Global Issues in Water Policy 31

Daniela Rivera
Guillermo Donoso *Editors*

# Droughts in Chile

## Impacts, Monitoring, and Adaptation (Management) Policies

Springer

# Global Issues in Water Policy

Volume 31

**Global Issues in Water Policy is now indexed in SCOPUS.**

Policy work in the water sector has grown tremendously over the past two decades, following the Rio Declaration of 1992. The existing volume of water-related literature is becoming dominant in professional outlets, including books and journals. Because the field of water resources is interdisciplinary in nature, covering physical, economic, institutional, legal, environmental, social and political aspects, this diversification leads in many cases to partial treatment of the water issues, or incomplete analysis of the various issues at stake. Therefore, treating a whole host of a country's water resources issues in one set of pages will be a significant contribution to scholars, students, and other interested public. This book series is expected to address both the current practice of fragmented treatment of water policy analyses, and the need to have water policy being communicated to all interested parties in an integrated manner but in a non-technical language. The purpose of this book series is to make existing knowledge and experience in water policy accessible to a wider audience that has a strong stake and interest in water resources. The series will consist of books that address issues in water policy in specific countries, covering both the generic and specific issues within a common and pre-designed framework.

Daniela Rivera • Guillermo Donoso
Editors

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ISSN 2211-0631 ISSN 2211-0658 (electronic)
Global Issues in Water Policy
ISBN 978-3-031-85039-4 ISBN 978-3-031-85040-0 (eBook)
https://doi.org/10.1007/978-3-031-85040-0



This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

*To our families and to all those who work every day for water security.*

# Foreword

*Droughts in Chile: Impacts, Monitoring, and Adaptation Policies*, edited by Daniela Rivera and Guillermo Donoso, is a timely and welcome addition to the body of literature on drought management and policy. The book captures the status of drought management in Chile and presents new options for improved drought management.

Globally, there have been significant advances in integrated drought management in the past decade. These advances have augmented our monitoring capability for the early detection of drought and its severity. Improved methods and tools for communicating this information to decision makers and the public in a timely manner have also provided opportunities for impact reduction. In addition, risk or vulnerability assessment methodologies have been developed and applied in many countries. These assessments are aimed at determining who and what is at risk and why, a key step toward risk reduction. Applying the results of these assessments can be instructive for the implementation of proactive measures that target those sectors most at risk in advance of future drought events.

Much of the progress over the past decade can be traced to the High-level Meeting on National Drought Policy (HMNDP), held in March 2013. This meeting served as a catalyst to promote the development of national drought policies, and the concepts associated with integrated drought management. Convened by three organizations of the United Nations—the World Meteorological Organizational (WMO), the Food and Agriculture Organization (FAO), and the Convention to Combat Desertification (UNCCD)—this collaboration facilitated a global dialogue on the importance of formulating national drought policies aimed at reducing the risks and, therefore, the vulnerability of all nations to this insidious natural hazard. Our changing climate, the increased frequency, severity, and duration of extreme weather and climate events, and the spiraling impacts of drought are significant motivating factors for all drought-prone nations to lessen societal vulnerability to drought by adopting a paradigm shift emphasizing integrated drought management.

What emerged from HMNDP was a regional and national emphasis on the need to develop national drought management policies. The Integrated Drought Management Programme (IDMP), established during the HMNDP by WMO and the Global Water Partnership (GWP), adopted the widely accepted 10-step drought

planning methodology, commonly referred to the three pillars of drought policy and preparedness, as a mechanism to improve drought preparedness by shifting the paradigm for drought management from a reactive approach to a proactive risk management approach, i.e., transitioning from managing disasters to managing risk.[1]

I applaud the efforts of Daniela Rivera and Guillermo Donoso to document the current, albeit reactive, approach to drought management and preparedness in Chile. However, this book also presents new options for drought management in Chile through the development of comprehensive monitoring and early warning systems and the adoption of integrated water management techniques and other policy options to reduce the economic, social, environmental impacts of drought to achieve greater drought resilience.

The publication of this volume could not be more timely given the international meeting on Drought Resilience, i.e., the High-level Meeting on National Drought Policy+10, that was held in the fall of 2024. This meeting brought together scientists, policy makers, government officials, and stakeholders to assess progress on drought management over the past 10 years and identify key pathways moving forward. While the lessons learned from the chapters in *Drought in Chile* provide critical information to water managers and other officials in Chile and beyond, these lessons and recommendations may also help to inform outcomes from HMNDP+10.

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[1] World Meteorological Organization (WMO) and Global Water Partnership (GWP) (2014) National Drought Management Policy Guidelines: A Template for Action (D.A. Wilhite). Integrated Drought Management Programme (IDMP) Tools and Guidelines Series 1. WMO, Geneva, Switzerland and GWP, Stockholm, Sweden.

# Acknowledgments

This text originates from the research project awarded and funded by the National Agency for Research and Development (Agencia Nacional de Investigación y Desarrollo, ANID) of Chile, ANID Sequía FSEQ210018, entitled "Integrating drought monitoring and public policy design towards the proactive management of drought."

This project was executed by an interdisciplinary team of 16 professors from the Pontificia Universidad Católica de Chile: as principal investigators, Jorge Gironás (director), Sebastián Vicuña, Daniela Rivera, María Molinos and Oscar Melo; and, as associate investigators, Aurora Gaxiola, Camilo del Río, Francisco Suárez, Marcelo Miranda, David Morales, Francisco Meza, Guillermo Donoso, Eduardo Leiva, Pablo Pastén, Alonso Pérez, and Álvaro Lorca. In addition, an important number of postdoctoral researchers (Felipe Lobos and Cristian Jordán); support professionals (Marialina Núñez, Carolina Córdova, Nicolás Millie, Valentina Bravo, Paula Toledo, Catalina Aránguiz, Diego González, Javier Vargas, Sebastián González, Mauricio Montecinos, Alejandra Vega, José Antonio Díaz, Carolina Rodríguez, Francisca Contardo, Daniela Madrazo, Sara Acevedo, Fernanda Cepeda, Bastián Silva, Felipe Suárez, Kevin Unda, and María Valenzuela); and students (Fernando González, Rosa Vargas, Klaus Keim, Vicente Espinoza, Eduardo Viollier, Juan Figueroa, Antonia Ávila, Pamela Pimentel, Victoria Armas, Antonia Durán, and Marcel Favereau) participated. Most of them are involved as authors or co-authors of this book.

We would especially like to thank the National Agency for Research and Development (Agencia Nacional de Investigación y Desarrollo, ANID) of Chile, the authors who are part of this collective publication, all those who participated in the development of the aforementioned project FSEQ210018, and Daniela Madrazo for her support in editing this work. We hope that this book will be a contribution to review, evaluate, and improve drought management policies in Chile and other countries, given that this is an extreme hydrological phenomenon whose rigorous and proactive treatment is one of the key factors to advance in water security.

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# Editors and Authors

## About the Editors

**Daniela Rivera** has a bachelor's degree in Legal Sciences, a master's degree in Legal Science, and a PhD in Law. She is part of the faculty members of the Center for Water Law and Management of the Pontificia Universidad Católica de Chile, created in July 2015, integrated by five faculties of the same university, and of which she was director between July 2017 and July 2023. She is an Assistant Professor of the Faculty of Law of the Pontificia Universidad Católica de Chile. Her research focuses on water law and management, a field in which she is the author of several publications, has participated in various academic seminars, in Chile and abroad, and develops several projects funded by ANID, FONDECYT, CORFO, and other public and private entities.

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**Sarah Ann Wheeler** is a Professor of Water Economics in the School of Economics and Public Policy at the University of Adelaide and is also on the university's Environment Institute's executive management board. She is a past President and a Distinguished Fellow of the Australasian Agricultural and Resource Economics Society (AARES), and a Fellow of the Academy of the Social Sciences in Australia. She graduated with her PhD in 2007, was an ARC Future Fellow (2014–2018), and has over 140 peer-reviewed outputs in the research areas of irrigated farming, climate change, Murray-Darling Basin, organic farming, water markets, water scarcity, mental health, and food waste. She is an Associate Editor of *Agricultural Economics*, and has been past editor of the *Australasian Journal of Water Resources*, and past Associate Editor of *Water Resources and Economics*, the *Australian Journal of Agricultural and Resource Economics* and guest editor for a special issue of *Agricultural Water Management*. Sarah is on a number of editorial boards, including: *International Review of Environmental and Resource Economics*, *Australian Journal of Agricultural and Resource Economics* and *Water*. In 2023, Sarah was awarded the Jill Hudson award for environmental protection at the SA Environment Awards.

**Donald Wilhite** is a Professor and Director emeritus of Applied Climate Science, School of Natural Resources at the University of Nebraska-Lincoln, USA. Prior to August 2012, he served as director of the School of Natural Resources, a position he held from 2007 to 2012. Don founded the US National Drought Mitigation Center at the University of Nebraska-Lincoln in 1995 and served as its director until 2007. He was elected fellow of the American Meteorological Society in 2013. Don's research and outreach activities have focused on issues of drought monitoring, planning, mitigation, and policy; the use of climate information in decision-making; and

climate change. He has collaborated with and led many efforts by US states, federal agencies, foreign governments, and United Nations agencies to improve drought management following a risk-based management approach he developed, the 10-step planning process. This process has become the international standard for drought planning. Don is the editor or co-editor of numerous books, including his most recent book, *Drought and Water Crises: Integrating Science, Management, and Policy*, 2nd edition (CRC Press, 2018). He is also coauthor of two reports on the implications of climate change for Nebraska, published in 2014 and 2016, and coeditor of the *Atlas of Nebraska* (University of Nebraska Press, 2017).

**Alec Zuo** is an Applied Economist specializing in agricultural, environmental, and resource economics. Alec's research has addressed issues and questions that are fundamental to UN World Development Goals and Australian National Research Priorities. His research has contributed significantly to understanding the impact of climate change and resources on irrigation farming, farmer adaptation strategies, and market-based instruments for water resource management. His research has been published in leading international journals (e.g., *Global Environment Change*, *American Journal of Agricultural Economics*, *European Review of Agricultural Economics*, *Energy Economics*, etc.) and he has collaboration with researchers from over 20 organizations worldwide on agricultural, resource, environment, and development issues across 11 countries in four continents. Alec has substantial experience in initiating and managing large research projects. His research has been funded by the Australian Research Council (an ARC Future Fellow from 2023 to 2027), the Australian National Commission for UNESCO, the National Climate Change Adaptation Research Facility, the federal Department of Agriculture, Fisheries and Forestry, the Australian Centre for International Agricultural Research, the Australian Consumer & Competition Commission, and the Murray Darling Basin Authority.

# Abbreviations

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|---|---|
| AAO | Antarctic Oscillation |
| ACADES | Asociación Chilena de Desalinización—Chilean Desalination Association |
| ADI | Aggregate Drought Index |
| AEMET | Agencia Estatal de Meteorología |
| AFP | Pension Fund Administrators |
| AGRITEMPO | Agrometeorological Information System |
| Al | Aluminum |
| AMD | Acid mine drainage |
| AMP | Productivity amplitude |
| ANID | Agencia Nacional de Investigación |
| AOPs | Advanced oxidation processes |
| APEC | Asia-Pacific Economic Cooperation |
| ARB | Antibiotic resistance genes |
| ARG | Argentina |
| As | Arsenic |
| AUD | Australian dollars |
| AVHRR | Advanced Very High-Resolution Radiometer |
| AWS | Amount of water in storage |
| BOD5 | Biochemical oxygen demand over 5 days |
| BOL | Bolivia |
| BRA | Brazil |
| BVP | Base productivity value |
| CAPEX | Capital expenditure |
| CASEN | Encuesta de Caracterización Socioeconómica Nacional—National Socioeconomic Characterization Survey |
| CAZALAC | Centro del Agua para Zonas Áridas y Semiáridas de América Latina y el Caribe—Water Center for Arid and Semi-arid Zones of Latin America and the Caribbean |
| CC | Climate change |
| Cd | Cadmium |

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|---|---|
| CDI | Combined Drought Indicator |
| CDPMN | Caribbean Drought and Precipitation Monitoring Network |
| CDWR | California Department of Water Resources |
| CECs | Contaminants of emerging concern |
| CEDEX | Centro de Estudios y Experimentación de Obras Públicas |
| CF | Coliformes Fecales—Fecal coliforms |
| CFU | Colony-forming unit |
| CIAU | Management of the Integral Urban Water Cycle |
| CIIFEN | Centro Internacional para la Investigación del Fenómeno de El Niño—International Center for the Investigation of El Niño Phenomenon |
| CLP | Chilean pesos |
| CMF | Comisión para el Mercado Financiero—Financial Market Commission |
| CMI | Crop Moisture Index |
| CMIP5 | Coupled Model Intercomparison Project version 5 |
| CMIP6 | Coupled Model Intercomparison Project version 6 |
| CNE | National Energy Commission |
| CNR | National Irrigation Commission |
| Co | Cobalt |
| CODELCO | Corporación Nacional del Cobre de Chile—National Copper Corporation of Chile |
| COL | Colombia |
| Cr | Chromium |
| CR2 | Centro de Ciencia del Clima y la Resiliencia—Climate and Resilience Science Center |
| CRS-OCA | Regional Climate Center for Western South America |
| CRC-OSA | Regional Climate Center for Western South America |
| CRC-SAS | Regional Climate Center for South America |
| CSDI | Crop Specific Drought Index |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| CTCN | UN Climate Technology Centre and Network |
| Cu | Copper |
| CVP | Central Valley Project |
| DFL | Decreto Fuerza Ley—Decree Force of Law |
| DGA | Dirección General de Aguas—General Water Directorate |
| DIPRES | Dirección de Presupuesto—Budget Directorate |
| DIRECTEMAR | Maritime Water Agency |
| DPI | Department of Primary Industries |
| DMC | Dirección Meteorológica de Chile—Meteorological Directorate of Chile |
| DOH | Dirección de Obras Hidráulicas—Department of Hydraulics |
| DRAMP | Drought Resilience, Adaptation and Management Policy |
| DRM | Disaster Risk Management |
| DRR | Disaster Risk Reduction |

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| DSI | Drought Severity Index |
| DWTP | Drinking Water Treatment Plant |
| EC | European Commission |
| ECOLEX | Information Service on Environmental Law |
| ECs | Exceptional circumstances |
| ECU | Ecuador |
| EDO | European Drought Observatory |
| EDII | European Drought Impact Inventory |
| ELAW | Environmental Law Alliance Worldwide |
| EM-DAT | The International Disaster Database. Centre for Research on the Epidemiology of Disasters |
| ENAP | Empresa Nacional del Petróleo—National Petroleum Company |
| ENDESA | Chile's National Electricity Company |
| ENSO | El Niño-Southern Oscillation |
| EOS | End of season |
| ESVA | Water Supply and Sanitation Firm for Viña del Mar and Valparaíso |
| ETDI | Evapotranspiration Deficit Index |
| Euroclima+ | European Union's flagship regional cooperation programme |
| EVI | Enhanced Vegetation Index |
| EWS | Early Warning Systems |
| FAL | Autumn productivity |
| FAO | Food and Agriculture Organization |
| FC | Fecal coliforms |
| Fe | Iron |
| FE | Fixed Effects Panel Data |
| FMD | Farm management deposit |
| FONASA | Fondo Nacional de Salud—National Health Fund |
| g/L | Gram per liter |
| GDP | Gross domestic product |
| GFCF | Gross fixed capital formation |
| GHG | Greenhouse gas emissions |
| GMC | Global climate model |
| GOES | Geostationary Operational Environmental Satellites |
| GUY | Guyana |
| GWP | Global Water Partnership |
| HAB | Harmful algal blooms |
| Hg | Mercury |
| HMNDP | High-level Meeting on National Drought Policy |
| HTSP | Hydrothermal scheduling problem |
| hm | Hectometer |
| $hm^3$ | Cubic hectometer |
| HMNDP | High-level Meeting on National Drought Policy |
| HTSP | Hydrothermal scheduling problem |
| IC | Infrastructure capacity |

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| IED | Income Equalisation Deposit |
| IMF | International Monetary Fund |
| INA | National Water Institute |
| INMHI | National Institute of Meteorology and Hydrology |
| INDAP | Agricultural Development Institute |
| INE | Instituto Nacional de Estadísticas—National Institute of Statistics |
| INIA | Agricultural Research Institute |
| IPCC | Intergovernmental Panel on Climate Change |
| IPO | Interdecadal Pacific Oscillation |
| IPR | Indirect potable reuse |
| IRI | Climate and Society Map Room |
| ISAPRE | Instituciones de Salud Previsional—Social Security Health Institutions |
| IWA | International Water Association |
| $K^+$ | Potassium |
| $KgCO_2eq/m^3$ | Kilogram of carbon dioxide equivalent per kilogram per cubic meter |
| $km^2$ | Square kilometer |
| KWh/year | Kilowatt-hour per year |
| l/s | Liters per second |
| LAC | Latin America and the Caribbean Region |
| LCDP | Liters per capita |
| LIN | Seasonal integral |
| LOS | Length of season |
| M2 | Money supply |
| MCM | Million cubic meters |
| MD | Megadrought |
| MED | Multiple effect distillation |
| MEI | Multivariate ENSO Index |
| MERCOSUR | Mercado Común del Sur |
| MILP | Mixed-integer linear programming |
| MINAGRI | Ministry of Agriculture |
| MINDEF | Ministry of National Defense |
| MINEN | Ministry of Energy |
| MINVU | Ministerio de Vivienda y Urbanismo—Ministry of Housing and Urban Planning |
| MITERD | Ministry for Ecological Transition and Demographic Challenge |
| MJO | Madden-Jullian Oscillation |
| Mn | Manganese |
| MODFLOW | US Geological Survey Modular Finite-Difference Flow Model |
| MSDF | Ministerio de Desarrollo Social y Familia—Ministry of Social Development and Family of Chile |
| MMA | Ministry of Environment |
| MODIS | Moderate Resolution Imaging Spectroradiometer |

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| MOP | Ministerio de Obras Públicas—Ministry of Public Works |
| MSF | Multistage flash distillation |
| MVA | Maximum productivity value |
| MW | Megawatts |
| MWh | Megawatts hour |
| NADAM | North American Drought Monitor |
| NDA | National Drought Agreement |
| NDRA | Natural Disaster Relief Arrangements |
| NDVI | Normalized Difference Vegetation Index |
| NDWI | Normalized Difference Water Index |
| NIDIS | National Integrated Drought Information System |
| $NH_4^+$ | Ammonium |
| $NO_2^-$ | Nitrogen oxides |
| $NO_3^-$ | Nitrates |
| NOAA | National Oceanic and Atmospheric Administration |
| NSCA | Normas de Calidad Secundaria de Agua—Secondary Water Quality Standards |
| NSW | New South Wales |
| OECD | Organisation for Economic Co-operation and Development |
| OLI | Operational Land Imager |
| OLS | Ordinary least squares |
| OMEGA | Office for Monitoring Agricultural Emergencies |
| OPEX | Operation expenditure |
| PAHO | Pan American Health Organization |
| Pb | Lead |
| PDI | Policía de Investigaciones—Investigation Police |
| PDO | Pacific Decadal Oscillation |
| PER | Peru |
| PET | Peak of time |
| PH | Potential of Hidrogen—Acidity measure |
| PDSI | Palmer Drought Severity Index |
| PEM | Plan Especial de Emergencia—Emergency Plan for Drought Situations |
| PERH | Planes Estratégicos de Recursos Hídricos—Strategic Plans for Water Resources |
| PES | Special warning and eventual drought plan |
| PGU | Pensión Garantizada Universal—Universal Guaranteed Pension |
| PLP | Long-term planning |
| PMCCA | Observation Network in Surveillance Programs of NSCA |
| PMP | Positive mathematical programming |
| $PO_4^{3-}$ | Phosphate |
| PP | Primary productivity |
| PPP | Purchasing power parity |
| Pywr | Open-source Python library for water resources simulator |
| PRY | Paraguay |

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| RAI | Rainfall Anomaly Index |
| RBD | River Basin Districts |
| RCL | Revenue contingent loan |
| RCP | Representative Concentration Pathway |
| RDI | Reclamation Drought Index |
| RO | Seawater reverse osmosis |
| RSDI | Regional Streamflow Deficiency Index |
| S-WEI | S-Water Exploitation Index |
| S2ID | Integrated Disaster Information System |
| SDDP | Stochastic dual dynamic programming |
| SDDiP | Stochastic Dual Dynamic Integer Program |
| SEIA | Environmental Impact Assessment System |
| SEN | National Electric System |
| SENAMIH | National Meteorology and Hydrology Service of Peru |
| SENAPRED | National Disaster Prevention and Response Service |
| SEREMI | Regional Ministerial Secretariats |
| SFI | Standardized Flow Index |
| SIAT | Information and Early Warning System of the Southwest of Buenos Aires |
| SIC | Central Interconnected System |
| SISS | Superintendencia de Servicios Sanitarios |
| SISSA | Information System on Drought for Southern South American Region |
| SGWI | Standardized Groundwater Storage Index |
| SMA | Superintendency of Environment |
| SMDI | Soil Moisture Deficit Index |
| SNAPP | Science for Nature and People Partnership |
| SOI | Southern Oscillation Index |
| SOS | Start of season |
| SP | Spring productivity |
| SPEI | Standardized Precipitation Evapotranspiration Index |
| SPI | Standardized Precipitation Index |
| SRI | Standardized Runoff Index |
| SSI | Standardized Streamflow Index |
| SSMI | Standardized Soil Moisture Index |
| SUBTEL | Subsecretaria de telecomunicaciones—Undersecretariat of Telecommunications |
| SWP | State Water Project |
| SWSI | Surface Water Supply Index |
| TAO/TRITON | Tropical Atmosphere Ocean Array |
| TCI | Temperature Condition Index |
| tCO2eq | Quantity of greenhouse gases expressed as the product of the weight of the greenhouse gases in metric tonnes multiplied by their global warming potential |
| TM | Thematic Mapper |