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Malawi's vulnerability to threshold behaviour of Lake Malawi: A lake-basin modelling study for informing adaptation decision making under uncertainty

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In developing countries, climatic uncertainty is playing alongside uncertain socio-economic change, which makes decision making a challenge. Decision Making Under Uncertainty (DMUU) approaches can usefully support adaptation decision making, but there are few applications in developing country contexts. The water, energy and food security of Malawi, a least developed country, depends critically on the Lake Malawi. The Lake Malawi outflows into the Shire River, and this sustains 98% of Malawi's hydropower, most of its irrigation and sustains biodiversity of a Ramsar wetland. Future plans of increasing canal-based irrigation and hydropower expansion will increase water demand, and consequently increase future risks. Evidently, future climate change has implications for the Lake Malawi Shire River Basin (LMSRB) but it is a challenging region to investigate climate change impacts. The LMSRB covers Malawi, Tanzania and Mozambique, and straddles regions dominated by the East African Monsoon and Southern African precipitation regimes. Therefore, a combination of different drivers, some of them not well understood, influence precipitation in the LMC and lead to deep uncertainty in how future precipitation could change.

To investigate the risks and evaluate adaptation options under climatic and socio-economic uncertainty, we applied a combined modelling-stakeholder engagement DMUU approach. We engaged key sectoral stakeholders to identify performance requirements and potential adaptation options for the three sectors. We set up a Water Evaluation And Planning (WEAP) model to explore this lake-basin decision context and incorporate sectoral requirements. We modelled Lake Malawi as a reservoir and its catchments using the FAO rainfall-runoff method, and calibrated (1961-1990) and validated (1991-2016) it using Lake Malawi levels. We forced the WEAP model (2025-2050) using 38 CMIP5 model projections, downscaled using the monthly delta factor method. For each climate projection we incorporated four stakeholder-validated water demand projections for the LMSRB to simulate potential changes in Lake Malawi levels and Shire River outflows. We then assessed the robustness of adaptation options; ability to satisfy diverse stakeholder-prioritized performance metrics against the wide range of scenarios.

The WEAP model satisfactorily reproduces the Lake Malawi levels from 1961-2016, giving reasonable confidence to simulate future changes. We find that the Lake Malawi levels are sensitive to future precipitation and water demand changes. The Lake Malawi outflow occurs above the 471.5 masl. threshold and in some future scenarios there are periods without outflow. Even for time-steps with outflow sectoral performance requirements are not met across a large number of potential future conditions, indicating the extent of their sensitivity and vulnerability. Application of some adaptation options does improve individual sector performance requirements, but options demonstrate limited robustness across all three sectors. This suggests that individual options may not sufficiently address future changes; implying residual risk after adaptation. Overall, modelling this complex and threshold-affected basin by engaging sectoral stakeholders in the assessment was important for co-producing decision-relevant information and highlighting the impacts of uncertain future changes.