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Editorial

Climate–Water–Ecosystem–Interactions: Insights from Four Continent's Case Studies

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Abstract: The interaction of climate with aquatic ecosystems is a multidisciplinary field of research involving water quantity and quality issues and having strong socio-economic implications. This special issue hosts 10 studies undertaken in 7 countries of 4 continents: Asia, Africa, Europe, and North America. The issue provides a wide spectrum of natural and artificial case-studies and covers a broad range of climatic conditions. Most of the studies adopted a modelling (50%) or a field (40%) approach and focused on water-quantity (60%), while the remaining were equally subdivided between water-quality and biogeochemistry. Forty percent of the papers directly face climate change. The diversity of approaches and case studies is the main aspect characterizing this special issue. Despite this high diversification, in relation to water-quantity related issues, we can identify the following messages: high attention to extreme meteorological events, drought in particular, even in regions once considered rich in water (e.g., northern Italy); fragility of agricultural and water supply systems in the face of extreme weather events, in particular in low-income countries (e.g., Madagascar); more attention to climate change compared to land cover/use change but importance of natural land cover to efficiently face the incoming climate change, in particular, in agriculture ecosystems. From a water quality biogeochemistry point of view, we can point out: sensitivity of lakes to climate change with the risk of biodiversity loss; need to reduce nutrient loads to mitigate eutrophication related problems, exacerbated by climate change; in particular, reduction of nitrogen loads from agriculture run-off, to reduce N_2O emissions in large-shallow Chinese environments.

Keywords: irrigation; water yield; land surface processes; run-off forecast; water supply; water level regulation; microbial contamination; phytoplankton community; nitrification-denitrification; chromophoric dissolved organic matter

1. Introduction

Climate–water–ecosystem interactions is a broad and multi-disciplinary field of research dealing with physical, chemical, biological, and engineering disciplines and having important economic and social implications [1,2].

Climate drives the global water cycle [3] and directly impacts on the thermal stratification of both oceans [4] and lakes [5] with strong implications on the biogeochemistry and ecology of these ecosystems [6]. Biogeochemical cycles in aquatic environments are enhanced by the increase of water temperature [7,8] with consequences for plankton [9] and fish [10] productivity. Climate also drives the hydrological cycle of remote areas such as the Arctic and Antarctic poles [11] with feedbacks between the physical environment and the biogeochemical cycles [12]. Globally climate influences the quantity and quality of the water resource [13].

In recent years, the attention on the impact of climate on the water ecosystems and resources has grown, because of the awareness on the incoming climate change [3]. Climate change is modifying the intensity and distribution of precipitation events, making them more difficult to model and predict [14]; this influences our capability to foresee the occurrence of flooding [15] and drought [16]. The reduction of mountain glaciers, furthermore, is reducing the reserves of water stored in these environments, with direct implications for the downstream ecosystems [17] and for the provision of the ecosystem services associated to these environments [18,19]. Climate change is also increasing the frequency of extreme events [20] determining important human health drawbacks related to the contamination of surface waters [21] and water supply systems [22]. These problems are particularly relevant in low-income and developing countries where water supply systems and sanitary infrastructures are scarcer or at least less efficient [23]. In high anthropized zones, the increase of impervious areas is enhancing the surface run-off, augmenting the release of nutrients from sewage overflows and from diffuse agricultural sources [24,25]. Climate also influences the water yield of aquifers, the water storage capacity of reservoirs, and consequently the availability of water for agricultural systems and urban aggregates [3,26]. Fluctuations of the water stored in strategic reservoirs also influence the capacity of hydroelectric power production [27], with repercussions on the energy balance of many countries. All these climate driven impacts necessitate a great capacity of adaptation and mitigation of the society as a whole [28], in order to increase its resilience capacity [26].

The papers of this special issue deal with different research and management topics above outlined. Probably the main interest of this issue lies in the heterogeneity of the topics covered by the different contributions and in the diversity of the geographical areas and environments considered. The combination of these single pieces provides a rather interesting puzzle of different research approaches having the common goal of studying the climate–water–ecosystem interactions.

After the introduction, the paper is structured in two main sections. In the next one (Section 2), we will sketch the main features of the papers composing this special issue (Table 1), and then, we will summarize the contribution of each single paper following the order reported in Table 1. In the final section (Section 3), we will try to outline the final considerations and to underline the most important messages emerging from the heterogeneous collection of papers hosted in this issue.

Table 1. Summary of the paper contents in this special issue. Papers are sorted based on the main topic first and on the country secondarily. DWN = drinking water network; BGC = biogeochemistry; CC = climate change.

Paper	Country	Environment	Climate	Approach	Scale	Main Topic	Other Topics
Danvi et al. 2018	Benin	Agricultural	Subtropical	Model	Basin	Quantity	CC
Lian et al. 2019	China	Salt lake	Continental	Model	Basin	Quantity	CC
Jing et al. 2019	China	Agricultural	Subtropical, monsoon	Model	Basin	Quantity	
Liu et al. 2019	China	Rivers	Subtropical, monsoon	Model	Basin	Quantity	
Romano et al. 2018	Italy	Reservoirs, lake	Alpine, temperate, Mediterranean	Model	Basin	Quantity	
Hu et al. 2018	China	Reservoir	Subtropical, monsoon	Field	Basin	Quantity	Quality
Bastaraud et al. 2018	Madagascar	DWN	Tropical	Field	Country	Quality	Pathogens
Lenard et al. 2019	Poland	Lakes	From continental to temperate	Field	Ecosystem	Quality	BGC, ecology, CC
Li et al. 2019	Alaska-USA, Canada	Sea	Artic	Laboratory	Ecosystem	BGC	ecology
Liu et al. 2018	China	Lake	Subtropical, monsoon	Field	Ecosystem	BGC	Ecology, CC

2. Contributions

A total of 10 articles make up this special issue (Table 1); the studies were undertaken in 7 countries/ regions belonging to 4 continents as follows: Asia (China), Africa (Benin and Madagascar), Europe (Italy and Poland), and North America (Alaska-USA and Canada). Four studies in particular were carried out in China [29–32], which is the most represented country. The papers consider both natural and artificial environments including: lakes and reservoirs (5), rivers (1), seas (1), agricultural systems (2), and drinking water networks (1). The climate range spans from artic to hot and arid climates with the prevalence of sub-tropical ones (4). Most of the studies adopted a modelling (5) or a field (4) approach, while only one paper used a laboratory-oriented methodology [33]. Five papers developed a basin-scale approach, three focused on the ecosystem level (i.e., lake and sea), and one [34] undertook a country-scale research (Madagascar) study. Most of the papers (6) deal with water quantity, 2 papers deal with water quality, while 2 others are more biogeochemical-ecological oriented. Finally, 4 out of 10 papers face climate change related problems [32,35–37].

The papers of this special issue therefore consider different types of case studies, having a rather wide geographical distribution and covering a broad range of climatic conditions. The papers also present a marked diversification of the methodological approaches. The contribution of each individual paper is summarized in Table 1. Papers are sorted based on the main topic first and on the country secondarily.

2.1. Water Quantity

Danvi et al. 2018 [37] assessed the impact of climate and land use change on the hydrological processes of three small (<5 km^2) headwater inland valley watersheds located in central Benin and subjected to the intensification of the rice cultivation. The three watersheds were characterized by different land-use coverage and by a crescent agricultural impact. The most natural watershed was covered by 99% of savannah woodland, while in the other two, savannah covered 92% and 66% of the watershed area, respectively. The evaluation was carried out through the SWAT (Soil and Water Assessment Tool) model, fed by forcing data from two IPCC (Intergovernmental Panel on Climate Change) climate change scenarios (A1B and B1). Land use change scenarios was simulated assuming that 25% and 75% of lowland savannah were converted into rice fields. The simulations were performed based on the traditional and the rainfed-bunded rice cultivation systems and analyzed up to the year 2049. Compared to land use, climate change impact on hydrological processes was predominant in all watersheds. The watersheds with a high portion of cultivated areas resulted more sensitive to changes in climate resulting in a decrease of water yield of up to 50% (145 mm). Bunded fields cause a rise in surface run-off projected to be up to 28% (18 mm) in their lowlands, while processes were insignificantly affected in the vegetation dominated watershed.

Lian et al. 2019 [36] used the InVEST (Integrated Valuation of Environmental Services and Tradeoffs) model to simulate the dynamic change of water yield in the Qinghai lake watershed (central western China) as a function of temporal and spatial changes in precipitation and land use/cover, in the period 1977–2018. In 1977, about 63% of the watershed area (29,646 km^2) was covered by grasslands, while water areas, unused lands, forestlands, and cultivated lands accounted for about 18%, 15%, 1.6%, and 1.5% respectively; built-up areas covered less than 1%. Between 1977 and 2004, cultivated and unused lands increased by about 50% and 6% at the expense of forested and water areas. In the following period 2004–2018 the extension of cultivated lands remained stable while unused areas decreased. Grasslands revealed a slight decrease of about 1% during the whole 1977–2018 period, while built-up areas' increase was about 20-fold. Overall the authors show that in the period 1977–2018 the water yield increased showing maximum correlation with precipitation and significant positive correlation with built-up and forested areas. The authors explained the positive relationship between water yield and build-up areas assuming that these surfaces form an impermeable layer, which reduces the infiltration and consequently increases the water yield.

Jing et al. 2019 [30] applied the SiB2 (Simple Biosphere model 2) model to an irrigated farmland in the low-hilly red soil region of southern China. The paper faces the issue that the conventional model does not perform well in irrigated farmland, because of the lack in considering the influence of land surface water processes. The SiB2 model was parameterized and validated in a typical farmland of the region, using field observations and remote sensing data. The results showed that SiB2 well simulated the net radiation flux and soil heat flux, while underestimated latent heat flux (16.0%) and overestimated sensible heat flux (16.7%). The single factor sensitivity analysis of net radiation flux, heat flux, and latent heat flux modeled by SiB2 indicated that the downward shortwave radiation and downward longwave radiation had a significant effect on the simulated net radiation flux. Downward shortwave radiation, downward longwave radiation, and wind speed were the main factors causing a distinct change in sensible heat flux. According to the results of the sensitivity analysis, an irrigation module was added to the original SiB2 model to simulate the influence of irrigated paddy fields.

Liu et al. 2019 [29] performed an extended-range run-off forecasting in two rivers (Yiluo rivers and Beijiang) located in central and southern eastern China, respectively. Extended-range run-off forecasting is important for water resources management and energy planning. The hindcast was based on an extended-range climate model and a semi-distributed hydrological model (HBV-D). The hydrological model was calibrated in the period 1970–2000. The skill of the run-off forecasts was explored through 5 indices in three experimental 51-day periods during flood season between 1991 and 2016. All five daily indices examined in this study showed decreasing trends for both rivers during the three considered periods and varying length of the continuous longest skillful time slice from 3 days to 6 weeks depending on index, period, and river location. In most cases, skillful abnormal terciles forecast occurred more often or with similar frequency to deterministic forecasts.

Romano et al. 2018 [38] proposed a modelling framework to address the occurrence of shortage in water supply systems whose resource is constituted by natural or artificial reservoirs. The proposed methodology aims at identifying management triggers for possible mitigation measures, using standardized indices to promote information sharing. The implemented tool is structured into five modules: hydrological, scenarios, reservoir, indices of shortage, and support to early warning. The whole procedure has been applied to one Italian natural lake and two Italian reservoirs located in northern (Lake Maggiore), central (Ridracoli reservoir) and southern Italy (Occhito reservoir), respectively. For each water body, a case specific shortage early warning system, based on standardized precipitation indices has been identified, allowing the implementation of efficient local mitigation measures.

Hu et al. 2018 [31] studied the influence of hydro-meteorological factors and human regulation of the Three Gorges Reservoir on the Long River, one of its smaller inflow. Three Gorges Reservoir is one of the largest artificial basins in the world formed by the construction of a dam on the Yangtze River. Its building determined both relevant socio-economic benefit and ecological problems, and thus, there is strong attention to the impact of the reservoir on the surrounding environment. The authors described the water environment of the Long River in 6 sampling stations through 17 water quality variables. They found a significant longitudinal gradient between the Yangtze River backwater and the upstream of the Long River; the impact of the backwater was higher in proximity of the estuary and lower upstream. The influence of the inflow instead was opposite. Six hydro-meteorological variables also have significant influences on the water environment of the Long River. In particular, the perennial backwater area was mostly affected by water level fluctuations, whereas the fluctuation of the backwater area and the upstream inflow area were most affected by cumulative precipitation. The authors however underlined that at the macroscale the water environment of Long River is mainly affected by external input driven by the monsoon climate.

2.2. Water Quality

Bastaraud et al. 2018 [34] examined 16 years (1999–2015) of microbial quality data related to water supply systems in 32 urban areas of Madagascar, with the aim to individuate the parameters modulating the microbial contamination of these systems. Microbial contamination varied among the different urban areas with percentage of contaminated sites ranging from 3.3% to 17.5%. About 78% of the supply systems showed large variations among years or months; microbial contamination increased as a result of heavy rainfall and dry periods. The authors individuated 8 main drivers of contamination including: type of water source, implemented treatment, location of the site, population growth, lack of protection, agriculture, urbanization/sanitation, and flooding threats. Overall the contamination increased within the 16-year long period, reaching alarming levels.

Lenard et al. 2019 [35] examined the complex of climatic factors determining the development of phytoplankton communities during the vegetative growth season in eutrophic lakes located in a European temperate zone (eastern Poland). Through their analysis, the authors were able to divide the data into two different periods: years with a cold winter and low total precipitation and years with a mild winter and high total precipitation. The analysis showed that soluble and total nitrogen content, concentration of chlorophyll-a, total phytoplankton biomass, and biomasses of Cyanobacteria and Cryptophyceae were significantly higher during the vegetative growth season in the year after a mild winter, whereas the soluble and total phosphorus content and phytoplankton biodiversity were significantly lower in these years. The authors suggest that in this temperate zone, climate warming indirectly led to the loss of biodiversity in the phytoplankton communities in lake ecosystems. The authors also tested the effects of increases in air temperature and total precipitation on phytoplankton communities over short time periods (14 and 28 days). The results showed that the total phytoplankton biomass and the chlorophyll-a concentration were only positively correlated with the air temperature.

2.3. Biogeochemistry

Li et al. 2019 [33] conducted laboratory culture incubations to assess the potential role of ice algae in the accumulation of chromophoric dissolved organic matter in Arctic sea ice (i.e., Alaska-USA, and Canada). Chromophoric dissolved organic matter is highly enriched in bottom sea ice in the Arctic during the spring season. The high ultraviolet absorbing nature of chromophoric dissolved organic matter mitigates photo-damage to sympagic organisms, whereas the absorption of visible radiation by sea-ice chromophoric dissolved organic matter decreases the light availability to photosynthesis in the under-ice water column. Along with its colorless counterpart, chromophoric dissolved organic matter is an important substrate for fueling sea-ice heterotrophs and photooxidation. After sea-ice chromophoric dissolved organic matter is released into seawater during the melting season, it becomes a potentially significant player in water-column optics, heat budget, and biogeochemical cycling. The authors grew non-axenic monocultures of *Attheya septentrionalis* and *Nitzschia frigida* and a natural ice algal assemblage at 4 °C in a sterilized medium under cool white fluorescent light. Culture samples were collected several days apart throughout the exponential, stationary, and senescent phases, and analyzed for chromophoric dissolved organic matter absorbance, chlorophyll-a, and bacterial cell abundance. The cultures displayed apparent specific growth rates of algal and bacterial cells comparable to those in the field. Accumulations of chromophoric dissolved organic matter were observed in all cultures during the time-course incubations, with the senescent phase showing the largest accumulations and the highest production rates. The senescent-phase production rate for natural ice algal assemblage was ~40% higher than that for *A. septentrionalis*. The chlorophyll-a normalized chromophoric dissolved organic matter production rates in the cultures were comparable to those reported for Arctic first-year sea ice. The absorption spectra of chromophoric dissolved organic matter in the cultures exhibited characteristic short-ultraviolet shoulders similar to those previously identified in sea ice.

Liu et al. 2018 [32] investigated the N_2O fluxes and nitrification-denitrification rates at the sediment-water interface in different areas of the large (2338 km^2) and shallow (2 m) Lake Taihu (China) over a one-year period. The issue is of particular interest due to the large lake surface, the high level of eutrophication, and the risk of intense N_2O emission and consequent strong greenhouse effect. The authors found a seasonality in the nitrification (0 to 1.18 μmol N m^{-2} h^{-1}) and denitrification

(0.01–235.51 μmol Nm^{-2} h^{-1}) rates with a certain spatial heterogeneity related to the algal production. The N_2O flux showed little variability (−0.64 to 31.49 μmol N m^{-2} h^{-1}) with sporadic peaks related to high algal productivity. The N_2O flux at the sediment-water interface was significantly positively correlated with nitrification and denitrification rates in most lake zones with a predominant role played by nitrification that seems to drive the flux of N_2O. Dissolved nitrogen significantly affected the nitrification rate at the sediment-water interface, and Chlorophyll-a concentrations were positively correlated with both the nitrification rate and the N_2O flux, indicating that algal blooms may promote nitrification and N_2O production whereas no clear relationship was found between water temperature and nitrification rate. Eventually, this study suggests that nitrification at the sediment–water interface in Taihu Lake can be limited by the lower water nitrogen concentrations.

3. Final Considerations and Messages

Hydrology and water quantity related disciplines are the most represented in this special issue. Rather surprisingly, only a minor part (i.e., two out of six) deals with climate change, which is one of the most appealing topics, connecting climate and water availability related issues. Two of the water quantity papers refer to agricultural ecosystems located in Benin and China, respectively [30,37]. Both papers emphasize the importance of water availability to maintain a suitable agricultural development. The paper of Danvi et al. 2018 [37] considered small headwater inland valley watersheds located in central Benin and highlights first that climate change, instead of land cover/use change, has the major impact on the hydrological processes in these small agriculture watersheds. However, they also stressed the need of an adequate balance between the portion of land cover dedicated to the cultivation of rice and that left to natural vegetation. The watershed with the largest natural cover, indeed, showed the highest capability to mitigate the impact of the incoming climate changes. This is not trivial given the strong economic and social pressures to increase rice production in these regions [39]. Jing et al. 2019 [30] instead put the attention on the need to integrate hydrology and land surface water processes to gain a correct estimation of the water availability in agricultural areas of southern China. In the Qinghai lake watershed (central western China) Lian et al. 2019 [36] found, similarly to Danvi et al. 2018 [37], that changes in precipitation affect more the water yield than changes in the land use/cover. The problem of water availability for agriculture and other uses is addressed even by Romano et al. 2018 [38], which presented a computational (statistical) tool to manage water supply under drought conditions, using past precipitation regimes. This tool is presented for three reservoirs located in northern, central, and southern Italy. Indirectly, this paper highlights that the problem of water scarcity in Italy is no longer just an issue of the central-southern regions, as it has been historically considered, but that it is becoming a concern also for northern Italy, normally considered a water rich region [40]. Liu et al. 2019 [29] focus the attention on the extended-range river run-off forecast. Projections were carried out in two rivers (Yiluo and Beijiang rivers) located in central and southern eastern China. The authors suggest the use of ensemble probability forecasting to improve the quality of these projections. Hu et al. 2018 [31] direct our attention to the large artificial lakes and to their impact on the surrounding environment. In particular, the authors studied the influence of hydro-meteorological factors and human level regulation of the Three Gorges Reservoir on the water environment of the Long River, one of its smaller inflows. The authors found a certain influence of the Three Gorges Reservoir on the Long River inflow, but they also suggest that, at the macroscale, its water environment is mainly affected by monsoon driven factors. This paper can be considered as a passage between the contributions dealing with water quantity and those related with water quality and biogeochemistry.

The water quality group includes two papers [34,35]. Bastaraud et al. 2918 [34] analyzed the microbial contamination of the water supply system of Madagascar, over a 16-year period (1999–2015), relating it to different stressors, including climate. The authors found an increasing contamination over the study periods and related this increase to the occurrence of both flood and drought periods. This paper, through the case of Madagascar, draws our attention to the fragility of low-income country water supply systems to extreme weather conditions. The paper from Lenard et al. 2019 [35] underlines the sensitivity of lakes to climate change that can lead to a marked reduction in biodiversity.

The biogeochemistry group includes two papers [32,33]. The study of Li et al. 2019 [33] demonstrates that ice algal-derived chromophoric dissolved organic matter can account for the springtime accumulation of chromophoric dissolved organic matter, in Arctic sea ice. This has implications for both the in-ice and under-ice optics and biogeochemistry. Liu et al. 2018 [32] indicated that a progressive reduction of nutrients loads in Lake Taihu, with particular respect to dissolved nitrogen diffusive loads from agriculture, could not only reduce the eutrophication of the lake water, but also reduce the emission of N_2O at the water-sediment interface, in this large-shallow and strategic lake.

The diversity of approaches and case studies is certainly the most important contribution and characterizing aspect of this special issue. Such a diversification, however, makes difficult to synthesize the salient aspects of the different papers. Despite this difficulty, we can underline the following relevant points and messages: high attention in extreme meteorological events, drought in particular, even in regions once considered rich in waters (e.g., northern Italy); fragility of agricultural and water-supply systems to extreme weather events, in particular in low in-come countries (e.g., Madagascar); more attention to climate change compared to land cover/use change but importance of natural land cover to efficiently face the incoming climate change, in particular in agriculture ecosystems. From a water quality-biogeochemistry point of view, we can point out the high sensitivity of lakes to climate change with the risk of biodiversity loss and the need to reduce nutrient loads to mitigate eutrophication related problems exacerbated by climate change, in particular, reduction of nitrogen loads from agriculture run-off, to reduce N_2O emissions in large-shallow Chinese lakes.

Finally, all the papers in this special issue deal with natural or environmental sciences, while no author accepted the challenge contained in the special issue call to integrate: "natural sciences with economic and social sciences". This is likely the main lack of the issue, as the coupling of environmental and socio-economic approaches is one of the main challenges facing both environmental researchers and decision makers. Any environmental planning and intervention, indeed, must consider social consequences and economic sustainability [41]. Although not directly addressed, these arguments are however recalled by different contributions.

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