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Editorial

Water Resource Variability and Climate Change

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Abstract: A significant challenge posed by changing climates is how water cycling and surficial and subsurface water availability will be affected at global and regional scales. Such alterations are critical as they often lead to increased vulnerability in ecosystems and human society. Understanding specifically how climate change affects water resource variability in different locations is of critical importance to sustainable development in different parts of the world. The papers included in this special issue focus on three broad perspectives associated with water resource variability and climate change. Six papers employ remote sensing, meteorological station-based observational data, and tree-ring records to empirically determine how water resources have been changing over historical time periods. Eight of the contributions focus on modeling approaches to determine how known processes are likely to manifest themselves as climate shifts over time. Two others focus on human perceptions and adaptation strategies in the midst of unstable or unsettled water availability. The findings and methods presented in this collection of papers provide important contributions to the increased study and awareness of climate change on water resources.

Keywords: water resource variability; climate change; hydrological model; perception and adaptation of climate change

1. Introduction

Climate change and increased anthropogenic pressure on earth–atmosphere interactions affect water quantity, quality, and water-related processes, such as sediment yield, on local, regional, and global scales [1–3]. Recent decades have seen continuously increasing temperatures in most parts of the world, and changes in precipitation patterns have increased the frequency of extreme climate events such as drought and flooding [4]. The impact of changing baseline conditions coupled with increased variability can be especially complicated in regions with rapid changes in population, land development (especially urbanization), and economic disruptions. While public discussions often focus more on temperature than water availability, ecosystems and human society are highly vulnerable to water stress [5–8]. Understanding the mechanisms and geographic patterns by which anthropogenic climate change is impacting water resource variability is of critical importance to sustainable development, environmental management, and human health.

A variety of approaches have been used to examine the relationships between atmospheric variability and surficial water resources. Instrumental data collected from meteorological and hydrological gauging stations can be used to investigate altered hydrologic regimes over the timespan of several decades to a few centuries in certain areas. Relatively long-term (hundreds to thousands of years) climate and environmental records can be reconstructed using various proxies such as tree rings, sediment cores, ice cores, and landform features [9,10]. More recently, the availability of various remote sensing datasets, such as Landsat/MODIS (Moderate Resolution Imaging Spectroradiometer) imagery, ICESAT (Ice, Clouds, and Land Elevation Satellite) altimetry, GRACE (Gravity Recovery and Climate

Experiment) gravity, and LiDAR (Light Detection And Ranging) measurements have facilitated remote sensing-based approaches to quantifying water resource changes [11–13]. Computational modeling approaches, ranging from global circulation models (GCMs) to regional or watershed hydrological models, are serving to simulate and forecast the projected nature of climate variability on water resources [14,15]. Social scientists have also been investigating how groups or local communities perceive the impacts of climate change and climate vulnerability in order to implement better adaptation practices and sustainable development in coping with changing water resources of different regions [16,17].

The papers included in this special issue address three broad perspectives associated with water resource variability and climate change: (1) the *quantification* of water resource variability altered by changing climates using remote sensing assessment, meteorological station-based observational datasets, and tree-ring record reconstruction; (2) the *simulation* of such impacts on water resource variability using modeling approaches; and (3) evaluating social *perceptions and adaptation strategies* in the face of unstable water resource variability. The following section summarizes the individual contributions within each perspective.

2. Contributions

Six of the papers assess the various impacts of climate change on water resources using a variety of datasets, empirical observations, and proxies. Li et al. [18] examine surface area fluctuations occurring in 10 major lakes in the arid province of Xinjiang, China, from 2000 to 2014 using MODIS time series imagery. The authors develop a classification method to accommodate varied spectral characteristics of water pixels and derived water bodies for April, July, and September in each year for 10 major lakes (>100 km^2) in the study area. Lakes in the lowland (close to urban and agriculture areas) showed a shrinking trend, while mountain lakes have diverse changing patterns (some shrinking, some expanding), and lakes on the Tibetan Plateau exhibited significant expanding trends. By observing varied patterns of lake surface changes across the region, the authors conclude that observed lake expansion is likely driven by rising temperature, leading to accelerated melting of snow and glaciers in high mountains and on the Tibetan Plateau, and increased precipitation in this region (especially in 2010), whereas the shrinking of some lakes is likely related to anthropogenic utilization based on agricultural and industrial needs.

Ning et al. [19] analyze recent changes in water resources and grassland in the Hulun Lake region, a semi-arid region in northeastern China, using monthly GRACE and Tropical Rainfall Measuring Mission (TRMM) data. Results indicate decreasing trends in overall water storage and precipitation between 2002 and 2007, followed by increasing trends in the period from 2007 to 2012. Water storage trends are mainly correlated to precipitation and temperature patterns. As a result, a large proportion of grassland recovered to its normal state in 2008–2012, and only a small proportion of grassland (16.5% of the study area) is classified as degraded. The authors conclude that degraded grassland areas in the region are more vulnerable to climate variability and require protective strategies to prevent further degradation.

Buma et al. [20] assess observed changes in hydrological conditions of Lake Chad basin based on the total water storage (TWS) derived from GRACE, lake levels taken from satellite altimetry, and water fluxes and soil moisture obtained from the Global Land Data Assimilation System (GLDAS). The authors observe a similar pattern between TWS and lake level changes and subsurface water volume changes. The derived values for subsurface water volume changes are found to be consistent with groundwater outputs calculated from the WaterGAP Global Hydrology Model (WGHM). By utilizing recently developed remote sensing datasets, this study provides an alternative means of generating information for the management of water resources in the Lake Chad basin.

Jiang et al. [21] summarize the changing patterns, causes, and implications of surface water discharge and sediment load in Chinese rivers from 1956 to 2012 based on monthly hydrological and daily meteorological data obtained from 725 rain gauge stations across the country. Numerous patterns can be observed during this period. Streamflow discharges manifest a decreasing trend, a relatively stable state, and an increasing trend within northern, southern, and western China, respectively. Excepting the Lancang River and Yarlung Zangbo River basins, sediment loads in most Chinese river basins show gradually decreasing trends, especially after 2000. Although patterns of streamflow and sediment load are affected by the interaction of varied meso-scale climate systems—including East and South Asian monsoons and westerlies—the authors determine that water consumption for industrial and residential purposes, soil, and water conservation engineering, hydraulic engineering, and land surface changes induced by other factors are likely the main causes of observed patterns of streamflow and sediment reduction.

Wang et al. [22] investigate the impact that climate change has had on the duration of flood seasons in the Fenhe River, China, from 1957 to 2014, based on daily precipitation data from 14 meteorological stations in the basin and an analysis of the variations in the onset and retreat dates of yearly flood seasons. The results show that the observed duration of the flood season has been extended since 1975. In particular, the onset of floods has advanced 15 days, although the retreat date is relatively stable. Based on these results, the authors recommend corresponding measures to adapt to the flood season variations.

Kwak et al. [23] conduct a drought analysis using a long-term streamflow record reconstructed using tree ring indices within the Sacramento Basin, California, USA. By first identifying annual streamflow patterns of the Sacramento River from 1560 to 1871 and then analyzing the hydrological drought return period in this river basin, the authors argue that drought with a 20-year return period can be considered a critical indicator of drought for water shortages in the Sacramento River basin.

Eight of the papers aim to simulate the impact of climate change on water resource variability using various climatological and hydrological models. Pechlivanidis et al. [24] investigate the impact of changing climates have on the hydro-climatology of the Indian subcontinent by comparing current and projected future water fluxes from three RCP (Representative Concentration Pathway) scenarios (RCP2.6, RCP4.5 and RCP8.5). These results are used to depict expected changes in the annual flow cycles of three major rivers from different hydro-climatic regions, while acknowledging that conclusions can be significantly influenced by statistical uncertainty embedded in the RCP scenarios. Based on this study, the models project a gradual increase in temperature and uneven changes (ranging from −20% to +50%) in long-term average precipitation and evapotranspiration. Potential surface runoff is also expected to change anywhere from −100% to +100%. The analysis of annual cycles for the three selected regions show that the impact of climate change on discharge and evapotranspiration varies between seasons, and the magnitude of change is primarily dependent on the hydro-climatic gradient in different regions.

Li and Gao [25] simulate the impact of various precipitation change scenarios on runoff and sediment yield in a hilly-gullied watershed typical of the Loess Plateau in China using the Soil and Water Assessment Tool (SWAT). This study indicates that runoff and sediment yield both increase with increasing precipitation, while the variation in sediment yield is more sensitive to smaller rainfall events. The authors determine that under these conditions, annual runoff and sediment yield fluctuate greatly and the magnitude of the variations was especially amplified when precipitation increased by 20%. Overall escalation in runoff and sediment caused by increased precipitation is greater than corresponding decreases coincident with reduced precipitation, and runoff is the more sensitive variable compared to sediment yield.

Ligaray et al. [26] assess the hydrological response of climate change in the Chao Phraya River Basin, Thailand. Streamflow variations were simulated using a combination of SWAT and meteorological data from 2003 to 2011 for various climate sensitivity and greenhouse gas emission scenarios. Simulation results reveal that streamflow variations correspond to the changes in rainfall totals and intensity, while increased air temperature likely leads to future water shortages. The simulation also suggests that high CO_2 concentration drives plant responses that may lead to a dramatic increase in streamflow. Specifically, increased streamflow variations to 6.8%, 41.9%, and 38.4% were simulated for the three greenhouse gas emission scenarios (A1B, A2, B1) in the reference period of 2003–2011.

Mahmood et al. [27] investigate the potential impacts of climate change on the water resources of the Kunhar River basin, Pakistan under A2 and B2 climate scenarios. Using the HEC-HMS (Hydrologic Engineering Center's Hydraulic Modeling System) hydrological model, the authors simulate streamflow for the periods: 2011–2040, 2041–2070, and 2071–2099, and compare them with the baseline period (1961–1990) to explore changes in different streamflow variables. The results indicate an overall increase in mean annual flow projected under both A2 and B2 scenarios, but with a high degree of variability. Stream discharge increases mainly in summer and autumn, but decreases throughout the spring and winter months. High and median flows are predicted to increase, with peak discharges shifting from June to July, while low flow conditions are projected to decrease. The Kunhar basin will face a higher degree of variability—both more floods and droughts—by the end of the 21st century, due to the projected increase in high flow, the decrease in low flow, and greater variations in peak discharges. This study highlights key impacts of climate change on water resources to help develop suitable policies for water resource use and management in this river basin.

Hesse and Krysanova [28] simulate the impacts of climatic shifts and changing management practices on water quality and in-stream processes in the Elbe River Basin using a semi-distributed watershed model (SWIM) with implemented in-stream nutrient (N+P) turnover and algal growth processes. The set of modeled climate scenarios show a projected increase in temperature (+3 °C) and precipitation (+57 mm) on average until the end of the century, leading to varied changes in discharge (+20%), nutrient loads (NO_3-N: 5%; NH_4-N: 24%; PO_4-P: +5%), phytoplankton biomass (4%), and dissolved oxygen concentration (5%) in the Elbe River Basin. The authors utilize the model to examine the ways in which changes in climatic variables fundamentally impact the ways by which land use and nutrients are managed to reduce nutrient emissions to the river.

Liu and Chan [29] assess impacts on water quality in the Danshuei River estuarine system in northern Taiwan using a coupled three-dimensional hydrodynamic and water quality model driven by changes in climatic variables. The model is calibrated and validated using observed data and then applied to simulate water quality projections under various climate change scenarios. Results indicate that dissolved oxygen concentrations are likely to significantly decrease in the Danshuei, whereas nutrients will increase in response to expected climate changes. In particular, dissolved oxygen concentrations will be reduced to less than 2 mg/L in the main stream, failing to meet accepted water quality standards. This study suggests an appropriate strategy for effective water quality management in estuarine systems such as the Danshuei is needed to adapt to the water quality changes likely to accompany anthropogenic climate change.

Wei et al. [30] estimate flood risk that is likely to occur under the heightened hydrologic variability driven by climate change in the Tsengwen River Basin, Taiwan, using a SOBEK model (Deltares, The Netherlands). Simulated results indicate that the discharge of the Tsengwen is at increasing risk of exceeding the designed maximum streamflow at three stations from different areas of the watershed for three projected periods of 1979–2003, 2015–2039, and 2075–2099. Model results indicate that the exceedance frequency for the designed flood is 2 in 88 events in the base period (1979–2003), 6 in 82 events in the near future (2015–2039), and 10 in 81 events at the end of the century (2075–2099).

Okamoto et al. [31] turn our attention from streamflow to water fluxes driving hillslope processes. They investigate the optimal soil hydraulic parameters for simulating unsaturated flow based on a case study from the island of Miyakojima, Japan. The authors optimize the parameters for root water uptake and then examine the influence of soil hydraulic parameters on simulations of evapotranspiration. From there, they compare volumetric water content between the simulation results and those using pedotransfer estimates obtained from ROSETTA software. The resulting comparison highlights the importance of using soil hydraulic parameters based on measured data to simulate evapotranspiration and unsaturated water flow processes.

The last two papers in this special issue examine the ways by which different perceptions of climate change and adaptation strategies impact management and water resource variability. Ndamani and Watanabe [32] analyze farmer perceptions of adaptation practices using semi-structured questionnaires and focus group discussions of 100 farmer-households from four communities in the Lawra district of Ghana. The results show that adaptation is largely driven by response to dry spells and droughts (93.2%) rather than floods. Farmers in the region ranked improved crop varieties and irrigation as the most important adaptation measures, but largely lacked the capacity to implement these adaptation practices. The study also revealed that unpredictable weather, high cost of farm inputs, limited access to reliable weather information, and lack of water resources were the most critical barriers to successful adaptation. This study highlights the critical linkage between climate, hydrology, perception, and environmental management.

Shandas et al. [33] present a study of differing perspectives from the field on stressors and strategies for managing urban water scarcity in two urbanizing regions of the western US: Portland, Oregon and Phoenix, Arizona. The results show that long-term drought, population growth, and outdoor water use are the most important stressors to urban water systems, and indicate more agreement across cities than across professions in terms of effective strategies, suggesting that land-use planners and water managers remain divided in their conception of the solutions to urban water management. The authors also recommend potential pathways for coordinating the fields of land and water management to streamline strategies for urban sustainability.

3. Conclusions

This collection of papers focuses on a range of research topics influenced by the overriding hydrologic mechanisms associated with anthropogenic climate change and associated water resource variability. This includes a wide range of problems ranging from changes in surficial water levels, streamflow, sediment yields, and water quality in lakes, rivers, watersheds, and estuarine systems. The authors have brought a number of methodological tools to bear on these problems by examining various datasets and techniques, such as remote sensing, meteorological station-based observational data, tree-ring records, climate forecasts, and hydrological models used to simulate climatic impacts on streamflow, sediment yield, and water quality. Because consequent environmental problems and strategies for coping and mitigating deleterious effects must be defined in a social context, it is also important to include research examining perception, vulnerability, and adaptation. This collection of 16 papers emphasizes the importance of understanding the various interrelated facets that changing climates have on water resource variability and how focused investigations will help ground suitable strategies for mitigating and adapting to anthropogenic climate change.

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