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Studies on Heavy Precipitation in Portugal: A Systematic Review

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Supplementary Material

Table S1. PRISMA 2020 for the abstract checklist.

Section and Topic	Item #	Checklist item	Reported (Yes/No)
TITLE			
Title	1	Identify the report as a systematic review.	Yes
BACKGROUND			
Objectives	2	Provide an explicit statement of the main objective(s) or question(s) the review addresses.	Yes
METHODS			
Eligibility criteria	3	Specify the inclusion and exclusion criteria for the review.	Yes
Information sources	4	Specify the information sources (e.g. databases, registers) used to identify studies and the date when each was last searched.	Yes
Risk of bias	5	Specify the methods used to assess risk of bias in the included studies.	Yes
Synthesis of results	6	Specify the methods used to present and synthesise results.	Yes
RESULTS			
Included studies	7	Give the total number of included studies and participants and summarise relevant characteristics of studies.	Yes
Synthesis of results	8	Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and confidence/credible interval. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).	Yes
DISCUSSION			
Limitations of evidence	9	Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency and imprecision).	Yes
Interpretation	10	Provide a general interpretation of the results and important implications.	Yes
OTHER			
Funding	11	Specify the primary source of funding for the review.	Yes

Section and Topic	Item #	Checklist item	Reported (Yes/No)
Registration	12	Provide the register name and registration number.	No

Table S2. PRISMA 2020 checklist.

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Page 1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Table S1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Section 1
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Section 1
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Section 2.1.1
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Section 2.1.2
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Section 2.1.3
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Section 2.2
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Section 2.2
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Section 2.2

Section and Topic	Item #	Checklist item	Location where item is reported
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Section 2.2
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Section 2.2
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Section 2.2
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Section 2.2
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Section 2.2
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Section 2.2
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Section 2.2
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Section 2.2
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Section 2.2
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Section 2.2
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Section 2.2
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Section 3.1

Section and Topic	Item #	Checklist item	Location where item is reported
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Section 2.2
Study characteristics	17	Cite each included study and present its characteristics.	Section 3.2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	N/A
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Section 3.2
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	N/A
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Section 3.2
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Section 3.2
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Section 3.2
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Section 3.2
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Section 4
	23b	Discuss any limitations of the evidence included in the review.	Sections 4 and 5
	23c	Discuss any limitations of the review processes used.	Sections 4 and 5

Section and Topic	Item #	Checklist item	Location where item is reported
	23d	Discuss implications of the results for practice, policy, and future research.	Section 5
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	N/A
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	N/A
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N/A
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Page 20, Funding section
Competing interests	26	Declare any competing interests of review authors.	Page 20, Conflicts of Interest section
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Page 20; Data Availability Statement section

Table S3. Selection criteria applied on research platforms.

Scopus	Web of Science (WoS)
Limited to subject area: Earth and Planetary Sciences; Environmental Science; Agricultural and Biological Sciences	**Limited to web of science categories:** Environmental Sciences; Geosciences Multidisciplinary; Meteorology Atmospheric Sciences; Geography Physical; Environmental Studies; Geography; Agriculture Multidisciplinary
Limited to document type: Article; Review	**Limited to document type:** Article; Review
Limited to language: English	**Limited to language:** English
Limited to keyword Portugal; Floods; Flooding Climate Change; Extreme Event; Risk Assessment; Lisboa [Portugal]; Flood; Rain; Rainfall; Numerical Model; Runoff; Vulnerability; Storms; Precipitation Intensity; Precipitation (climatology); Lisbon; Tagus Estuary; Seasonal Variation; Extreme Precipitation; Coimbra [Portugal]; Flood Damage; Precipitation (meteorology); Aveiro [Portugal]; Weather Forecasting; Ria De Aveiro; Faro [Portugal]; Precipitation; Landslide; Climate Effect; Precipitation Assessment; North Atlantic Oscillation; Landslides; Climate Modeling; Atlantic Ocean (North); Algarve; Extreme Rainfall; Regional Climate; Climate Variation; Weather; Rainfall-runoff Modeling; Porto [Portugal]; Numerical Models; Extreme Weather Events; Atmospheric Pressure; Agriculture	**Limited to citation topics meso** Oceanography, Meteorology & Atmospheric Sciences; Climate Change; Environmental Sciences **Limited to citation topics micro** Evapotranspiration; Climate Change Adaptation; Enso; Tropical Cyclones; Stormwater; Clouds

Table S4. Articles selected for the analysis of observed changes and future projections.

Authors	Title	Reference
Costa and Soares, 2009	Trends in extreme precipitation indices derived from a daily rainfall database for the South of Portugal	[42]
Durao *et al.*, 2009	Indices of precipitation extremes in Southern Portugal-a geostatistical approach	[43]
Durao *et al.*, 2010	Spatial-temporal dynamics of precipitation extremes in southern Portugal: A geostatistical assessment study	[44]
Gallego *et al.*, 2011	Trends in frequency indices of daily precipitation over the Iberian Peninsula during the last century	[48]
Costa *et al.*, 2012	Climate change scenarios for precipitation extremes in Portugal	[46]
Santos and Fragoso, 2013	Precipitation variability in Northern Portugal: Data homogeneity assessment and trends in extreme precipitation indices	[45]
De Lima *et al.*, 2013a	Recent changes in daily precipitation and surface air temperature extremes in mainland Portugal, in the period 1941-2007	[36]
De Lima *et al.*, 2013b	Recent precipitation variability over 67 years in mainland Portugal	[41]
Ramos *et al.*, 2014	A ranking of high-resolution daily precipitation extreme events for the Iberian Peninsula	[49]
Espírito Santo *et al.*, 2014	Seasonal changes in daily precipitation extremes in mainland Portugal from 1941 to 2007	[34]
de Lima *et al.*, 2015	Trends and correlations in annual extreme precipitation indices for mainland Portugal, 1941-2007	[37]
Soares *et al.*, 2015	Climate change and the Portuguese precipitation: ENSEMBLES regional climate models results	[52]
Bartolomeu *et al.*, 2016	Recent trends of extreme precipitation indices in the Iberian Peninsula using observations and WRF model results	[35]
Santos *et al.*, 2017	Regionalization and susceptibility assessment to daily precipitation extremes in mainland Portugal	[38]
Ramos *et al.*, 2017	Ranking of multi-day extreme precipitation events over the Iberian Peninsula	[50]
Soares *et al.*, 2017	Future precipitation in Portugal: high-resolution projections using WRF model and EURO-CORDEX multi-model ensembles	[53]
Santos *et al.*, 2019	Recent and future changes of precipitation extremes in mainland Portugal	[39]
Portela *et al.*, 2020	Long-Term Rainfall Trends and Their Variability in Mainland Portugal in the Last 106 Years	[54]
Coelho *et al.*, 2020	Climate-Change Adaptation Framework for Multiple Urban Areas in Northern Portugal	[33]
Espinosa *et al.*, 2022	Climate Change Trends in a European Coastal Metropolitan Area: Rainfall, Temperature, and Extreme Events (1864–2021)	[55]
Lima *et al.*, 2023	A multi-variable constrained ensemble of regional climate projections under multi-scenarios for Portugal – Part I: An overview of impacts on means and extremes	[51]
Fonseca *et al.*, 2023	Exposure of Portuguese viticulture to weather extremes under climate change	[40]
Sanderson *et al.*, 2023	The probability of unprecedented high rainfall in wine regions of northern Portugal	[56]

Table S5. Articles selected for the analysis of large-scale atmospheric patterns.

Authors	Title	Reference
Trigo and DaCamara, 2000	Circulation weather types and their influence on the precipitation regime in Portugal	[16]
Goodess and Jones, 2002	Links between circulation and changes in the characteristics of Iberian rainfall	[63]
Trigo *et al.*, 2005	The Influence of the North Atlantic Oscillation on rainfall triggering of landslides near Lisbon	[64]
Fragoso and Tildes Gomes, 2008	Classification of daily abundant rainfall patterns and associated large-scale atmospheric circulation types in Southern Portugal	[72]
Fernández-Montes et al., 2014	Circulation types and extreme precipitation days in the Iberian Peninsula in the transition seasons: Spatial links and temporal changes	[71]
Santos *et al.*, 2015	Historical damaging flood records for 1871-2011 in Northern Portugal and underlying atmospheric forcings	[6]
Ramos *et al.*, 2015	Daily precipitation extreme events in the Iberian Peninsula and its association with atmospheric rivers	[65]
Trigo *et al.*, 2016	The deadliest storm of the 20th century striking Portugal: Flood impacts and atmospheric circulation	[73]
Santos *et al.*, 2017	Atmospheric driving mechanisms of flash floods in Portugal	[5]
Pereira *et al.*, 2018	A centennial catalogue of hydro-geomorphological events and their atmospheric forcing	[10]
Ramos *et al.*, 2018	Extreme Precipitation Events in Summer in the Iberian Peninsula and Its Relationship With Atmospheric Rivers	[22]
Lavers *et al.*, 201	Earlier awareness of extreme winter precipitation across the western Iberian Peninsula	[70]
Barbosa *et al.*, 2018	Analysis of the 1 November 2015 heavy rainfall episode in Algarve by using weather radar and rain gauge data	[75]
Rebelo *et al.*, 2018	Meteorological driving mechanisms and human impacts of the February 1979 extreme hydro-geomorphological event in Western Iberia	[74]
Stojanovic *et al.*, 2021	Consecutive extratropical cyclones daniel, elsa and fabien, and their impact on the hydrological cycle of mainland portugal	[76]
Santos and Belo-Pereira, 2022	Sub-Hourly Precipitation Extremes in Mainland Portugal and Their Driving Mechanisms	[14]
Cruz *et al.*, 2023	Dynamic and Thermodynamic Drivers of Severe Sub-Hourly Precipitation Events in Mainland Portugal	[47]

Table S6. Articles selected for the evaluation of different databases and the performance of Numerical Weather Prediction (NWP) models.

Authors	Title	Reference
Ramos *et al.*, 2012	Numerical simulation of a heavy rainfall event over Portugal using mesoscale model	[80]
Pereira *et al.*, 2013	Simulation of a persistent medium-term precipitation event over the western Iberian Peninsula	[81]
Ferreira *et al.*, 2014	On the influence of physical parameterisations and domains configuration in the simulation of an extreme precipitation event	[79]
Benevides *et al.*, 2015	On the inclusion of GPS precipitable water vapour in the nowcasting of rainfall	[78]
Ramos *et al.*, 2021	Uncertainty in different precipitation products in the case of two atmospheric river events	[77]

Table S7. Articles selected for the analysis of other extreme events.

Authors	Title	Reference
Soriano *et al.*, 2001	Relationship between convective precipitation and cloud-to-ground lightning in the Iberian Peninsula	[83]
Leitão, 2003	Tornadoes in Portugal	[87]
Santos *et al.*, 2012	Cloud-to-ground lightning in Portugal: Patterns and dynamical forcing	[84]
Santos *et al.*, 2013	Forcing factors of cloud-to-ground lightning over Iberia: Regional-scale assessments	[85]
Sousa *et al.*, 2013	Statistical-dynamical modelling of the cloud-to-ground lightning activity in Portugal	[24]
Belo-Pereira *et al.*, 2017	A long-lived tornado on 7 December 2010 in mainland Portugal	[90]
Santos and Belo-Pereira, 2019	A comprehensive analysis of hail events in Portugal: Climatology and consistency with atmospheric circulation	[23]
Leitao and Pinto, 2020	Tornadoes in Portugal: An overview	[88]
Campos *et al.*, 2024	ECMWF Lightning Forecast in Mainland Portugal during Four Fire Seasons	[86]

Table S8. Summary of the number of studies conducted by country.

Countries	Number of studies
Portugal	46
Spain	3
United Kingdom	4
Brazil	1