Climate Variability and Climate Change Impacts on Land Surface, Hydrological Processes and Water Management

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Abstract: During the last several decades, Earth´s climate has undergone significant changes due to anthropogenic global warming, and feedbacks to the water cycle. Therefore, persistent efforts are required to understand the hydrological processes and to engage in efficient water management strategies under changing environmental conditions. The twenty-four contributions in this Special Issue have broadly addressed the issues across four major research areas: (1) Climate and land-use change impacts on hydrological processes, (2) hydrological trends and causality analysis faced in hydrology, (3) hydrological model simulations and predictions, and (4) reviews on water prices and climate extremes. The substantial number of international contributions to the Special Issue indicates that climate change impacts on water resources analysis attracts global attention. Here, we give an introductory summary of the research questions addressed by the papers and point the attention of readers toward how the presented studies help gaining scientific knowledge and support policy makers.

1. Introduction

It is commonly recognized that Earth´s atmosphere is subject to anthropogenic climate change due to enhanced greenhouse gas concentrations in the lower atmosphere. This development also influences hydrological processes across a range of spatial scales, reaching from the singular catchment to regional and global scales. To cope with these changes, it is necessary to implement efficient water management strategies at country, regional or global scale adaptation. To better grasp the mechanism and response to climate variability and climate change, it is crucial to stimulate multidisciplinary studies involving multiple cross-cutting disciplines such as hydrology, meteorology, remote sensing, ecology, engineering, and agriculture.

To address these challenges, continuing efforts need to be undertaken to gain insights on hydrological processes, and engage in more efficient water management strategies in a changing environment across spatial and temporal scales. This Special Issue of Water contributes toward this aim through broad research work on the hydrological consequences of climate and land use change and hydrological modeling approaches. We published twenty-four peer-reviewed papers, and grouped them into four categories (Table 1):

- Climate change and land use change impacts on hydrological processes;
- Trends and variation of hydrological variables, such as precipitation, runoff, actual evapotranspiration, and soil moisture;
- Hydrological modeling in simulating and predicting hydrological variables, such as precipitation, evapotranspiration and soil moisture in data-sparse regions, and
- Reviews on water prices and climate extremes

Table 1. Summary of 24 papers published in the special issue "Climate Variability and Climate Change Impacts on Land Surface, Hydrological Processes and Water Management" in Water Journal.

Categories	Authors	Title	Research Area	Research Fields
Climate change and land use change impacts on hydrological processes	Sridhar et al. [1]	Human-Induced Alterations to Land Use and Climate and Their Responses for Hydrology and Water Management in the Mekong River Basin	Mekong River Basin	Land use; Climate change; Water resources management; Hydrology model
	Guo et al. [2]	Quantifying the Impacts of Climate Change, Coal Mining and Soil and Water Conservation on Streamflow in a Coal Mining Concentrated Watershed on the Loess Plateau, China	Yulin	Climate change; Coal mining; Soil and water conservation
	Pousa et al. [3]	Climate Change and Intense Irrigation Growth in Western Bahia, Brazil: The Urgent Need for Hydroclimatic Monitoring	Western Bahia, Brazil	Climate change; Water security
	Shang et al. [4]	Land Use and Climate Change Effects on Surface Runoff Variations in the Upper Heihe River Basin	Upper Heihe River Basin	Climate change; Land use; scenario simulation; Hydrological simulation
	Gao and Zhang [5]	Effects of the Three Gorges Project on Runoff and Related Benefits of the Key Regions along Main Branches of the Yangtze River	Yangtze River	Runoff changes; Flood control
	Deng et al. [6]	Analyzing the Impacts of Climate Variability and Land Surface Changes on the Annual Water–Energy Balance in the Weihe River Basin of China	Weihe River Basin	Budyko; Climate variability; Land surface change
	Tian et al. [7]	Quantifying the Impact of Climate Change and Human Activities on Streamflow in a Semi-Arid Watershed with the Budyko Equation Incorporating Dynamic Vegetation Information	Wuding River Watershed	Budyko; Climate variability; Land surface change
	Wu et al. [8]	Analysis of Natural Streamflow Variation and Its Influential Factors on the Yellow River from 1957 to 2010	Yellow River	Streamflow variation; Intra-annual climate change
Hydrological trends and causality analysis	Gedefaw et al. [9]	Analysis of the Recent Trends of Two Climate Parameters over Two Eco-Regions of Ethiopia	Ethiopia	Trend analysis; Precipitation; Temperature
	Dorjsuren et al. [10]	Observed Trends of Climate and River Discharge in Mongolia's Selenga Sub-Basin of the Lake Baikal Basin	Selenga Sub-Basin of the Lake Baikal Basin	Precipitation; Temperature; River discharge
	Zhu et al. [11]	Four Decades of Estuarine Wetland Changes in the Yellow River Delta Based on Landsat Observations Between 1973 and 2013	Yellow River Delta	Estuarine wetlands; Spatiotemporal change analysis

Categories	Authors	Title	Research Area	Research Fields
	Li et al. [12]	Spatiotemporal Variation of Snowfall to Precipitation Ratio and Its Implication on Water Resources by a Regional Climate Model over Xinjiang, China	Xinjiang	Snowfall to precipitation ratio; WRF model
	Yan [13]	Meteorological Factors Affecting Pan Evaporation in the Haihe River Basin, China	Haihe River Basin	Evapotranspiration
	Li et al. [14]	Assessing the Influence of the Three Gorges Dam on Hydrological Drought Using GRACE Data	Yangtze River	Hydrological drought; Three Gorges Dam; GRACE
Hydrological model simulations and predictions	Kim et al. [15]	The Use of Large-Scale Climate Indices in Monthly Reservoir Inflow Forecasting and Its Application on Time Series and Artificial Intelligence Models	Han River basin in South Korea	Climate variability; Large-scale climate indices; Artificial intelligence model
	Wu et al. [16]	Influence of Power Operations of Cascade Hydropower Stations under Climate Change and Human Activities and Revised Optimal Operation Strategies: A Case Study in the Upper Han River, China	Upper Han River	Climate change; human activities; Power operation
	Paul et al. [17]	Comparative Study of Two State-of-the-Art Semi-Distributed Hydrological Models	Baitarani river basin in India	Grid-based; HRU-based
	Ri et al. [18]	A Statistical–Distributed Model of Average Annual Runoff for Water Resources Assessment in DPR Korea	DPR Korea	Runoff map; Hydrological model
	Cho and Lee [19]	Multiple Linear Regression Models for Predicting Nonpoint-Source Pollutant Discharge from a Highland Agricultural Region	Lake Soyang basin of South Korea	Diffuse pollutant discharge; Multiple regression model; Climate change
	Liu et al. [20]	Integrating Field Experiments with Modeling to Evaluate the Freshwater Availability at Ungauged Sites: A Case Study of Pingtan Island (China)	Pingtan Island in southeast China	Predictions in ungauged basins; Rainfall-runoff experiments; Distributed hydrological model
	Zhou et al. [21]	The Effects of Litter Layer and Topsoil on Surface Runoff during Simulated Rainfall in Guizhou Province, China: A Plot Scale Case Study	Guizhou province	Runoff; Simulated rainfall; Litter layer; Topsoil
	Nyaupane et al. [22]	Evaluating Future Flood Scenarios Using CMIP5 Climate Projections	Carson River in the desert of Nevada	Flood; Climate change; CMIP5
Review	Soto Rios et al. [23]	Explaining Water Pricing through a Water Security Lens	-	Water security; Water pricing; Sustainable water management
	Hao et al. [24]	Compound Extremes in Hydroclimatology: A Review	-	Compound extremes; Climate change; Multivariate distribution

2. Contributed Papers

2.1. Climate Change and Land Use Change Impacts on Hydrological Processes

There are eight papers published in this category. Sridhar et al. [1] evaluated human-induced alterations to land use and climate and their responses to hydrology and water management in the Mekong river basin. Authors used two hydrological models to evaluate the impacts of natural and climate-induced changes on water budget components, particularly streamflow. Model simulations show that wet season flows were increased by up to 10% and there was no significant change in dry season flows under natural conditions. Their results suggest an increasing trend in streamflow without the effect of dams, while the inclusion of a few major dams resulted in decreased river streamflow of 6% to 15%, possibly due to irrigation diversions and climate change. Guo et al. [2] quantified the

impacts of climate change, coal mining, and soil and water conservation on streamflow in a coal mining concentrated watershed on the Loess Plateau, China. They found that relative to the baseline period, i.e., 1955–1978, the mean annual streamflow reduction in 1979–1996 was mainly affected by climate change, which was responsible for a decreased annual streamflow of 12.70 mm (70.95%). However, in a recent period of 1997–2013, the impact of coal mining on streamflow reduction was dominant, reaching 29.88 mm (54.24%). Pousa et al. [3] analyzed climate change and intense irrigation growth in western Bahia, Brazil and concluded that urgent management is required for hydroclimatic monitoring. They found that the irrigated area has increased over 150-fold in 30 years, and in the most irrigated regions, has increased by 90% in the last eight years only. Their findings suggest that a monitoring system in which the availability and demand of water resources for irrigation are actually measured and monitored is the safest path to provide water security to this region. Shang et al. [4] separated climate change impacts on surface runoff variations from land use impacts in the upper Heihe river basin. Authors found that in this region the contribution rate of climate change is 87.1%, while the contribution rate of land use change is only 12.9%. The climate change scenario simulation analysis shows that the change in runoff is positively correlated with the change in precipitation. The relationship with the change in temperature is more complicated, but the influence of precipitation change is stronger than the change in temperature. Under the economic development scenario of land use simulation, the runoff decreases, whereas under the historical trend and ecological protection scenario of land use simulation, the runoff increases. Gao and Zhang [5] analyzed the effects of the Three Gorges Project (TPG) on runoff and related benefits of the key regions along main branches of the Yangtze River. Their results show that the main benefits of TGP on flood control are remarkable in the reduction of disaster-affected population, the decrease of agricultural disaster-damaged area, and the decline of direct economic loss. Due to torrentially seasonal and non-seasonal precipitation, the sharp rebounds of three standards for Hubei and Anhui occurred in 2010 and 2016, and the percentage of agricultural damage area of five regions in the core and extended areas did not decline synchronously and performed irregularly. The five key regions along the main branches of the Yangtze River should establish a flood control system and promote the connectivity of infrastructures at different levels to meet the significant functions of TGP. Deng et al. [6] analyzed the impacts of climate variability and land surface changes on the annual water–energy balance in the Weihe river basin of China. Authors used the Budyko framework in which the catchment properties represent land surface changes, climate variability comprises precipitation (P) and potential evapotranspiration, and found that the contribution of land surface changes to runoff reduction in period I was less than that in period II, indicating that changes in human activity further decreased runoff. Tian et al. [7] used the Budyko framework incorporating dynamic vegetation information to quantify the impact of climate change and human activities on streamflow in Wuding river basin, a semi-arid basin within the Yellow River Basin. Their results show that climate change generated a dominant effect on the streamflow and decreased it by 72.4% in this basin. This climatic effect can be further explained with the drying trend of the Palmer severity drought index, which was calculated based only on climate change information. Wu et al. [8] analyzed natural streamflow variation and its influential factors on the Yellow River from 1957 to 2010. They found that the reduction of annual streamflow was mainly caused by a precipitation decline and a rise in temperature for all Yellow River regions before 2000, whereas the contribution of anthropogenic interference increased significantly—more than 45%, except for Tang-Tou region after 2000. In the humid Yellow River region, annual streamflow was more sensitive to annual precipitation than temperature, and the opposite situation was observed in the arid region.

2.2. Hydrological Trends and Causality Analysis

There are six papers published in this category. Gedefaw et al. [9] analyzed the recent trends of precipitation and temperature over two eco-regions of Ethiopia. Authors found that the effects of precipitation and temperature changes on water resources are significant after 1998 and the consistency in the precipitation and temperature trends over the two eco-regions confirms the robustness of

the changes. Dorjsuren et al. [10] used observed data detecting trends of annual precipitation, air temperature, and river discharge at five selected stations in Mongolia's Selenga sub-basin of the Lake Baikal Basin. The observation results indicate that the average air temperature has significantly increased by 1.4 °C in the past 38 years and there exists a significantly decreasing trend in river discharge during that period. Zhu et al. [11] investigated estuarine wetland changes in the Yellow River Delta based on Landsat observations between 1973 and 2013. Their results show that natural wetlands are significantly decreased, meanwhile, the artificial wetlands are significantly increased. The main reason for wetland degradation in the Yellow River Delta is human activities such as urban construction, cropland expansion, and oil exploitation. Li et al. [12] investigated spatiotemporal variation of snowfall to precipitation ratio and its implication on water resources by a regional climate model over Xinjiang, China. Their results reveal that the snowfall is increased in the southern edge of the Tarim Basin, the Ili Valley, and the Altay Mountains, but decreased in the Tianshan Mountains and the Kunlun Mountains. However, the trends in snowfall/precipitation ratio are opposite in low-elevation regions and mountains of the study area. Yan et al. [13] attributed meteorological factors affecting pan evaporation in the Haihe River Basin (HRB). The average temperature, maximum temperature, and minimum temperature of the HRB increased, while precipitation, relative humidity, sunshine duration, wind speed and evaporation observed from pan exhibited a downward trend. Attribution analysis shows a significant reduction in sunshine duration, which was found to be the primary factor in the pan evaporation decrease, while declining wind speed was the secondary factor. Li et al. [14] assessed the influence of the Three Gorges Dam (TGD) on hydrological drought using GRACE remote sensing data. They proposed the dam influence index (DII) to assess the influence of the TGD on hydrological drought in the Yangtze River Basin (YRB) in China, and found that impoundments of the TGD between 2003 and 2008 slightly alleviated the hydrological drought in the upper sub-basin and significantly aggravated the hydrological drought in the middle and lower sub-basins, which is consistent with the Palmer drought severity index.

2.3. Hydrological Model Simulations and Predictions

There are eight papers published in this category. Kim et al. [15] used large-scale climate indices in monthly reservoir inflow forecasting for considering climate variability. They demonstrate that there exists potential to use climate indices in artificial intelligence models to improve the model performance, and the ARX-ANN and AR-RF models generally show the best performance among the employed models. Wu et al. [16] proposed an optimal operation model of cascade power stations based on the simulation model to generate single and joint optimal operation charts for future hydrological scenarios. Their modeling results show that under existing hydrological conditions, the modified single and joint operation charts would increase power generation by about 32 million and 47 million kWh for a case study carried out in the upper Han River, China. Paul et al. [17] developed a semi-distributed hydrological model (SHM) whose simulation appears to be superior in comparison to SWAT simulation in Baitarani River Basin in India for both calibration and validation periods. Furthermore, the SHM model is superior to the SWAT model in annual peak flow, monthly flow variability, and different flow percentiles. Differences in data interpolation techniques and physical processes of the models are identified as the probable reasons behind the differences among the models' outputs. Ri et al. [18] developed a statistical–distributed model of average annual runoff for water resources assessment in DPR Korea. The model was derived from 50 years' observations of 200 meteorological stations in DPRK, considering the influence of climatic factors. Based on the water balance equation and assumptions, the empirical relationship for runoff depth and impact factors was established and calibrated. Cho and Lee [19] used multiple linear regression (MLR) models for predicting nonpoint-source pollutant discharge from a highland agricultural region in South Korea. The explanatory variables used in the MLR models are the percentage of fields, sub-basin area, and mean slope of sub-basin as topographic parameters, and the number of preceding dry days, rainfall intensity, rainfall depth, and rainfall duration as rainfall parameters. The MLR models are good for

simulating and predicting pollutant load except for total nitrogen. Liu et al. [20] integrated field experiments with modeling to evaluate the freshwater availability at ungauged sites in Pingtan Island, China. The simulation results indicate high heterogeneity and distinct seasonal dynamics in freshwater availability across the entire island. This is pioneering Prediction in Ungauged Basin (PUB) study for Chinese islands, which could provide reference for planning and management of freshwater in a water shortage area. Zhou et al. [21] conducted a plot scale study to investigate the effects of litter layer and topsoil on surface runoff during simulated rainfall. They investigated three kinds of plots: The thin litter layer with low soil bulk density type (T-L type), the thick litter layer with high soil bulk density type (T-H type), and the moderate litter depth and soil bulk density type (M type), and three artificial rainfall intensities (30 mm/h, 70 mm/h, 120 mm/h). The runoff volume was largest in the T-H type plot at different rainfall intensities and durations. Runoff in the M type plot had characteristics of both the T-L and T-H type plots. The runoff yielding speed was significantly higher and the runoff yielding time was significantly lower in the T-H type plot. Nyaupane et al. [22] evaluated future flood scenarios under CMIP5 climate projections for Carson River in the desert of Nevada. Altogether, 97 projections from 31 models with four emission scenarios were used to predict the future flood flow over 100 years using a best fit distribution. The developed floodplain map for the future streamflow indicated a larger inundation area compared with the current Federal Emergency Management Agency's flood inundation map, highlighting the importance of climate data in floodplain management studies.

2.4. Review

There are two papers published in this category. Soto Rios et al. [23] reviewed water pricing through a water security lens. This paper analyzed how water pricing can be used as a tool to enact the water security agenda, Three facets were reviewed for tackling water crises, including (i) economic aspects—the multiple processes through which water is conceptualized and priced, (ii) analysis of water pricing considering its effect in water consumption, and (iii) arguments for assessing the potential of water pricing as a tool to appraise water security. Hao et al. [24] reviewed compound extremes in hydroclimatology. This review covers different approaches for the statistical characterization and modeling of compound extremes in hydroclimatology, including the empirical approach, multivariate distribution, the indicator approach, quantile regression, and the Markov Chain model. Several key challenges in the statistical characterization and modeling of compound extremes include the limitation in the data availability to represent extremes and lack of flexibility in modeling asymmetric/tail dependences of multiple variables/events.

3. Conclusions

Over the last several decades, Earth´s climate has experienced substantial changes because of global warming linked to increased anthropogenic atmospheric greenhouse gas concentrations. This process affects the hydrological cycle at different levels of observations, ranging from plot to catchment, regional and global scales. Enhancing our overall knowledge on this topic requires multi-disciplinary efforts to learn about hydrological processes and to engage in more efficient water management strategies under changing environmental conditions across those scales.

The research papers published in this Special Issue contribute significantly toward our understanding of the hydrological impacts of climate and land-use change as well as on hydrological modeling approaches in four main subject areas:

- Climate and land use change impacts on hydrological processes;
- Trends and variability of hydrological quantities, such as precipitation, runoff, actual evapotranspiration, and soil moisture;
- Hydrological modeling in simulating and predicting hydrological variables, such as precipitation, evapotranspiration and soil moisture in data-sparse regions; and
- Reviews on water prices and climate extremes

The twenty-four papers presented in this Special Issue reflect on the fact that climate change impact analysis on water resources is a very relevant, albeit challenging topic because of hydrological nonstationary under conditions of global change and the uncertainty related to model inputs, model parameterization, and model structure. The papers published in this issue can not only advance water sciences but support policy makers toward more sustainable and effective water management.

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