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Editorial

Hydrology in the Caribbean Basin

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1. Introduction

The idea for this Special Issue emerged from the recognition that the Caribbean Basin is fascinatingly diverse (26 countries border it), and a vast majority of its population are under threat from the intense pressures of climate change and human impacts. Unsurprisingly, a considerable effort is underway to research the impacts of these factors on issues such as tourism, water availability, subsistence farming, and the commercial production of value crops such as coffee, cocoa, and sugar cane. In this Special Issue, the editors seek to present an overview of the relevant research areas and topics that are currently being addressed, such as climate in the Caribbean, water budgets and flows, precipitation patterns, and the ecological aspects surrounding the use and availability of water. The scope of topics addressed is substantial and not necessarily always aligned with specific hydrologic topics, but it illustrates a general concern and/or interest from various disciplines surrounding the topic of "Caribbean Water", be it in the air, on the soil surface, in plants, or at the interface of land and the atmospheric layers.

The Caribbean Basin carries is vital for tourism and agribusiness and is home to over 150 million people. Its composition is diverse, consisting of a chain of islands stretching from the Greater Antilles (Cuba, Jamaica, Cayman Islands, Hispaniola, and Puerto Rico) eastwards to the Leeward and Windward Islands, and then to the Cancun peninsula, the countries of Central American, and the countries in the northern region of South America (Columbia and Venezuela). Climate change is predicted to have a dramatic impact on the weather patterns for this region, with anticipated changes that include more prolonged periods of droughts, an overall decline in annual rainfall volumes, and an increased occurrence of extreme events, such as tropical storms and hurricanes. There are also anthropogenic changes due to deforestation and agribusiness, requiring water from ground and surface water sources and tourism development that strains freshwater resources. All of the above mechanisms have, and will continue to have, a significant impact on the water resources in the region, with potentially vast adverse consequences. This Special Issue aims to explore both the current state of hydrologic research in the region and important aspects to focus on, which emerge as challenges grow for the countries in this region and their populations.

2. Contributed Papers

The articles in this Special Issue address a wide variety of topics reflecting the challenges mentioned above and can be roughly grouped into three categories: hydro-climate, hydrologic processes, and hydro-models.

2.1. Hydro-Climate

The paper **"Resolution-Dependent Perspectives on Caribbean Hydro-Climate Change"** [1] by Mark Jury explores the seasonal hydro-climate variability and its regional controls. Near-surface winds around the mountainous Caribbean islands contribute to orographic lifting

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and thermal, diurnal rainfall that requires an analysis at the mesoscale. Here, a new perspective is presented via high-resolution satellite and reanalysis products. When summertime trade winds weaken, the daytime confluence around Caribbean islands enlarges, gathering and lifting more moisture. In addition to static, geographic forcing, transient easterly waves impart the majority of marine rainfall between June and September. Higher-resolution products capture the thermal orographic effect and reveal upward trends in island rainfall and soil moisture over the satellite era, while lower resolution products fail to identify this effect. Existing studies show that the climate of mountainous Caribbean islands is trending toward increased runoff and soil moisture.

The article **"Tropical Convection in the Caribbean and Surrounding Region during a Regional, Warming Sea-Surface Temperature Period, 1982–2020"** [2], by Equisha Glenn, Thomas Smith, Jorge Galvez, Michael Davison, Keneshia Hibbert, and Jorge Gonzalez, shows that warming sea-surface temperatures (SST) have a profound impact on the Caribbean climate. Using the Galvez–Davison Index (GDI), their paper examines the changes in tropical convection. The results show that regional SSTs are warming annually and per season, while regionally averaged GDI values are decreasing annually and in the dry season. Spatial analyses show that the GDI demonstrates higher, statistically significant correlations with precipitation across the region, compared to those with annual and seasonal sea-surface temperatures. Moreover, the GDI climatology results show that regional convection exhibits a bimodal pattern resembling the characteristic bimodal precipitation pattern experienced in many parts of the Caribbean and surrounding regions.

The paper **"Assessment of Precipitation Variability and Trends Based on Satellite Estimations for a Heterogeneous Colombian Region"** [3], by Enrique Morales-Acuna, Jean Linero-Cueto, and Fausto Canales, evaluates the long-term spatiotemporal variability and trends of the average monthly precipitation in the Magdalena Department, Colombia, for the 1981–2018 period. An analysis of spatial variability allowed for the determination of four different subregions based on the differences in the average values of precipitation and the degree of rainfall variability. The trend analysis indicates that the current rainfall patterns contradict previous estimates of a progressive decrease in annual averages due to climate change in the study region, where this study found reductions of between 10 mm yr^{-1} and 30 mm yr^{-1}. This study also suggests some links between precipitation patterns with regional phenomena of climate variability and solar activity.

The paper **"Flood Impacts on Critical Infrastructure in a Coastal Floodplain in Western Puerto Rico during Hurricane María"** [4], by Said Mejia Manrique, Eric Harmsen, Reza Khanbilvardi, and Jorge Gonzalez, evaluates the depth and extent of impacts inflicted by floods on critical infrastructures and communities on the Añasco coastal flood plain in Western Puerto Rico in the aftermath of storm Maria. The team developed a numerical model based on GSSHA code that was forced using WRF-based hydro-climate variables to model various flooding scenarios: (1) The use of an observed discharge hydrograph from the upper watershed as an inflow boundary condition for the coastal floodplain area, along with the WRF rainfall in the coastal flood plain; (2) The use of WRF rainfall to simulate runoff in the upper watershed and coastal flood plain; and (3) the use of bias-corrected WRF rainfall. Flooding results were compared with forty-two values of flood depth obtained during face-to-face interviews with residents of the affected communities. Model results were compared to narratives by locals, and impacts were assessed for inundation levels larger than 20 cm, which showed higher impact levels for water than for electrical infrastructure.

2.2. Hydrologic Processes

The paper **"Hydrological Mapping in the Luquillo Experimental Forest: New Local Datum Improves Watershed Ecological Knowledge"** [5], by Miguel Leon, Tamara Heartsill-Scalley, Ivan Santiago, and William McDowell documents the recent collaborative and multi-institutional work to improve hydrological network information and identify knowledge gaps. The methods used to delimit and densify stream networks include establishing and incorporating new and updated vertical data for Puerto Rico, LIDAR derived elevation and

a combination of visual–manual and automated digitalization processes. This collaborative effort has resulted in improved watershed delineation, the densification of hydrologic networks to reflect the scale of ongoing studies, and the identification of constraining factors such as unmapped roadways, culverts, and other features of the built environment that interrupt water flow and alter runoff pathways.

The article **"Calcium and Potassium Nutrition Increases the Water Use Efficiency in Coffee: A Promising Strategy to Adapt to Climate Change"** [6], by Victor Ramirez-Builes and Jürgen Küster, examines the sustainability of coffee production with regard to air temperature increases and changes in rainfall patterns and volumes in the Caribbean region. Incremental adaptation strategies, including proper soil and water management, contribute to improved water use efficiency (WUE) and should be the first action to adapt the coffee crop to the changing growing conditions. The research objective was to conduct a five-year evaluation at the field level on the influence of fertilization with calcium (Ca^{+2}) and potassium (K^{+}) on WUE in two coffee arabica varieties: cv. Castillo and cv. Caturra. WUE was influenced by yield changes during the years by climate variability due to El Niño–ENSO conditions and coffee leaf rust (CLR) incidence. The results indicates that adequate nutrition with Ca^{+2} and K^{+} could improve WUE in the long term, even under water deficit conditions and after the substantial CLR incidence.

The paper entitled **"Validation of Soil Survey Estimates of Saturated Hydraulic Conductivity in Major Soils of Puerto Rico"** [7], by Fernando Juliá, Victor Snyder, and Miguel Vazquez, examines ranges or "classes" of probable saturated hydraulic conductivity values (K_{sat}) listed for all soils in the USDA-NRCS Soil Survey reports, which were determined using a pedotransfer function (PTF) rather than direct measurements. To validate the PTF, the paper compares the estimated Ksat classes with measured values in various horizons of nine major soil series of Puerto Rico. For most horizons, measured K_{sat} values are distributed among the rated K_{sat} class and the next higher class, indicating that the PTF systematically underestimated the Ksat distributions but by less than one order of magnitude, suggesting a reasonable conservative estimation.

The paper **"A Catalogue of Tropical Cyclone Induced Instantaneous Peak Flows Recorded in Puerto Rico and a Comparison with the World's Maxima"** [8], by Carlos Ramos-Scharrón, Caroline Garnett, and Eugenio Arima, compiles 1922 area-normalized peak streamflow rates recorded during tropical cyclones in Puerto Rico from 1899 to 2020. The peak flows reflect how a changing climate impacts tropical cyclone intensity and the associated hydrologic response. The results show that the highest peak flow values recorded on the island were within the range of the world's maxima for watersheds with drainage areas from 10 to 619 km^2. Although higher average tropical cyclone rainfall and streamflow rates were observed only for the central–eastern half of Puerto Rico, maximum cyclone-related peaks were recorded throughout the entire island when caused by tropical depressions, tropical storms, or hurricanes.

2.3. Hydro-Models

The paper **"Development of Predictive Models for Water Budget Simulations of Closed-Basin Lakes: Case Studies of Lakes Azuei and Enriquillo on the Island of Hispaniola"** [9], by Mahrokh Moknatian and Michael Piasecki, examines historical water level fluctuations of the two neighboring Caribbean lakes of Azuei and Enriquillo on Hispaniola, which showed random periods of synchronous and asynchronous behaviors despite being exposed to the same climatic forces. This paper examines their systems' main drivers and constraints, which are used to develop numerical models for the lakes. The authors use a water balance approach to model the lakes on an interannual scale and examine the assumptions of surface and subsurface processes. These assumptions are made based on field observations and prior studies. The models yield a "good" performance for volume change and "very good" outcomes for volume simulations.

The article **Water and Energy Balance Model GOES-PRWEB: Development and Validation** [10], by Eric Harmsen, John Mecikalski, Victor Raventos, Estefania Perez, Sopuruchi

Uwakweh, and Christie Garcia, introduces the creation of a data service that uses the GOES solar radiation and other parameters to compute radiation-based evapotranspiration methods. The authors describe the theoretical background and technical approach to estimating the daily water and energy balance components. Model validation results are presented for reference and actual evapotranspiration, soil moisture, and streamflow. The model has been used for various practical applications, including irrigation scheduling, drought and aquifer recharge analyses, estimating crop water use as part of a water withdrawal and use study, and for establishing soil moisture initial conditions for hydrologic models. This research represents a preliminary step in developing a suite of gridded hydro-climate products for the Caribbean Region.

The paper **"Quo Vadis Lakes Azuei and Enriquillo: A Future Outlook for Two of the Caribbean Basin's Largest Lakes"** [11], by Mahrokh Moknatian and Michael Piasecki, examines the future development of Lakes Azuei and Enriquillo on Hispaniola Island, which expanded from 2005 to 2016. The paper outlines the approach chosen to look forward with regard to climate change scenarios developed by the Intergovernmental Panel on Climate Change. It uses numerical representations of the two lakes, and it examines how the lakes might evolve, deploying three different forcing mechanisms: a mechanism of weather and drift due to climate change; a mechanism of extreme events, such as hurricanes, and a mechanism of anthropogenic impacts, such as unintended water transfers between adjacent watersheds. The results are not precise and vary significantly as the forecast horizon expands, creating expanding envelopes of outcomes. Although some outcomes suggest a continued rise in lake levels, most scenarios yield a reduction and recession in lake waters.

The paper **"Evaluation of Debris Flows for Flood Plain Estimation in a Small Ungauged Tropical Watershed for Hurricane Otto"** [12], by Sebastian Salazar and Alejandra Gonzalez, evaluates different scenarios for estimating flooded areas in Costa Rica for Newtonian (clean water), and non-Newtonian flows with volumetric sediment concentrations (Cv) of 0.3, 0.45, 0.55, and 0.65 using Hydro-Estimator (HE), rain gauge station, and the 100-year return period event. HEC–HMS modeled the rainfall products, and FLO-2D modeled the hydrographs and Cv combinations. The results indicated no significant differences in flood depths between hydrological scenarios with clean-water simulations, with a difference of 8.38% in the peak flow. Additionally, the flood plain generated with HE rainfall and clear-water conditions presented similar results when compared with the rain gauge input source, suggesting that there is little difference in flood plain generation using clear, fresh water and those flows with heavy sediment load.

3. Conclusions

This Special Issue explores many aspects of hydrologic research spanning several geovolume layers, i.e., the atmosphere, the Earth's surface, the sub-surface, and approaches to data gathering, such as satellite information and in situ measurements, and those sets generated from numerical modeling. As such, this paper collection is a broad representation of the general concerns of hydrology, focusing on the Caribbean Basin in particular. It also shows that the Caribbean Basin is a microcosm of the field of hydrology and that the efforts to address and understand hydrologic processes, challenges and environmental problems that arrive at the nexus of water and adjacent disciplines are strong, reflecting a considerable diversity in the research community located around the Caribbean Basin.

The idea for this Special Issue was largely born from the efforts of the two Guest Editors who both conduct research work on the islands of the Caribbean Basin (Hispaniola and Puerto Rico), but not entirely. Through connections to other researchers in this region, visiting colleagues, and by following the research of others (not necessarily in the area of hydrology), a network of fellow Caribbean Basin scientists has emerged, growing and broadening their horizons, eventually conceiving the idea that there is a lot more that can be published and showcased than one's own work. This first Special Issue can be considered a success, and it is no surprise that a call for a second Special Issue has already been made.

However, there are challenges that remain; one contribution could not be included because the authors could not guide the manuscript past internal government institution roadblocks; one paper did not make the final cut because the data collected were deemed too sensitive in a geopolitical context; and then there is the timing issue (as always) that often interferes with the natural progression of publishable material, which is simply not ready when the issue deadlines arrive. Nonetheless, the two Guest Editors tremendously enjoyed compiling this issue and are looking forward to potentially following it up in a few years; the vibrant Caribbean Basin research community certainly gives rise to this hope.

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