ADVANCING DROUGHT DETECTION AND MANAGEMENT TO IMPROVE THE RESILIENCE OF MULTI-SECTOR SYSTEMS UNDER CLIMATE CHANGE

Abstract

Rapid climate change and intensifying hydroclimatic non-stationarity have made drought adaptation a critical priority. However, current modeling and monitoring frameworks are often insufficient to address the dual challenges of accurate drought detection and effective water resource management. Current drought assessments frequently rely on frameworks that focus exclusively on observing anomalies in hydro-meteorological variables, while ignoring downstream dynamic responses and operational stress. To overcome these limitations, this dissertation proposes a multi-scale, impact-based approach designed to enhance the precision of both detection and management strategies.

The primary contribution is the improvement of drought detection, shifting the analytical focus from mere hydro-meteorological anomalies to sector-specific impact signals. At the catchment scale, the established Framework for Index-based Drought Analysis (FRIDA) is extended into a multi-task model for the Adda River basin, identifying how lake regulation and seasonal inflows trigger systemic risks for agriculture, hydropower, and recreational services. Leveraging these insights, this impact-based detection is then scaled up to the European scale by extending the FRIDA methodology to construct novel impact-based Combined Drought Indices (iCDIs), which utilize vegetation stress as a proxy to better detect drought impacts on crops and plants. Under future climate scenarios, these indices reveal a significant geographical shift in vulnerability, identifying Central Europe as an emerging hotspot for severe drought impacts, a structural transition that traditional indices fail to capture. Building on this detection capability, the research advances into proactive management by evaluating structural interventions, specifically dam heightening in the Adda River basin, as a drought adaptation strategy. To this end, a novel Multi-Criteria Decision Analysis (MCDA) framework was developed to assess the technical feasibility of these heightening options. By coupling this localized screening with a downstream dynamic simulation model, this study quantifies basin-wide trade-offs, revealing that strategic capacity expansions inevitably induce multi-sectoral conflicts between energy revenues and downstream water security.

Ultimately, this research provides the methodological bridge required to integrate advanced drought detection with proactive adaptation strategies, shifting water resource management from reactive emergency responses toward a holistic framework that balances competing sectoral needs to ensure long-term drought resilience.