerability to cold weather conditions and may help to design adequate measures. Nonetheless, the existence of statistical associations between the characteristics of places of residence (municipalities) and sEWDr should be carefully interpreted in terms of causality (Jokela 2014).

Despite the strong association between vulnerability to cold weather and age, it was not possible to calculate age-standardized mortality rates due to constraints involving the availability of data. Thus, excess winter mortality may be overestimated in more aged municipalities.

Deprivation indexes were calculated based on 2011 census data, but mortality data cover the period between 2002 and 2011. Although data availability did not allow further deprivation measures between 2002 and 2011, the geographical pattern, between the last two censuses, remains similar.

In addition, due to data constraints, it was not possible to analyse the relationship between EWD and socio-economic deprivation at the neighbourhood level. This would have been of great interest in the two major metropolitan areas.

In future studies, different dimensions of deprivations must be addressed.

Conclusions

This research has studied seasonal mortality in Portugal at municipal level and found a significant association between two deprivation dimensions (socio-material and housing deprivation) and EWDs.

Our findings suggest that EWD spatial variations are related to deprivation. Thus, the vulnerability to seasonal cold weather could be tackled by the reduction of exposure to the cold through the improvement of socio-material and housing conditions. Mitigation policies should also include measures to improve housing quality (e.g., insulation) in existing and new buildings, as well as those under renovation. In municipalities with higher excess winter mortality, vulnerable groups should be alerted to the dangers of exposure to the cold and advised on how to protect themselves more efficiently (i.e., low budgets insulation measures and more efficient heating systems).

Despite these findings, much debate still remains to be held on the role of socio-economic determinants to cold weather vulnerability, and further studies addressing these issues are needed.

Acknowledgements This research was conducted within the FCT doctoral fellowship SFRH/BD/92568/2013, supported by the European Regional Development Fund, through the Operational Competitiveness Program and partly supported by the CEGOT group Cities, competitiveness and well-being (UID/GEO/04084/2013).

Compliance with ethical standards

Funding This study was funded by FCT doctoral fellowship SFRH/BD/92568/2013 and by CEGOT group Cities, competitiveness, and well-being (UID/GEO/04084/2013).

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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4.4 Artigo III - Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case[3]

[3] A versão originalmente submetida ao jornal encontra-se disponível no anexo I

International Journal of Biometeorology (2019) 63:873–883
https://doi.org/10.1007/s00484-019-01700-6

ORIGINAL PAPER

Excess winter mortality and morbidity before, during, and after the Great Recession: the Portuguese case

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Received: 26 July 2018 / Revised: 7 February 2019 / Accepted: 18 February 2019 / Published online: 7 March 2019

Abstract

Although winter mortality and morbidity are phenomena common to most European countries, their magnitude varies significantly from country to country. The geographical disparities among regions with similar climates are the result of several social, economic, demographic, and biological conditions that influence an individual's vulnerability to winter conditions. The impact of poor socioeconomic conditions may be of such magnitude that an economic recession may aggravate the seasonal mortality pattern. This paper aims to measure the seasonal winter mortality, morbidity, and their related costs during the Great Recession (2009–2012) in mainland Portugal and its Regional Health Administrations (RHAs) and to compare it with the periods preceding and following it. Monthly mortality and morbidity data were collected and clustered into three periods: Great Recession (2009–2012), Pre-Recession (2005–2008), and Post-Recession (2013–2016). The impact of seasonal winter mortality and morbidity during the Great Recession in Portugal and its Regional Health Administrations was measured through the assessment of age-standardized excess winter (EW) death and hospital admissions rate and index, expected life expectancy gains without EW deaths, EW rate of potential years of life lost, and EW rate of emergency hospital admission costs. Important increases of winter deaths and hospital admissions were identified, resulting in an important number of potential years of life lost (87 years of life lost per 100,000 inhabitants in 2009–2012), life expectancy loss (1 year in 2009–2012), and National Health Service costs with explicit temporal and spatial variations. These human and economic costs have decreased consistently during the analyzed periods, while no significant increase was found during the Great Recession. Despite its reduction, the winter excess morbidity and mortality highlight that Portugal still faces substantial challenges related to a highly vulnerable population, calling for investments in better social and health protection.

Keywords Excess winter mortality · Excess winter morbidity · Great Recession · Economic crisis

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Abbreviations

RHA	Regional Health Administrations
EW	Excess winter
NHS	National Health Service
LVT	Lisboa e Vale do Tejo
PYLL	Potential years of life lost

Background

The monthly distribution of mortality throughout the year—i.e., the so-called seasonal behavior—is well-known, and is generally characterized by a winter peak, often referred to as excess winter (EW) mortality (Dimitriou et al. 2016). A relationship between socioeconomic conditions and excess winter mortality is often found (Healy 2003). The impact of poor socioeconomic conditions may be of such magnitude that an

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economic recession may aggravate the seasonal mortality pattern.

Most of EW mortality is related to diseases of the circulatory and respiratory system (Rau 2004; Antunes et al. 2017). Exposure to low temperatures can have severe biological consequences, producing changes in blood pressure, causing vasoconstriction, and increasing the levels of plasma fibrinogen and cholesterol (Mercer 2003; Sartini et al. 2016), while the inhalation of cold air is related to higher risk of bronchitis, pneumonia, and acute exacerbation of chronic lung diseases (Ou et al. 2013). The consequences of the exposure to harmful weather conditions are greater in older people (Rudge and Gilchrist 2005; Benmarhnia et al. 2014) where the overlapping of biological and social fragility is frequent.

Despite being common to most European countries, the EW mortality spatial pattern is heterogeneous (Keatinge 1997). In regions with harsher winters, individuals may benefit from a better protective attitude towards cold weather and a better adapted built environment; therefore, despite the evidence of the biological effects of cold on human health, the fact that the seasonality of the diseases is more evident in areas with mild climate suggests that EW mortality is strongly associated with socioeconomic determinants (Davie et al. 2007). Healy (2003) identified a positive association, at country level, between EW mortality and income measures, such as estimated gross domestic product based on purchasing power parity.

Portugal is one of the European countries with higher EW mortality (Healy 2003; Fowler et al. 2015; Liddell et al. 2016); the seasonal mortality patterns are often characterized by important winter increases (Pinheiro 1990; Freire 1996; Nogueira and Paixão 2007; Almendra et al. 2016, 2017). Among the conditions most often referred to justify geographical differences in the vulnerability to winter cold weather are those related to poverty and its consequences, such as deprivation (Healy 2003; Almendra et al. 2017), poor housing conditions (Healy 2003; Almendra et al. 2017), fuel poverty (Hajat et al. 2006), or limited access to healthcare services (Hales et al. 2012).

Portuguese social and economic structures were among the most hardly shaken by the Great Recession, which, in accordance with the technical definition of recessions (two quarters of negative growth), lasted from 2009 to 2011. Those years of economic recession had severe consequences, such as strong unemployment increases (from 8.8% in 2008 to 15.8% in 2012) (Perelman et al. 2015), loss of purchasing power, and important emigration flows (136,615 registered emigrants between 2009 and 2012). In 2011, with the introduction of the Economic Adjustment Programme, an agreement to implement several reforms, the often mentioned "austerity measures," was established to reduce public expenditures (including those in the National Health Service (NHS)) (European Commission 2014). It has been mentioned that this bail-out program might have had important impacts on healthcare provision, leading to increasing health inequalities, barriers to access to health services, especially for vulnerable groups, such as the elderly (Doetsch et al. 2017).

Also, it may be hypothesized that the deterioration of socioeconomic conditions and greater impoverishment of the population most likely contributed to an aggravation of an individual's vulnerability to cold weather given how they change the complex combination of physiological, social, and cultural adaptation factors to harmful temperatures (Hales et al. 2012; Benmarhnia et al. 2014): hence, the drop in income during the Great Recession could have influenced the ability to intervene in the environment where people live (e.g., inability to improve the housing conditions or keep them warm), and the NHS cuts may be affecting the utilization of hospital services (Perelman et al. 2015). Regardless of economic circumstances, biological vulnerability may also be growing due to the aging trend of Portuguese population.

The assessment of the health impacts of the Great Recession is an important topic among Public Health researchers (Perelman et al. 2015; Tapia Granados and Rodriguez 2015). However, the results obtained seem to be somehow contradictory, varying from the identification of significant harmful consequences of the economic recession in healthcare provision (Legido-Quigley et al. 2016) and health outcomes (Benmarhnia et al. 2014), in particular those related to mental health (Karanikolos et al. 2013; Frasquilho et al. 2015), to some "protective effect," particularly in mortality indicators (Regidor et al. 2014; Tapia Granados and Rodriguez 2015).

The impact of the economic crisis in the seasonal mortality pattern was addressed in Spain by Benmarhnia et al. (2014), but a study assessing the EW mortality and morbidity toll in Portugal is still missing, despite being recognized as one of the European countries with higher EW mortality. Thus, this paper aims to (i) measure the seasonal winter mortality, morbidity, and its related costs during the Great Recession (2009–2012) in mainland Portugal and its Regional Health Administrations (RHAs) and (ii) compare it with the 4-year period that preceded (2005–2008) and followed it (2013–2016).

Data and methods

Study area

Mainland Portugal (hereafter referred to as Portugal) is located in Western Europe (Fig. 1) in a transitional region between the subpolar depression zones in north and the sub-tropical anticyclone area in the south. Mean monthly air temperature values vary regularly during the year, reaching their maximum in August and minimum in January. According to the

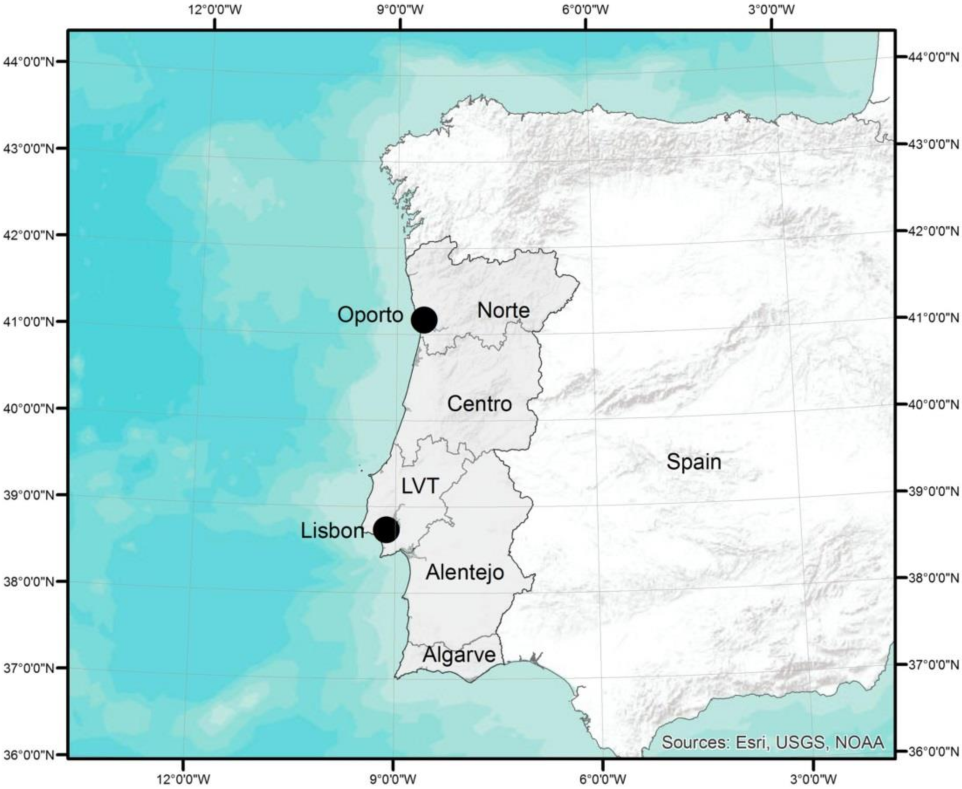

Fig. 1 Location of the study area

Köppen–Geiger classification, it has a typical Mediterranean climate with mild, wet winters, and warm and dry summers (Csa in the South and Csb in the North). During the period under analysis, nine winters were colder than normal and three warmer; 2016 was the warmest winter and 2005 the coldest (the years represented by the dots cluster information of January and February months and December from previous year) (Fig. 2).

In accordance with the Statistics Portugal, Portugal has a population of nearly 10 million, the majority of which lives in the coastal area and the two most populous cities, Lisbon and Oporto, which account for 4.5 million inhabitants.

Decree-Law 11/93 of 15 January indicates that the Portuguese National Health Service is organized in five RHAs (Norte, Centro, Lisboa e Vale do Tejo (LVT), Alentejo, and Algarve), which are legally distinct entities, executing their own functions of planning, distribution of resources, administration and coordination of activities, human resources management, technical, and administrative support. However, the Portuguese NHS is very centralized so that RHAs have in practice little autonomy. The RHAs were used in this study because they reflect relevant socio-demographic differences within the country.

In 2011, Alentejo was the region with highest aging index (189.2) and Norte with the lowest (114.1); the number of official public hospitals beds per inhabitant was largest in Centro (3.2) and lowest in Algarve (1.9); LVT had the highest upper secondary education rate (43.8%) and Norte the lowest (33.2%).

Data

To assess the magnitude of EW seasonal mortality and morbidity by RHA monthly mortality and hospital admissions, data was collected. Mortality data is collected

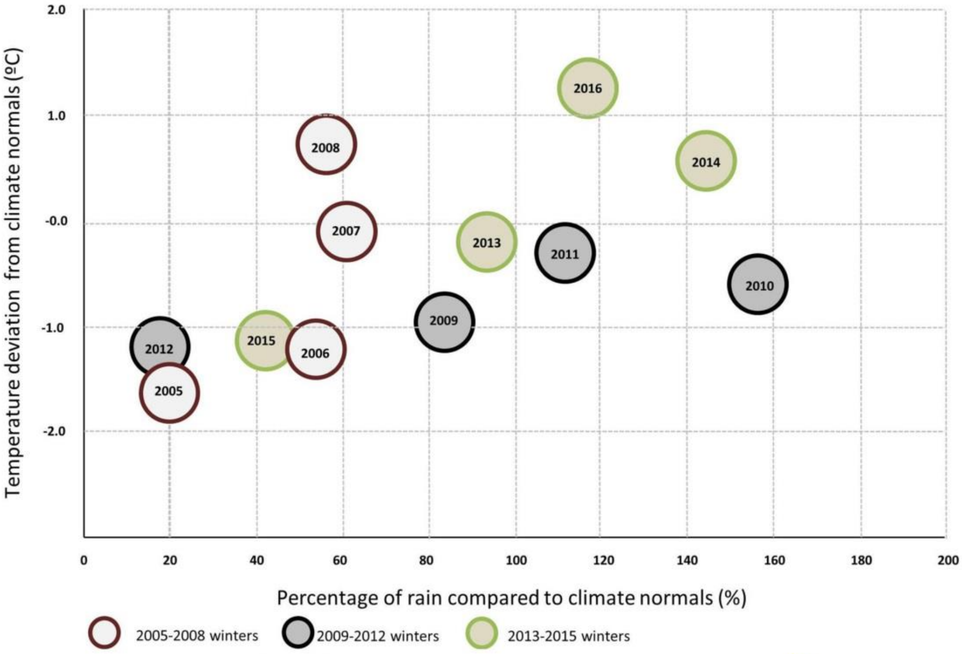

Fig. 2 Winter temperature and precipitation deviation from climate normal (2005 to 2015 winters). Adapted from IPMA (2018)

by the National Statistics Institute according to European Standards. Morbidity data is reported by public hospitals to the Central Administration of the Health System. The Central Administration of the Health System of the Portuguese Ministry of Health collects administrative and clinical data of all admissions to National Health hospitals, which covers almost the whole resident population of mainland Portugal (Froes et al. 2013). When the patient leaves the hospital, the admission record is created and classified according to national norms (e.g., diagnosis cause is attributed, release status, DRG group).

The number of deaths by all causes (International Classification of Diseases (ICD) 10: A00-Y89) was obtained from Statistics Portugal, and the number of emergency hospital admissions (all hospital admissions that are not planned in advance) in public hospitals (ICD9: 001-629; 760-E99 and ICD 10: A00-N99; P00-Y89) by all causes, except conditions related with pregnancy, childbirth, and puerperium, from the Central Administration of the Health System. Twelve years of data were collected and clustered into three 4-year periods: (i) Great Recession (2009–2012), (ii) Pre-Recession (2005–2008), and Post-Recession (2013–2016) (Table 1).

Methods

The number of EW deaths was calculated following the method proposed by Johnson and Griffiths (2003), which compares the number of winter deaths (December to March) with the average number of deaths in non-winter months (April to November). Monthly data were collected and normalized into standard 30-day months by multiplying the monthly number of deaths and emergency hospital admissions by the quotient resulting from the division between 30 and the number of days in the correspondent month. According to the Office for National Statistics (Office for National Statistics 2017), the EW death index is the ratio between the number of EW deaths and the average of non-winter deaths, multiplied by 100; it expresses the percentage of extra deaths that occurred in winter. The emergency EW hospital admissions number and index were estimated following the same method. The age-standardized EW death (hospitalizations) rate is calculated as a weighted average of the age-specific EW mortality (hospitalizations) rates per 100,000 persons, where the weights are the proportions of persons in the corresponding age groups of the European standard population.

The measurement of potential years of life lost (PYLL) is one of the most frequently used measures for monitoring the

Table 1 Number of deaths and hospital admissions by period

Time periods	Total number of deaths	Total number of hospital admissions
2005–2008	397,430	1,791,328
2009–2012	400,961	1,819,880
2013–2016	410,602	1,843,110

health of a population (Parrish 2010). It expresses the number of years that, theoretically, an individual will not live in the event of a premature death (deaths before reaching age 70); it differs from the standardized death rate, presented before, in that it assigns more weight to deaths occurring at younger ages (Mackenbach et al. 2013). The PYLL was calculated by multiplying the sum of the deaths in each age group by the number of years theoretically remaining (until reaching age 70). In the same way that this measure is calculated to measure the burden of specific causes of death, it can also be used with EW deaths. The excess winter PYLL rate is the quotient between average winter and non-winter PYLL.

Regular life tables summarize population mortality behavior, providing measures of longevity or life expectancy (Carey 1989) that are used to evaluate the general health status of a population (Santana and Nogueira 2001). The application of multiple decrement life tables allows the estimation of the likelihood of dying if the specific cause of death was reduced or eliminated (Preston et al. 2001) and, therefore, quantify the impact of that cause in life expectancy. To estimate the potential life expectancy gains if EW mortality would be reduced, multiple decrement life table was calculated as proposed by Macken and Chiang (1986) and Preston et al. (2001).

Rudge and Gilchrist (2007) state that addressing the impacts of cold on health through morbidity provides a different understanding of the phenomenon as it allows for the assessment of costs to and winter pressures on health services. Every hospital admission is clustered in a diagnosis-related group (DRG); each one has an official surcharge based on the pathology and complexity of treatment. Therefore, the costs of EW hospital admissions can be proxied by (1) identifying the number of EW hospitalizations in each DRG and (2) assigning to each EW hospital admission the prices defined by law (Ordinance 839-A/2009 (for 2005–2008), Ordinance 839-A/2009 (for the Great Recession period), and Ordinance 234/2015 (for 2013–2016)). This estimation did not consider the length of stay for the patients. The impact of the costs with EW hospital admissions was addressed by the rate of EW hospital admissions costs in the total hospitalizations costs.

All indicators were calculated for the entire country, for each of the three periods, and then replicated for each RHA, in order to evaluate within-country disparities and their trend.

Data availability Availability of data and material: Mortality datasets analyzed during the current study are available in National Statistics (www.ine.pt).

Morbidity data that support part of the findings of this study are available from Central Administration of the Health System, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are, however, available from the Central Administration of the Health System upon request.

Results

Mortality

Four mortality measures were addressed to compare the EW mortality during the Great Recession (2009–2012) with the periods immediately before and after. In Portugal, winter deaths during the Great Recession were almost 30% higher than the number for non-winter mortality; this value was significantly (without overlapping confidence intervals) lower than that of the previous period and significantly higher than that of the following (EW death index in 2005–2008, 31.6%; 2009–2012, 29.0%; 2013–2016, 28.1%) (Fig. 3a). This decreasing trend was common to all regions, except for Alentejo, where the EW mortality index increased in both the 2005–2008 and 2009–2012 periods. The highest values were recorded in the North RHA.

Following the same tendency, the standardized EW death rate was lower during the Great Recession period than in the Pre-Recession period, and higher than in the following (110 EW deaths per 100,000 inhabitants in 2005–2008, 90 during the Great Recession period, and 80 in 2013–2016) (Fig. 3b). Important disparities were found between RHAs, where, generally, high values are found in the Norte and LVT Regions, and low values in Algarve Region. Through the three periods, regional disparities increased: RHA with lower values improved more than the regions with higher standardized EW deaths.

With a similar evolution, the rate of EW PYLL slightly decreased between the first and the last period; there were 93 years of life lost per 100,000 inhabitants in 2005–2008, 87 years in 2009–2012, and 88 in the last period (Fig. 3c). Despite this decrease, the ratio between EW PYLL and non-winter PYLL is increasing along the period under analysis (2005–2008, 9.9; 2009–2012, 10.9; 2013–2016, 12.6). Higher values were observed in the Alentejo and Norte RHAs, and lower values in the Algarve RHA.

In 2005–2008, the life expectancy in Portugal was 81.42 years; if the EW deaths would have been totally avoided, life expectancy would have theoretically been prolonged by nearly 1 year, reaching 82.39 years (Fig. 3d). Like the other mortality measures, the results suggest a decreasing trend where the Great Recession is the intermediate period. Alentejo is the RHA where the decrease of excess winter deaths would have higher impacts on health expectancy.

Morbidity

In winter months, there were approximately 10% more hospitalizations than in the non-winter period; the highest winter increase was recorded in 2005–2008 (11.2%) and has been decreasing since then (9.6% and 9.2% during the Great Recession and in 2012–2016, respectively) (Fig. 4a). The RHA values are very irregular, changing significantly between periods; the highest values were recorded in LVT (2005–2008), Norte (2009–2012), and Alentejo (2013–2016).

In Portugal, nearly 55,000 EW hospital admissions were recorded during the Great Recession period, corresponding to 157 excess winter hospital admissions per 100.000 inhabitants (Fig. 4b); this value is intermediate with the period before and after (181 and 141 excess winter hospital admissions per 100,000 inhabitants, respectively). The standardized EW hospitalization rate decreased in all regions, except in Alentejo.

During the Great Recession, the costs in terms of EW hospitalizations were at their lowest value. In 2009–2012, excess winter admission costs an additional 214 million euros, representing 4.4% of the total costs with hospital admissions. In 2005–2008, the cost estimation was of 226 million euros (4.7% of the total cost) and in 2013–2016 was of 227 million euros (5.9%) (Fig. 4c). The highest values were recorded in Algarve Region in 2013–2016, where nearly 7% of the total costs are due to EW hospitalizations. In 2009–2012, the estimation of EW hospitalizations costs per number of hospitalization was, on average, 2749 euros, being higher in Alentejo (2842 euros) and Algarve (3057 euros).

Discussion

Summary of findings

This study compares several measures of EW mortality and morbidity during the Great Recession (2009–2012) with the periods preceding and following. It identified important winter increases of deaths and hospital admissions resulting in an important amount of PYLL, life expectancy loss, and National Health Service costs with explicit temporal and spatial variations. These human and economic costs did not increase during the Great Recession, and, except for the EW hospitalization costs, a consistent decrease was found during the periods analyzed. Although common to all RHAs, the EW mortality and morbidity varies between regions. From the assessment of the EW mortality indicators, Norte and Alentejo RHAs were identified as having higher winter mortality burdens in all indicators. The morbidity indicator pattern is marked by higher variability: Centro shows higher winter increase of emergency hospitalizations; the standardized EW hospitalization rate is larger at Norte RHA; and Algarve has the highest cost with increased EW hospitalizations. The evolution of the RHA EW mortality and morbidity indicators is in conformity with country level patterns.

Comparison with previous work

Despite the decreasing trend, the winter excess mortality burden in Portugal is still extremely high. During the Great Recession period, the EW mortality index was 29%, while in England and Wales, according to the Office for National Statistics, it was almost half (16.8 in the winter of 2009/2010, 16.9 in 2010/2011, and 15.5 in 2011/2012); the magnitude of these values is in conformity with previous studies assessing excess winter mortality in Portugal (Healy 2003; Fowler et al. 2015; Almendra et al. 2016). Benmarhnia et al. (2014) found in a study addressing the seasonal mortality trends in the years before and after the Great Recession in Spain that the winter mortality increase was systematically more pronounced during the crisis than before the crisis. The measurement of the impact of winter mortality in life expectancy or the number of excess winter PYLL is not often estimated; therefore, the comparison of Portugal with other countries was not possible.

Evidence showed that excess winter morbidity and mortality resulted in additional pressure on hospitals, primary care settings, and other health services (NICE 2015). There were around 10% more emergency hospital admissions in the winter period compared with the average of non-winter months. This pattern of winter increase in hospital admissions was also found by several authors analyzing diseases of the respiratory and circulatory systems (Maheswaran et al. 2004; Rudge and Gilchrist 2005). The EW hospitalizations resulted in a cost increase of 4.5%, close to values found in Yorkshire and the Humber Region in the UK (Bland et al. 2015). The reduced EW hospitalization rate and costs during the economic crisis may result from the impact of the Economic Adjustment Programme on public hospital financing, which imposed severe budget cuts, possibly explaining the reduction of expenditures during that period.

Regional disparities are often found when addressing the impacts of seasonal winter mortality, even when assessing regions from the same country with similar climate (Hajat et al. 2006). The RHA differences found in this study are generally in accordance with the results from previous work

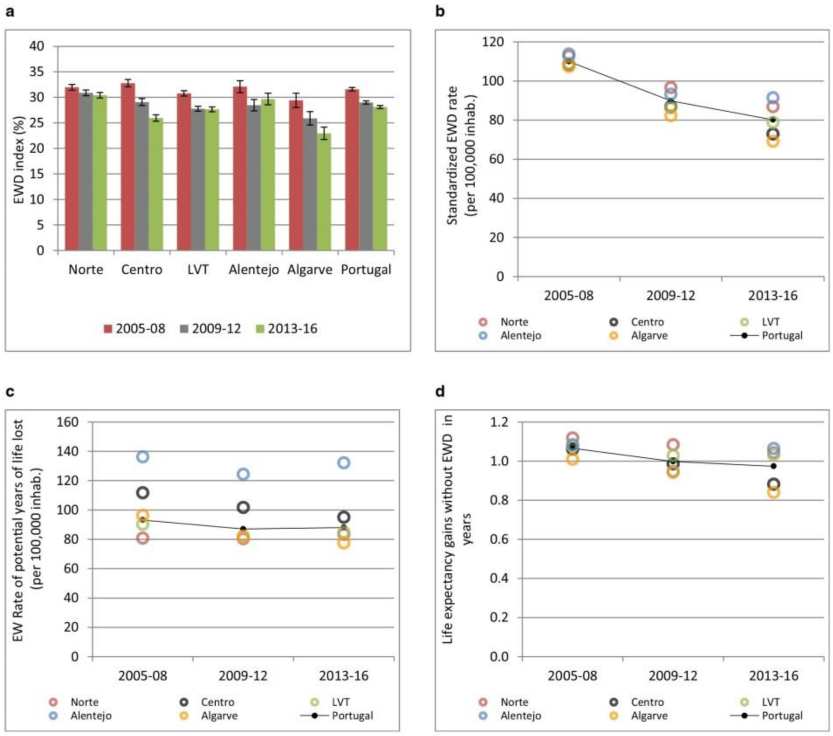

Fig. 3 Excess winter mortality measures by Regional Health Administration (**a**: Excess Winter Deaths index; **b**: Standardized Excess Winter Deaths rate; **c**: Excess Winter Rate id potential years of life lost; **d**: Life expectancy gains without Excess Winter Deaths)

assessing the geographical seasonal mortality patterns in Portugal (Almendra et al. 2016).

Factors influencing annual and regional variations

Similar to most European countries, Portugal is exhibiting a long trend in terms of mortality decrease. This evolution must be taken into account when considering certain mortality measures, such as the standardized EW mortality rates or PYLL, once it is possible that the observed decrease may be related to the long-term trend (Benmarhnia et al. 2014; Tapia Granados and Rodriguez 2015).

The inter-annual variation of EW mortality observed in this study may have been influenced by several environmental (e.g., winter temperature, air quality) and epidemiological (e.g., influenza) factors (Conlon et al. 2011; Phu Pin et al. 2012; Vestergaard et al. 2017), although according to Fowler et al. (2015), the relative influence of this factors is still to be estimated. This would require indeed microdata with information on lifelong exposure to adverse effects, which is far beyond the scope of this study.

The winters of 2005, 2006, 2012, and 2015 were classified as colder than the normal (between one and two degrees colder) and the winters of 2008 and 2016 as warmer than the normal (between half and two degrees warmer); normal is referred to as the climate normal of 1971–2000 (IPMA 2018). The influenza severity data are only available after 2007; the winters between 2009 and 2012 were marked by a high incidence rate of flu syndrome, and in the period after the Great Recession, only the winter of 2015 had high incidence rate (INSA 2017). Moreover, Monteiro et al. (2018) identified a significant improvement in air quality in Portugal, directly related to the reduction of energy consumption as a consequence of the economic crisis. The characterization of these factors may help to understand the evolution of excess winter mortality and morbidity, offering a possible explanation for the lower EW mortality during the Great Recession, i.e., that the less severe winters compensated the more difficult socio-economic conditions.

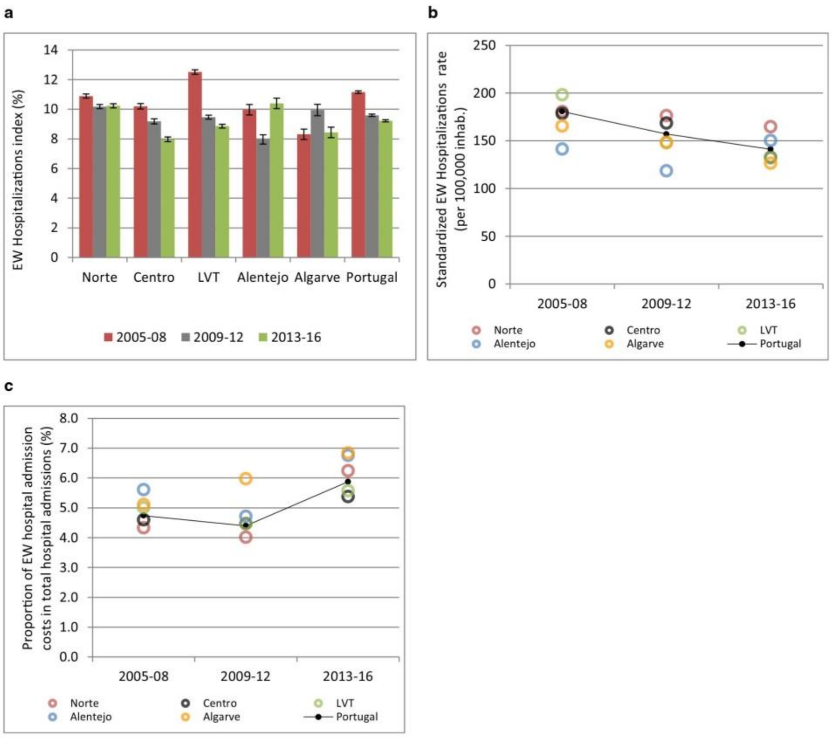

Fig. 4 Excess winter hospital admission measures by Regional Health Administration (**a**: Excess Winter Hospitalizations index; **b**: Standardized Excess Winter Hospitalizations rate; **c**: Proportion of Excess Winter hospitalizations costs in total hospital admissions)

By assessing the regional disparities, Alentejo is the RHA with the worst performance in all the EW mortality indicators. Individual and contextual conditions such as aging and housing characteristics are important factors to explain these results. Alentejo is the region with both the highest aging ratio (according to Statistics Portugal, the Aging ratio in 2011 was 189 in Alentejo, whereas the country average was 130) and the worst housing conditions (Almendra et al. 2017). A lower winter mortality burden was found in Algarve, which may also be related to the particular climatic conditions of Algarve Region (being Portugal's southern-most, its average yearly temperatures are warmer than in the other four regions).

Excess winter mortality and morbidity during and after the Great Recession

Several authors found associations between poor socioeconomic conditions and EW mortality and morbidity (Healy 2003; Howieson and Hogan 2005; Hales et al. 2012; Marmot and Bell 2012; Almendra et al. 2017; Marí-Dell'Olmo et al. 2018). The results presented in our study indicate that the aggravation of socioeconomic conditions during the Great Recession did not coincide with significantly higher winter increases in mortality and morbidity, when compared to the other periods under analysis. Numerous reasons may have contributed to these results. Basic healthcare has resisted the crisis quite well and may have played an important role in providing health support to the population; Dimitrovová and Perelman (2018) state that in Portugal, the probability of reporting difficulties in accessing primary care services was 10.8% lower in 2012, in comparison with 2007. Rolden et al. (2014) found that downward cycles in economy are coincident with mortality decreases; the winter mortality results may also be influenced by this trend.

The incapacity of maintaining adequate thermal comfort indoors during winter is most likely to be the key determinant for exposure to cold weather (Vasconcelos et al. 2011), and therefore, the response given to extreme cold events may probably only address a part of the cold-related illnesses.

Measures to prevent indoor exposure to cold during prolonged periods can be achieved through the improvement of housing insulation combined with efficient heating devices (Dear and McMichael 2011). It thus becomes necessary to consider the Eurostat data which express how the price of electricity in Portugal has increased 70% from 2005 to 2016 (during the Great Recession, it increased 30%) and nearly half of the housing units equipped with heating systems use electricity as the main source of energy. The price growth of electricity may have resulted in higher vulnerability to cold weather for an important number of socially vulnerable households, even if the EW mortality and morbidity did not increase.

The EW mortality and morbidity during the last period (2013–2016) might have been minimized by several multi-level cold weather response plans. The current Portuguese Contingency Seasonal Health Plan–Winter Module is active from November to March and in periods of extreme cold aims to minimize the negative effects of extreme cold and respiratory infections (Direcção-Geral da Saúde 2017). According to Hajat et al. (2016), assessing the development of Public Health England's Cold Weather Plan, the all-year planning for cold weather (levels 0, year-round planning) and the winter preparedness phase (level 1, winter preparedness and action) are crucial components in comparison to the alerts to minimize the vulnerability to cold.

Improving the understanding of the effects of the economic crisis on the vulnerability to seasonal cold weather is an important step towards prevention of possible avoidable human and economic costs (Benmarhnia et al. 2014). Even though this study contributes to that understanding, further studies addressing the impact of economic crisis in the vulnerability to cold weather are still needed.

Limitations

This study aims to measure the seasonal winter mortality and morbidity during the Great Recession and not to assess its impacts on the evolution of EW mortality and morbidity, which would require detailed microdata on socioeconomic changes and health outcomes.

This study compares several morbidity and mortality measures in different periods on a RHA scale. It is possible that the time periods are too short to capture the full influences of the economic recession (Zapata Moya et al. 2015). A longer observation period would permit to determine whether there have been substantial modifications in the time trend during the economic crisis, possibly allowing the causality measurement. At the same time, the scale of analysis hides sub-regional patterns and socioeconomic disparities as well as different responses to the economic recession. Different regional and temporal patterns could have been found if the analysis would have been stratified by cause of death. Moreover, despite the partial change in the hospital classification from ICD 9 to ICD 10 during the last year under analysis, the yearly variation of hospital admissions was very small.

The inter-annual variations of EW mortality and morbidity are strongly influenced by environmental and epidemiological factors. The access to seasonal influenza data by RHA would have been useful to identify the inter-annual epidemic pattern and to compare it with our results. Moreover, the understatement of current results would have been improved by the access to winter temperature.

Cyclical trends in hospital admissions and also in mortality, related to days, months, and seasons, are well known. However, our study was not designed to model such effects, but, on the contrary, to compare values across longer periods.

Conclusions

This work found that in Portugal, the winter increases in mortality and morbidity were not higher during the Great Recession. Nevertheless, the degree of excess winter mortality and morbidity resulting in potential avoidable years of life lost, lower life expectancy, and costs to the National Health System was found to be extremely high in Portugal. Although on a different scale, this phenomenon is common to all regions.

This study draws attention to the extent of excess winter mortality and morbidity and its evolution during the Great Recession period in Portugal. It highlights the necessity of a better understanding on excess winter mortality and morbidity determinants, in order to implement more effective mitigation strategies.

Authors' contributions RA, PS, JP, and JV contributed to the study conception and design. RA was responsible for the acquisition of data. RA, PS, JP, and JV contributed to the analysis and interpretation of data. RA was responsible for drafting of manuscript. RA, PS, JP, and JV contributed to the critical revision and final version of the manuscript.

Funding RA and PS are part of CEGOT, Research Centre in Geography and Spatial Planning, that is supported by the European Regional Development Funds, through the COMPETE 2020 – Operational Programme "Competitiveness and Internationalization," under Grant POCI-01-0145-FEDER-006891; and by National Funds through the Portuguese Foundation for Science and Technology (FCT) under Grant UID/GEO/04084/2013. RA was funded by FCT doctoral fellowship SFRH/BD/92568/2013 and by the CEGOT group Cities, competitiveness, and well-being (UID/GEO/04084/2013) through COMPETE 2020.

Compliance with ethical standards

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare that they have no competing interests.

Authors' information (optional) Not applicable.

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4.5 Artigo IV - Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London. Implications for health promotion [4].

[4] A versão submetida ao jornal encontra-se disponível no anexo II

Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London.

Implications for health promotion

Abstract

The effect of cold weather on health is an important public health concern, considered responsible for a significant mortality and morbidity burden. Vulnerability to cold, resulting from biological, socioeconomic and built environment factors, varies considerably between regions and can lead to important geographical disparities. We address a lack of quantitative estimates of cold-related mortality, particularly for the cities of Lisbon and Athens.

The aim of this study is to estimate the mortality burden attributable to low temperature in Athens, Lisbon and London from 2002 to 2011 and to discuss related inequalities in socioeconomic conditions.

To estimate the mortality burden attributable to low temperature, time-series regression analyses were carried out on daily mortality with respect to daily mean temperature for the three metropolitan areas to estimate the relative risk associated with a decrease in temperature. The number of cold-related deaths was estimated using the population Attributable Fraction.

Lisbon presents higher relative risk (RR) than London and Athens; the RR for Athens is lower than for London. The cold-related death rate is higher in Lisbon (53.2 deaths per 100,000 inhabitants) than in Athens (32.6) and London (37.6). The spatial heterogeneity between the three metropolitan areas in the risk estimates and cold-related mortality may result from the significant disparities in the built environment.

The results highlight the mortality burden attributable to cold as an important public health problem across these three cities. Adequate public health planning and preventive measures in the built environment may help reduce cold-related deaths and decrease vulnerability to cold in European cities.

1. Introduction

The effect of cold weather is currently an important public health concern, considered responsible for a significant mortality and morbidity burden (Analitis et al., 2008; Gasparrini et al., 2015). This burden, associated with non-optimum temperature, will be affected by climate change, as shown by studies assessing the effect of climate change on temperature-related mortality (Gasparrini et al., 2017; Vardoulakis et al., 2014).

The relationship between temperature and mortality has previously been described as having a non-linear shape, with increasing numbers of deaths associated with high and low temperatures. Despite the general relationship being common to several locations worldwide, the magnitude of the increase and the shape of the temperature-mortality curve can vary significantly depending on local conditions and the extent of population vulnerability (Analitis et al., 2008; Curriero et al., 2002; de’ Donato et al., 2015; Gasparrini et al., 2015; Vardoulakis et al., 2014).

In Europe, most temperature related deaths are associated with cold rather than heat (Braga et al., 2002; Hajat et al., 2014; Rau, 2004) and, despite the climate change trend, the mortality attributable to low temperatures is likely to remain higher than the one related to heat (Vardoulakis et al., 2014). Moreover, most of the temperature-related mortality burden has been attributed to relatively cold but not extreme cold temperatures (Gasparrini et al., 2015).

Studies comparing European countries (Fowler et al., 2015; Healy, 2003) or cities (Analitis et al., 2008) report that the vulnerability to cold tends to be higher in regions where the winters are milder. Significant spatial disparities in cold–related mortality are not only found when looking across cities, regions and countries, but also amongst specific population groups (Conlon et al., 2011).

The heterogeneity in the spatial pattern of vulnerability to cold is a reflection of the complex combination of built environment and physiological, social and cultural adaptations to the effects of adverse temperatures (Hales et al., 2012). Features of the place where people live (e.g. housing quality, urban design) as well as socioeconomic characteristics (e.g. education, income) (Almendra et al., 2017; Anderson and Bell, 2012; Healy, 2003; Marí-Dell’Olmo et al., 2018; O’Neill et al., 2003) may be important modifying factors of the relationship between temperature and mortality, thus representing significant explanatory factors for the geographical disparities concerning vulnerability to cold. Other environmental and epidemiological factors (e.g. air pollution, influenza and other viral epidemics) with important geographical disparities may also contribute to the spatial variations found in cold-related mortality (Analitis et al., 2008; Conlon et al., 2011; Vestergaard et al., 2017)

Although hypothermia may be considered the main direct cause of death attributable to exposure to cold, mortality from this cause is residual, and most cold-related mortality is associated with diseases of the circulatory and respiratory system (Rau, 2004). In addition, low temperature has been considered an important risk factor for several other diseases, such as diabetes (Li et al., 2014) or external causes (Orru and Åström, 2017) suggesting the existence of multiple biological pathways on which cold affects human health (Analitis et al., 2008).

Comparisons of the health impacts of cold in different regions with different socioeconomic, environmental and climatic conditions can contribute to the identification of risk factors to be addressed in the planning of suitable public health interventions (Marí-Dell'Olmo et al., 2018; Vardoulakis et al., 2014). Thus, the aim of this paper is to estimate the mortality burden attributable to low temperature and to discuss socioeconomic conditions and environmental inequalities between the three metropolitan areas. For this reason, we have selected three large metropolitan areas, Athens, Lisbon and London, with contrasting climatic, socioeconomic and built environment characteristics in Southern, Western and Northern Europe.

Moreover, this study addresses the lack of quantitative estimates of cold-related mortality, particularly for Lisbon and Athens, where the mortality burden of cold has not been previously estimated.

2. Data and Methods

2.1. Study areas

The climate of the Lisbon and Athens metropolitan areas is classified as Hot-summer Mediterranean climate according to the Koppen classification, characterized by warm and dry summers and mild and wet winters. The London metropolitan area has a Temperate Oceanic climate, with mild summers and cold winters (Rubel & Kottek, 2010).

Comparing the three metropolitan areas, London has a larger population (population in 2011: Athens-3.1 million; Lisbon-2.8 million; London-8.2 million). In the three metropolitan areas, higher population density is found in the central municipalities and tends to decrease as the distance from the city centre increases; Athens has the highest population density with 9054 inhabitants per square km (figure 1). Similarly, the more central municipalities also have a higher ageing index (the ratio between population aged 65 and above to the population aged between 0 and 14 years old, multiplied by 100); Athens and Lisbon have, on average, an ageing index of 1.3 and 1.1, respectively, while London is near 0.6. Education levels are highest in Athens and lowest in Lisbon, with, on average, 76.5% and 38.3% of inhabitants aged 25-64 with upper secondary or tertiary education attainment, respectively; London's average rate is 55.5%. The percentage of households with central heating is higher in London, where near 98% of households have central heating, 89% in Athens, while in Lisbon that value is lower than 10% and in no municipality does the value reach 20% (figure 1).

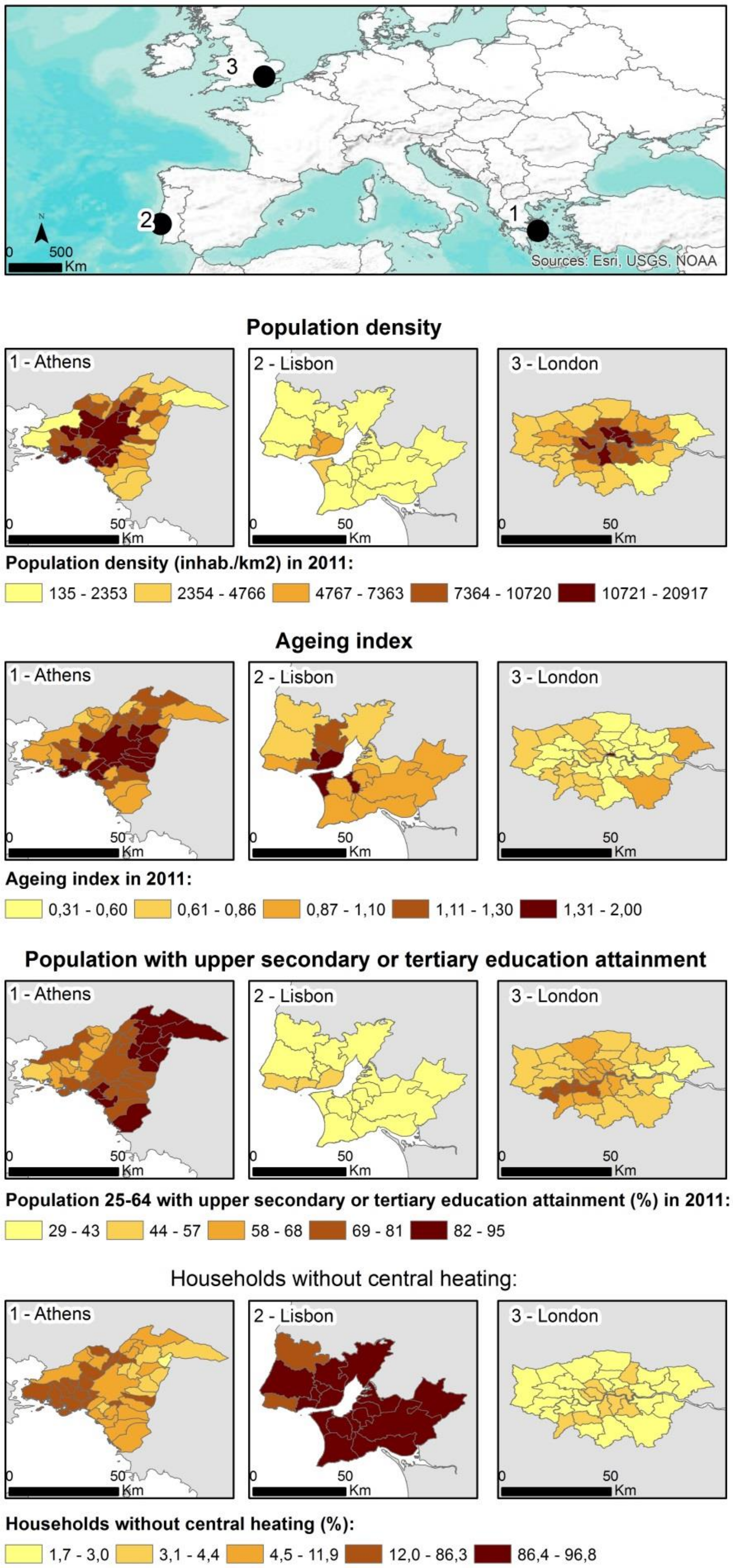


Figure 1. Location and characterization of the metropolitan areas

Source: Eurohealthy data platform (available at https://eurohealthydata.uc.pt for authorised users)

2.2. Mortality, meteorological and air quality data

To estimate the mortality burden attributable to low temperature, ten years of daily data (2002-2011) was collected from the Athens, Lisbon and London metropolitan areas (table 1). One meteorological station with good data coverage was selected from each Metropolitan Area to collect the daily mean temperature and relative humidity (Athens- Thision; Lisbon- Gago Coutinho Meteorological Station; London-Heathrow Station). Hourly concentrations of particulate matter with aerodynamic diameter <10µm (PM_{10}) were collected from urban background monitoring stations, with at least 75% data coverage, and averaged into daily values for each city.

Table 1. Data collected and sources

Variable	Source		
	Athens	Lisbon	London
Deaths by all causes (n.º)	Hellenic Statistical Authority (EL. STAT)	Portuguese national statistics institute	Office for National Statistics
Average temperature (ºC)	National Observatory of Athens	National Climatic Data Centre online	National Climatic Data Centre online
Relative Humidity (%)	National Observatory of Athens	National Climatic Data Centre online	National Climatic Data Centre online
PM_{10} (µg/m^3)	Ministry of Environment & Energy	Portuguese Environment Agency	UK Department for Environment Food and Rural Affairs (DEFRA)

Athens had the highest mean daily temperature (18.7 ºC), and also the widest temperature range, with values ranging from -6.7 ºC to 36.4 ºC (for 50% of the days, the mean temperature varied between 12.9 and 25.2 ºC) (table 2). The lowest mean temperature was recorded in London (11.6 ºC). Lisbon has the narrowest temperature range, where 50% of days have temperatures between 12.9 ºC and 20.5 ºC.

Table 1. Descriptive statistics of mortality, meteorological and air quality data

Variable	Source								
	Athens			Lisbon			London		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Daily deaths by all causes (n.º)	40	79.5	127	38	70.3	154	85	141.9	282
Mean daily temp (C.º)	-6.7	18.7	36.4	3.9	16.8	32.3	-3.2	11.6	28.3
Mean daily Relative Humidity (%)	20.7	64.2	100.0	20.5	69.7	100.0	36.1	74.3	100.0
Mean daily PM_{10} concentrations(µg/m^3)	4.9	31.5	362.5	6.4	28.2	187.4	5.8	24.7	90.4

2.3. Health impact assessment

The estimation of cold-related deaths, between 2002 and 2011, was carried out in three stages: a) assessment of the relationship between daily mean temperature and daily mortality and identification of the temperature thresholds for health effects; b) estimation of the relative risks associated with a temperature decrease below the cold threshold; c) quantification of cold-related deaths.

To identify the temperature thresholds of the three Metropolitan Areas, individual quasi-Poison time series regression analysis was applied using the R statistical software with the DLNM and MGCV packages, as in previous studies (Antunes, Silva, Marques, Nunes, & Antunes, 2017; Gasparrini et al., 2015).

The association between daily deaths and temperature was modelled by applying a distributed lag non-linear model: the lag-response curve was modelled with a natural cubic B-spline with an intercept and three internal knots placed at equally spaced values in the log scale. Based on previous studies, we considered a lag period of 28 days for cold effects on mortality (Bhaskaran et al., 2010; Vardoulakis et al., 2014); the exposure-response relationship was modelled with a quadratic B-spline with three internal knots placed at the 10th, 75th, and 90th percentiles. Potential confounders of the relationship between daily deaths and outdoor temperature, such as relative humidity, PM10, day of the week and time, were considered in the model. Relative humidity and time were modelled through natural cubic splines with 3 and 60 (6 per year) degrees of freedom (df), respectively. PM10 concentration was modelled linearly. Day of the week was added to the model using six indicator terms. The model parameters were selected based on a sensitivity analysis where preference was given to the lower Generalized Cross Validation values.

Through the model previously presented, it was possible to assess the relationship between temperature and mortality (RR and CI) and, therefore, to identify the temperature below which mortality increases significantly, when compared to the median temperature for each Metropolitan Area (both RR and CI are higher than 1). These temperature values were considered as cold temperature thresholds for health effects.

On the second stage, linear threshold models were applied to estimate the relative risk associated with the temperature decrease below the cold threshold temperature. The same modelling options were applied as for the previous stage.

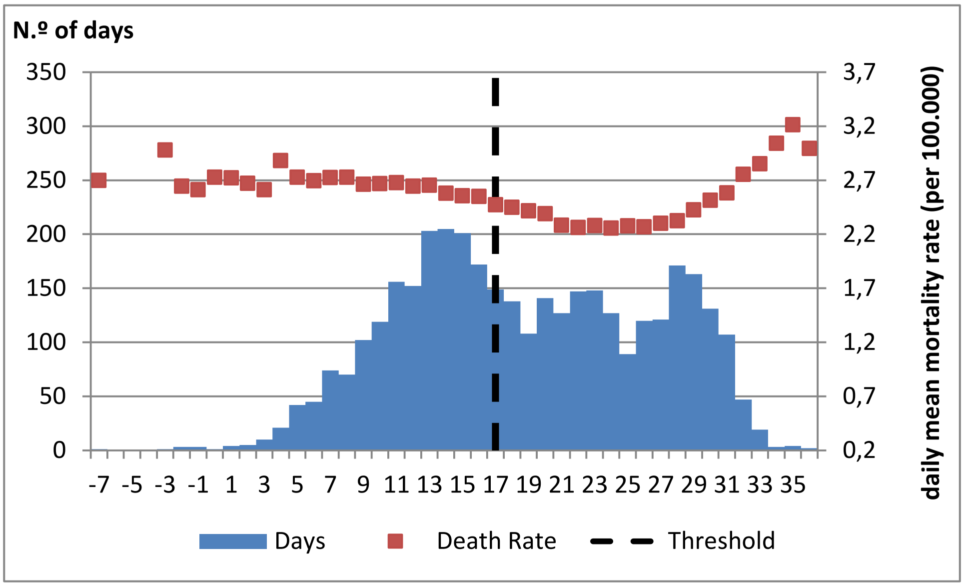
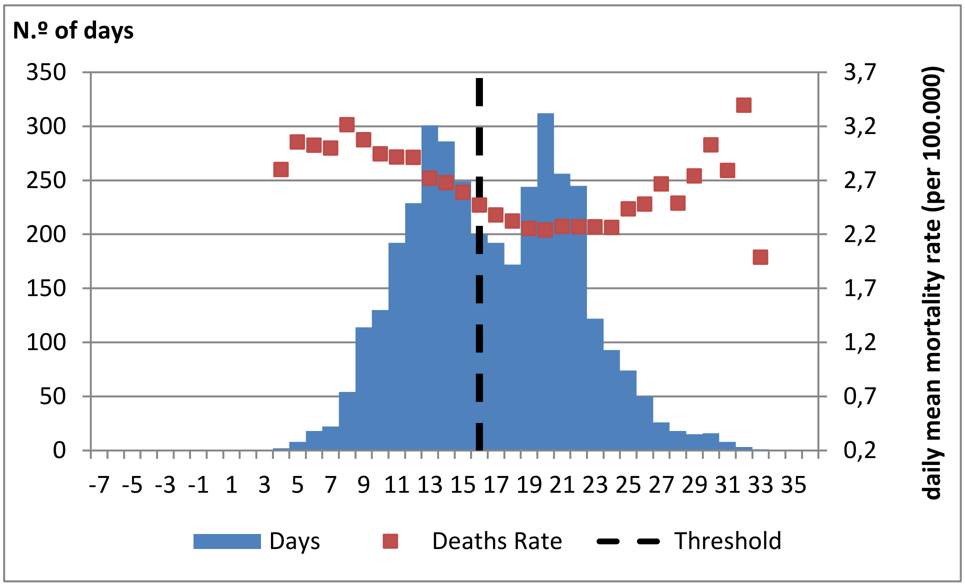
The number of cold-related deaths was estimated using the population Attributable Fraction (AF), which represents the mortality burden that would have occurred without the exposure to cold (Steenland & Armstrong, 2006). The attributable fraction is as follows: $AF = \frac{RR^{\Delta T}-1}{RR^{\Delta T}}$

Where ΔT corresponds to the daily mean temperatures below the Metropolitan Area cold threshold, and RR is the relative risk of mortality derived from the linear threshold models.

3. Results

Between 2002 and 2011, there were around 290,000 deaths in Athens, 257,000 in Lisbon and 518,000 in London, resulting in an average daily death rate for the 10-year period of 2.5, 2.5 and 1.8 deaths per 100,000 inhabitants, respectively.

The assessment of the relationship between daily mean temperature and daily mortality allowed for the identification of cold thresholds of 17.0 ºC in Athens; 16.5 ºC in Lisbon; and 11.5 ºC in London (figure 2).

Athens

Lisbon

London

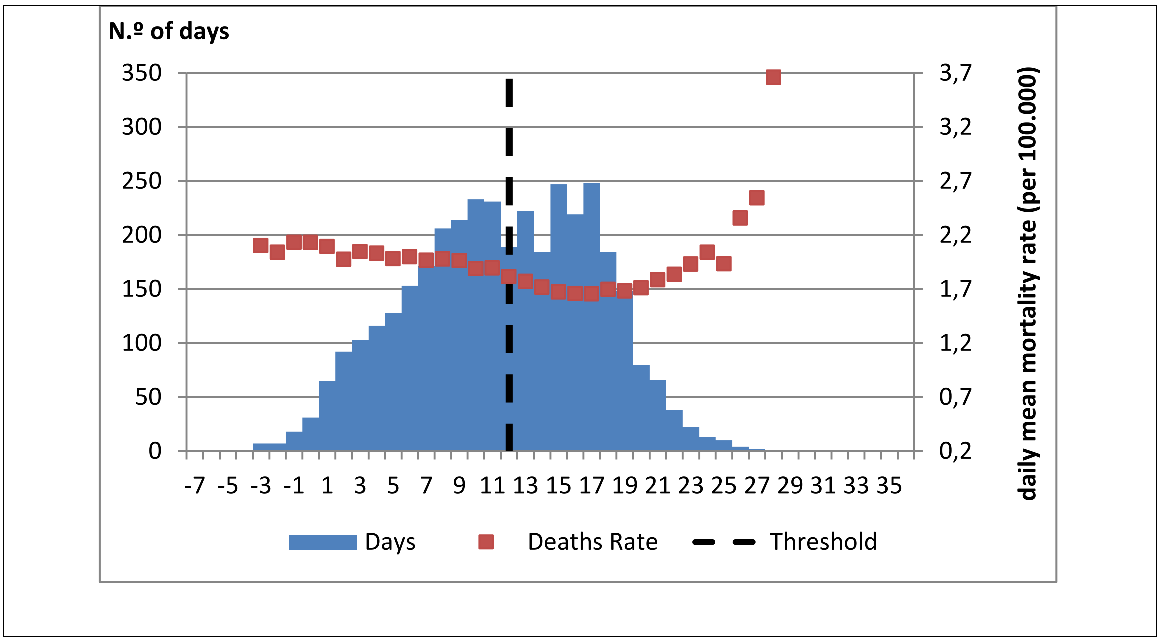


Figure 2. Mean daily death rate, number of days by daily mean temperature and cold thresholds in Athens, Lisbon and London Metropolitan Areas.

Table 3 shows the cold temperature threshold, RR in all-cause mortality per 1°C decrease in daily mean temperature below the threshold, the cold-related deaths per 100,000 inhabitants and the percentage of all-cause mortality attributable to cold. In all Metropolitan Areas, there was a significant increased risk in mortality associated with cold exposure (RR>1). The mortality increase per 1°C drop in temperature below the cold threshold was 1.6% (95% CI 1.0 to 2.2) in Athens, 3.0% (95% CI 2.1 to 3.9) in Lisbon and 2.6% (95% CI 2.2 to 3.0%) in London.

The mortality burden of cold, expressed here by the cold-related death rate, is higher in Lisbon (53.2 deaths per 100,000 inhab.), followed by London (37.6 deaths per 100,000 inhab.) and Athens (32.6 deaths per 100,000 inhab.). The cold-attributable mortality fraction was 5.7% (95% CI 4.2 to 7.2) in Lisbon, 5.6% (95% CI 4.7 to 6.4) in London and 3.6 (95% CI 2.2 to 4.9) in Athens.

Table 2. Estimated cold temperature threshold, RRs, cold related deaths and Fraction of all-cause mortality attributable to cold

Metropolitan Area	Cold temperature threshold (°C)	RR (CI)	Cold-related deaths rate (per 100,000 inhab.) (CI)	Fraction of all-cause mortality attributable to cold (%)
Athens	17.0	1.02 (1.01 - 1.02)	32.6 (20.2 - 44.6)	3.6 (2.2 - 4.9)
Lisbon	16.5	1,03 (1.02 - 1.04)	53.2 (38.9 - 67.0)	5.7 (4.2 - 7.2)
London	11.5	1,03 (1.02 - 1.03)	37.6 (31. 8 - 43.2)	5.6 (4.7 - 6.4)

4. Discussion

This study estimates the mortality burden attributable to low temperature in Athens, Lisbon and London from 2002 to 2011. The three metropolitan areas have different climates and present strong disparities in terms of population density, ageing index, education attainment and household central heating availability. The results indicate that London (11.5ºC) has the lowest temperature threshold while in Lisbon and Athens it is very similar, and around 5 degrees higher. Lisbon has higher relative risk than London and Athens (but with overlapping CIs), the RR for Athens is lower than for London. The cold-related death rate is highest in Lisbon.

The contrast in cold-related mortality between the metropolitan areas reinforces the findings from previous studies which compare the vulnerability to cold among cities from different climates, observing that people living in places with milder winters are more vulnerable to cold weather than those living in places with colder winters (Analitis et al., 2008; Eurowinter, 1997). These results highlight the impact of factors relating to local conditions in the place of residence, as this contrast may be a consequence of different socioeconomic conditions, behaviour and physiological acclimatization, which exacerbate exposure to cold and its consequences (Marí-Dell'Olmo et al., 2018; Medina-Ramón & Schwartz, 2007; Rodopoulou et al., 2015).

Cold-related mortality is generally higher for older age groups (Shakoor Hajat et al., 2014), as the elderly are more vulnerable than the general population to harmful weather conditions due to behavioural factors, biological and social vulnerability. According to Carter et al. (2016), with increasing age there is a progressive loss of psychological resilience and deterioration of health, adoption of less healthy lifestyles and a tendency towards loneliness and social isolation. Results from the Eurowinter group (1997) show that in relatively warm countries, the elderly often fail to wear protective clothing and do not remain indoors, and so are exposed to cold weather conditions outdoors. Therefore, the ageing index gradient between London (0.6), Athens (1.3) and Lisbon (1.1) suggests disparities with respect to vulnerability among the populations of the three Metropolitan Areas.

From the socioeconomic indicators presented here, Lisbon presents the lowest education levels (population with upper secondary or tertiary education), and has central heating in less than 10% in metropolitan households (according to Portuguese national statistics, 60% of households use mobile heating devices, such as electric heaters or gas heaters, as these are the most frequently available systems). The effects of housing conditions on cold-related mortality have been highlighted by several authors, stating that the inability to keep the house at a comfortable temperature increases one's vulnerability to cold (Dear & McMichael, 2011; Rudge & Gilchrist, 2007). The difficulty of keeping housing at comfortable temperatures can be influenced by the lack of a heating system (e.g. households without central heating), the thermal response of the building (e.g. existence of doubled glazed windows) or the behaviour of the household (e.g. use of heating devices) (Bøkenes, Mercer, MacEvilly, Andrews, & Bolle, 2011; Vasconcelos, Freire, Almendra, Silva, & Santana, 2013).

The inability to keep one's house at an adequate temperature due to economic reasons is referred to as Fuel Poverty, and it can be related to excessive energy consumption in terms of household income or the need to self-ration to avoid high energy consumption costs (Boardman, 2013). Living in cold homes and experiencing fuel poverty has been linked to adverse effects on physical and mental health as well as to negative impacts on social well-being (W. Anderson, White, & Finney, 2012). Moreover, socioeconomic conditions such as social isolation, low income and stress are associated with fuel poverty and may also contribute to the aggravation of one's health status (Marmot Review Team, 2011).

Less educated individuals have been reported as being more vulnerable to cold weather (O'Neill et al., 2003) as education level may be a predictor of low socioeconomic status and can influence the access to adequate housing conditions (e.g. central heating, thermal insulation) or the ability to keep the houses at a comfortable temperature (Marí-Dell'Olmo et al., 2018; Marmot Review Team, 2011).

In line with previous studies, the results presented here show that the harmful effects of cold on mortality can be identified at relatively mild temperatures, which can be experienced outside the typical definition of the Northern Hemisphere winter (December to February). Moreover, in previous studies, it was observed that the mortality related to the effect of extreme temperature was substantially less than the mortality attributable to milder but non-optimum weather (Gasparrini et al., 2015) and extreme cold days are responsible for only a small fraction of the cold-related mortality burden (Arbuthnott, Hajat, Heaviside, & Vardoulakis, 2018).

Although the direct comparison with previous studies is limited by different methodological techniques, the results presented here are still comparable to a certain extent. The assessment of the vulnerability to cold through the estimation of temperature thresholds, the RR associated to cold or the measurement of the mortality burden attributable to low temperatures in London has been assessed by several authors. Vardoulakis et al. (2014) and Hajat et al. (2014) estimated the RR associated with a 1-degree decrease to be around 2% and associated with 60.5 and 77.3 cold-related deaths per 100,000 inhabitants, respectively. The difference of the estimates between these results and the figures presented in this study may be related to different approaches addressing the cold temperature thresholds (in this study the threshold was almost two degrees lower: 11.5oC), and the different periods under analysis.

Previous studies have addressed the influence of extreme cold on mortality (Antunes et al., 2017), but temperature thresholds, the quantification of the mortality increase for each degree and the cold-related mortality are estimated here for the first time, as far as the authors are aware. According to Antunes et al. (2017), in Lisbon, mortality by all causes increased significantly with low temperatures (3.84% per 1 °C drop), identifying cold as an important public health problem.

In 1997, the Eurowinter group estimated that between 1988 and 1992 the increase in all-cause mortality per 1°C drop in temperature below 18°C in Athens was 2.15% (Keatinge, 1997). No further studies assessing the mortality burden of cold in Athens have been conducted.

The impacts of cold weather are predictable and can be minimized (S. Hajat et al., 2016) with the implementation of well-designed plans or public health measures. The plans implemented to reduce the vulnerability to cold weather or to minimize the effects of cold in each city can also be considered as a significant factor potentially modifying vulnerability to cold weather (Conlon et al., 2011; S. Hajat et al., 2016; Monteiro, Carvalho, Góis, & Sousa, 2013).

The first Portuguese Contingency Seasonal Health Plan – Winter Module was implemented in 2015, and therefore did not influence the results presented in this study. It aims to minimize the negative effects of extreme cold and respiratory infections. The plan is active from November to March and in periods of extreme cold, and it includes a set of actions involving health professionals, civil protection departments and local communities (Direcção-Geral da Saúde, 2017). From the 2015 edition of the plan (Direção-Geral da Saúde, 2015) to the one from 2017 (Direcção-Geral da Saúde, 2017) an increasing awareness of the health consequences of cold weather throughout winter and the need for preventive measures is present. Despite this, the latest version of the plan still does not include a prevention phase throughout the year. This is important because even though there is a significant health impact associated with extreme cold (Antunes et al., 2017; Monteiro et al., 2013), the results of this study show that in Lisbon cold-related deaths already occur at much milder temperatures (the threshold is near 16ºC) even outside the winter season.

The Cold Weather Plan for England was introduced in 2011; it aims to prevent the major avoidable effects on health during periods of cold weather by raising public awareness and enabling appropriate responses (Public Health England, 2017). The plan includes five different levels of action, from year-round planning for cold weather, winter and severe cold weather action to a major national emergency. Each alert level triggers a series of appropriate actions from the national level (e.g. NHS England, Public Health England, Met Office) through social care organizations and professionals, communities and individuals. According to Hajat et al., (2016) when assessing the development of Public Health England's Cold Weather Plan, the all-year planning for cold weather (level 0: year round planning) and the winter preparedness phase (level 1: winter preparedness and action) are crucial components in combination with the alerts. Greece, for its part, does not have a specific national plan to tackle the effects of cold on health.

Limitations of this work

Temperature–mortality relationships depend to some extent on the statistical methods applied to derive them, such as the lag structures used and controlling variables. Despite the importance of seasonal influenza to explain the relationship between temperature and health, the results of this study are not adjusted by this factor due to the unavailability of comparable influenza data amongst the three metropolitan areas. Although adjustment for PM10 was carried out, other air pollutants with significant influence on temperature-related mortality were not addressed due to data availability limitations.

5. Conclusions

This study assessed cold-related mortality in Athens, Lisbon and London over a 10-year period from 2002 to 2011. The results highlight the mortality burden attributable to cold as an important public health concern across these three cities to varying degrees. The cold-related mortality burden per population size was higher in Lisbon than in London and Athens over the study period; the spatial heterogeneity in risk estimates and cold-related mortality between the three metropolitan areas may have resulted from disparities in physiological, behavioural and built environment factors. The low prevalence of central heating in Lisbon is likely to have contributed to the higher cold mortality risk in this city compared to Athens and London. Adequate public health planning and preventable measures in terms of built environment may reduce cold-related deaths and decrease vulnerability to cold in European cities.

Acknowledgements

RA is funded by FCT doctoral fellowship SFRH/BD/92568/2013 and by the CEGOT group entitled “Cities, competitiveness, and well-being” (UID/GEO/04084/2013) through COMPETE 2020. RA and PS are members of CEGOT, Research Centre in Geography and Spatial Planning, which is supported by European Regional Development Funds through COMPETE 2020 – Operational Programme ‘Competitiveness and Internationalization’, under Grant POCI-01-0145-FEDER-006891, and by National Funds through the Portuguese Foundation for Science and Technology (FCT) under Grant UID/GEO/04084/2013

The authors gratefully acknowledge the Hellenic Statistical Authority for having provided the Athens data.

This research is embedded in the Euro-Healthy project, which received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 643398

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4.6 Artigo V - Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon

Science of the Total Environment 647 (2019) 127–133

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon

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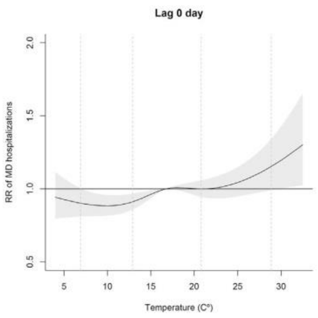
HIGHLIGHTS

- Hospital admissions by mental disorders increase significantly with high temperatures.
- Hospital admissions by mental disorders tend to decrease with low temperatures.
- Women with mental disorders are more vulnerable than men to high temperatures.
- Strengthen preventive measures following extreme high temperatures alerts

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 15 March 2018
Received in revised form 19 June 2018
Accepted 23 July 2018
Available online 01 August 2018

Editor: SCOTT SHERIDAN

Keywords:
Ambient temperature
Mental disorders
Hospital admissions
Distributed lag non-linear model
Portugal

ABSTRACT

Background: Individuals with mental disorders are often susceptible to the effects of extreme ambient temperatures. The aim of this study is to assess the short-term impacts of daily mean temperature on hospitalizations for mental disorders in the Lisbon Metropolitan Area, Portugal.
Methods: To assess the short-term impacts of daily mean temperature on hospitalizations for mental disorders (2008–2014), a quasi-Poisson generalized additive model combined with a distributed lag non-linear model was applied. The model was adjusted for day of the week, air pollution, relative humidity, time and seasonality.
Results: The number of hospital admissions for mental disorder during the study period was 30,139. Hospital admissions increase significantly with high temperatures on day of exposure, at lag 0–1 and at lag 0–2. Women are more vulnerable than men, and there was no difference between the age groups studied.
Conclusions: The exposure to high temperatures should be considered a significant risk factor for mental disorders; therefore, patient management services may need to be strengthened when extreme high temperature alerts are given.

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https://doi.org/10.1016/j.scitotenv.2018.07.337
0048-9697/© 2018 Published by Elsevier B.V.

1. Introduction

The effect of ambient temperature on human health is well known, with several studies providing evidence supporting the association between temperatures and several diseases (Ballester, 2003). These studies usually show an increasing trend for morbidity and mortality as the temperature deviates from the optimum temperature value (Curriero et al., 2002; Gasparrini et al., 2015). The magnitude of the morbidity and mortality increase changes significantly between diseases and regions, depending on environmental, socioeconomic and biological factors (Almendra et al., 2017; Bunker et al., 2016; Iñiguez et al., 2010).

When comparing to other diseases (*e.g.* cerebrovascular, cardiovascular, respiratory), the effects of temperature on mental health are not often studied (Bunker et al., 2016), probably due to the complexity of interactions between all the environmental and non-environmental determinants that may interfere with mental health and wellbeing. A common misbelief persists that mental illness is associated instead with winter weather conditions (Rau, 2004) when, in fact, the number of hospital admissions for mental diseases tends to increase with higher temperatures (Peng et al., 2017; Vida et al., 2012).

Individuals with mental illness are more vulnerable to the effects of extreme temperature due to the disruption of normal thermoregulation functions from the use of psychotropic medication, psychiatric illness, and due to behavioral issues (Hansen et al., 2008; Wang et al., 2014). Studies from Sulman (Sulman et al., 1978, 1970) have suggested that the increased vulnerability associated with heat may be attributed to atmospheric electrical changes, in particular, air ion concentrations and the ion polarity ratio, which interfere with the serotonin system.

Several other environmental factors such as air pollution and pollen concentration may play an important role in the development of mental disorders. Shin et al. (2018) identified a positive association between high concentrations of air pollutants (PM10, NO2, and CO) and the prevalence of high stress, depressiveness, diagnosis of depression, and suicide ideation. Allergic symptoms due to pollen concentration was found to be associated with aggravation of anxiety symptoms (Postolache et al., 2008), with the worsening of depression In patients with bipolar disorders (Manalai et al., 2012) or suicide behavior (Besancenot et al., 2011).

In 2014, Portugal ranked second amongst the European Union countries with highest percentage of people reporting depressive symptoms (Eurostat, 2018) and third with respect to higher prevalence of chronic depression (OECD, 2017). Despite the significant extent of Mental Disorders (MD) and their social and economic consequences, the role of ambient temperature in mental health is still to be addressed. It is believed that a better understanding of the relationship between temperature and mental illness may contribute to better response care and preparedness of the medical system. Thus, this study aims to assess the short-term impacts of daily mean temperature on hospitalizations for MD in the Lisbon (Portugal) Metropolitan Area (henceforth referred to as Lisbon).

2. Data and methods

2.1. Location

The Lisbon Metropolitan Area is an administrative region organized into 18 municipalities distributed along the north and south shores of the Tagus River (Fig. 1). Lisbon has the largest population concentration in Portugal, and nearly 96% of the population live in predominantly urban areas. According to the Statistics Portugal (2017), 2,821,349 inhabitants lived in Lisbon in 2016, and the percentage of women was slightly higher than men, corresponding to 53% and 47%, respectively. About 23% of women and 19% of men were over age 65 in 2016.

Lisbon is characterized by a typical Mediterranean climate with mild and wet winters and dry and warm summers (Csa according to the Köppen-Geiger classification). Annual medium air temperature for the period of 1971–2000 reached an average of 15.2 °C and minimum air temperature of 10.0 °C: Warm periods in Lisbon occur during the

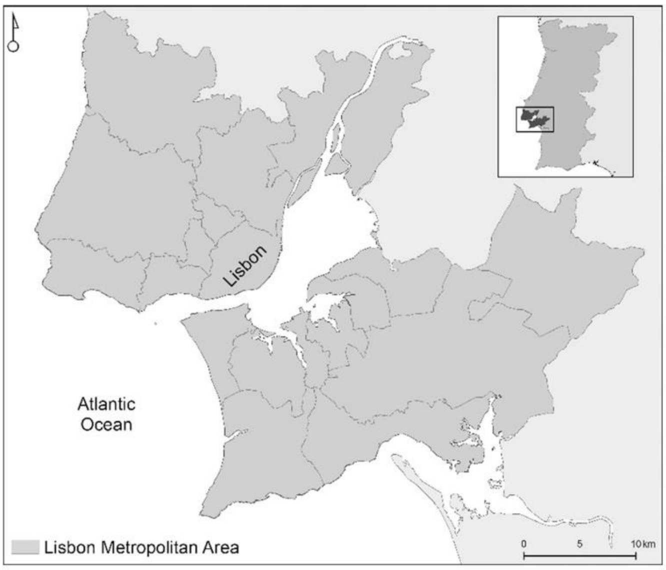

Fig. 1. Location of the study area.

months of July and August where the 30-year average maximum air temperature was 27.8 °C. During this period, Lisbon registered an average of 92 days with maximum air temperature above 25 °C. Lisbon has an average annual rainfall of 691 mm, mostly concentrated in period from October to March. The driest month has a precipitation difference of 103 mm in relation to the wettest month. The driest month is July, with 3 mm. The month of heaviest precipitation is November, with an average of 106 mm.

2.2. Data collection

From 1 January 2008 to 31 December 2014, the daily number of hospital admissions with primary diagnosis of mental disorders (ICD-9: 291–293; 295–298; 300; 3071; 3074; 3075; 3078; 303–305; 308–309; 311; 316) or with main external cause of suicide and self-inflicted injury (ICD 9: E95) were collected from the Diagnosis Related Groups general database, provided by the Portuguese Health System Central Administration (Table 1).

Meteorological measures (average temperature and relative humidity) were gathered from the National Climatic Data Center online for the Gago Coutinho Meteorological Station.

Data on air pollutants (PM10 and O3) were obtained from the Portuguese Environment Agency. Urban background monitoring stations located in the study area, with at least 75% of data coverage, were considered valid for the analysis (11 stations were used). Measures correspond to daily averages of PM10 stations and 8 h (between 10 h and 18 h) averages of O_3 stations.

2.3. Statistical analysis

To assess the short-term impacts of daily mean temperature on hospitalizations for MD, a quasi-Poisson generalized additive model combined with a distributed lag non-linear model (DLNM) was applied, as in previous studies (Peng et al., 2017; Wang et al., 2014). The usage of DLNM allows for the estimation of possible non-linear exposure-response dependencies across a chosen lag by combining two functions, the prediction and the lag effect, into a bi-dimensional matrix (cross-basis) (Gasparrini, 2014). The implementation of the DLNM provides measures of interest such as the immediate effect of the event of interest (lag 0), the lagged effect on day N after the event (lag N) and a cumulative effect during the period (lag 0-N) (Gasparrini, 2011; Gasparrini and Armstrong, 2010).

Potential confounders of the relationship between MD and outdoor temperature such as relative humidity, air pollutants (PM10 and O3), day of the week and time were added to the model. Time was modeled through natural cubic splines with 7 degrees of freedom (*df*) per year.

Table 1
International Classification of Disease (ICD 9) codes for mental disorders used in the present study.

ICD 9	Description
291, 303	Alcohol use-related mental disorders
293	Transient mental disorders
296, 311	Mood disorders
295–298	Functional psychoses
300	Anxiety, dissociative, somatoform disorders
301	Personality disorders
292, 304, 305	Drug use-related mental disorders
306	Physiological malfunction arising from mental factors
3071, 3075	Eating behavior-related mental disorders
3074	Non-organic sleep disorders
3078	Psychogenic-related mental disorders
308	Acute reaction to stress
309	Adjustment reactions
316	Specific factors associated with diseases classified elsewhere
E95	Suicide and intentionally self-inflicted injuries

Day of the week was added to the model as a factor variable with 6 levels (Monday to Friday, followed by two week-end days).

Based on previous studies, a maximum lag of 7 days was defined for the meteorological and air pollutants variables (Peng et al., 2017; Tong et al., 2014). The model parameters were selected through a sensitivity analysis where several df were assessed: the space of lag was modeled through a cubic spline with natural constraint, with 2, 3 and 4 df assessed; the space of the predictor was assessed as linear and through natural cubic splines with 3, 4 and 5 df.

Each variable was assessed individually to identify the combination of df with lower Generalized Cross Validation (GCV) values, in case of similar GCV values, the parsimony criterion was applied. In the selected model (Eq. (1)), with a GCV of 1.1771, the: a) space of lag for temperature, relative humidly and O3 was smoothed using 3df and Pm10 through 2 df; b) space of the predictors for relative humidity and O3 was modeled through 3 df, temperature through 4 df and Pm10 linearly. This is:

$$\lambda_i = L_3(temperature_i) + L_3(relative\ humidly_i) + L_3(O_{3i}) + L_2(Pm10_i)$$
$$\mu_i = S_4(temperature_i) + S_3(relative\ humidly_i) + S_3(O_{3i}) + \beta Pm10_i + S_{7\times 7}(Time) + DOW \quad (1)$$

where λ_i and μ_i are the MD hospital admissions means for the 7 days lag and prediction model components, respectively, and $L_k(\cdot)$ and $S_k(\cdot)$ are the corresponding space of lag DF and spline non-linear effects with k degrees of freedom.

A stratified analysis by sex and age group (0–44 and higher than 44) was developed. All statistical analyses were performed using the R statistical project with the DLNM and MGCV packages.

3. Results

3.1. Descriptive analysis

Between 2008 and 2014, 30,139 hospital admissions for MD were recorded (median of 12 hospitalizations per day), 14,200 for men and roughly 16,000 for women (Table 2). The median daily temperature was 16.8 °C, ranging between 3.9 °C and 32.7 °C. The median relative humidity was 72.1% (minimum: 15.6%; maximum: 100%). The median mean daily concentration of O3 was 70.5 μg/m^3 and 20.8 μg/m^3 for Pm10.

3.2. Distributed lagged effects of temperature on hospital admissions

The association between daily mean temperature and MD was estimated over a 7-day period and is summarized in Fig. 2. It shows the change of the RR of hospital admissions through the temperature values.

A significant increase in hospital admissions by MD was found above 30 °C on the day of exposure, and 27 °C at lag 0–1 and lag 0–2. When comparing the 99th percentile of the daily temperature with the median temperature, there was a significant increase from the day after the exposure (lag 0–1; RR = 1.2; CI = 1.03–140) until lag 0–3 and started to decrease gradually afterwards (Fig. 2).

Hospital admissions are significantly lower with temperatures around the 1st percentile of the daily mean temperature, when compared to the 50th percentile, between lag 0–3 and lag 0–6.

The stratified analysis by sex indicates important differences between men and women. While in men the exposure to extreme temperature (1st and 99th percentiles) seems not to be associated with hospital admissions, in women there is a significant increase of hospital admissions at the 99th temperature percentile from the day of occurrence to a lag of 4 days, and significant decreases at the 1st temperature percentile, between lag 0–1 and lag 0–6 (Table 3).

The stratified analysis by age does not show significant differences between the two age groups under analysis (Table 3).

Table 2
Summary of daily hospital admissions for mental disorders, meteorological measures and air pollution in Lisbon, 2008–2014.

		Unit	Minimum	25th percentile	50th percentile	75th percentile	Maximum	Standard deviation
Hospital admissions	Total	n.	1	8	12	15	30	4.5
	Men	n.	0	3	5	7	15	2.8
	Women	n.	0	4	6	8	20	2.9
	≥45 Years old	n.	0	4	6	8	21	2.9
	<45 Years old	n.	0	4	6	8	16	2.8
Temperature		C°	3.9	12.9	16.8	20.8	32.7	4.9
Relative humidity		%	15.6	62.7	72.1	81.0	100	14.7
PM_{10}		μg/m^3	6.8	16.0	20.8	28.6	90.9	10.3
O_3		μg/m^3	8.9	55.7	70.5	85.8	159.4	22.7

4. Discussion

To our knowledge, this is the first study assessing the association between ambient temperature and hospital admissions for MD in Portugal. The methods applied in this study are widely used to analyze lag-exposure-response relationship in time-series studies (Antunes et al., 2017; Gasparrini et al., 2015; Peng et al., 2017).

A significant positive association between mean daily temperature and hospital admissions by MD was found above 30 °C between on the day of exposure, and 27 °C at lag 0–1 and lag 0–2. The stratification analysis showed that women are more vulnerable than men and did not identify significant differences between the age groups under analysis.

Although the direct comparison with previous studies is limited by different methodological options (*e.g.* lag structures, causes of

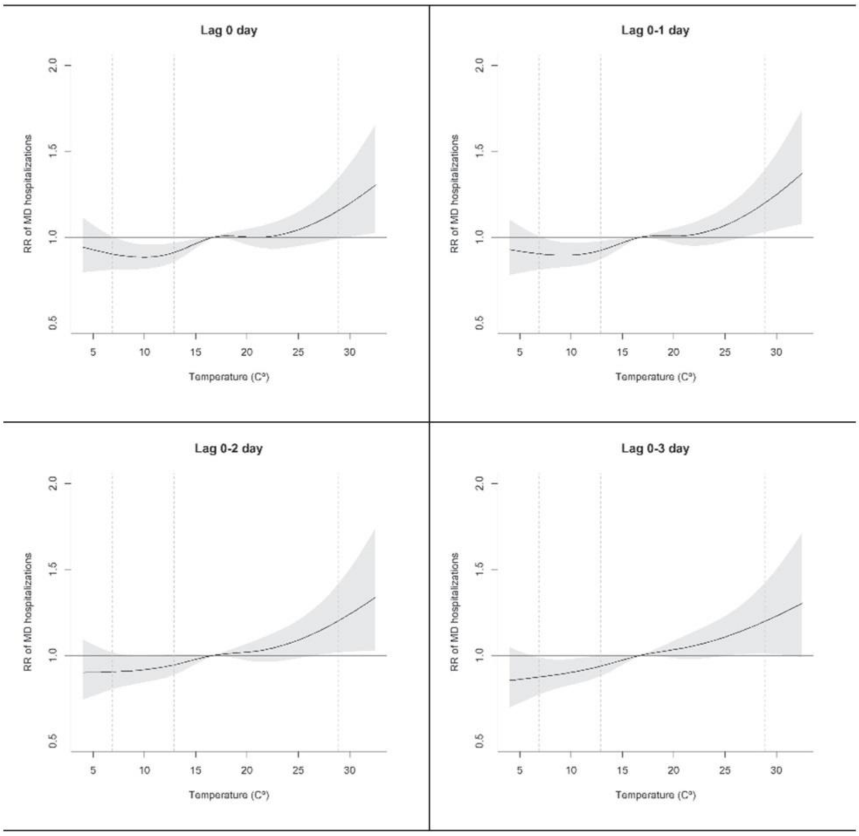

Fig. 2. Exposure-response curves of mean temperature (°C) and cumulative relative risk of hospitalizations for mental disorder (reference temperature at 16.8 °C) for men and women and all ages. Vertical lines correspond to the 1st, 25th, 75th and 99th temperature percentile.

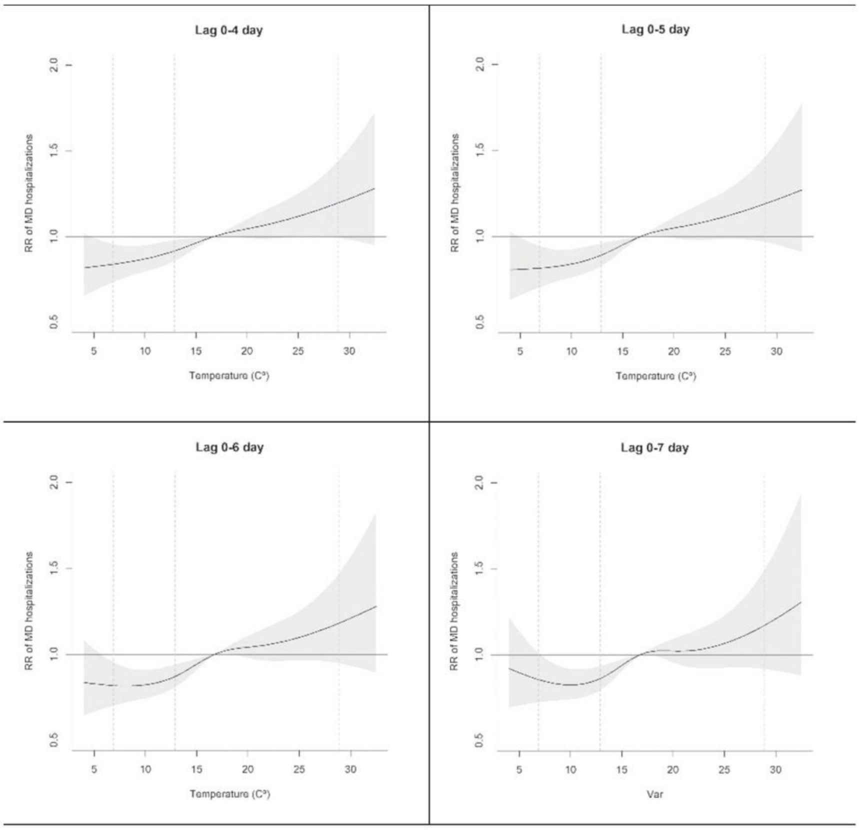

Fig. 2 (*continued*).

Table 3
Cumulative relative risk of hospitalization for mental disorders at 1st and 99th daily mean temperature percentile *vs* median temperature (16.8 °C) by sex and age.

	Men		Women		<44		>45	
	1st *vs* 50th	99th *vs* 50th	1st *vs* 50th	99th *vs* 50th	1st *vs* 50th	99th *vs* 50th	1st *vs* 50th	99th *vs* 50th
Lag 0	0.93 (0.80–1.09)	1.06 (0.85–1.33)	0.87 (0.76–1.01)	1.25* (1.02–1.54)	0.89 (0.77–1.03)	1.22 (0.99–1.51)	0.92 (0.79–1.06)	1.09 (0.88–1.36)
Lag 0–1	0.98 (0.84–1.14)	1.06 (0.85–1.33)	0.83* (0.72–0.96)	1.35* (1.10–1.65)	0.88 (0.76–1.02)	1.21 (0.98–1.49)	0.92 (0.79–1.07)	1.20 (0.97–1.49)
Lag 0–2	1.02 (0.86–1.20)	1.05 (0.83–1.34)	0.81* (0.69–0.94)	1.36* (1.08–1.70)	0.89 (0.76–1.05)	1.17 (0.93–1.47)	0.92 (0.78–1.08)	1.24 (0.98–1.57)
Lag 0–3	0.99 (0.83–1.18)	1.06 (0.82–1.36)	0.77* (0.66–0.91)	1.34* (1.06–1.69)	0.87 (0.74–1.03)	1.19 (0.94–1.51)	0.87 (0.74–1.04)	1.21 (0.95–1.55)
Lag 0–4	0.93 (0.78–1.12)	1.07 (0.81–1.41)	0.75* (0.63–0.90)	1.32* (1.03–1.70)	0.84 (0.71–1.01)	1.23 (0.95–1.59)	0.83 (0.69–1.00)	1.16 (0.89–1.52)
Lag 0–5	0.88 (0.72–1.08)	1.07 (0.79–1.45)	0.75* (0.62–0.92)	1.31 (0.99–1.74)	0.82 (0.67–1.00)	1.25 (0.93–1.67)	0.81* (0.66–0.99)	1.14 (0.84–1.53)
Lag 0–6	0.84 (0.68–1.05)	1.05 (0.76–1.45)	0.79* (0.64–0.97)	1.32 (0.98–1.78)	0.81* (0.66–1.00)	1.21 (0.89–1.65)	0.82 (0.67–1.02)	1.15 (0.84–1.58)
Lag 0–7	0.83 (0.66–1.05)	1.00 (0.70–1.43)	0.87 (0.70–1.08)	1.35 (0.97–1.87)	0.82 (0.66–1.03)	1.12 (0.80–1.58)	0.88 (0.70–1.11)	1.23 (0.87–1.73)

* p-value < 0.05.

hospitalization included as MD) the results here presented are comparable to a certain extent. The increase in hospital admissions on days of higher temperature, as found in this study, is consistent with previous studies that analyzed the temperature-MD relationship in different places with different climates: Page et al. (2007) in England, Peng et al. (2017) in Shangai, Vida et al. (2012) in Quebec and Wang et al. (2014) in Toronto. The vulnerability of individuals with mental illness to extreme high temperatures was also reported in studies assessing the effect of heatwaves in Australia (Hansen et al., 2008), California (Sherbakov et al., 2018), Adelaide (Nitschke et al., 2007) or Northern Vietnam (Trang et al., 2016). Page et al. (2007) refer sociological (*e.g.* use of excess alcohol consumption), biological (*e.g.* serotonin metabolism) and psychological (*e.g.* aggressive and violent behaviors) mechanisms by which heat could enhance suicidal behavior, supporting a causal effect of temperature in MD outcomes. In contrast, the study developed by Shiue et al. (2016), in Germany, identified higher risk of hospital admissions due to common mental and behavioral disorders at lower temperatures.

The results from the stratified analysis by sex revealed important differences. It was found that women are more vulnerable to high temperatures than men (the RR for women is significant from lag 0 to lag 0–4). Significant regional variations are found when comparing the impact of heat on both sexes (Åström et al., 2011), with previous studies reporting no differences between sexes (Page et al., 2007; Wang et al., 2014), identifying higher heat vulnerability for men (Trang et al., 2016) or, in conformity with the results of this study, providing evidence of higher RR for women suffering from dementia, organic MD, disorders of psychological development and senility (Hansen et al., 2008). Nonetheless, the results presented in this study seem to be supported by the work of D'Ippoliti et al. (2010).

Previous studies (Nitschke et al., 2007; Peng et al., 2017) found a discrepancy between age groups, where higher risk of hospital admissions due to heat was identified in the older age groups (Monteiro et al., 2013). This increasing risk can be explained by biological factors, such as the deterioration of the thermoregulatory function with age, which affects the ability to regulate the core temperature (Blatteis, 2012) and social characteristics, such as the greater likelihood that elderly will live in isolated situations (Bogdanović et al., 2013). Nevertheless, the results presented in this study are not conclusive, suggesting that the risk of hospitalization is higher in the younger group-age (<44 years old) at lag 0, 0–1, 0–4, 0–5, 0–6 and higher risk in the older age-group (≥ 45 years old) at lag 0–2 and 0–7. The instability of results may be attributed to the definition of the age-groups, which fails to measure the vulnerability of the elderly and to the absence of individual socio-economic factors like living condition, education and income information, that may have significant inequalities between different age groups (Peng et al., 2017). Further research is needed in order to understand the individual conditions of temperature exposure.

According to current climate forecasts, the likelihood of extreme hot temperatures in Europe will see an increase in the coming years, causing a wide range of direct and indirect effects on human health, including the increase of heat-related mortality and morbidity (Vardoulakis et al., 2014). In this context, there must be adequate public health responses at the ready to address the heat-related hospital admissions for mental illness.

4.1. Limitations

The main limitation of this study is the small sample size (median daily hospital admissions of 12 patients), which did not allow further analysis: a) assessment of more specific age groups (*e.g.* 75 years and older); b) assessment of specific causes of hospitalization instead of entire group MD.

Due to limitation on the availability of data it was not possible to include in the model important confounders, such as airborne pollen concentration (Besancenot et al., 2011).

In this study, the relationship between temperature and MD was addressed in only one city; further studies assessing different Portuguese cities are needed in order to better understand this relationship.

5. Conclusion

The findings of this study are in conformity with similar studies applied in different locations, suggesting that high temperatures are indeed a significant risk for MD in the Lisbon Metropolitan Area. The results of this study highlight the need to strengthen patient management services following extreme high temperatures alerts and to include measures to decrease the vulnerability of individuals in healthcare programs.

Acknowledgments

This study was funded by FCT doctoral fellowship SFRH/BD/92568/2013 and by the CEGOT group Cities, competitiveness, and well-being (UID/GEO/04084/2013) through COMPETE 2020. Giovani Silva was partially funded by FCT-Portugal project UID/MAT/00006/2013.

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4.7 Artigo VI - The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal

Int J Biometeorol (2017) 61:325–333
DOI 10.1007/s00484-016-1214-z

ORIGINAL PAPER

The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal

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Received: 13 April 2016 / Revised: 11 July 2016 / Accepted: 12 July 2016 / Published online: 27 July 2016

Abstract The aim of this paper is to analyze the relationship between North Atlantic Oscillation (NAO), meteorological variables, air pollutants, and hospital admissions due to diseases of circulatory systems in Lisbon (Portugal) during winter months (2003–2012). This paper is one of the few studies analyzing the impact of NAO on health through its influence on thermal stress and air pollution and is the first to be conducted in Lisbon. This study uses meteorological data (synthetized into a thermal comfort index), air pollutant metrics, and the NAO index (all clustered in 10-day cycles to overcome daily variability of the NAO index). The relationship between morbidity, thermal comfort index, NAO index, and air pollutants was explored through several linear models adjusted to seasonality through a periodic function. The possible indirect effect between the NAO index and hospital admissions was tested, assuming that NAO (independent variable) is affecting hospital admissions (outcome variable) through thermal discomfort and/or pollution levels (tested as individual mediators). This test was conducted through causal mediation analysis and adjusted for seasonal variation. The results from this study suggest a possible indirect relationship between NAO index and hospital admissions. Although NAO is not significantly associated with hospital admissions, it is significantly associated with CO, $PM_{2.5}$, NO, and SO_2 levels, which in turn increase the probability of hospitalization. The discomfort index (built with temperature and relative humidity) is significantly associated with hospital admissions, but its variability is not explained by the NAO index. This study highlights the impacts of the atmospheric circulation patterns on health. Furthermore, understanding the influence of the atmospheric circulation patterns can support the improvement of the existing contingency plans.

Keywords North Atlantic Oscillation · Circulatory system diseases · Air pollution · Hospital admissions

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Introduction

Environmental health determinants such as atmospheric pollution or extreme temperatures are important public health concerns and significant risk factors to several diseases (Mercer 2003, Borrego et al. 2009).

In recent years, the impacts of extreme temperatures have become an important matter of concern to the epidemiology scientific community (Basu 2009). Despite the higher levels of cold-related mortality, the impacts of heat waves on health continue to attract attention from the media (Rau 2006, Berko et al. 2014). To analyze the consequences of exposure to extreme ambient temperature, several authors have synthetized biological resistance to weather conditions by calculating composite indexes (Steadman 1979, Panagiotakos et al. 2004, Monteiro et al. 2012, Vasconcelos et al. 2013) that combine metrics of multiple weather variables (Basu 2009) (i.e., temperature, relative humidity, dew point temperature, wind speed) and are, theoretically, more effective than standard meteorological metrics.

The association between mortality and temperature has been described as a nonlinear J- or U-shaped relationship (Kalkstein and Greene 1997). Exposure to low temperatures leads to several biological responses from the human body such as a higher concentration of red and white cells, platelets, cholesterol and fibrinogen, and increased blood viscosity that increases the likelihood of death (Eurowinter Group 1997, Keatinge 2002, Wilson et al. 2010). On the other hand, when the body temperature rises, blood flow generally shifts from the vital organs to underneath the skin's surface in an effort to cool down increasing the stress of heart and lungs (Basu 2009).

In the same way, exposure to high levels of atmospheric pollution is linked with several health impacts, such as diseases of the respiratory, circulatory, immune, hematological, and neurological systems (Curtis et al. 2006). Furthermore, Peters et al. (2001) and Lee et al. (2002) found a significant statistical association between pollution and diseases of the circulatory and respiratory systems even when the concentration levels of pollutions were below the threshold established by the World Health Organization (WHO), suggesting that the air quality thresholds may not be indicative of clean air.

Additionally, the effect of air temperature and air quality on health are also related to each other as the effects of extreme temperatures are maximized by exposure to high levels of air pollution. At the same time, individuals exposed to extreme temperatures are more vulnerable to high levels of air pollution (Gordon 2003, Ren et al. 2006, Burkart et al. 2013).

Both meteorological variables and air pollutants can be affected by global-scale phenomena such as ENSO in South America and other regions or the North Atlantic Oscillation (NAO), in Europe. The NAO is one of the major modes of atmospheric circulation in the Northern Hemisphere, influencing the ecological and environmental systems, energy production and consumption, agriculture, industry, environmental conditions, and human health (Bojariu and Gimeno 2003), mainly during the winter period (McGregor 2005). The NAO index is traditionally defined as the difference of sea level pressure between the tropical Azores high and polar Icelandic low; it indicates the variability in atmospheric pressure and has two phases.

Positive NAO phases are characterized by high differences between the two centers of action (Ulbrich et al. 2012) and are responsible for minimal cloud cover and dry conditions in the southern European countries (López-Moreno and Vicente-Serrano 2008) and positive temperature anomalies during the day in the Iberian Peninsula (more intense at the center of Iberian Peninsula) (Trigo et al. 2002).

Negative phases are characterized by the weakening of the gradient between the Azores and Iceland centers of action (López-Moreno and Vicente-Serrano 2008). During this phase, the westerly flow is weaker allowing weather fronts with a western path (associated with high precipitation levels) to come into the Iberian Peninsula (López-Moreno and Vicente-Serrano 2008, Ulbrich et al. 2012).

NAO controls meteorological factors that influence the transport, dispersion, and concentration of pollutants (Christoudias et al. 2012), which are both of natural and anthropic genesis. Precipitation provokes wet deposition, wind promotes transport and dispersion, while solar radiation and temperature can increase chemical and photochemical reactions (Jacob and Winner 2009, Jerez et al. 2013).

Given the impacts of NAO on meteorological conditions and air quality, it should be treated as an important factor influencing several diseases. Nonetheless, the relationship between NAO and health has not yet been completely explored. Several studies assess its impact on weather conditions (Trigo et al. 2002, Hurrell et al. 2003, López-Moreno and Vicente-Serrano 2008) and on air quality (Creilson et al. 2003, Christoudias et al. 2012, Jerez et al. 2013); however, fewer studies address the relationship between NAO and health. In order to assess the influence of NAO on health, some authors have analyzed the direct relationship between the NAO index and morbidity or mortality (Messner et al. 2003, Hubálek 2005), while others have explored the causal relation between NAO, weather conditions, and diseases (McGregor 2005) or between NAO, air quality, and diseases (Pausata et al. 2013).

The aim of this paper is to analyze the influence of NAO on morbidity due to diseases of the circulatory system during winter months (2003–2012) in Lisbon (Portugal). The "Results" section presents the results of the relationship between: (a) NAO and morbidity; (b) thermal comfort and morbidity; (c) air quality and morbidity; and (d) NAO, thermal comfort, air quality and health.

Data and methods

Location

The study focused on the region (third level of the European nomenclature of territorial units for statistics) of Great Lisbon (hereafter called Lisbon) in Portugal, Iberian Peninsula (Fig. 1). Lisbon is located at 38° 42' N and 9° 00' W and is characterized by a rugged terrain of up to 300 m of altitude and is influenced by a typical Mediterranean climate with mild and wet winters and dry and warm summers (Csa according to the Köppen-Geiger classification). Lisbon is the most populous Portuguese region and

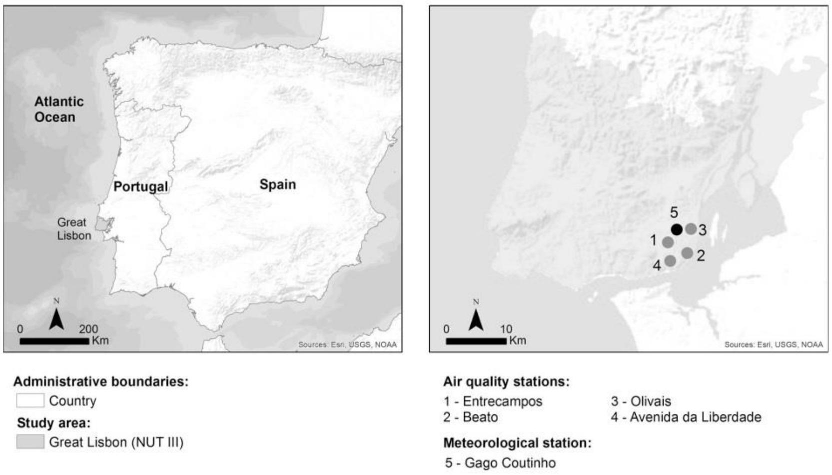

Fig. 1 Location of the study area and selected stations

economically the most dynamic, with about 20 % of all the country's population (nearly 2 million) and contributing to 36 % of the gross domestic product (INE 2014).

Data

To analyze the relationship between NAO, environmental conditions, and health impact, daily data were collected from 2003 to 2012:

(a) The daily NAO index was provided by the *National Oceanic and Atmospheric Administration*;
(b) The daily temperature (median, maximum, and minimum), precipitation, relative humidity, and wind speed were provided by *NNDC climate data online* for the Gago Coutinho meteorological station;
(c) Hourly concentrations (μg/m^3) of carbon monoxide (CO), PM_{10}, nitrogen dioxide (NO_2), nitric oxide (NO), sulfur dioxide (SO_2), $PM_{2.5}$, and ozone (O_3) were provided by the Portuguese Environment Agency. Four stations were selected according to the availability of data: Entrecampos ($PM_{2.5}$), Beato (O_3), Avenida da Liberdade (CO, PM_{10}), and Olivais (NO, NO_2, SO_2) (Fig. 1). In case of missing values, they were estimated by calculating the average value of the nearest four stations.
(d) The numbers of daily urgent hospital admissions of Lisbon inhabitants due to diseases of the circulatory systems (ICD9: 390–459) were provided fully anonymized by the *Administração Central do Sistema de Saúde.*

Methods

According to Feldstein (2000) and Bojariu and Gimeno (2003), the daily variability of the NAO index can be controlled by using cycles of 9.5 days. Thus, daily values were clustered in discrete 10-day block cycles (first cycle goes from the January 1st until the 10th, second from the 11th to the 20th and so on until the end of the year, restarting in the following year). To each cycle, several metrics were calculated: (a) average values of the thermal comfort index, wind speed, NAO index, $PM_{2.5}$, CO, SO_2, NO_2, NO, O_3 (average of the daily maximum values) and (b) the accumulated values of hospital admissions and precipitation were calculated.

Cycles starting in the winter months were selected for inclusion in the analysis. In accordance with previous works, December, January, February, and March were selected as winter months (Trigo et al. 2002, Johnson and Griffiths 2003, Almendra et al. 2012).

In order to synthetize the human vulnerability to weather conditions, four thermal comfort indexes were tested (Table 1): discomfort index (DI) according to Giles et al. (1990), effective temperature (ET) according to Ono and Kawamura (1991), effective temperature taking into account the effect of wind (ETw) according to Suping et al. (1992), and wind chill equivalent temperature (WC) according to Osczevski and Bluestein (Osczevski and Bluestein 2005). All indexes were analyzed with maximum, average, and minimum temperatures, resulting in four sets with three indexes each.

The relationships between weather and morbidity were explored through linear regression models. According to Pollock

Table 1 Thermal comfort indexes

	DI_{min}	DI	DI_{max}	ET_{min}	ET	ET_{max}	ETw_{min}	ETw	ETw_{max}	WC_{min}	WC	WC_{max}
Formula	T−0.55 × [(1–0.1 × RH) × (T−14.5)]			T−0.4 × [(1−RH/100) × (T−10)]			37–(37−T)/(0.68–0.0014 × RH + 1/(1.76 + 1.4 × W0.75))−0.29 × T × (1−RH/100)			13.12 + 0.6215 × T−11.37 × W + 0.3965 × T × W		

DI discomfort index, *ET* effective temperature, *ETw* effective temperature with wind, *WC* wind chill, *T* temperature, *RH* relative humidity, *W* wind speed

(1999), in order to control for seasonal variation, the fitted models included a periodic function:

$$y = \beta_0 + \beta_1 \sin\left(\left(\frac{2\pi}{P}\right)t\right) + \beta_2 \cos\left(\left(\frac{2\pi}{P}\right)t\right) + \epsilon_t$$

where β_0 is the intercept, β_1 and β_2 are the trigonometrical functions of frequencies, P corresponds to the period and t to the length. Several models were fitted using the R package Hmisc (http://cran.r-9project.org/web/packages/Hmisc/index.html) to explore the association between the following: (a) NAO index and hospital admissions, (b) NAO index and thermal comfort indexes, (c) thermal comfort indexes and hospital admissions, (d) NAO index and pollution levels, (e) pollution levels and hospital admissions, and (vi) pollution levels and the thermal comfort indexes. Both β_1 and β_2 terms were kept in the models despite their significance value in order to maintain the results adjusted for seasonal variation and to provide better comparison between the several models tested.

This study looked for possible indirect effects between the NAO index and hospital admissions, assuming that the effect of NAO (independent variable) on hospital admissions (outcome variable) can be through thermal discomfort and/or pollution levels (tested as individual mediators). In order to perform the corresponding analysis, the R-mediation package (http://cran.r-norg/web/packages/mediation/index.html) was used (Tingley et al. 2014). This takes various standard model objects, which correspond to mediator and outcome model components (both fitted for seasonal variation according to the proposed method). We used linear regression model for the mediator and outcome components and nonparametric bootstrapping (1000 resamples) for the corresponding variance estimation (Efron and Tibshirani 1994).

In regression analysis, although we usually aim to estimate casual effects of a covariate (independent variable) on an outcome (dependent variable), we can sometimes be interested in the process in which the covariate casually affects the outcome. Mediation analysis specifies the relationship between an independent variable and a dependent variable by considering a mediator variable to explaining the mechanism by which they are related. This method provides information about the average causal mediation effect (ACME) and average direct effect (ADE) representing, respectively, the effect of the independent variable on the dependent that is explained by

Table 2 Descriptive statistics of the variables under analysis

		Mean	Minimum	Maximum	Standard deviation
Hospital admissions	Diseases of the circulatory system (*n*)	601	503	740	46.5
Meteorological conditions	Average temperature (°C)	11.9	8.0	17.0	2.0
	Maximum temperature (°C)	15.7	11.1	22.8	2.4
	Minimum temperature (°C)	8.8	4.8	12.8	2.0
	Precipitation (mm)	23.8	0.0	142.0	29.5
	Relative humidity (%)	73.8	49.7	92.0	9.4
	Wind speed (m/s)	3.2	1.9	5.2	0.7
Atmospheric circulation	NAO index	0.13	−1.6	1.5	0.7
Air pollutants	CO (μg/m3)	53.7	280.3	1198.0	191.4
	O_3 (μg/m3)	69.0	30.5	114.2	16.2
	NO_2 (μg/m3)	44.0	23.9	73.9	11.2
	PM_{10} (μg/m3)	31.1	13.8	61.2	10.0
	NO (μg/m3)	29.9	3.5	106.8	21.9
	$PM_{2.5}$ (μg/m3)	20.0	8.0	50.0	9.1
	SO_2 (μg/m3)	1.7	0.1	6.5	1.5

Table 3 Association between comfort indexes and hospital morbidity

Hospital admissions	Comfort indexes	DI		ET		WC		ETw	
		Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error
Circulatory system	Minimum	−7.51*	3.06	−6.17*	2.75	−4.52*	1.98	−4.42*	1.98
	Average	−7.80*	3.16	−6.85*	2.91	−5.08*	2.06	−4.30*	1.96
	Maximum	−5.94*	2.86	−5.56*	2.69	−4.07*	1.85	−3.27	1.75

*$p <= 0.05$

a given set of mediators and the effect of the independent variable on the dependent variable unexplained by those same mediators. ACME is identified under specific assumption of conditional independence among outcome, mediator (pollutants), and treatment (NAO index); that assumption may be strong in many applied settings. Thus, we assessed the sensitivity of an estimated ACME to unmeasured confounding, also implemented in mediation R package, considering different values of the correlation between outcome and mediator model residuals (Imai et al. 2010, Richiardi et al. 2013).

Results

In our study, 66,162 hospital admissions for diseases of the circulatory system were recorded during 110 cycles of 10 days each (Table 2). The mean concentration of air pollutants per cycle was 53.7, 44.0, 31.1, 29.9, 20.0, 1.7, and 69.0 μg/m3 for CO, NO_2, PM_{10}, NO, $PM_{2.5}$, SO_2, and O_3, respectively. The average air temperature was 11.9 °C. The NAO index ranges between 1.6 and 1.5, with an average of 0.13.

North Atlantic Oscillation and hospital admissions

The association between the NAO index and hospital admissions through diseases of the circulatory system was not statistically significant (coeff.: −0.80, std. error: 6.18, *p* value: 0.89).

Thermal comfort and hospital morbidity

Four sets of thermal indexes were calculated: WC uses temperature and wind, DI and ET are built using temperature and relative humidity, and ETw adds wind. To identify the index that best expresses vulnerability to thermal conditions, linear models associating hospital admissions and the comfort index were built (Table 3).

The comfort indexes are significantly associated with hospital morbidity, and the coefficients tend to be higher when the discomfort indexes do not include wind. Although only winter months are being analyzed, thermal comfort indexes built with average temperature are strongly associated with hospital morbidity due to diseases of the circulatory system than those indexes using minimum temperature.

Considering the results, the DI was selected as the comfort index that best characterizes vulnerability to thermal conditions (being also the thermal comfort index with lower *p value* in the models).

Air quality and hospital admissions

The relationship between the selected air pollutants and hospital admissions was analyzed. Excepting O_3, all pollutants are positively associated with hospital admissions for diseases of the circulatory system and only NO_2 is not significantly associated (Table 4).

North Atlantic Oscillation, thermal comfort, air quality, and hospital admissions

No significant association was found between the NAO index and DI (coeff.: 0.28, std. error: 0.18, *p* value: 0.12) (the comfort indexes that included wind are significantly associated with NAO in their average and maximum component, but not in the minimum). As mentioned before, the DI combines

Table 4 Association between air pollutants and hospital admissions

Hospital admissions	CO (μg/m3)		O_3 (μg/m3)		$PM_{2.5}$ (μg/m3)		NO (μg/m3)		SO_2 (μg/m3)		NO_2 (μg/m3)		PM_{10} (μg/m3)	
	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error
Circulatory system	0.12**	0.02	−1.14**	0.38	2.30**	0.44	0.71**	0.22	14.88**	2.63	0.43	0.40	0.90*	0.43

*$p <= 0.05$; **$p <= 0.01$

Table 5 Comparison between the cycles with higher and lower NAO index under analyses

Date (month/year)	NAO index	Average temperature (°C)	Maximum temperature (°C)	Minimum temperature (°C)	Precipitation (mm)	Relative humidity (%)
01/2005	1.5	9.4	13.3	6.1	0	77.6
12/2009	−1.6	10.5	13.9	7.9	19.1	81.3

temperature and relative humidity, and none of them is significantly associated with the NAO index. In fact, both high and low NAO indexes can be related to different synoptic situations that are linked with similar temperature and relative humidity but completely different precipitation levels (Table 5).

NAO index is significantly associated with CO, $PM_{2.5}$, NO, NO_2, and PM_{10} (Table 6). Similarly, the air pollutant level significantly decreased while the wind speed and precipitation increased, except O_3 which has a different behavior, associated with fair weather, no wind, and strong sunlight. NAO is also significantly associated with precipitation (coeff.: −17.7, std. error, 3.69, *p* value: 0.00) and wind speed (coeff.: −0.31, std. error: 0.09, *p* value: 0.00) (Fig. 2).

As previously mentioned, no significant linear association between the NAO index and morbidity was found. The absence of direct association was also supported by the results of the causal mediation analyses: the average direct effect and total effect of NAO index in hospital admissions are not significant. However, NAO influences air quality and, through this indirect effect, can also affect human health (Fig. 2). The estimated average causal mediation effect is significantly different from zero in some pollutants (CO, $PM_{2.5}$, NO, and SO_2). The results suggest that the NAO is associated with CO, $PM_{2.5}$, NO, and SO_2 levels, which in turn increase the probability of hospitalization due to diseases of the circulatory system. The estimated average increase in hospitalizations resulting from the indirect effect of NAO is 6.84 (p value <0.01) through CO, 5.86 (p value <0.01) through $PM_{2.5}$, 4.92 (p value <0.01) through NO, and 5.27 through SO_2 (Table 7).

The results from sensitivity analyses supported the robustness of our findings, by checking ACME estimation for several referential NAO index values; it was possible to conclude that ACME increases as NAO index increases, and there is no change on the statistical significance of ACME and ADE.

Discussion

This study assesses the influence of NAO on health in Lisbon (during the winter months from 2003 to 2012). The results from this analysis show a possible indirect relationship between NAO and hospital admissions from circulatory diseases. This relationship is established through the indirect effect of pollution: NAO is associated with CO, $PM_{2.5}$, NO, and SO_2 levels, which in turn increase the probability of hospitalization. Hospital morbidity significantly increases with thermal stress (the DI is significantly associated with hospital morbidity due to diseases of the circulatory system diseases), although, thermal stress is not explained by the NAO index. Previous studies conducted in Europe have shown the effects of NAO on health. Messner et al. (2003) found a consistent positive relation between increasing NAO index and an increase in acute myocardial mortality in Sweden. Hubálek (2005) analyzed the impact of NAO on the incidence of some infectious diseases in the Czech Republic and found significant correlations between them. McGregor (2005) found statistically significant inverse associations between mortality from ischemic heart disease and the climate index representing the interaction between the NAO and temperature across England. Pausata et al. (2013), assessing the particulate matter variability induced by NAO in Europe during winter and the potential impact on human health, found that positive shift in the mean winter NAO of one standard deviation would lead to about 5500 additional premature deaths in Mediterranean countries due to the increase in particulate matter concentration.

Nevertheless, as described above, we found significant positive linear associations between the NAO index and CO, $PM_{2.5}$, NO, and NO_2. Similar results were also mentioned by Jerez et al. (2013) and Christoudias et al. (2012) which

Table 6 Association between air pollutants, NAO index, precipitation, and wind speed

	CO (μg/m3)		O_3 (μg/m3)		$PM_{2.5}$ (μg/m3)		NO (μg/m3)		SO_2 (μg/m3)		NO_2 (μg/m3)		PM_{10} (μg/m3)	
	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error
NAO index	54.96*	23.5	0.45	1.51	2.43*	1.18	6.43*	2.53	0.34	0.20	3.65*	1.43	2.83*	1.35
Precipitation	−1.93**	0.54	0.01	0.04	−0.08**	0.03	−0.18**	0.06	−0.01*	0.00	−0.13**	0.03	−0.10**	0.03
Wind speed	−123.3**	21.18	3.71*	1.49	−6.41**	1.05	−16.96**	2.06	−0.74**	0.19	−9.98**	1.13	−7.85**	1.16

*p < =0.05; **p < =0.01

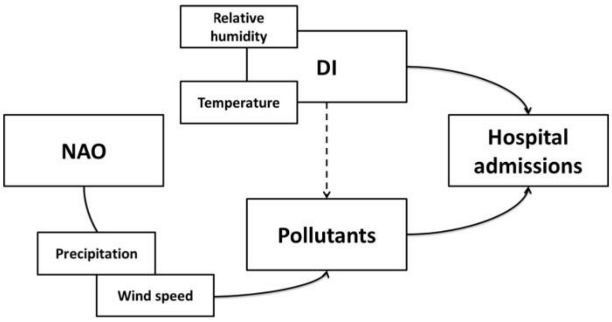

Fig. 2 Proposed framework model of the influence of North Atlantic Oscillation on hospital admissions for circulatory diseases

reported lower concentration of pollutants in southern Europe during NAO negative phases. These results show the processes of transport and deposition of air pollutants through the effect of wind and precipitation.

Air pollutants are positively associated with hospital admissions (except O_3 and NO_2); previous studies analyzing the health impact of several air pollutants also reported important differences between them: Forastiere et al. (2005), in Rome, identified significant increases of out-of-hospital coronary deaths with CO and PM_{10}, but not with NO_2; Cendon et al. (2006) found stronger positive correlations between SO_2 and daily hospitalizations for myocardial infarctions than between CO, O_3, NO_2, and PM_{10}.

O_3 is negatively associated with hospital admissions; however, there is no causal relationship between the decreasing levels of ozone and the hospital admission increase. This apparent protective effect results from the O_3 increase on warm days, while the relation between hospital admissions and temperature is inverse (Moolgavkar et al. 1995, Ito et al. 2005, Medina-Ramón et al. 2006). Similar results were found in the previous research (Moolgavkar et al. 1995, Medina-Ramón et al. 2006).

The thermal comfort index is not significantly associated with the NAO index. Unlike the countries of Central and North Europe where a strong association is found between the NAO index and temperature (Osborn et al. 1999, Trigo et al. 2002, Hurrell et al. 2003), in Lisbon, this relationship was not recorded. The results of this study are supported by the study of Ulbrich et al. (2012), showing that the relationship between the NAO index and temperature is not linear in the Iberian Peninsula.

Summarizing, hospital morbidity is positively associated with the pollutant levels (except ozone and NO_2, as reported previously) and is negatively associated with the thermal comfort index, although no significant direct association with NAO was found. A similar pattern was also found in previous studies addressing vulnerability to cold weather (Almendra et al. 2012, 2016, Vasconcelos et al. 2013) or exposure to high levels of air pollution (Borrego et al. 2009, Slezakova et al. 2011) in Portugal.

Table 7 Summary of indirect effect of North Atlantic Oscillation over hospital admissions

Mediators	Average causal mediation effect	Average direct effect
DI	−2.26	1.45
CO	6.84**	−7.64
$PM_{2.5}$	5.86*	−6.66
O_3	−0.52	−0.29
NO	4.92**	−0.80
SO_2	5.27*	−6.07
NO_2	1.7	−2.51
PM_{10}	2.68	−3.49

$*p \leq 0.05$; $**p \leq 0.01$

Strengths and limitations

This study is one of the few analyzing the impact of NAO on health and is the first to be conducted in Lisbon. Considering the geographical and socioeconomic context of Portugal and the high vulnerability to harmful environmental conditions is fundamental to have a better understanding of the relationship between atmospheric conditions and health to effectively assess environmental risks. Thus, this study represents an important contribution to the current body of literature.

However, the results of this study must be interpreted with caution. Time series analyses were carried out for one location as such; the results should not be derived to other regions with different geographic and socioeconomic frameworks.

The methods applied in this study tested for direct and indirect linear associations; however, the relationship between environmental conditions and health is often studied by nonlinear modeling providing better fitting models. Therefore, the linear mediation model is an alternative to (direct) nonlinear models and can also be employed as an exploratory and complementary tool to those models.

Conclusions

This study investigated the effects of NAO on emergency hospital admissions from diseases of the circulatory system during the winter months in Lisbon. It was found that the NAO influences human health through its impacts on atmospheric pollutants. Positive NAO phases are associated with higher levels of air pollutants. No significant association was found between NAO and the discomfort index (built with temperature and relative humidity).

Although it is not possible to extrapolate from this to other countries or other areas of Portugal, this study draws attention to the impacts of the patterns of atmospheric circulation in the North Atlantic on human health and to the vulnerability to environmental factors.

This article can provide insights to improve public health policies and alert systems. A better understanding of the relationship between the NAO and health can help improve existing contingency plans, develop more effective adaptation strategies, and ensure they are put into action in a timely manner, thereby helping to decrease the health impacts of harmful environmental conditions.

Acknowledgments This research was conducted within the international cooperation framework of INCLINE (INter-disciplinary CLimate Investigation cEnter) and partly supported by the European Regional Development Fund, through the Operational Competitiveness Program (FCT doctoral fellowship SFRH/BD/92568/2013). T.A. acknowledges the partial support from CNPq and FAPESP. G.S. acknowledges the partial support from CT - Fundação para a Ciência e a Tecnologia, Portugal, through the project UID/MAT/00006/2013.

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5. Discussão e conclusões

5.1 Introdução ao capítulo

Nesta secção os principais resultados são sumariados e contextualizados em relação aos objetivos propostos, confrontando-os com outros estudos relevantes. São discutidos os principais contributos do estudo para o tema desenvolvido, as possíveis implicações dos resultados obtidos na elaboração de medidas de minimização ou de mitigação dos efeitos do frio na saúde, os principais pontos fortes, as limitações e trabalhos futuros, terminando com uma breve nota conclusiva.

5.2 Sumário dos resultados

Os artigos que constituem esta dissertação analisam e quantificam o impacto das variações sazonais da mortalidade e da morbilidade e caracterizam os fatores que contribuem para o aumento da vulnerabilidade ao frio em Portugal.

O Artigo I - *Seasonal mortality patterns and regional contrasts in Portugal* demonstra que a distribuição mensal da mortalidade ao longo do ano não é homogénea, aumentando tendencialmente nos meses mais frios. Apesar de esta oscilação sazonal ser comum à maioria das causas de morte, o aumento relativo dos óbitos durante os meses de inverno varia consideravelmente conforme a causa de morte em análise. Destacam-se os óbitos por doenças do aparelho circulatório e do aparelho respiratório devido ao elevado número de óbitos em excesso no inverno (39.972 óbitos em excesso por doenças do aparelho circulatório e 18.116 devido a doenças do aparelho respiratório, entre 2000 e 2009), seguindo-se os óbitos por doenças endócrinas, nutricionais e metabólicas (4.950, entre 2000 e 2009). Outras causas de morte, como as causas externas de lesão e envenenamento, apresentam um comportamento diferente, marcado por um aumento durante os meses de verão.

Caso este aumento sazonal da mortalidade (pelas causas identificadas) fosse causado apenas por condições meteorológicas, seria espectável que o padrão geográfico fosse relativamente homogéneo, aumentando nas unidades territoriais onde as temperaturas no inverno são mais baixas. No entanto, os resultados dos Artigos I - *Seasonal mortality patterns and regional contrasts in Portugal* e II - *Evidence of social deprivation on the spatial patterns of excess winter mortality* revelam desigualdades espaciais que não podem ser apenas explicadas por diferentes condições climáticas. A mortalidade em excesso no inverno por doenças do aparelho circulatório e respiratório é tendencialmente superior nos municípios do interior Norte, Centro e Alentejo. Este padrão geográfico foi identificado nas duas escalas de análise territorial: município e NUT III.

O facto de unidades territoriais próximas, e com características climáticas semelhantes, apresentarem padrões de mortalidade em excesso no inverno significativamente distintos revela a necessidade de considerar a influência de outros fatores na relação entre frio e mortalidade. O Artigo II - *Evidence of social deprivation on the spatial patterns of excess winter mortality* identificou associações estatisticamente significativas entre o padrão espacial do excesso de mortalidade no inverno por doenças do aparelho circulatório e as duas dimensões da privação socioeconómica avaliadas. Verificou-se que a vulnerabilidade ao frio tende a ser superior nos municípios em que as condições sociomaterial e habitacional são mais desfavoráveis: os municípios que fazem parte do quintil de maior privação sociomaterial têm 71% maior probabilidade de apresentarem excesso de mortalidade no inverno, comparativamente ao quintil de menor privação; os municípios no quintil de maior privação habitacional têm 82% maior probabilidade.

As consequências da vulnerabilidade ao frio sazonal no inverno são graves e traduzem-se em custos sociais e económicos. O Artigo III - *Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case* apresenta os óbitos e internamentos em excesso no inverno e os seus impactos em termos de anos de vida potencialmente perdidos em excesso no inverno (87 por 100.000 habitantes em 2009-12), em decréscimos na esperança média de vida (1 ano em 2009-2012) e em custos para o SNS com internamentos hospitalares em excesso (214 milhões de euros, representando 4,4% dos custos com internamentos hospitalares). São comparados, ainda, os impactos do frio no período da recessão económica (2009-2012) com o período antecedente (2005-2008) e posterior (2013-2016), tendo-se verificado uma tendência de decréscimo entre os três períodos, sem agravamento significativo durante o período da recessão.

Fica claro o impacto da vulnerabilidade ao frio e a sua geografia, mas será que a mortalidade em excesso no inverno apenas se regista em períodos de frio intenso? Que fração dos óbitos em excesso são atribuíveis ao frio? O Artigo IV – *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London* responde a estas questões, comparando a Área Metropolitana de Lisboa com as Áreas Metropolitanas de Atenas e de Londres. Verificou-se que em Lisboa a mortalidade aumenta significativamente quando a temperatura é inferior a 16,5ºC (11,5ºC em Londres e 17ºC em Atenas), sendo que 5,7% dos óbitos foram estatisticamente associados ao impacto do frio (3,6% em Londres e 5,6% em Atenas). A desigualdade entre as três áreas metropolitanas poderá estar também associada às desigualdades socioeconómicas e das condições da habitação.

Apesar da mortalidade e da morbilidade aumentarem durante o Inverno há doenças com comportamentos distintos, no Artigo V - *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon* avaliou-se a relação entre as perturbações mentais e a temperatura, tendo-se verificado um aumento estatisticamente significativo dos internamentos por perturbações mentais com temperaturas superiores aos 30ºC (o efeito do calor é estatisticamente significativo no dia da exposição e prolonga-se por mais dois dias). Contrariamente à hipótese inicial deste estudo, não se verificou um aumento estatisticamente significativo dos internamentos por perturbações mentais com temperaturas baixas.

Outros fatores do ecossistema global como os padrões de circulação da atmosfera têm importantes impactos indiretos na saúde humana. O Artigo VI - *The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal* identificou uma associação indireta entre a Oscilação do Atlântico Norte e os internamentos hospitalares por doenças do aparelho circulatório em Lisboa durante o inverno: a associação entre a Oscilação do Atlântico Norte e os internamentos hospitalares, quando mediada por alguns poluentes atmosféricos (CO, $PM_{2.5}$, NO, e SO_2), é estatisticamente significativa.

5.3 Discussão dos principais resultados

Os principais resultados evidenciam: i) aumento significativo da mortalidade e morbilidade durante o inverno; ii) desigualdades espaciais na mortalidade e na morbilidade sazonal; iii) aumento da vulnerabilidade ao frio associada a condições socioeconómicas e habitacionais precárias; iii) agravamento das condições de saúde, traduzidas em anos de vida potencialmente perdidos, na diminuição da esperança de vida; iv) gastos potencialmente evitáveis com internamentos em excesso no inverno no SNS; e v) necessidade para desenvolver sistemas de avaliação, monitorização e alerta que contribuam para a diminuição da vulnerabilidade às temperaturas adversas.

A mortalidade aumenta significativamente durante o inverno, este acréscimo varia entre causas e apresenta heterogeneidade espacial

O padrão sazonal de mortalidade em Portugal é semelhante ao encontrado noutras regiões do mundo, caracterizando-se, genericamente, por aumentos de mortalidade durante os meses de inverno. Este padrão foi identificado em vários países europeus como, por exemplo, a França (Boulay et al., 1999), Holanda (Kunst et al., 1991), Espanha (Ballester-Díez et al., 1997; Benmarhnia et al., 2014), Inglaterra (Lawlor et al., 2000; Liddell et al., 2016), Nova Zelândia (Davie et al., 2007), Dinamarca (Rau, 2004). Estudos prévios em Portugal já tinham descrito esta tendência (Pinheiro, 1990; Freire, 1996; Nogueira et al., 2009; Vasconcelos, 2012).

Rau (2004) refere que o aumento da mortalidade durante os meses de inverno está principalmente associado às doenças do aparelho respiratório e circulatório, sendo que as doenças do aparelho respiratório apresentam maior variabilidade sazonal e as doenças do aparelho circulatório causam o maior número de óbitos em excesso no inverno. Os resultados obtidos no Artigo I - *Seasonal mortality patterns and regional contrasts in Portugal* confirmam a reprodução deste padrão em Portugal.

Este acréscimo de mortalidade por doenças do aparelho circulatório e respiratório resulta das diversas consequências fisiológicas (descritas na secção *Resposta fisiológica do corpo humano a temperaturas adversas*) associadas à exposição ao frio, principalmente no que se refere ao processo de vasoconstrição (doenças do aparelho circulatório) e diminuição da resistência a infeções (doenças do aparelho respiratório) (Keatinge, 1997, 2002; Clayton et al., 2011).

A magnitude do aumento sazonal da mortalidade é superior em Portugal comparativamente aos restantes países da Europa (Healy, 2003; Fowler et al., 2015). No entanto, como é comum nos climas temperados mediterrâneos, os riscos para a saúde causados pelo frio, apesar de muito graves são, em Portugal, subestimados pelas autoridades de saúde e da proteção civil (Monteiro et al., 2013).

A heterogeneidade espacial nos padrões sazonais de mortalidade parece ser uma constante, tendo diversos estudos comparativos identificado importantes desigualdades entre territórios, quer à escala do país (Healy, 2003; Fowler et al., 2015), quer a uma escala de maior pormenor (Lawlor et al., 2000; Aylin et al., 2001; Maheswaran et al., 2004; Davie et al., 2007; Hales & Howden-Chapman, 2007). Os resultados obtidos nesta dissertação contribuem para a consolidação desta tendência, uma vez que se verificaram importantes desigualdades espaciais entre territórios, em todas as escalas analisadas (concelhos e NUT III).

Estas disparidades espaciais devem-se, não só às características do ambiente natural de cada território, mas também às desigualdades ao nível das condições individuais e de contexto (grau de envelhecimento, características socioeconómicas, acesso a cuidados de saúde, por exemplo).

Condições socioeconómicas das populações relativas à privação material e habitacional, são elementos de vulnerabilidade ao frio

Apesar dos padrões de mortalidade sazonais estarem relacionados com a exposição ao frio, não é possível explicar a heterogeneidade espacial sem referir vários fatores socioeconómicos, culturais ou comportamentais. Verificou-se que os municípios com maior excesso de mortalidade durante o inverno coincidem com os que apresentam parque habitacional com piores condições e maior privação material.

A associação estatística encontrada entre a privação socioeconómica (habitacional e material) e o EMI em Portugal Continental era espectável, à semelhança do que já havia sido verificado por outros autores (Healy, 2003; Davie et al., 2007; Marí-Dell’Olmo et al., 2018). Todavia alguns estudos apresentam resultados diferentes, principalmente estudos ecológicos desenvolvidos à escala local (Lawlor et al., 2000; Aylin et al., 2001; Maheswaran et al., 2004; Davie et al., 2007).

A privação socioeconómica está associada a condições de exposição acrescida ao frio e a consequências mais graves decorrentes dessa exposição (Fairburn & Braubach, 2010). Fatores como o rendimento (Hales et al., 2012), escolaridade (Marmot Review Team, 2011) e ocupação (Marí-Dell’Olmo et al., 2018) são frequentemente identificados como elementos determinantes na explicação da vulnerabilidade ao frio.

As pessoas, principalmente os mais idosos, tendem a passar a maioria do tempo nas suas casas e, por isso, as condições da habitação são frequentemente referidas como um importante condicionante da saúde (Fairburn & Braubach, 2010). As habitações podem, por um lado, ser um elemento de proteção contra o frio ou, por outro lado, ser responsáveis por uma exposição acrescida a elementos adversos (Deguen et al., 2012). Más condições do edificado são frequentemente descritas como causadoras de desconforto térmico, uma vez que para manter o ambiente interior a uma temperatura confortável é exigido esforço energético e económico acrescido (Rudge & Gilchrist, 2005; Marmot et al., 2008) que uma percentagem importante da população poderá não conseguir suportar.

A exposição ao frio parece ser superior em Portugal, comparativamente ao que se verifica na Europa, sendo as más condições do parque habitacional uma possível razão. Em Portugal, 22% da população vive em habitações com infiltrações, humidade nas paredes, no teto ou no chão ou com sinais de apodrecimento da caixilharia das janelas (a média da União Europeia é de 15%) e cerca de 90% das casas não têm aquecimento central, enquanto a média da União Europeia é de 12% (Rybowska & Schneider, 2011; Santana et al., 2017). Segundo o Eurostat (2018) o preço da eletricidade aumentou cerca de 70% entre 2005 e 2016 (em 2016, Portugal era o quarto país da União Europeia com eletricidade mais cara para agregados familiares de média dimensão), acrescendo a este facto, quase metade dos alojamentos familiares utilizam aparelhos elétricos como principal sistema de aquecimento (INE, 2018).

Segundo Vasconcelos et al. (2011), num estudo conduzido em Portugal, e direcionado a pacientes hospitalizados por acidentes coronários, 26% dos inquiridos referiram que apenas tinham nas suas habitações um aparelho de aquecimento e, metade destes, não o tinham utilizado no inverno anterior. Nunes (2018) refere que, em Lisboa, os indivíduos inquiridos têm de escolher entre manter um ambiente térmico confortável nas habitações e pagar a renda, adquirir alimentação ou medicamentos, optando por negligenciar o conforto térmico.

<u>A vulnerabilidade ao frio traduz-se em anos de vida potencialmente perdidos, na diminuição da esperança de vida e em gastos acrescidos no SNS</u>

As consequências da vulnerabilidade ao frio, expressas em anos de vida potencialmente perdidos, decréscimo de esperança de vida e em gastos acrescidos no SNS, são extremamente elevadas. Os resultados obtidos no Artigo III - *Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case* indicam que a mortalidade é cerca de 30% superior no inverno do que no período não inverno, enquanto em Inglaterra e País de Gales o aumento é próximo dos 16%.

A literatura tem vindo a revelar que o excesso de mortalidade e de morbilidade no inverno resulta numa pressão adicional sobre os serviços de cuidados de saúde primários e hospitalares (NICE, 2015c). Verificámos, neste trabalho, que em Portugal Continental as urgências hospitalares aumentaram cerca de 10% durante o inverno, de modo idêntico ao identificado noutros estudos (Maheswaran et al., 2004; Rudge & Gilchrist, 2005). O aumento de internamentos hospitalares durante o inverno resultou num aumento de custos para o SNS na ordem dos 4,5%, valor próximo ao identificado por Bland et al. (2015) para a região de saúde de *Yorkshire & the Humber* no Reino Unido.

A medição dos impactos do excesso de mortalidade no inverno em termos de anos de vida potencialmente perdidos e de decréscimos na esperança de vida não é frequente, não sendo, por isso, possível comparar os resultados de Portugal com os registados noutros países.

Apesar da influência das condições socioeconómicas na vulnerabilidade ao frio não se verificou um aumento da mortalidade em excesso no inverno durante a grande recessão, contrariamente ao que foi identificado em Espanha. Segundo Benmarhnia et al. (2014), o aumento sazonal da mortalidade no inverno foi superior durante o período de recessão, quando comparado com o ocorrido em anos anteriores, consequência da deterioração das condições socioeconómicas da população verificada durante os anos de recessão económica.

Outros fatores, para além das consequências da recessão económica, podem ter contribuído para estes resultados. Condicionantes do ambiente natural (temperatura no inverno, qualidade do ar, por exemplo) e epidemiológicos (gripe sazonal) desempenham um papel fundamental na variabilidade anual da mortalidade em excesso no inverno (Conlon et al., 2011; Phu Pin et al., 2012; Vestergaard et al., 2017), apesar de não estar ainda estimado o contributo de cada um destes fatores (Fowler et al., 2015). Neste sentido, é importante identificar, de forma mais detalhada, de que modo o conforto térmico dos indivíduos é afetado pelas circunstâncias macroeconómicas.

De modo semelhante aos restantes países da União Europeia, Portugal apresenta um longo percurso de diminuição da mortalidade. Esta evolução deve também ser tida em conta na interpretação destes resultados, uma vez que o possível decréscimo do excesso de mortalidade, ou dos anos de vida potencialmente perdidos em excesso no inverno, pode estar relacionado com esta tendência (Benmarhnia et al., 2014; Tapia Granados & Rodriguez, 2015).

Fatores meteorológicos estão associados a aumentos significativos de mortalidade e morbilidade

O relatório do Painel Intergovernamental sobre Alterações Climáticas (Intergovernmental Panel on Climate Change, 2014), indica uma tendência de aquecimento e um aumento de eventos meteorológicos extremos, com significativos impactos na saúde humana. Portugal não é exceção, segundo Carvalho et al. (2014) o projeto SIAM (*Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures*) destacava as possíveis consequências das alterações climáticas no aumento da mortalidade associada ao calor, das doenças parasitárias e no agravamento dos efeitos da poluição na saúde.

A exposição a temperaturas adversas tem impactos significativos na saúde. Os resultados apresentados no Artigo IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London. Implications for health promotion* sugerem que em Lisboa os efeitos do frio na mortalidade são observados em temperaturas relativamente amenas, que são frequentemente sentidas fora dos meses de inverno (tipicamente definido dezembro, janeiro e fevereiro, no hemisfério Norte).

Estudos prévios, realizados noutros países, identificaram que a mortalidade associada a temperaturas frias extremas é substancialmente menor que a mortalidade associada ao frio moderado (Gasparrini et al., 2015) e que dias de frio extremo são responsáveis por uma pequena fração dos óbitos associados ao frio (Arbuthnott et al., 2018).

A comparação entre os resultados obtidos nesta dissertação e em trabalhos prévios está condicionada pelas diferentes opções metodológicas. Alguns autores avaliaram a associação estatística entre a temperatura e o frio em Lisboa: Antunes et al. (2017) identificaram um aumento da mortalidade por todas as causas por cada grau que a temperatura descia, alertando para os impactos do frio para a saúde; Vasconcelos et al. (2013) referiram um aumento significativo dos internamentos por enfarte agudo do miocárdio associado ao frio; Burkart et al. (2013) indicam um aumento da mortalidade associada ao desconforto térmico devido ao frio.

Alguns aspetos da associação entre o frio e a saúde não haviam sido estudados em Lisboa (de acordo com o nosso conhecimento). A quantificação do número de óbitos associados ao frio foi estimada pela primeira vez neste estudo, sendo, portanto, impossível comparar com resultados prévios.

Como identificado anteriormente, nem todas as doenças apresentam o mesmo comportamento relativamente à temperatura. O Artigo V - *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon* avalia a associação entre internamentos por perturbações mentais e temperatura média diária, tendo identificado um aumento significativo dos internamentos com temperaturas elevadas. Estes resultados estão em conformidade com estudos prévios realizados em diferentes cidades (Page et al., 2012; Vida et al., 2012; Wang et al., 2014; Peng et al., 2017). Segundo Page et al. (2007), o calor potencia comportamentos suicidários através de fatores sociais e comportamentais (consumo excessivo de álcool, por exemplo), biológicos (níveis de serotonina, por exemplo) e psicológicos (tendência para comportamentos agressivos e violentos, por exemplo), justificando, desse modo, a acrescida vulnerabilidade ao calor. O estudo desenvolvido por Shiue et al. (2016), na Alemanha, identificou um padrão diferente, caracterizado pelo aumento dos internamentos por perturbações mentais associados ao frio, o que não se observou em Portugal.

O Artigo VI – *The influence of the winter North Atlantic Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal* avalia o efeito acumulado que diferentes fatores meteorológicos e do ambiente natural têm na saúde.

A Oscilação do Atlântico Norte influência diversos aspetos da saúde humana (Bojariu & Gimeno, 2003; Christoudias et al., 2012), principalmente durante o período de inverno (McGregor, 2005). Estudos, conduzidos na Europa referem associações estatisticamente significativas entre o índice da Oscilação do Atlântico Norte e a mortalidade por enfarte agudo do miocárdio (Messner et al., 2003), doença isquémica cardíaca (McGregor, 2005), asma (Majeed & Moore, 2018), doenças infeciosas (Hubálek, 2005) ou a mortalidade por todas as causas (Pausata et al., 2013). Estes resultados foram suportados pela influência que este padrão de circulação atmosférica tem nos fatores meteorológicos, que por sua vez também influenciam os processos de transporte, dispersão e concentração de poluentes atmosféricos (Christoudias et al., 2012).

Em Lisboa não se verificou uma associação estatística entre o valor do índice da Oscilação do Atlântico Norte e os resultados em saúde. Todavia, foi observada uma associação indireta estatisticamente significativa. Contrariamente ao observado no Norte e no Centro da Europa (Osborn et al., 1999; Trigo et al., 2002; Hurrell et al., 2003), a associação entre a Oscilação do Atlântico Norte e a temperatura média diária é mais fraca na Península Ibérica (Ulbrich et al., 2012), consequentemente os impactos na saúde deste padrão de circulação da atmosférica estabelecem-se principalmente através dos efeitos que têm nos poluentes atmosféricos.

5.4 Contributos para a elaboração de medidas de minimização ou de mitigação dos efeitos do frio na saúde

Os impactos do frio na saúde são, em grande parte, previsíveis e podem ser minimizados através da implementação de planos ou ações de saúde pública, tendo em vista a redução da vulnerabilidade a temperaturas baixas e as consequências da exposição ao frio (Conlon et al., 2011; Ana Monteiro et al., 2013a; Hajat et al., 2016). Os resultados obtidos nos artigos que constituem esta dissertação podem contribuir para a elaboração ou melhoria de medidas de minimização ou de mitigação dos efeitos do frio na saúde.

A identificação de prioridades é a primeira etapa para a elaboração de intervenções de saúde pública (De Zoysa et al., 1998) e os resultados obtidos permitem identificar territórios onde a intervenção é, de facto, prioritária. Apesar de Portugal Continental apresentar, na generalidade do seu território, valores elevados de excesso de mortalidade no inverno, há municípios que se destacam pela negativa e que exigem que os atores com responsabilidades ao nível da saúde pública e da qualidade de vida desenhem e coloquem em prática intervenções específicas, adequada ao contexto da população. Por isso, seria importante estabelecer um sistema de monitorização regular do excesso de mortalidade no inverno.

A estimativa dos custos sociais e económicos do excesso de mortalidade e morbilidade no inverno à escala das regiões de saúde (ARS) pode contribuir para a consciencialização informada dos impactos do frio, incentivar a aplicação dos planos de contingência existentes e a elaboração de medidas adaptadas às características de cada ARS.

A associação estatística existente entre o excesso de mortalidade no inverno e os índices de privação material e habitacional sugerem que intervindo nestas dimensões do ambiente físico, social e económico é possível diminuir a vulnerabilidade ao frio. No Reino Unido têm sido desenvolvidos programas para melhorar as condições de habitação, promover a utilização de sistemas de aquecimento, através de incentivos monetários, e, deste modo intervir na diminuição da exposição ao frio dentro das habitações (NICE, 2015b; Armstrong et al., 2018). Segundo a avaliação efetuada, o impacto destes programas teria sido superior se os mesmos tivessem sido direcionados aos casos onde a exposição ao frio é extrema (Armstrong et al., 2018).

A aplicação destes programas no Reino Unido esteve associada a investimentos importantes. Há, no entanto, várias medidas que exigem menores esforços de implementação. No inverno de 2018/2019 decorreu uma campanha promovida pela DGS, nos órgãos de comunicação social, que divulgava algumas estratégias dirigidas às condições de habitação, como manter as casas e os seus habitantes confortáveis (ou menos desconfortáveis), com medidas de baixo custo.

São, ainda assim, necessárias medidas urgentes para garantir que os edifícios respondem aos requisitos mínimos de conforto térmico, quer os que estão em fase de construção quer os que fazem parte do parque habitacional.

Outros resultados obtidos nesta dissertação podem ainda contribuir para a melhoria dos planos existentes e dos sistemas de alerta. A identificação da temperatura a partir da qual a mortalidade aumenta significativamente devido ao frio tem impactos significativos no modo como se interpretam os planos de contingência para temperaturas adversas em vigor, e para a elaboração dos futuros. A consciencialização de que as consequências do frio na mortalidade se fazem sentir com temperaturas médias diárias, que o senso comum descreveria como amenas, enfatiza a necessidade de prevenção ao longo do ano e não apenas durante os dias mais frios do inverno. Devem ser colocadas como prioritárias as vertentes da prevenção relacionadas com a exposição ao frio e conforto térmico às quais é frequentemente dada menor importância.

A identificação do aumento da morbilidade hospitalar por perturbações mentais durante períodos de maios calor coloca em evidência a necessidade de reforçar os serviços hospitalares após alertas de calor extremos e de incluir medidas para diminuir a vulnerabilidade de indivíduos com perturbações mentais nos programas de promoção da saúde mental.

O aprofundamento dos estudos que avaliam a relação entre a Oscilação do Atlântico Norte e a saúde humana pode contribuir para o desenvolvimento de estratégias de adaptação mais eficazes e para a sua ativação de modo mais atempado e eficiente.

Numa última nota, seria importante efetuar uma avaliação sistemática do impacto dos diversos planos de contingência e programas de apoio às famílias (onde se incluem crianças e idosos) mais carenciadas na diminuição da vulnerabilidade ao frio, tendo em conta o peso da doença atribuível ao frio, o grau de implementação dos planos e a estimativa dos ganhos potenciais à implementação dos mesmos.

5.5 Pontos fortes e limitações

Esta dissertação contribui para o aumento do conhecimento sobre os impactos do frio na saúde e dos fatores de vulnerabilidade ao frio em Portugal. Alguns dos resultados obtidos e divulgados foram inovadores: a quantificação dos impactos do excesso de mortalidade e de morbilidade no inverno e sua distribuição geográfica; a avaliação da associação entre condições socioeconómicas e excesso de mortalidade; o cálculo de óbitos associados ao frio.

No desenvolvimento dos artigos foram utilizados métodos robustos e inovadores como a aplicação de modelos de mediação causal (Artigo VI - *The influence of the winter North Atlantic*

Oscillation index on hospital admissions through diseases of the circulatory system in Lisbon, Portugal) de modelos não lineares com desfasamento (Artigos IV - *Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London* e V - *Short-term impacts of air temperature on hospitalizations for mental disorders in Lisbon*).

A utilização de diversas escalas de análise representa um dos pontos fortes desta dissertação. Esta variação de escala de análise do concelho (Artigo II - *Evidence of social deprivation on the spatial patterns of excess winter mortality*), à escala da Administração Regional de Saúde (Artigo III - *Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case*), e da sub-região (NUT III) (Artigo I - Seasonal *mortality patterns and regional contrasts in Portugal*), possibilitou uma análise exaustiva da vulnerabilidade ao frio em Portugal.

Por fim, considerando que os impactos do frio em Portugal são frequentemente subestimados pelas autoridades (Monteiro et al., 2013), um dos pontos fortes desta dissertação relaciona-se com o destaque que os artigos científicos publicados tiveram na comunicação social, tendo desse modo contribuído para o debate social sobre os impactos do frio enquanto um significativo fator de risco para a saúde.

Existem, contudo, algumas limitações. Os trabalhos desenvolvidos e apresentados nesta dissertação analisam a mortalidade e a morbilidade hospitalar, no entanto, o ambiente térmico pode condicionar o individuo e o seu bem-estar sem implicar internamento ou óbito. Neste sentido, os resultados apresentados revelam, apenas as consequências extremas da influência de temperaturas adversas nos indivíduos.

De modo semelhante a outros trabalhos que recorrem a métodos de análise ecológicos, verificaram-se vários constrangimentos relacionados com a disponibilidade e o acesso a dados desagregados a escalas geográficas de pormenor (município) e a outra informação detalhada de cariz demográfico e socioeconómico. No período decorrido, desde o início desta dissertação, verificaram-se alterações nas condições de acesso aos dados o que contribuiu, também, para o recurso a diferentes escalas de análise e a diferentes agrupamentos de causas de morte e de internamento.

5.6 Trabalhos futuros

A partir dos resultados a que se chegou perspetivam-se linhas de investigação que poderão ser exploradas. Por exemplo: i) avaliação regular e sistemática do excesso de mortalidade no inverno e da mortalidade associada ao frio; ii) avaliação sistemática do impacto dos planos de contingência para temperaturas adversas e do seu custo-benefício; iii) identificação de medidas e ações que promovam o conforto térmico dos indivíduos; iv) identificação de grupos populacionais de intervenção prioritária; v) avaliação da interação entre os efeitos da temperatura e de poluentes atmosféricos.

À semelhança do que tem sido feito nos últimos anos pretende-se aprofundar as ligações com grupos disciplinares (geofísica, saúde publica, epidemiologia, ciências do ambiente, bioestatística, economia da saúde) com quem se tem vindo a trabalhar na Universidade de São Paulo (Brasil), no Instituto Superior Técnico da Universidade de Lisboa, Escola Nacional de Saúde Publica da Universidade Nova de Lisboa, *Public Health England* do *Department of Health and Social Care*, Universidade de Maastricht e WHO European Centre for Environment and Health.

5.7 Conclusões

A vulnerabilidade ao frio resulta de um vasto conjunto de fatores e tem importantes impactos sociais e económicos na sociedade portuguesa. Apesar de haver uma tendência para desvalorizar o impacto do frio na saúde humana, estudos prévios referem que, mesmo considerando a tendência de aquecimento global, as consequências do frio continuarão a ser significativas.

O presente trabalho analisou e quantificou o impacto das variações sazonais de mortalidade e morbilidade, caracterizando os fatores que contribuem para o aumento da vulnerabilidade ao frio em Portugal. Foram identificadas as causas de morte com maior variação sazonal e os seus padrões geográficos, descritas condições socioeconómicas que contribuem para um aumento da vulnerabilidade ao frio, quantificados os custos sociais e económicos (no SNS) associados ao excesso de mortalidade e morbilidade no inverno e avaliados os impactos de fatores meteorológicos na mortalidade e morbilidade.

O excesso de mortalidade e morbilidade no inverno e a mortalidade associada ao frio podem ser evitáveis, ou pelo menos minimizados, através de intervenções adequadas. Ações direcionadas à redução da exposição ao frio deviam fazer parte dos planos de contingência existentes e das políticas de promoção da saúde.

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Anexos

Anexo I: Artigo III - Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case

Versão original submetida a 26 de Julho de 2018 e re-submetida, após revisão, em Dezembro de 2018.

International Journal of Biometeorology

Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case

--Manuscript Draft--

Manuscript Number:	IJBM-D-18-00275R1
Full Title:	Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case
Article Type:	Original Research Paper
Keywords:	Excess winter mortality; Excess winter morbidity; Great Recession; Economic Crisis
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Funding Information:	Portuguese national funding agency for science, research and technology (SFRH/BD/92568/2013) — Mr Ricardo Almendra
Abstract:	Background: Although winter mortality and morbidity are phenomena common to most European countries, their magnitude varies significantly from country to country. The geographical disparities among regions with similar climates are the result of several social, economic, demographic and biological conditions that influence an individual's vulnerability to winter conditions. The impact of poor socioeconomic conditions may be of such magnitude that an economic recession may aggravate the seasonal mortality pattern. This paper aims to measure the seasonal winter mortality, morbidity and their related costs during the Great Recession (2009-2012) in mainland Portugal and its Regional Health Administrations (RHA) and to compare it with the periods preceding and following it. Methods: Monthly mortality and morbidity data were collected and clustered into three periods: Great Recession (2009-2012) Pre-Recession (2005-2008) and Post-Recession (2013-2016). The impact of seasonal winter mortality and morbidity during the Great Recession in Portugal and its Regional Health Administrations was measured through the assessment of age-standardized Excess Winter (EW) death and hospital admissions rate and index, expected life expectancy gains without EW Deaths, EW Rate of Potential Years of Life Lost and EW Rate of emergency hospital admission costs. Results: Important increases of winter deaths and hospital admissions were identified, resulting in an important number of potential years of life lost (87 years of life lost per 100,000 inhabitants in 2009-12), life expectancy loss (1 year in 2009-12) and National Health Service costs with explicit temporal and spatial variations. These human and economic costs have decreased consistently during the analyzed periods, while no significant increase was found during the Great Recession.

	Conclusions: Despite its reduction, the winter excess morbidity and mortality highlights that the Portugal still faces substantial challenges related to a highly vulnerable population, calling for investments in better social and health protection.

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Title: Excess winter mortality and morbidity before, during and after the Great Recession: the Portuguese case

Abstract

Background: Although winter mortality and morbidity are phenomena common to most European countries, their magnitude varies significantly from country to country. The geographical disparities among regions with similar climates are the result of several social, economic, demographic and biological conditions that influence an individual's vulnerability to winter conditions. The impact of poor socioeconomic conditions may be of such magnitude that an economic recession may aggravate the seasonal mortality pattern.

This paper aims to measure the seasonal winter mortality, morbidity and their related costs during the Great Recession (2009-2012) in mainland Portugal and its Regional Health Administrations (RHA) and to compare it with the periods preceding and following it.

Methods: Monthly mortality and morbidity data were collected and clustered into three periods: Great Recession (2009-2012) Pre-Recession (2005-2008) and Post-Recession (2013-2016). The impact of seasonal winter mortality and morbidity during the Great Recession in Portugal and its Regional Health Administrations was measured through the assessment of age-standardized Excess Winter (EW) death and hospital admissions rate and index, expected life expectancy gains without EW Deaths, EW Rate of Potential Years of Life Lost and EW Rate of emergency hospital admission costs.

Results: Important increases of winter deaths and hospital admissions were identified, resulting in an important number of potential years of life lost (87 years of life lost per 100,000 inhabitants in 2009-12), life expectancy loss (1 year in 2009-12) and National Health Service costs with explicit temporal and spatial variations. These human and economic costs have decreased consistently during the analyzed periods, while no significant increase was found during the Great Recession.

Conclusions: Despite its reduction, the winter excess morbidity and mortality highlights that the Portugal still faces substantial challenges related to a highly vulnerable population, calling for investments in better social and health protection.

Keywords: Excess winter mortality; Excess winter morbidity; Great Recession; Economic Crisis

1. Background

The monthly distribution of mortality throughout the year -i.e, the so-called seasonal behavior - is well known, and is generally characterized by a winter peak, often referred to as Excess Winter (EW) Mortality (Dimitriou et al. 2016). A relationship between socioeconomic conditions and excess winter mortality is often found (Healy 2003). The impact of poor socioeconomic conditions may be of such magnitude that an economic recession may aggravate the seasonal mortality pattern.

Most of Excess Winter (EW) mortality is related to diseases of the circulatory and respiratory system (Rau 2004; Antunes et al. 2017). Exposure to low temperatures can have severe biological consequences, producing changes in blood pressure, causing vasoconstriction, and increasing the levels of plasma fibrinogen and cholesterol (Mercer 2003; Sartini et al. 2016), while the inhalation of cold air is related to higher risk of bronchitis, pneumonia, and acute exacerbation of chronic lung diseases (Ou et al. 2013). The consequences of the exposure to harmful weather conditions are greater in older people (Rudge and Gilchrist 2005; Benmarhnia et al. 2014) where the overlapping of biological and social fragility is frequent.

Despite being common to most European countries, the EW Mortality spatial pattern is heterogeneous (Keatinge 1997). In regions with harsher winters, individuals may benefit from a better protective attitude towards cold weather and a better adapted built environment; therefore, despite the evidence of the biological effects of cold on human health, the fact that the seasonality of the diseases is more evident in areas with mild climate suggests that EW mortality is strongly associated with socioeconomic determinants (Davie et al. 2007). Healy (2003) identified a positive association, at country level, between EW mortality and income measures, such as estimated gross domestic product based on purchasing power parity.

Portugal is one of the European countries with higher EW mortality (Healy 2003; Fowler et al. 2015; Liddell et al. 2016); the seasonal mortality patterns are often characterized by important winter increases (Pinheiro 1990; Freire 1996; Nogueira and Paixão 2007; Almendra et al. 2016, 2017). Among the conditions most often referred to justify geographical differences in the vulnerability to winter cold weather are those related to poverty and its consequences, such as deprivation (Healy 2003; Almendra et al. 2017), poor housing conditions (Healy 2003; Almendra et al. 2017), fuel poverty (Hajat et al. 2006), or limited access to healthcare services (Hales et al. 2012).

Portuguese social and economic structures were amongst the most hardly shaken by the Great Recession, which, in accordance with the technical definition of recessions (two quarters of negative growth), lasted from 2009 to 2011. Those years of economic recession had severe consequences, such as strong unemployment increases (from 8.8% in 2008 to 15.8% in 2012) (Perelman et al. 2015), loss of purchasing power, and important emigration flows (136,615 registered emigrants between 2009 and 2012). In 2011, with the introduction of the Economic Adjustment Programme, an agreement to implement several reforms, the often mentioned 'austerity measures', were established to reduce public expenditures (including those in the National Health Service) (European Commission 2014). It has been mentioned that this bail-out programme might have had a important impacts on health care provision, leading to increasing health inequalities, barriers to access to health services, especially for vulnerable groups, such as the elderly (Doetsch et al. 2017).

Also, it may be hypothesized that the deterioration of socioeconomic conditions and greater impoverishment of the population most likely contributed to an aggravation of an individual's vulnerability to cold weather given how they change the complex combination of physiological, social, and cultural adaptation factors to harmful temperatures (Hales et al. 2012; Benmarhnia et al. 2014): hence, the drop in income during the Great Recession could have influenced the ability to intervene in the environment where people live (e.g. inability to improve the housing conditions or keep them warm); and the NHS cuts may be affecting the utilization of hospital services (Perelman et al. 2015). Regardless of economic circumstances, biological vulnerability may also be growing due to the ageing trend of Portuguese population.

The assessment of the health impacts of the Great Recession is an important topic among Public Health researchers (Perelman et al. 2015; Tapia Granados and Rodriguez 2015). However, the results obtained seem to be somehow contradictory, varying from the identification of significant harmful consequences of the economic recession in health care provision (Legido-Quigley et al. 2016) and health outcomes (Benmarhnia et al. 2014), in particular those related to mental health (Karanikolos et al. 2013; Frasquilho et al. 2015), to some "protective effect", particularly in mortality indicators (Regidor et al. 2014; Tapia Granados and Rodriguez 2015).

The impact of the economic crisis in the seasonal mortality pattern was addressed in Spain by Benmarhnia et al. (2014), but a study assessing the EW mortality and morbidity toll in Portugal is still missing, despite being recognized as one of the European countries with higher EW mortality. Thus, this paper aims to: i) measure the seasonal winter mortality, morbidity and its related costs during the Great Recession (2009-2012) in mainland Portugal and its Regional Health Administrations (RHA); and ii) compare it with the four years period that preceded (2005-2008) and followed it (2013-2016).

2. Data and methods

2.1 Study area

Mainland Portugal (hereafter referred to as Portugal) is located in Western Europe (figure 1) in a transitional region between the subpolar depression zones in north and the sub-tropical anticyclone area in the south. Mean monthly air temperature values vary regularly during the year, reaching their maximum in August and minimum in January. According to the Köppen–Geiger classification, it has a typical Mediterranean climate with mild, wet winters and warm and dry summers (Csa in the South and Csb in the North). During the period under analysis 9 winter were colder than normal and 3 warmer, 2016 was the warmest winter and 2005 (the year represented by the dots has information of January and February months and December from previous year) (figure 2).

In accordance with the Statistics Portugal, Portugal has a population of nearly 10 million, the majority of which lives in the coastal area and the two most populous cities, Lisbon and Oporto, which account for 4.5 million inhabitants.

Decree-Law 11/93 of 15 January indicates that the Portuguese National Health Service is organized in 5 Regional Health Authorities (RHA) (Norte, Centro, Lisboa e Vale do Tejo (LVT), Alentejo, and Algarve), which are legally distinct entities, executing their own functions of planning, distribution of resources, administration and coordination of activities, human resources management, technical, and administrative support. However, the Portuguese NHS is very centralized, so that RHAs have in practice little autonomy. The RHA were used in this study because they reflect relevant socio-demographic differences within the country.

In 2011, Alentejo was the region with highest ageing index (189.2) and Norte with the lowest (114.1); the number of official public hospitals beds per inhabitant was largest in Centro (3.2) and lowest in Algarve (1.9); LVT had the highest upper secondary education rate (43.8%) and Norte the lowest (33.2%).

Figure 1. Location of the study area

Figure 2. Winter temperature and precipitation deviation from climate normal (2005 to 2015 winters)
Source: adapted from IPMA (2018)

2.2 Data

To assess the magnitude of EW seasonal mortality and morbidity by RHA monthly mortality and hospital admissions data was collected. The number of deaths by all causes was obtained from Statistics Portugal, and the number of emergency hospital admissions in public hospitals (ICD9: 001-629; 760-799 and ICD 10: A00-N99; P00-Y89) from the Central Administration of the Health System. Twelve years of data were collected and clustered into three four-year periods: i) Great Recession (2009-2012); ii) Pre-Recession (2005-2008) and Post-Recession (2013-2016) (table 1).

Table1. Number of deaths and hospital admissions by period

Time periods	Total number of deaths	Total number of hospital admissions
2005-2008	397,430	1,791,328
2009-2012	400,961	1,819,880
2013-2016	410,602	1,843,110

2.3 Methods

The number of EW deaths was calculated following the method proposed by (Johnson and Griffiths 2003), which compares the number of winter deaths (December to March) with the average number of deaths in non-winter months (April to November). Monthly data were collected and normalized into standard 30-day months by multiplying the monthly number of deaths and emergency hospital admissions by the quotient resulting from the division between 30 and the number of days in the correspondent month. According to the Office for National Statistics (Office for National Statistics 2017), the EW deaths index is the ratio between the number of EW deaths and the average of non-winter deaths, multiplied by 100; it expresses the percentage of extra deaths that occurred in winter. The emergency EW hospital admissions number and index were estimated following the same method. The age-standardized EW Deaths (hospitalizations) rate and is calculated as a weighted average of the age-specific EW mortality (hospitalizations) rates per 100,000 persons, where the weights are the proportions of persons in the corresponding age groups of the European standard population.

The measurement of Potential Years of Life Lost (PYLL) is one of the most frequently used measures for monitoring the health of a population (Parrish 2010). It expresses the number of years that, theoretically, an individual will not live in the event of a premature death (deaths before reaching age 70); it differs from the standardized death rate, presented before, in that it assigns more weight to deaths occurring at younger ages (Mackenbach et al. 2013). The PYLL was calculated by multiplying the sum of the deaths in each age group by the number of years theoretically remaining (until reaching age 70). In the same way that this measure is calculated to measure the burden of specific causes of death, it can also be used with EW deaths. The excess winter PYLL rate is the quotient between average winter and non-winter PYLL.

Regular life tables summarize population mortality behavior, providing measures of longevity or life expectancy (Carey 1989) that are used to evaluate the general health status of a population (Santana and Nogueira 2001). The application of multiple decrement life tables allows the estimation of the likelihood of dying if the specific cause of death was reduced or eliminated (Preston et al. 2001) and, therefore, quantify the impact of that cause in life expectancy. To estimate the potential life expectancy gains if EW mortality would be reduced, multiple decrement life table was calculated as proposed by (Macken and Chiang 1986) and (Preston et al. 2001).

Rudge and Gilchrist (2007) state that addressing the impacts of cold on health through morbidity provides a different understanding of the phenomenon as it allows for the assessment of costs to and winter pressures on health services. Every hospital admission is clustered in a Diagnosis Related Group (DRG); each one has an official surcharge based on the pathology and complexity of treatment. Therefore, the costs of EW hospital admissions can be proxied by: 1) identifying the number of EW hospitalizations in each DRG; 2) assigning to each EW hospital admission the prices defined by law (Ordinance 839-A/2009 (for 2005-08), Ordinance 839-A/2009 (for the Great Recession period) and Ordinance 234/2015 (for 2013-16).) This estimation did not consider the length of stay for the patients. The impact of the costs with EW hospital admissions was addressed by the rate of EW hospital admissions costs in the total hospitalizations costs.

All indicators were calculated for the entire country, for each of the three periods, and then replicated for each RHA, in order to evaluate within-country disparities and their trend.

3. Results

3.1 Mortality

Four mortality measures were addressed to compare the EW mortality during the Great Recession (2009-2012) with the periods immediately before and after. In Portugal, winter deaths during the Great Recession were almost 30% higher than the number for non-winter mortality; this value was significantly (without overlapping confidence intervals) lower than that of the previous period and significantly higher than that of the following (EW death index in 2005-08: 31.6%; 2009-12: 29.0%; 2013-16: 28.1%) (Figure 3-A). This decreasing trend was common to all regions, except for Alentejo, where the EW hospitalization index increased in both the 2005-2008 and 2009-2012 periods. The highest values were recorded in the North RHA.

Following the same tendency, the standardized EW Deaths rate was lower during the Great Recession period than in the Pre-Recession period, and higher than in the following (110 EW deaths per 100,000 inhabitants in

2005-2008, 90 during the Great Recession period and 80 in 2013-2016) (figure 3-B). Important disparities were found between RHAs, where, generally, high values are found in the Norte and LVT regions, and low values in Algarve region. Through the three periods, regional disparities increased: RHA with lower values improved more than the regions with higher standardized EW Deaths.

With a similar evolution, the rate of EW PYLL slightly decreased between the first and the last period; there were 93 years of life lost per 100,000 inhabitants in 2005-2008, 87 years in 2009-2012, and 88 in the last period (Figure 3-C). Despite this decrease, the ratio between EW PYLL and non-winter PYLL is increasing along the period under analysis (2005-08: 9.9; 2009-12: 10.9; 2013-16: 12.6). Higher values were observed in the Alentejo and Norte RHAs, and lower values in the Algarve RHA.

In 2005-2008, the life expectancy in Portugal was 81.42 years; if the EW deaths would have been totally avoided, life expectancy would have theoretically been prolonged by nearly 1 year, reaching 82.39 years (Figure 3-D). Like the other mortality measures, the results suggest a decreasing trend where the Great Recession is the intermediate period. Alentejo is the RHA where the decrease of excess winter deaths would have higher impacts on health expectancy.

Figure 3. Excess winter mortality measures by Regional Health Administration

3.2 Morbidity

In winter months there were approximately 10% more hospitalizations than in the non-winter period; the highest winter increase was recorded in 2005-2008 (11.2%) and has been decreasing since then (9.6% and 9.2% during the Great Recession and in 2012-2016, respectively) (Figure 4-A). The RHA values are very irregular, changing significantly between periods; the highest values were recorded in LVT (2005-08), Norte (2009-12) and Alentejo (2013-16).

In Portugal, nearly 55.000 EW hospital admissions were recorded during the Great Recession period, corresponding to 157 excess winter hospital admissions per 100.000 inhabitants (Figure 4-B); this value is intermediate with the period before and after (181 and 141 excess winter hospital admissions per 100.000

inhabitants, respectively). The standardized EW hospitalization rate decreased in all regions, except in Alentejo.

During the Great Recession, the costs in terms of EW hospitalizations were at their lowest value. In 2009-2012, excess winter admission cost an additional 214 Million Euros, representing 4.4% of the total costs with hospital admissions. In 2005-2008, the cost estimation was of 226 Million Euros (4.7% of the total cost) and in 2013-2016 was of 227 Million Euros (5.9%) (Figure 4-C). The highest values were recorded in Algarve region in 2013-2016, where nearly 7% of the total costs are due to EW hospitalizations. In 2009-2012, the estimation of EW hospitalizations costs per number of hospitalization was, on average, 2749 Euros, being higher in Alentejo (2842 Euros) and Algarve (3057 Euros).

Figure 4. Excess winter hospital admission measures by Regional Health Administration

4. Discussion

<u>Summary of findings</u>

This study compares several measures of EW mortality and morbidity during the Great Recession (2009-2012) with the periods preceding and following. It identified important winter increases of deaths and hospital admissions resulting in an important amount of PYLL, life expectancy loss and National Health Service costs with explicit temporal and spatial variations. These human and economic costs did not increase during the Great Recession, and except for the EW hospitalization costs, a consistent decrease was found during the periods analyzed. Although common to all RHAs, the EW mortality and morbidity varies between regions. From the assessment of the EW mortality indicators Norte and Alentejo RHA were identified as having higher winter mortality burdens in all indicators. The morbidity indicators pattern is marked by higher variability: Centro shows higher winter increase of emergency hospitalizations; the standardized EW hospitalization rate is larger at Norte RHA; Algarve has the highest cost with increased EW hospitalizations. The evolution of the RHA EW mortality and morbidity indicators is in conformity with country level patterns.

Comparison with previous work

Despite the decreasing trend, the winter excess mortality burden in Portugal is still extremely high. During the Great Recession period, the EW mortality index was 29% while in England and Wales, according to the Office for National Statistics, it was almost half (16.8 in the winter of 2009/10, 16.9 in 2010/11 and 15.5 in 2011/12); the magnitude of these values is in conformity with previous studies assessing excess winter mortality in Portugal (Healy 2003; Fowler et al. 2015; Almendra et al. 2016). Benmarhnia et al (2014), found in a study addressing the seasonal mortality trends in the years before and after the Great Recession in Spain, that the winter mortality increase was systematically more pronounced during the crisis than before the crisis. The measurement of the impact of winter mortality in life expectancy or the number of excess winter PYLL is not often estimated; therefore, the comparison of Portugal with other countries was not possible.

Evidence showed that excess winter morbidity and mortality resulted in additional pressure on hospitals, primary care settings, and other health services (NICE 2015). There were around 10% more emergency hospital admissions in the winter period compared with the average of non-winter months. This pattern of winter increase in hospital admissions was also found by several authors analyzing diseases of the respiratory and circulatory systems (Maheswaran et al. 2004; Rudge and Gilchrist 2005). The EW hospitalizations resulted in a cost increase of 4,5%, close to values found in Yorkshire & the Humber region in UK (Bland et al. 2015). The reduced EW hospitalization rate and costs during the economic crisis may result from the impact of the Economic Adjustment Programme on public hospital financing, which imposed severe budget cuts, possibly explaining the reduction of expenditures during that period.

Regional disparities are often found when addressing the impacts of seasonal winter mortality, even when assessing regions from the same country with similar climate (Hajat et al. 2006). The RHA differences found in this study are generally in accordance with the results from previous work assessing the geographical seasonal mortality patterns in Portugal (Almendra et al. 2016).

Factors influencing annual and regional variations

Similar to most European countries, Portugal is exhibiting a long trend in terms of mortality decrease. This evolution must be taken into account when considering certain mortality measures, such as the standardized EW mortality rates or PYLL, once it is possible that the observed decrease may be related to the long term trend (Benmarhnia et al. 2014; Tapia Granados and Rodriguez 2015).

The inter-annual variation of EW mortality observed in this study may have been influenced by several environmental (e.g. winter temperature, air quality) and epidemiological (e.g. influenza) factors (Conlon et al. 2011; Phu Pin et al. 2012; Vestergaard et al. 2017), although according to Fowler et al. (2015) the relative influence of this factors is still to be estimated. This would require indeed micro data with information on lifelong exposure to adverse effects, which is far beyond the scope of this study.

The winters of 2005, 2006, 2012 and 2015 were classified as colder than the normal (between one and two degrees colder) and the winters of 2008 and 2016 as warmer than the normal (between half and two degrees warmer) (IPMA 2018). The Influenza severity data are only available after 2007; the winters between 2009 and 2012 were marked by a high incidence rate of flu syndrome, and in the period after the Great Recession only the winter of 2015 had high incidence rate (INSA 2017). Moreover, Monteiro et al. (2018) identified a significant improvement in air quality in Portugal, directly related to the reduction of energy consumption as a consequence of the economic crisis. The characterization of these factors may help to understand the evolution of excess winter mortality and morbidity, offering a possible explanation for the lower EW mortality during the Great Recession, i.e., that the less severe winters compensated the more difficult socioeconomic conditions.

By assessing the regional disparities of EW mortality indicators, Alentejo was identified as the RHA presenting the highest results. Individual and contextual conditions such as ageing and housing characteristics are important factors to explain these results. Alentejo is the region with both the highest ageing ratio (according to Statistics Portugal, the Ageing ratio in 2011 was 189 in Alentejo, whereas the country average was 130) and the worst housing conditions (Almendra et al. 2017). A lower winter mortality burden was found in Algarve, which may also be related to the particular climatic conditions of Algarve region (being Portugal's southern-most, its average yearly temperatures are warmer than in the other four regions).

Excess winter mortality and morbidity during and after the Great Recession

Several authors found statistic associations between poor socioeconomic conditions and EW mortality and morbidity (Healy 2003; Howieson and Hogan 2005; Hales et al. 2012; Marmot and Bell 2012; Almendra et al. 2017; Marí-Dell'Olmo et al. 2018). The results presented in our study indicate that the aggravation of socioeconomic conditions during the Great Recession did not coincide with significantly higher winter increases in mortality and morbidity, when compared to the other periods under analysis. Numerous reasons may have contributed to these results. Basic healthcare has resisted the crisis quite well and may have played an important role in providing health support to the population; Dimitrovová & Perelman (2018) state that in Portugal, the probability of reporting difficulties in accessing primary care services was 10.8% lower in 2012, in comparison with 2007. Rolden, van Bodegom, van den Hout, & Westendorp (2014), found that downward cycles in economy are coincident with mortality decreases; the winter mortality results may also be influenced by this trend.

The incapacity of maintaining adequate thermal comfort indoors during winter is most likely to be the key determinant for exposure to cold weather (Vasconcelos et al. 2011), and therefore the response given to extreme cold events may probably only address a part of the cold-related illnesses. Measures to prevent indoor exposure to cold during prolonged periods can be achieved through the improvement of housing insulation combined with efficient heating devices (Dear and McMichael 2011). It thus becomes necessary to consider the Eurostat data which express how the price of electricity in Portugal has increased 70% from 2005 to 2016 (during the Great Recession it increased 30%) and nearly half of the housing units equipped with heating systems use electricity as the main source of energy. The price growth of electricity may have resulted in higher vulnerability to cold weather for an important number of socially vulnerable households, even if the EW mortality and morbidity did not increase.

The EW mortality and morbidity during the last period (2013-2016) might have been minimized by several multi-level cold weather response plans. The current Portuguese Contingency Seasonal Health Plan – Winter Module is active from November to March and in periods of extreme cold aims to minimize the negative effects of extreme cold and respiratory infections (Direcção-Geral da Saúde 2017). According to Hajat et al (2016), assessing the development of Public Health England's Cold Weather Plan, the all year planning for cold weather (levels 0: year round planning) and the winter preparedness phase (level 1: winter preparedness and action) are crucial components in comparison to the alerts to minimize the vulnerability to cold.

Improving the understanding of the effects of the economic crisis on the vulnerability to seasonal cold weather is an important step towards prevention of possible avoidable human and economic costs (Benmarhnia et al. 2014). Even though, this study contributes to that understanding, further studies addressing the impact of economic crisis in the vulnerability to cold weather are still needed.

Limitations

This study aims to measure the seasonal winter mortality and morbidity during the Great Recession and not to assess its impacts on the evolution of EW mortality and morbidity, which would require detailed microdata on socioeconomic changes and health outcomes.

This study compares several morbidity and mortality measures in different periods on a RHA scale. It is possible that the time periods are too short to capture the full influences of the economic recession (Zapata Moya et al. 2015). A longer observation period would permit to determine whether there have been substantial modifications in the time trend during the economic crisis, possibly allowing the causality measurement. At the same time, the scale of analysis hides sub-regional patterns and socioeconomic disparities as well as different responses to the economic recession. Different regional and temporal patterns could have been found if the analysis would have been stratified by cause of death.

The inter-annual variations of EW mortality and morbidity are strongly influenced by environmental and epidemiological factors. The access to seasonal influenza and winter temperature by RHA would have helped to understand the current results.

5. Conclusions

This work found that in Portugal the winter increases in mortality and morbidity were not higher during the Great Recession. Nevertheless, the degree of excess winter mortality and morbidity resulting in potential avoidable years of life lost, lower life expectancy and costs to the National Health System was found to be extremely high in Portugal. Although on a different scale, this phenomenon is common to all regions.

Acknowledgments

This study was developed in CEGOT, Research Centre in Geography and Spatial Planning, and supported by the European Regional Development Funds, through the COMPETE 2020 – Operational Programme 'Competitiveness and Internationalization', under Grant POCI-01-0145- FEDER-006891; and by National Funds through the Portuguese Foundation for Science and Technology (FCT) under Grant UID/GEO/04084/2013. RA was funded by FCT doctoral fellowship SFRH/BD/92568/2013 and by the CEGOT group Cities, competitiveness, and well-being (UID/GEO/04084/2013) through COMPETE 2020.

List of abbreviations

RHA: Regional Health Administrations

EW: Excess Winter

NHS: National Health Service

LVT: Lisboa e Vale do Tejo

PYLL: Potential Years of Life Lost

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Availability of data and material: Mortality datasets analysed during the current study are available in National Statistics (www.ine.pt).

Morbidity data that support part of the findings of this study are available from Central Administration of the Health System but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the Central Administration of the Health System upon request and.

Competing interests: The authors declare that they have no competing interests.

Funding: RA and PS are part of CEGOT, Research Centre in Geography and Spatial Planning, that is supported by the European Regional Development Funds, through the COMPETE 2020 – Operational Programme 'Competitiveness and Internationalization', under Grant POCI-01-0145- FEDER-006891; and by National Funds through the Portuguese Foundation for Science and Technology (FCT) under Grant UID/GEO/04084/2013. RA was funded by FCT doctoral fellowship SFRH/BD/92568/2013 and by the CEGOT group Cities, competitiveness, and well-being (UID/GEO/04084/2013) through COMPETE 2020.

Authors' contributions: RA, PS, JP and JV contributed to the study conception and design. RA was responsible for the acquisition of data. RA, PS, JP and JV contributed to the analysis and interpretation of data. RA was responsible for drafting of manuscript. RA, PS, JP and JV contributed to the critical revision and final version of the manuscript.

Acknowledgements: Not applicable.

Authors' information (optional): Not applicable.

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Figure 1

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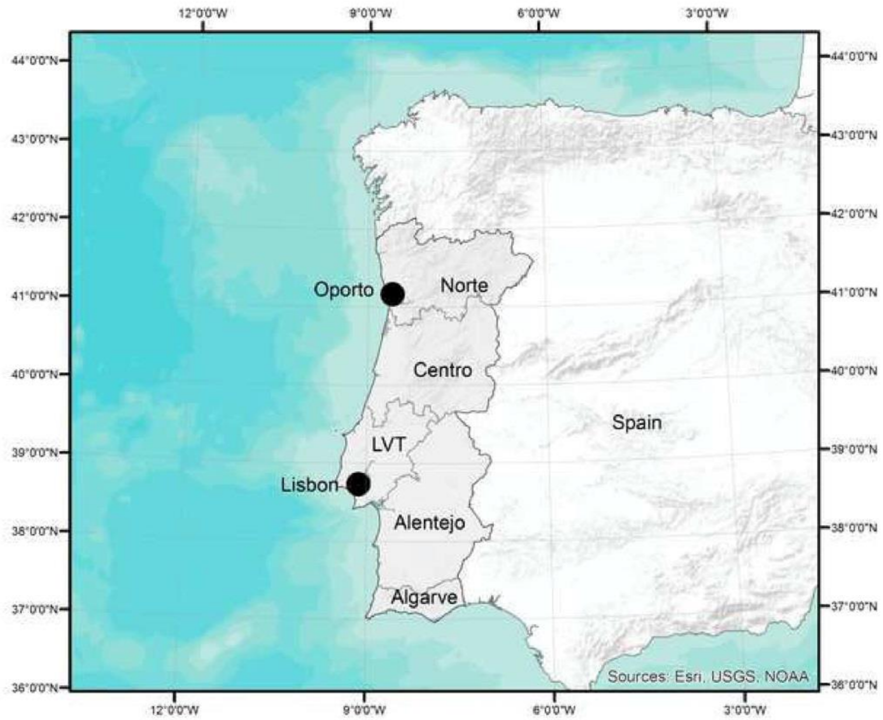


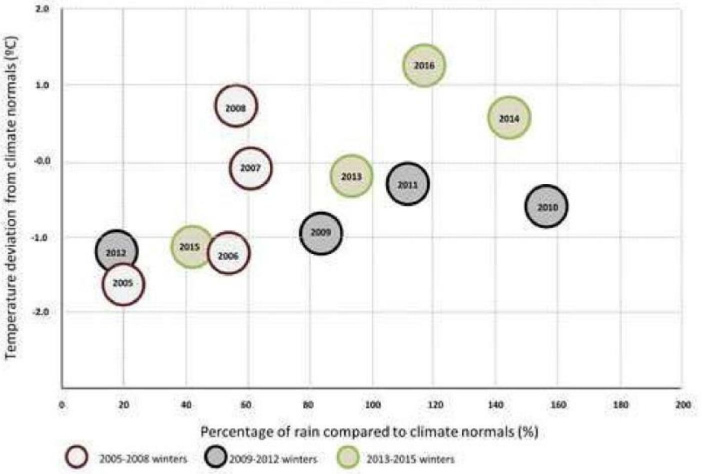

2.0
1.0
-0.0
-1.0
-2.0
Temperature deviation from climate normals (ºC)
2016
2008
2014
2007
2013
2011
2010
2009
2012
2015
2006
2005
0
20
40
60
80
100
120
140
160
180
200
Percentage of rain compared to climate normals (%)
2005-2008 winters
2009-2012 winters
2013-2015 winters

Figure 3

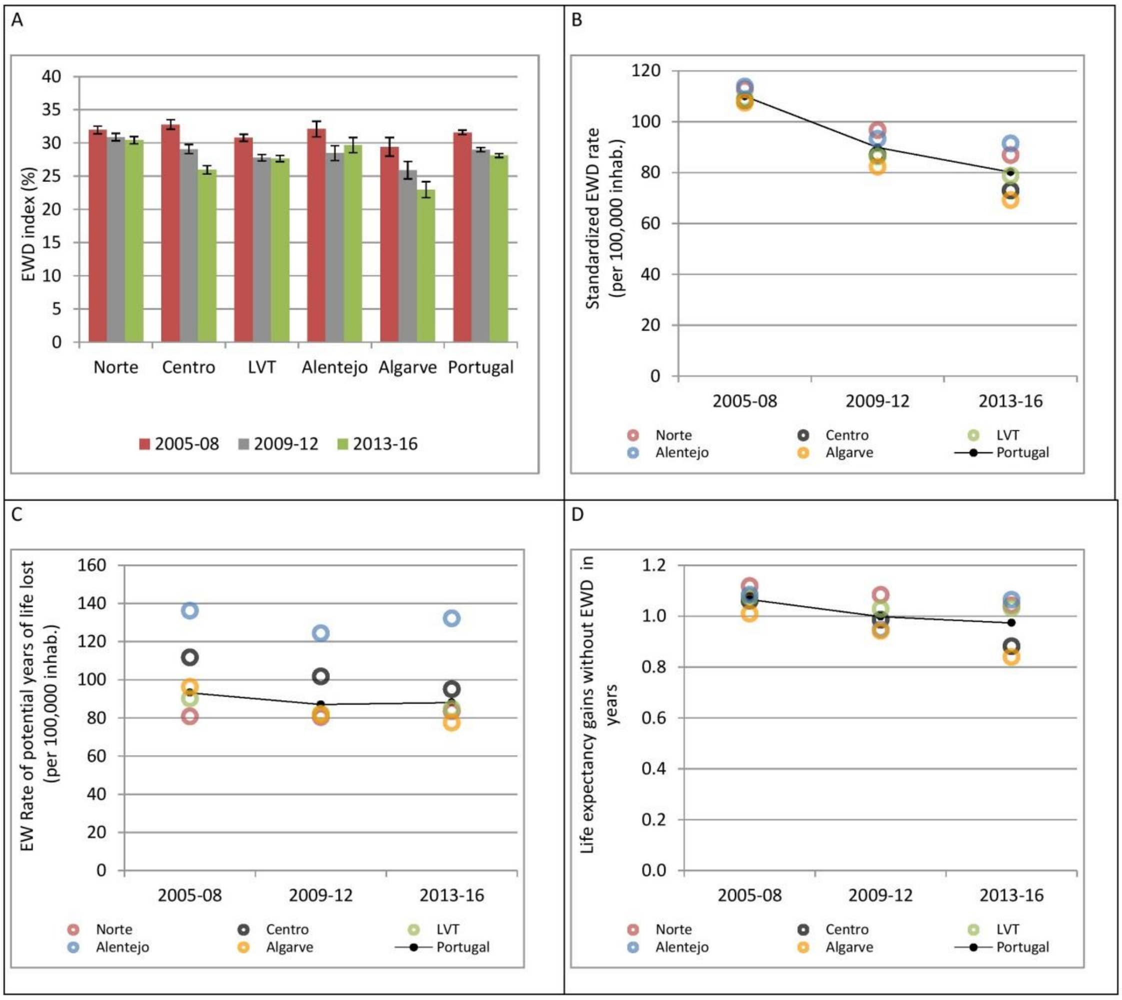
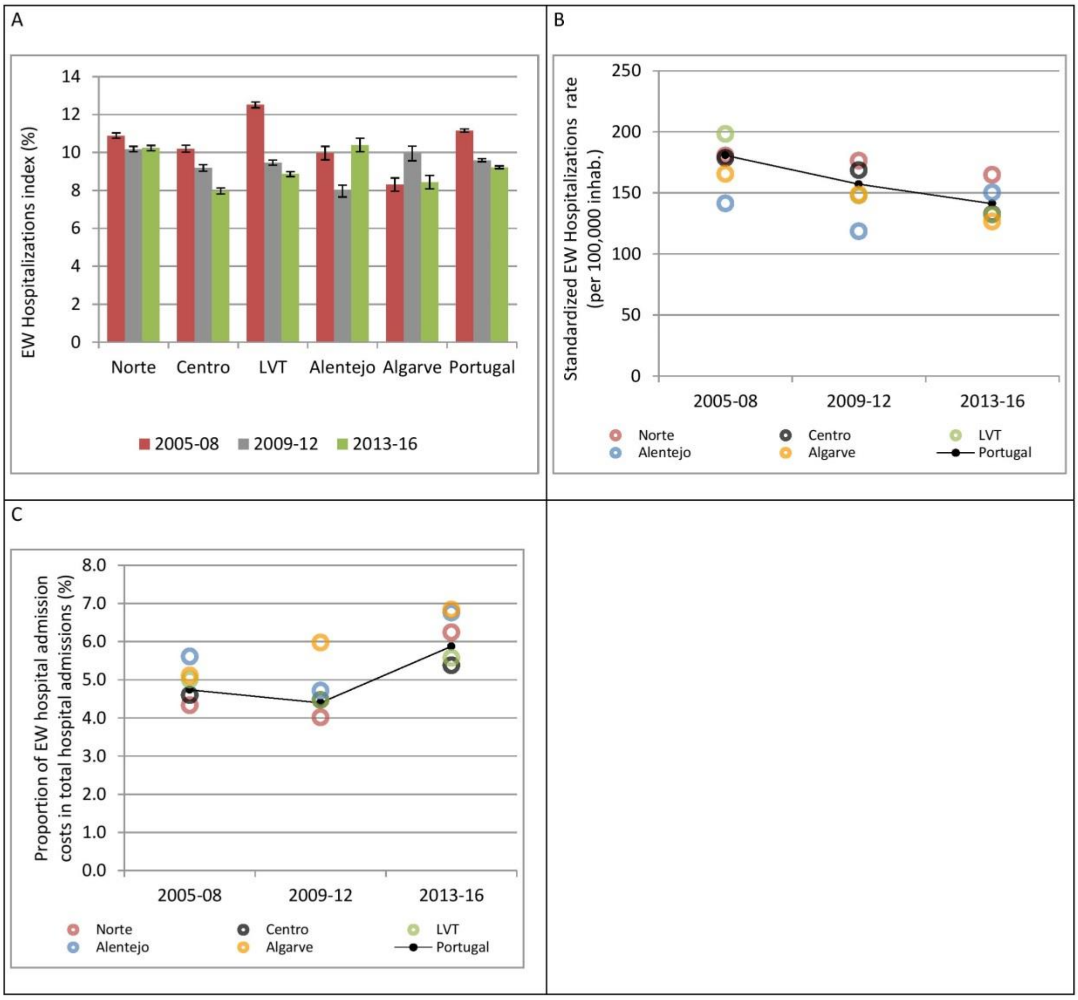

A
EWD index (%)
Norte
Centro
LVT
Alentejo
Algarve
Portugal
2005-08
2009-12
2013-16
B
Standardized EWD rate (per 100,000 inhab.)
C
EW Rate of potential years of life lost (per 100,000 inhab.)
D
Life expectancy gains without EWD in years

Figure 4


A
EW Hospitalizations index (%)
14
12
10
8
6
4
2
0
Norte
Centro
LVT
Alentejo
Algarve
Portugal
2005-08
2009-12
2013-16
B
Standardized EW Hospitalizations rate (per 100,000 inhab.)
250
200
150
100
50
0
2005-08
2009-12
2013-16
Norte
Centro
LVT
Alentejo
Algarve
Portugal
C
Proportion of EW hospital admission costs in total hospital admissions (%)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
2005-08
2009-12
2013-16
Norte
Centro
LVT
Alentejo
Algarve
Portugal

Anexo II: Artigo IV - Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London . Implications for health promotion

Versão original submetida a 15 de Outubro de 2018

*Title Page

Title:

Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London. Implications for health promotion

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Abstract

The effect of cold weather on health is an important public health concern, considered responsible for a significant mortality and morbidity burden. Vulnerability to cold, resulting from biological, socioeconomic and built environment factors, varies considerably between regions and can lead to important geographical disparities. We address a lack of quantitative estimates of cold-related mortality, particularly for the cities of Lisbon and Athens.

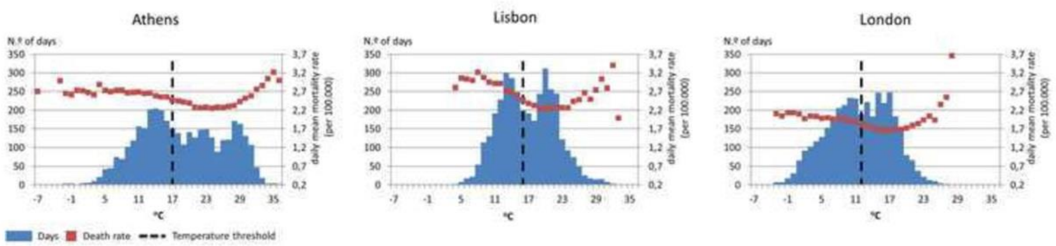
The aim of this study is to estimate the mortality burden attributable to low temperature in Athens, Lisbon and London from 2002 to 2011 and to discuss related inequalities in socioeconomic conditions.

To estimate the mortality burden attributable to low temperature, time-series regression analyses were carried out on daily mortality with respect to daily mean temperature for the three metropolitan areas to estimate the relative risk associated with a decrease in temperature. The number of cold-related deaths was estimated using the population Attributable Fraction.

Lisbon presents higher relative risk (RR) than London and Athens; the RR for Athens is lower than for London. The cold-related death rate is higher in Lisbon (53.2 deaths per 100,000 inhabitants) than in Athens (32.6) and London (37.6). The spatial heterogeneity between the three metropolitan areas in the risk estimates and cold-related mortality may result from the significant disparities in the built environment.

The results highlight the mortality burden attributable to cold as an important public health problem across these three cities. Adequate public health planning and preventive measures in the built environment may help reduce cold-related deaths and decrease vulnerability to cold in European cities.

*Graphical Abstract



***Highlights (for review : 3 to 5 bullet points (maximum 85 characters including spaces per bullet point)**

Highlights

- Cold has significant impacts on human health;
- Cold-related death rate is higher in Lisbon than in Athens and London;
- Vulnerability to cold may result from the built environment characteristics;
- Preventive measures may help to reduce cold-related deaths and vulnerability.

Cold-related mortality in three European metropolitan areas: Athens, Lisbon and London. Implications for health promotion

1. Introduction

The effect of cold weather is currently an important public health concern, considered responsible for a significant mortality and morbidity burden (Analitis et al., 2008; Gasparrini et al., 2015). This burden, associated with non-optimum temperature, will be affected by climate change, as shown by studies assessing the effect of climate change on temperature-related mortality (Gasparrini et al., 2017; Vardoulakis et al., 2014).

The relationship between temperature and mortality has previously been described as having a non-linear shape, with increasing numbers of deaths associated with high and low temperatures. Despite the general relationship being common to several locations worldwide, the magnitude of the increase and the shape of the temperature-mortality curve can vary significantly depending on local conditions and the extent of population vulnerability (Analitis et al., 2008; Curriero et al., 2002; de' Donato et al., 2015; Gasparrini et al., 2015; Vardoulakis et al., 2014).

In Europe, most temperature related deaths are associated with cold rather than heat (Braga et al., 2002; Hajat et al., 2014; Rau, 2004) and, despite the climate change trend, the mortality attributable to low temperatures is likely to remain higher than the one related to heat (Vardoulakis et al., 2014). Moreover, most of the temperature-related mortality burden has been attributed to relatively cold but not extreme cold temperatures (Gasparrini et al., 2015).

Studies comparing European countries (Fowler et al., 2015; Healy, 2003) or cities (Analitis et al., 2008) report that the vulnerability to cold tends to be higher in regions where the winters are milder. Significant spatial disparities in cold–related mortality are not only found when looking across cities, regions and countries, but also amongst specific population groups (Conlon et al., 2011).

The heterogeneity in the spatial pattern of vulnerability to cold is a reflection of the complex combination of built environment and physiological, social and cultural adaptations to the effects of adverse temperatures (Hales et al., 2012). Features of the place where people live (e.g. housing quality, urban design) as well as socioeconomic characteristics (e.g. education, income) (Almendra et al., 2017; Anderson and Bell, 2012; Healy, 2003; Marí-Dell'Olmo et al., 2018; O'Neill et al., 2003) may be important modifying factors of the relationship between temperature and mortality, thus representing significant explanatory factors for the geographical disparities concerning vulnerability to cold. Other environmental and epidemiological factors (e.g. air pollution, influenza and other viral epidemics) with important geographical disparities may also contribute to the spatial variations found in cold-related mortality (Analitis et al., 2008; Conlon et al., 2011; Vestergaard et al., 2017)

Although hypothermia may be considered the main direct cause of death attributable to exposure to cold, mortality from this cause is residual, and most cold-related mortality is associated with diseases of the circulatory and respiratory system (Rau, 2004). In addition, low temperature has been considered an important risk factor for several other diseases, such as diabetes (Li et al., 2014) or external causes (Orru and Åström, 2017) suggesting the existence of multiple biological pathways on which cold affects human health (Analitis et al., 2008).

Comparisons of the health impacts of cold in different regions with different socioeconomic, environmental and climatic conditions can contribute to the identification of risk factors to be addressed in the planning of suitable public health interventions (Marí-Dell'Olmo et al., 2018; Vardoulakis et al., 2014). Thus, the aim of this paper is to estimate the mortality burden attributable to low temperature and to discuss socioeconomic conditions and environmental inequalities between the three metropolitan areas. For this reason, we have selected three large metropolitan areas, Athens, Lisbon and London, with contrasting climatic, socioeconomic and built environment characteristics in Southern, Western and Northern Europe.

Moreover, this study addresses the lack of quantitative estimates of cold-related mortality, particularly for Lisbon and Athens, where the mortality burden of cold has not been previously estimated.

2. Data and Methods

2.1. Study areas

The climate of the Lisbon and Athens metropolitan areas is classified as Hot-summer Mediterranean climate according to the Koppen classification, characterized by warm and dry summers and mild and wet winters. The London metropolitan area has a Temperate Oceanic climate, with mild summers and cold winters (Rubel & Kottek, 2010).

Comparing the three metropolitan areas, London has a larger population (population in 2011: Athens-3.1 million; Lisbon-2.8 million; London-8.2 million). In the three metropolitan areas, higher population density is found in the central municipalities and tends to decrease as the distance from the city centre increases; Athens has the highest population density with 9054 inhabitants per square km (figure 1). Similarly, the more central municipalities also have a higher ageing index (the ratio between population aged 65 and above to the population aged between 0 and 14 years old, multiplied by 100); Athens and Lisbon have, on average, an ageing index of 1.3 and 1.1, respectively, while London is near 0.6. Education levels are highest in Athens and lowest in Lisbon, with, on average, 76.5% and 38.3% of inhabitants aged 25-64 with upper secondary or tertiary education attainment, respectively; London's average rate is 55.5%. The percentage of households with central heating is higher in London, where near 98% of households have central heating, 89% in Athens, while in Lisbon that value is lower than 10% and in no municipality does the value reach 20% (figure 1).

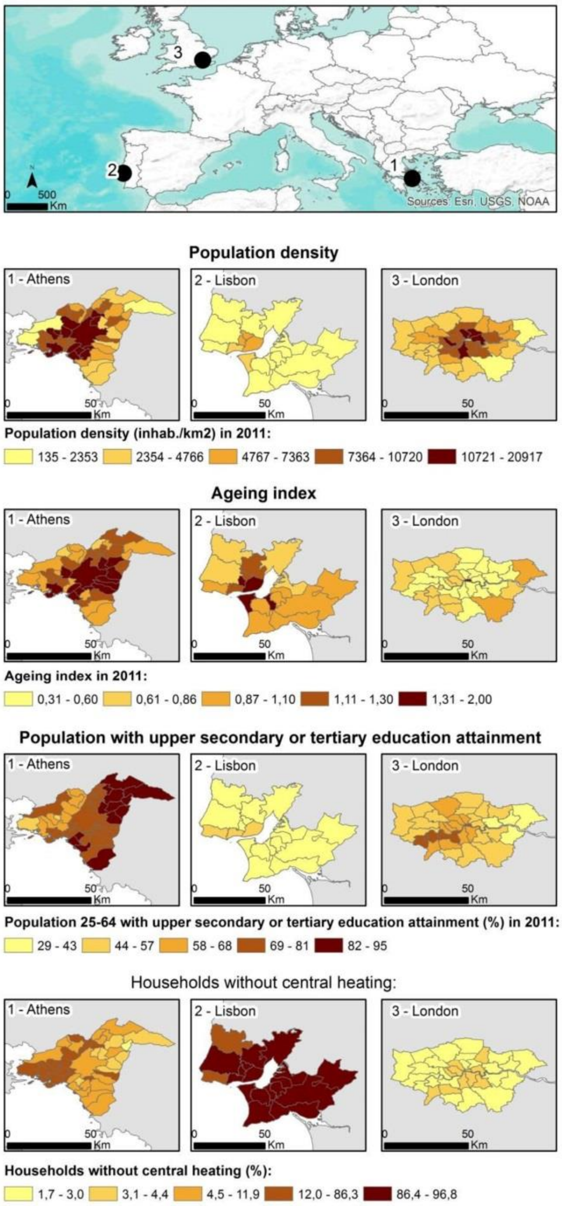


Figure 1. Location and characterization of the metropolitan areas

Source: Eurohealthy data platform (available at https://eurohealthydata.uc.pt for authorised users)

2.2. Mortality, meteorological and air quality data

To estimate the mortality burden attributable to low temperature, ten years of daily data (2002-2011) was collected from the Athens, Lisbon and London metropolitan areas (table 1). One meteorological station with good data coverage was selected from each Metropolitan Area to collect the daily mean temperature and relative humidity (Athens- Thision; Lisbon-Gago Coutinho Meteorological Station; London-Heathrow Station). Hourly concentrations of particulate matter with aerodynamic diameter <10µm (PM_{10}) were collected from urban background monitoring stations, with at least 75% data coverage, and averaged into daily values for each city.

Table 1. Data collected and sources

Variable	Source		
	Athens	Lisbon	London
Deaths by all causes (n.º)	Hellenic Statistical Authority (EL. STAT)	Portuguese national statistics institute	Office for National Statistics
Average temperature (°C)	National Observatory of Athens	National Climatic Data Centre online	National Climatic Data Centre online
Relative Humidity (%)	National Observatory of Athens	National Climatic Data Centre online	National Climatic Data Centre online
PM_{10} (µg/m^3)	Ministry of Environment & Energy	Portuguese Environment Agency	UK Department for Environment Food and Rural Affairs (DEFRA)

Athens had the highest mean daily temperature (18.7 ºC), and also the widest temperature range, with values ranging from -6.7 ºC to 36.4 ºC (for 50% of the days, the mean temperature varied between 12.9 and 25.2 ºC) (table 2). The lowest mean temperature was recorded in London (11.6 ºC). Lisbon has the narrowest temperature range, where 50% of days have temperatures between 12.9 ºC and 20.5 ºC.

Table 1. Descriptive statistics of mortality, meteorological and air quality data

Variable	Source								
	Athens			Lisbon			London		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Daily deaths by all causes (n.º)	40	79.5	127	38	70.3	154	85	141.9	282
Mean daily temp (C.º)	-6.7	18.7	36.4	3.9	16.8	32.3	-3.2	11.6	28.3
Mean daily Relative Humidity (%)	20.7	64.2	100.0	20.5	69.7	100.0	36.1	74.3	100.0
Mean daily PM_{10} concentrations($\mu g/m^3$)	4.9	31.5	362.5	6.4	28.2	187.4	5.8	24.7	90.4

2.3. Health impact assessment

The estimation of cold-related deaths, between 2002 and 2011, was carried out in three stages: a) assessment of the relationship between daily mean temperature and daily mortality and identification of the temperature thresholds for health effects; b) estimation of the relative risks associated with a temperature decrease below the cold threshold; c) quantification of cold-related deaths.

To identify the temperature thresholds of the three Metropolitan Areas, individual quasi-Poison time series regression analysis was applied using the R statistical software with the

DLNM and MGCV packages, as in previous studies (Antunes, Silva, Marques, Nunes, & Antunes, 2017; Gasparrini et al., 2015).

The association between daily deaths and temperature was modelled by applying a distributed lag non-linear model: the lag-response curve was modelled with a natural cubic B-spline with an intercept and three internal knots placed at equally spaced values in the log scale. Based on previous studies, we considered a lag period of 28 days for cold effects on mortality (Bhaskaran et al., 2010; Vardoulakis et al., 2014); the exposure-response relationship was modelled with a quadratic B-spline with three internal knots placed at the 10th, 75th, and 90th percentiles. Potential confounders of the relationship between daily deaths and outdoor temperature, such as relative humidity, PM_{10}, day of the week and time, were considered in the model. Relative humidity and time were modelled through natural cubic splines with 3 and 60 (6 per year) degrees of freedom (df), respectively. PM_{10} concentration was modelled linearly. Day of the week was added to the model using six indicator terms. The model parameters were selected based on a sensitivity analysis where preference was given to the lower Generalized Cross Validation values.

Through the model previously presented, it was possible to assess the relationship between temperature and mortality (RR and CI) and, therefore, to identify the temperature below which mortality increases significantly, when compared to the median temperature for each Metropolitan Area (both RR and CI are higher than 1). These temperature values were considered as cold temperature thresholds for health effects.

On the second stage, linear threshold models were applied to estimate the relative risk associated with the temperature decrease below the cold threshold temperature. The same modelling options were applied as for the previous stage.

The number of cold-related deaths was estimated using the population Attributable Fraction (AF), which represents the mortality burden that would have occurred without the exposure to cold (Steenland & Armstrong, 2006). The attributable fraction is as follows:

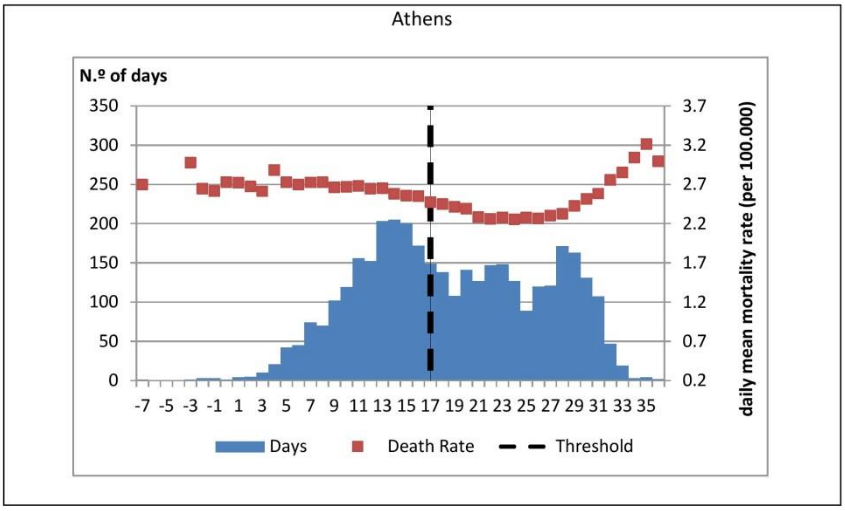
$$AF = \frac{RR^{\Delta T} - 1}{RR^{\Delta T}}$$

Where ΔT corresponds to the daily mean temperatures below the Metropolitan Area cold threshold, and RR is the relative risk of mortality derived from the linear threshold models.

3. Results

Between 2002 and 2011, there were around 290,000 deaths in Athens, 257,000 in Lisbon and 518,000 in London, resulting in an average daily death rate for the 10-year period of 2.5, 2.5 and 1.8 deaths per 100,000 inhabitants, respectively.

The assessment of the relationship between daily mean temperature and daily mortality allowed for the identification of cold thresholds of 17.0 ºC in Athens; 16.5 ºC in Lisbon; and 11.5 ºC in London (figure 2).



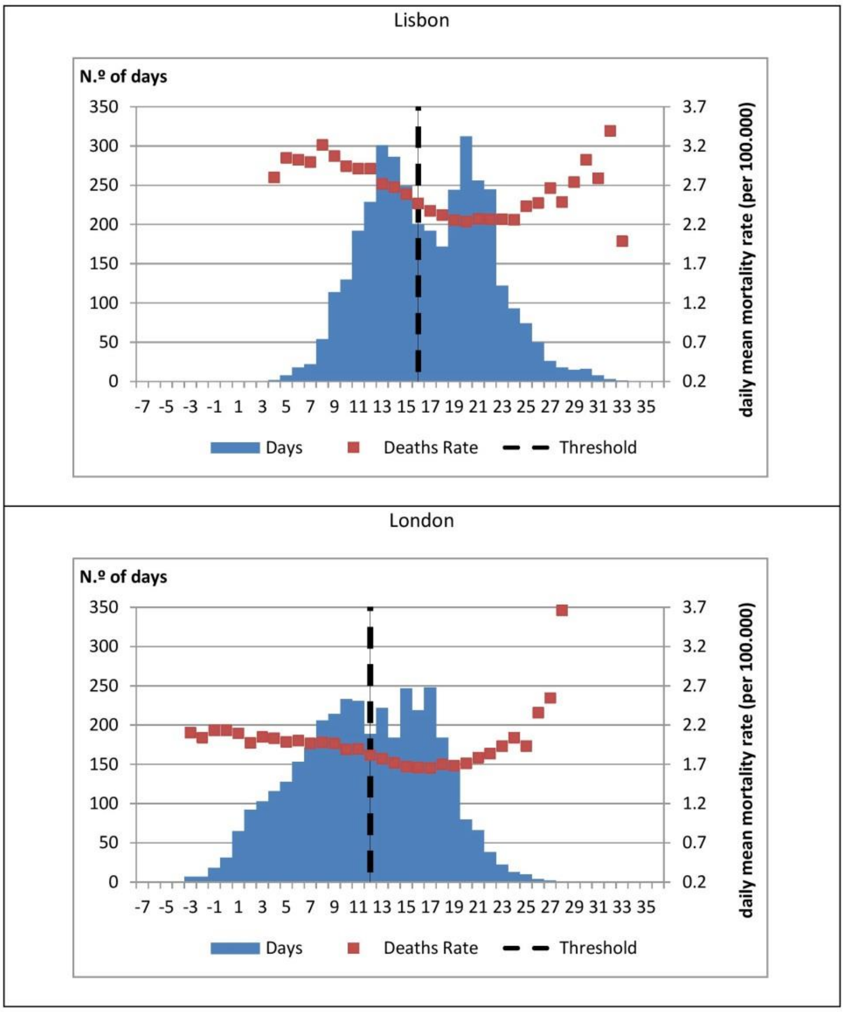


Figure 2. Mean daily death rate, number of days by daily mean temperature and cold thresholds in Athens, Lisbon and London Metropolitan Areas.

Table 3 shows the cold temperature threshold, RR in all-cause mortality per 1°C decrease in daily mean temperature below the threshold, the cold-related deaths per 100,000 inhabitants and the percentage of all-cause mortality attributable to cold. In all Metropolitan Areas, there was a significant increased risk in mortality associated with cold exposure (RR>1). The mortality increase per 1°C drop in temperature below the cold threshold was 1.6% (95% CI 1.0 to 2.2) in Athens, 3.0% (95% CI 2.1 to 3.9) in Lisbon and 2.6% (95% CI 2.2 to 3.0%) in London. The mortality burden of cold, expressed here by the cold-related death rate, is higher in Lisbon (53.2 deaths per 100,000 inhab.), followed by London (37.6 deaths per 100,000 inhab.) and Athens (32.6 deaths per 100,000 inhab.). The cold-attributable mortality fraction was 5.7% (95% CI 4.2 to 7.2) in Lisbon, 5.6% (95% CI 4.7 to 6.4) in London and 3.6 (95% CI 2.2 to 4.9) in Athens.

Table 2. Estimated cold temperature threshold, RRs, cold related deaths and Fraction of all-cause mortality attributable to cold

Metropolitan Area	Cold temperature threshold (°C)	RR (CI)	Cold-related deaths rate (per 100,000 inhab.) (CI)	Fraction of all-cause mortality attributable to cold (%)
Athens	17.0	1.02 (1.01 - 1.02)	32.6 (20.2 - 44.6)	3.6 (2.2 - 4.9)
Lisbon	16.5	1,03 (1.02 - 1.04)	53.2 (38.9 - 67.0)	5.7 (4.2 - 7.2)
London	11.5	1,03 (1.02 - 1.03)	37.6 (31. 8 - 43.2)	5.6 (4.7 - 6.4)

4. Discussion

This study estimates the mortality burden attributable to low temperature in Athens, Lisbon and London from 2002 to 2011. The three metropolitan areas have different climates and present strong disparities in terms of population density, ageing index, education attainment and household central heating availability. The results indicate that London (11.5ºC) has the lowest temperature threshold while in Lisbon and Athens it is very similar, and around 5 degrees higher. Lisbon has higher relative risk than London and Athens (but with overlapping CIs), the RR for Athens is lower than for London. The cold-related death rate is highest in Lisbon.

The contrast in cold-related mortality between the metropolitan areas reinforces the findings from previous studies which compare the vulnerability to cold among cities from different climates, observing that people living in places with milder winters are more vulnerable to cold weather than those living in places with colder winters (Analitis et al., 2008; Eurowinter, 1997). These results highlight the impact of factors relating to local conditions in the place of residence, as this contrast may be a consequence of different socioeconomic conditions, behaviour and physiological acclimatization, which exacerbate exposure to cold and its consequences (Marí-Dell'Olmo et al., 2018; Medina-Ramón & Schwartz, 2007; Rodopoulou et al., 2015).

Cold-related mortality is generally higher for older age groups (Shakoor Hajat et al., 2014), as the elderly are more vulnerable than the general population to harmful weather conditions due to behavioural factors, biological and social vulnerability. According to Carter et al. (2016), with increasing age there is a progressive loss of psychological resilience and deterioration of health, adoption of less healthy lifestyles and a tendency towards loneliness and social isolation. Results from the Eurowinter group (1997) show that in relatively warm countries, the elderly often fail to wear protective clothing and do not remain indoors, and so are exposed to cold weather conditions outdoors. Therefore, the ageing index gradient between London (0.6), Athens (1.3) and Lisbon (1.1) suggests disparities with respect to vulnerability among the populations of the three Metropolitan Areas.

From the socioeconomic indicators presented here, Lisbon presents the lowest education levels (population with upper secondary or tertiary education), and has central heating in less than 10% in metropolitan households (according to Portuguese national statistics, 60% of households use mobile heating devices, such as electric heaters or gas heaters, as these are the most frequently available systems). The effects of housing conditions on cold-related mortality have been highlighted by several authors, stating that the inability to keep the house at a comfortable temperature increases one's vulnerability to cold (Dear & McMichael, 2011; Rudge & Gilchrist, 2007). The difficulty of keeping housing at comfortable temperatures can be influenced by the lack of a heating system (e.g. households without central heating), the thermal response of the building (e.g. existence of doubled glazed windows) or the behaviour of the household (e.g. use of heating devices) (Bøkenes, Mercer, MacEvilly, Andrews, & Bolle, 2011; Vasconcelos, Freire, Almendra, Silva, & Santana, 2013).

The inability to keep one's house at an adequate temperature due to economic reasons is referred to as Fuel Poverty, and it can be related to excessive energy consumption in terms of household income or the need to self-ration to avoid high energy consumption costs (Boardman, 2013). Living in cold homes and experiencing fuel poverty has been linked to adverse effects on physical and mental health as well as to negative impacts on social well-being (W. Anderson, White, & Finney, 2012). Moreover, socioeconomic conditions such as social isolation, low income and stress are associated with fuel poverty and may also contribute to the aggravation of one's health status (Marmot Review Team, 2011).

Less educated individuals have been reported as being more vulnerable to cold weather (O'Neill et al., 2003) as education level may be a predictor of low socioeconomic status and can influence the access to adequate housing conditions (e.g. central heating, thermal insulation) or the ability to keep the houses at a comfortable temperature (Marí-Dell'Olmo et al., 2018; Marmot Review Team, 2011).

In line with previous studies, the results presented here show that the harmful effects of cold on mortality can be identified at relatively mild temperatures, which can be experienced outside the typical definition of the Northern Hemisphere winter (December to February).

Moreover, in previous studies, it was observed that the mortality related to the effect of extreme temperature was substantially less than the mortality attributable to milder but non-optimum weather (Gasparrini et al., 2015) and extreme cold days are responsible for only a small fraction of the cold-related mortality burden (Arbuthnott, Hajat, Heaviside, & Vardoulakis, 2018).

Although the direct comparison with previous studies is limited by different methodological techniques, the results presented here are still comparable to a certain extent. The assessment of the vulnerability to cold through the estimation of temperature thresholds, the RR associated to cold or the measurement of the mortality burden attributable to low temperatures in London has been assessed by several authors. Vardoulakis et al. (2014) and Hajat et al. (2014) estimated the RR associated with a 1-degree decrease to be around 2% and associated with 60.5 and 77.3 cold-related deaths per 100,000 inhabitants, respectively. The difference of the estimates between these results and the figures presented in this study may be related to different approaches addressing the cold temperature thresholds (in this study the threshold was almost two degrees lower: 11.5°C), and the different periods under analysis.

Previous studies have addressed the influence of extreme cold on mortality (Antunes et al., 2017), but temperature thresholds, the quantification of the mortality increase for each degree and the cold-related mortality are estimated here for the first time, as far as the authors are aware. According to Antunes et al. (2017), in Lisbon, mortality by all causes increased significantly with low temperatures (3.84% per 1 °C drop), identifying cold as an important public health problem.

In 1997, the Eurowinter group estimated that between 1988 and 1992 the increase in all-cause mortality per 1°C drop in temperature below 18°C in Athens was 2.15% (Keatinge, 1997). No further studies assessing the mortality burden of cold in Athens have been conducted.

The impacts of cold weather are predictable and can be minimized (S. Hajat et al., 2016) with the implementation of well-designed plans or public health measures. The plans implemented to reduce the vulnerability to cold weather or to minimize the effects of cold in each city can also be considered as a significant factor potentially modifying vulnerability to cold weather (Conlon et al., 2011; S. Hajat et al., 2016; Monteiro, Carvalho, Góis, & Sousa, 2013).

The first Portuguese Contingency Seasonal Health Plan – Winter Module was implemented in 2015, and therefore did not influence the results presented in this study. It aims to minimize the negative effects of extreme cold and respiratory infections. The plan is active from November to March and in periods of extreme cold, and it includes a set of actions involving health professionals, civil protection departments and local communities (Direcção-Geral da Saúde, 2017). From the 2015 edition of the plan (Direção-Geral da Saúde, 2015) to the one from 2017 (Direcção-Geral da Saúde, 2017) an increasing awareness of the health consequences of cold weather throughout winter and the need for preventive measures is present. Despite this, the latest version of the plan still does not include a prevention phase throughout the year. This is important because even though there is a significant health impact associated with extreme cold (Antunes et al., 2017; Monteiro et al., 2013), the results of this study show that in Lisbon cold-related deaths already occur at much milder temperatures (the threshold is near 16ºC) even outside the winter season.

The Cold Weather Plan for England was introduced in 2011; it aims to prevent the major avoidable effects on health during periods of cold weather by raising public awareness and enabling appropriate responses (Public Health England, 2017). The plan includes five different levels of action, from year-round planning for cold weather, winter and severe cold weather action to a major national emergency. Each alert level triggers a series of appropriate actions from the national level (e.g. NHS England, Public Health England, Met Office) through social care organizations and professionals, communities and individuals. According to Hajat et al., (2016) when assessing the development of Public Health England's Cold Weather Plan, the all-year planning for cold weather (level 0: year round planning) and the winter preparedness phase (level 1: winter preparedness and action) are crucial components in combination with the alerts. Greece, for its part, does not have a specific national plan to tackle the effects of cold on health.

Limitations of this work

Temperature–mortality relationships depend to some extent on the statistical methods applied to derive them, such as the lag structures used and controlling variables. Despite the importance of seasonal influenza to explain the relationship between temperature and health, the results of this study are not adjusted by this factor due to the unavailability of comparable influenza data amongst the three metropolitan areas. Although adjustment for PM10 was carried out, other air pollutants with significant influence on temperature-related mortality were not addressed due to data availability limitations.

5. Conclusions

This study assessed cold-related mortality in Athens, Lisbon and London over a 10-year period from 2002 to 2011. The results highlight the mortality burden attributable to cold as an important public health concern across these three cities to varying degrees. The cold-related mortality burden per population size was higher in Lisbon than in London and Athens over the study period; the spatial heterogeneity in risk estimates and cold-related mortality between the three metropolitan areas may have resulted from disparities in physiological, behavioural and built environment factors. The low prevalence of central heating in Lisbon is likely to have contributed to the higher cold mortality risk in this city compared to Athens and London. Adequate public health planning and preventable measures in terms of built environment may reduce cold-related deaths and decrease vulnerability to cold in European cities.

Acknowledgements

RA is funded by FCT doctoral fellowship SFRH/BD/92568/2013 and by the CEGOT group entitled "Cities, competitiveness, and well-being" (UID/GEO/04084/2013) through COMPETE 2020. RA and PS are members of CEGOT, Research Centre in Geography and Spatial Planning, which is supported by European Regional Development Funds through COMPETE 2020 – Operational Programme 'Competitiveness and Internationalization', under Grant POCI-01-0145- FEDER-006891, and by National Funds through the Portuguese Foundation for Science and Technology (FCT) under Grant UID/GEO/04084/2013

The authors gratefully acknowledge the Hellenic Statistical Authority for having provided the Athens data.

This research is embedded in the Euro-Healthy project, which received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 643398

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