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Editorial

Evaluating Hydrological Responses to Climate Change

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Abstract: This Special Issue of the journal *Water*, "The Evaluation of Hydrologic Response to Climate Change", is intended to explore the various impacts of climate change on hydrology. Using a selection of approaches, including field observations and hydrological modeling; investigations, including changing habitats and influences on organisms; modeling of water supply and impacts on landscapes; and the response of varying components of the hydrological cycle, the Issue has published nine articles from multi-institution, often multicountry collaborations that assess these changes in locations around the world, including China, Korea, Russia, Pakistan, Cambodia, United Kingdom, and Brazil.

Keywords: climate change; hydrology; watersheds; water balance; coastal fog; evapotranspiration; baseflows; habitats; recharge; streamflow; snowpack

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1. Introduction

One of the most obvious manifestations of climate change is its influence on water balance and hydrological processes across the globe, and there is notably a heightened awareness of hydrological responses to climate variations [1]. Impacts vary across the globe, with recent climate variations and developments impacting ecological conditions in the Small Aral Sea in Russia [2]; water shortages in Pakistan, which are among the most severe in the world [3] and further impact ecosystem services [4]; and increased droughts in the semi-arid northeastern region of Brazil, which is one of the poorest rural communities in the country [5]. The Tibetan Plateau in Pakistan, referred to as the "Water Tower of Asia", owing to its unique geographical characteristics, plays an important role in the East Asian and global atmospheric circulation patterns, and is experiencing warming with profound impacts on snowmelt and sustainable water resources for major rivers in Asia [6]. Threats to freshwater ecological systems and biodiversity are challenging locations like the Tonle Sap Lake basin in Cambodia, which is the most fertile and diverse freshwater ecosystem in Southeast Asia [7], and England's chalk streams, which due to their unique predominance of groundwater seeps have a significantly high level of biodiversity [8]. Assessing threats requires tools to characterize current climatic and hydrological conditions and potential future changes.

The approach of using existing hydrologic modeling tools that accurately reflect historical conditions and then using future climate data to force them in order to ascertain changes to watershed hydrology is complicated by several factors. First, climatic conditions are no longer stationary and historical calibrations that are changing with regard to trends and extremes are more difficult to represent with a model, much less project them into the future. Secondly, global climate models (GCMs) do not accurately reflect historical conditions and require bias correction to the historical record to create a correspondence of the historical runs by the GCMs so that the future simulations are not biased regarding relative change from current conditions. Finally, GCMs require downscaling to more local spatial scales to better reflect the processes and conditions in a watershed. These difficulties have been explored in the collection of papers in this Special Issue.

Addressing different parts of the water balance, from precipitation [6] and evapotranspiration [9] to runoff [1–3,7,8] and impacts to water resources [2–5,7,8], these papers investigated the performance of hydrological models and GCMs, projected ecological and hydrological changes to basins [1,2,4–8], and used a suite of analytical and numerical tools to improve both historical calibration/validation capabilities [2,8] and future climate modeling performance [4,5,9].

2. Summary of Papers

2.1. Climate Change Impact Assessment on Freshwater Inflow into the Small Aral Sea, by Ayzel and Ishitskiy (2019)

The rapid separation of the Small Aral Sea from the formal Aral Sea in Russia over the last few decades has been considered by the scientific community to be a clear example of a human-induced ecological disaster, coinciding with changes in the water balance with climatic changes. Ayzel and Ishitskiy sought to develop and validate a hybrid watershed model for the Syr Darya River basin, which is the primary source of freshwater inflows to the Small Aral Sea, and evaluate the impacts of future climate projections. Using the Hydrologiska Byrans Vattenbalansavdelning (HBV) model, they incorporated machine learning to perform extensive calibrations and validations for the historical period with reliable results. The impact of future climate was assessed using four Global Climate Models and three representative concentration pathway scenarios to show contradictory results among models; relative runoff changes are expected to be more pronounced with more aggressive scenarios.

2.2. Long-Term Variation of Runoff Coefficient during Dry and Wet Seasons Due to Climate Change by, Ha et al. (2019)

Using the Soil and Water Assessment Tool (SWAT) on five major river basins in South Korea, this study sought to evaluate the future long-term variation in the runoff coefficient calculated by the model using thirteen future climate models for two representative concentration pathway scenarios. Comparing trends for both wet and dry seasons, the estimates show a temporal increase rate of the runoff coefficient during the 21st century in both RCPs, in which the trend and uncertainty in the dry season is projected as higher than, and exhibits a strong contrast to, that in the wet season. There is also a spatial relationship determined between the variation in the future runoff coefficient and land cover/land use type, although the relationship is expected to vary with changes in temperature and precipitation during both seasons in all future climate periods.

2.3. Assessing the Performance of CMIP5 Global Climate Models for Simulating Future Precipitation Change in the Tibetan Plateau, by Jia et al. (2019)

The performance of 33 global climate models was tested in simulating historical precipitation over the Tibetan Plateau in China in this study. Future changes in precipitation were also estimated using a submultiple model ensemble for two representative concentration pathway (RCP) scenarios. They showed that most models could simulate the pattern of an annual precipitation cycle, but that all models overestimated the precipitation, especially in the spring and summer, and did not perform well in reproducing its spatial distributions. The future annual precipitation was projected to increase by about 6% in the near future, with increases of 12 and 17% for the last half of the century under RCP4.5 and RCP8.5 scenarios, respectively. Future changes in precipitation maintained similar spatial distributions under both scenarios and indicated most increases occurred in the northern Tibetan Plateau. Results are expected to provide valuable information for water resources and agricultural managers seeking to deal with the impacts of climate change.

2.4. Impact Assessment of Future Climate Change on Streamflows Upstream of Khanpur Dam, Pakistan using Soil and Water Assessment Tool, by Nauman et al. (2019)

This study aimed to evaluate the long-term changes in meteorological parameters and to quantify their impacts on water resources of the Haro River watershed located upstream of Khanpur Dam in Pakistan. Using the Soil and Water Assessment Tool (SWAT), the model was calibrated to historical meteorological and streamflow data. The MIROC-ESM global climate model was bias-corrected to the historical time period and used to assess changes in future streamflow for two representative concentration pathway scenarios. For this model, air temperature and precipitation were all projected to increase and streamflows for the basin and were projected to increase from 8.7 m^3/s to 9.3 m^3/s. This watershed supplies freshwater and irrigation water for several large cities, and understanding the variation in future streamflows will aid in devising future policies and management measures for the Khanpur Dam.

2.5. Assessing Climate Change Impacts on River Flows in the Tonle Sap Lake Basin, Cambodia, by Oeurng et al. (2019)

Another multicountry team, in this paper from Cambodia, New Zealand, the United States, France, and Thailand, sought to investigate the influence of climate change on the Tonle Sap Lake basin, Cambodia, the most fertile and diverse freshwater ecosystem in Southeast Asia. Along with rapid development in the basin, climate change threatens to impact the natural flows patters that sustain its diversity. Using the Soil and Water Assessment Tool (SWAT), flows in eleven sub-basins that drain to the lake were calibrated and validated to historical conditions. Then, three global climate models were used for a medium representative concentration pathway for three future time horizons to quantify the potential magnitude of future hydrological alterations in the basin. River flows for all models indicated a likely decrease in both wet and dry seasons, with mean annual projected flow reductions from 7 to 41% by end-of-century. Moreover, a decrease in extreme river flows implied that declines in flood magnitudes and increases in drought occurrences might be expected. These results provide insights for water resources planning and adaptation strategies for the river ecosystems, particularly during the dry season when water flows are projected to decrease the most.

2.6. Development of Threshold Levels and a Climate-Sensitivity Model of the Hydrological Regime of the High-Altitude Catchment of the Western Himalayas, Pakistan, by Saifullah et al. (2019)

This multicountry team from China, Pakistan, the United States, and Australia evaluated water shortages in Pakistan, which are considered among the most severe in the world due to ongoing changes in the hydro-meteorological conditions. Studying the high altitude Kunhar River basin, which drains to the Indus River in the western Himalayas, the authors evaluated historical trends in climate and streamflow. Using threshold levels of hydrological variables, they developed a nonparametric climate-sensitivity model of the basin. The runoff of the high elevation portion decreased, while the temperature increased, although the precipitation increased significantly. The runoff and temperature of the lower elevation portion of the basin increased but the precipitation decreased. To explain these trends, a two-dimensional visualization of the Pardé coefficient was used to show extreme drought events and indicated greater sensitivity of the hydrological regime to temperature than to precipitation. A modified climate-elasticity model further highlighted the sensitivity of the hydrological regime to temperature, which influences the snowmelt process. It was deemed important that the hydrological sensitivity to climate of the entire basin be characterized and understood for policy makers and water managers to made sustainable water resource management decisions.

2.7. Using a Hydrologic Model to Assess the Performance of Regional Climate Models in a Semi-Arid Watershed in Brazil, by Santos et al. (2019)

This study assessed the impact of climate change on the hydrological regime of the Paraguaçu River basin in the semi-arid region of northeastern Brazil. Recent drought in the region has affected agricultural activities, the economy, and society in this poor rural area, and climate change projections suggest increases in temperature, reductions in rainfall, and additional drought periods. Previously, the authors calibrated and validated a Soil and Water Assessment Tool (SWAT) in this watershed, which provided a basis for this model to be used with two Regional Climate Models and two representative concentration pathway (RCP) scenarios that they bias-corrected to the historical climate. The analysis of the impact of climate change on streamflow was done by comparing the maximum, average, and reference (Q90) flows of the simulated and observed streamflow records. Climate projections from both models showed reductions of mean monthly streamflow for all time periods under both RCPs, although they differed in the extent of the reduction. The results of this study provide information for guiding future water resource management in the Paraguaçu River Basin.

2.8. The Impact of Climate Change on Hydroecological Response in Chalk Streams, by Visser et al. (2019)

England's chalk streams, which generally provide clear and nutrient-rich water from predominantly baseflows to support high biodiversity, are in a poor state of health, with significant concerns regarding their resilience under a changing climate. This paper aimed to quantify the effect of climate change on hydroecological response for the River Nar, south-east England. To this end, the authors applied a coupled hydrological and hydroecological modelling framework, with the UK probabilistic climate projections 2009 (UKCP09) weather generator serving as input (CMIP3 A1B high emissions scenario, 2021 to the end-of-century). Under this high emissions scenario, the results indicate a minimal change in the long-term mean hydroecological response over this period. In terms of interannual variability, the median hydroecological response is subject to increased uncertainty, while lower probability extremes are virtually certain to become more homogeneous. A functional matrix, relating species-level macroinvertebrate functional flow preferences to functional food groups, revealed that under extreme conditions, key groups are underrepresented. To date, despite this limited range, the River Nar has been able to adapt to extreme events due to interannual variation. In the future, this variation will be greatly reduced, raising real concerns over the resilience of the river ecosystem, and chalk ecosystems more generally, under climate change.

2.9. Improving Meteorological Input for Surface Energy Balance System Utilizing Mesoscale Weather Research and Forecasting Model for Estimating Daily Actual Evapotranspiration, by Wang et al. (2020)

This paper focused on developing techniques to improve the estimation of actual evapotranspiration estimated by the Surface Energy Balance System (SEBS) by incorporating the heterogeneity of underlying surfaces that are used in the Weather Research and Forecasting (WRF) model simulations that are so often used in dynamically downscaling future climate projections. The meteorological conditions of the Hotan Oasis in China were simulated by WRF with significant improvements over mathematical interpolation methods typically used and provided more reliable input for SEBS modeling of actual evapotranspiration.

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