JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

AMERICAN WATER RESOURCES ASSOCIATION

CLIMATE AND WATER CONFLICTS COEVOLUTION FROM TROPICAL DEVELOPMENT AND HYDRO-CLIMATIC PERSPECTIVES: A CASE STUDY OF COSTA RICA[1]

Germain Esquivel-Hernández, Ricardo Sánchez-Murillo, Christian Birkel, and Jan Boll[2]

ABSTRACT: Costa Rica is a nation with a vast wealth of water resources; however, recently the country has faced water conflicts (WC) due to social, economic, legal, and political impediments in response to limited water availability during El Niño events and inefficient use of its water resources. This study presents a spatial distribution and temporal analysis of WC in Costa Rica from 2005 to 2015. In total, 719 WC were analyzed of which 54% were among private individuals and government. The largest urban areas and the Grande de Tárcoles Basin were identified as the main "hot spot" for the conflicts. WC were mainly caused by spills of wastewater, water pollution, water shortage, infrastructure damage, and flooding, and can be predicted using a multiple linear model including the population size and the number of hydro-meteorological events (HME) (R^2 = 0.77). The identified HME also coevolved significantly with the changes in precipitation regimes (r = 0.67, p = 0.021). Our results suggest that there is a need to recognize that water infrastructure longevity across the country concatenates and amplifies WC, mainly in the most populated area located in the Central Valley. Implications of our findings include the need for truly integrated water resources management plans that include, for example, WC as indicators of hydro-climatic changing conditions and water supply and sanitation infrastructure status.

(KEY TERMS: Costa Rica; water conflicts; climate variability; water supply; water sanitation; sustainability.)

Esquivel-Hernández, Germain, Ricardo Sánchez-Murillo, Christian Birkel, and Jan Boll, 2017. Climate and Water Conflicts Coevolution from Tropical Development and Hydro-Climatic Perspectives: A Case Study of Costa Rica. *Journal of the American Water Resources Association* (JAWRA) 1–20. https://doi.org/10.1111/1752-1688.12617

INTRODUCTION

Water is recognized as the most fundamental and indispensable of all natural resources. One of the sustainable development goals adopted by world leaders in September 2015 in Paris, France was to ensure the human right of access to water and sanitation for all by 2030 (Sustainable Development Goals: http://www.un.org/sustainabledevelopment), recognizing that clearly neither socioeconomic development nor environmental diversity can be sustained without water. Since the 1990s, water governance has attracted increased attention. It is being promoted as a normative concept to improve water resources management, seeking also increased stakeholder engagement, flexibility, and less hierarchical forms of interaction between the state and society (Schulz

[1]Paper No. JAWRA-16-0232-P of the *Journal of the American Water Resources Association* (JAWRA). Received December 15, 2016; accepted November 20, 2017. **Discussions are open until six months from issue publication**.

[2]PhD Candidate (Esquivel-Hernández) and Associate Professor (Sánchez-Murillo), Chemistry Department, National University of Costa Rica, PO Box 86-3000, Heredia, Costa Rica; Associate Professor (Birkel), Department of Geography, University of Costa Rica, San José, Costa Rica; and Professor (Boll), Department of Civil and Environmental Engineering, Washington State University, Pullman, Washington 99164 (E-Mail/Esquivel-Hernández: germain.esquivel.hernandez@una.cr).

et al., 2017; Woodhouse and Muller, 2017). However, doubts have been raised recently about the effectiveness of existing global water governance (Pahl-Wostl *et al.*, 2013; Kuzdas *et al.*, 2016b), because there is evidence that unequal distribution at different scales and unsustainable uses of water resources are creating tensions over allocation of water (Wang *et al.*, 2008). Water conflicts (WC) can be defined as social situations in which a minimum of two actors or parties attempt to obtain water resources simultaneously for domestic, municipal, agricultural, and industrial uses under water scarcity (Priscoli and Wolf, 2009). Kuzdas *et al.* (2016b) described a WC as a process with varying degrees of tension among actors that move through stages of higher or lower intensity. Low intensity conflicts include latent conflicts, which are inherent in water governance, and manifest disputes that show up when at least one actor takes action (i.e., political, legal, or economic action) against one or more actors. High intensity conflicts comprise conflicts related to civic dissent (e.g., acts of violence and nonpeaceful protest) and destabilization, when civic dissent increases in frequency and in amount. WC are also often related to the extent of people's dependence on water for their livelihoods, the occurrence of complex social phenomena such as human migrations from drought-affected areas, transboundary conflicts (Wolf *et al.*, 2003; Bernauer *et al.*, 2012; Bogardi *et al.*, 2012), and degraded water quality and pollution of surface and groundwater sources such as loss of potential sources of freshwater supply (Wang *et al.*, 2008; Bower, 2014; Woodhouse and Muller, 2017).

Overall, the occurrence of WC is linked with complex relationships between contextual factors that represent the spatial variability of diverse parameters such as population size and growth, governance, climate variability and climate change, geomorphological features, and water quality and quantity (Ashton, 2002; Wolf *et al.*, 2003). In a changing climate context, where periods of water scarcity are more likely to occur, an increasing dependence and demand for water could trigger conflicts among water users at different spatial and temporal scales by activating underlying and latent conflicts or by worsening the scope of present conflicts (Yoffe *et al.*, 2004; Salehyan, 2008; Funder *et al.*, 2012; Raleigh and Kniveton, 2012). Biswas (2008) and Kuzdas and Wiek (2014) have called for design and implementation of integrated water resources management plans in regions facing WC where traditional governance fails to resolve these water-related challenges.

In Central America, intensification of changes in regional climate is expected to impact local water cycle dynamics. Such short-term changes will affect the seasonal patterns of precipitation and evaporation, increase the probability of extreme hydro-meteorological events (HME) (i.e., flooding and droughts), and produce social stress at local and regional scales (Arnell, 2004; Stahl, 2005; Oki and Kanae, 2006). For example, in early 2016, drought and excessive rainfall affected more than 60 million people across the globe, including Central America (Hallegatte *et al.*, 2017). In 2012, this region was also classified as an economic water-stressed region by the United Nations, because it lacked the necessary infrastructure to efficiently supply water and sanitation (WWAP, 2012). Costa Rica currently has abundant precipitation (~3,300 mm/yr on average, Sánchez-Murillo and Birkel, 2016), and therefore can be considered a nation with a wealth of water resources. Social, economic, legal, and political impediments, however, have created a significant challenge for the efficient use of its water resources. For example, these obstacles have led to chronic contamination problems affecting surface and groundwater sources in the Central Region of the country, triggered by excessive use of fertilizers, uncontrolled use of septic tanks, and poor wastewater sanitation infrastructure (Guzmán-Arias and Calvo-Alvarado, 2013; Bower, 2014). In this regard, there is also a lack of information about the local and country-wide prevalence of WC in Costa Rica. Ramírez-Cover (2008) reported the socio-environmental problems that are related to water resources in the Pacific Northwest of Costa Rica. However, this work was focused on the relationship between WC and the characteristics of the style of economic model development. Alpízar-Rodríguez (2012) reported on ecological democracy and WC, focusing on the political participation during a long time period (1821–2010). Recent work by Kuzdas and Wiek (2014) and Kuzdas *et al.* (2014, 2016a, b) in Guanacaste explored the implementation of scenarios that portray alternative governance strategies in order to support positive change in regions that experience persistent water problems.

To our knowledge, a detailed analysis of the linkage of the spatial and temporal distribution of WC and climate variability in Costa Rica has not been conducted. Consequently, one important task is to compile and systematize information about the impact of climate variability on local water resources and the related social response to those changes that can be used by local governments in the planning of their water resources management strategies. In this work, we aim to: (1) identify the types and causes of WC in Costa Rica during a recent time period (2005–2015), (2) contrast the occurrence of these conflicts with the demographic and social conditions at a municipal level and with the water availability across the municipalities' boundaries of Costa Rica, and (3) identify possible relationships between the occurrence of WC and climate variability. Examples of climate variability include changes in precipitation regimes and the incidences of HME.

CASE STUDY BACKGROUND

Climate and Geographic Generalities of Costa Rica

Costa Rica is located in the Central American Isthmus, surrounded by the Caribbean Sea to the east and the Pacific Ocean to the west. The Costa Rican territory covers an area of 51,000 km^2. Administratively, the country is divided into seven major provinces that are further divided into 81 municipalities or local governments, which are the smallest governmental unit (see Figure 1). In 2015, the Costa Rican population (POP) was reported as 4.7 million inhabitants with a growth rate of ~72,000 inhabitants per year between 1990 and 2015. The country's average population density (POP-d) is 93 inhabitants per km^2 (PEN, 2015).

The Central Valley of Costa Rica is situated in an inter-mountainous region of volcanic origin with an average elevation of 1,100 meters above sea level (m a.s.l.) and encompasses an area of ~3,000 km^2. Within the Central Valley, an urban conglomerate comprises the four major cities of the country (namely Alajuela, Heredia, San José, and Cartago)

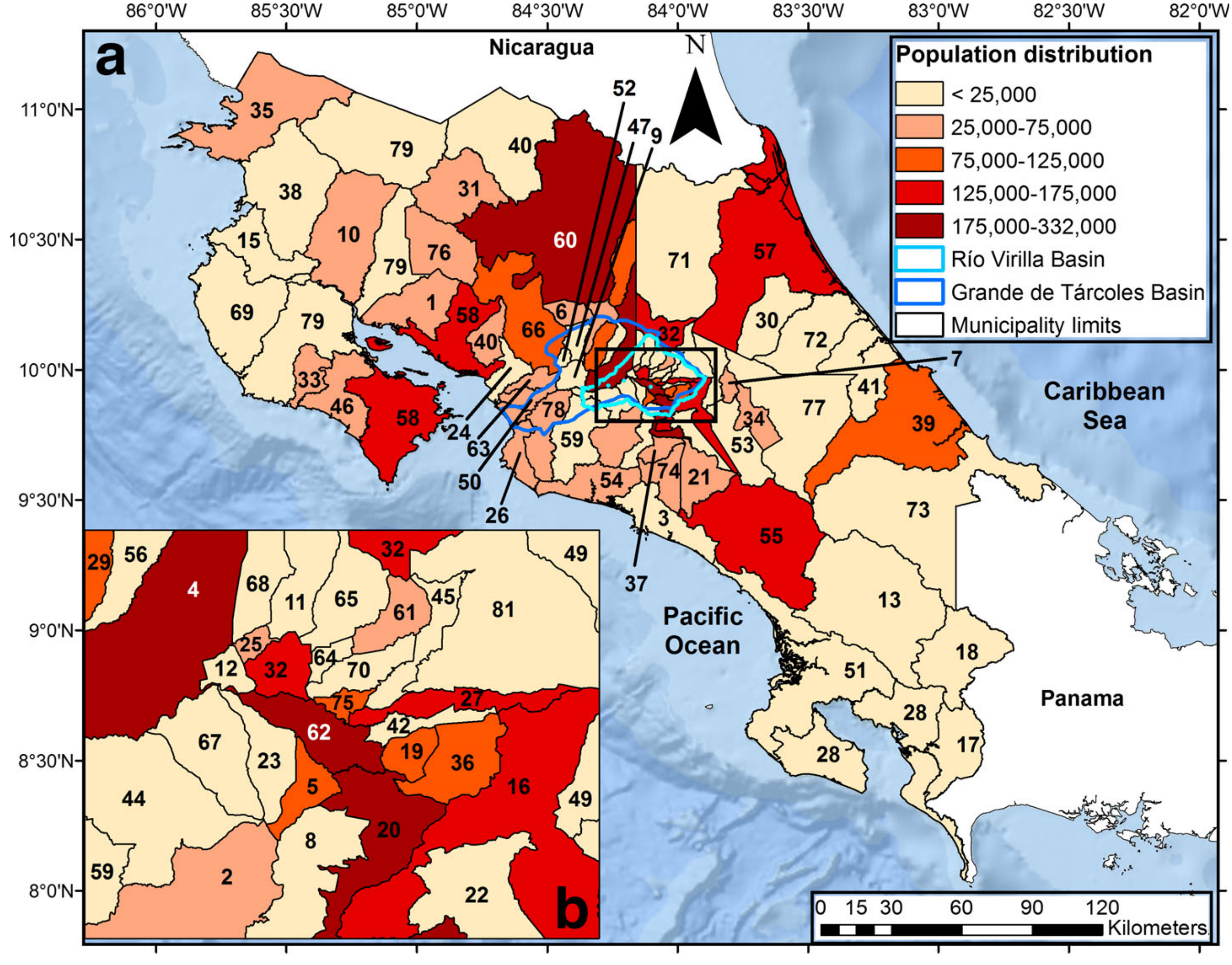

FIGURE 1. (a) Spatial Distribution of Population across the 81 Municipalities of Costa Rica Estimated for 2014–2015. Municipalities are denoted by black polygons and coded according to Table 2. The Río Virilla Basin and the Grande de Tárcoles Basin located in the Central Valley are identified by light blue and blue polygons, respectively, in the middle of the map. (b) Geographic distribution of population within the municipalities located in the Central Valley. The metropolitan area located inside the valley is formed by 31 municipalities.

and the surrounding suburbs. In this urban region, about 60% of the country's population is situated with an average population density of 870 inhabitants per km^2. The climate of Costa Rica is influenced by four regional air circulation types: NE trade winds; the latitudinal migration of the Intertropical Convergence Zone; cold continental outbreaks; and the sporadic Caribbean cyclones (Waylen, 1996; Hidalgo *et al.*, 2013; Saénz and Durán-Quesada, 2015). In the Central Valley, the dry season ranges from December to April and the wet season ranges from May to November. Strong orographic effects are caused by a NW to SE mountain range (or cordillera) with a maximum elevation of 3,820 m a.s.l. which divides the country into the Caribbean and Pacific slopes, each slope having distinct precipitation and runoff regimes. The observed cyclic deviations in the ocean-atmosphere domain can be described as "wet" and "dry" years throughout Costa Rica and are linked to changes in the sea surface temperature (SST), especially the warm/cold El Niño Southern Oscillation (ENSO) episodes (Waylen, 1996; Alfaro, 2002).

The Recent Water Resources Context in Costa Rica

By 2014–2015, the estimated legal withdrawals of surface and groundwater for various uses were ~1.66 km^3 (CTI-Agua, 2015). Water withdrawals for agriculture accounted for 73% of the removed water with 86% of this volume used for irrigation, and 14% for other undocumented uses. Human consumption, industry, and other services accounted for 27% of the total water use. In 2013–2014, only 16% of the wastewater collected in Costa Rica (~51 million m^3/yr) was subject to treatment and only 9% underwent treatment using secondary processes. Between 2010 and 2014, Costa Rica reported a wastewater treatment capacity of ~5,000 ton BOD per year (BOD, biochemical oxygen demand) with an efficiency of ~40% (CTI-Agua, 2015).

More than 20 government agencies in Costa Rica are dealing with water resources management. Bower (2014) provided a description of the main administrative entities and their mandates. Their jurisdictions are in most cases overlapping but they usually work without coordination (Blomquist *et al.*, 2007). These institutions also administer the intricate regulatory framework governing water conservation and water resources management in Costa Rica. This framework is based on the General Water Law, No. 276, which was approved in 1942. Between 1942 and 2015, 275 additional water regulations were ratified. These regulations were mainly concerned with the public use of water resources (60%), and they were intended to control public services (65%), energy generation (17%), and agricultural activities (5%) (PEN, 2016). However, the national legislation is generally recognized as inadequate for current social and economic conditions of the country and its high degree of development (Lager and Wikström, 2007; Bower, 2014). Moreover, it is well accepted that the tasks that are under the responsibility of most government agencies cannot be performed effectively because of the lack of sufficient human and financial resources (Segura-Bonilla, 2002). One of the main reasons is the relatively small amount of funding that is assigned to maintenance of the existing infrastructure or invested in new infrastructure or improvements, which has led to a decrease in the quality of the water infrastructure across the country (Blomquist *et al.*, 2007; Bower, 2014).

In Costa Rica, water used for human consumption is mostly under the responsibility of the Instituto Costarricense de Acueductos y Alcantarillados (AyA), considered the principal drinking water and wastewater systems operator at the national level. In provinces such as Heredia and Cartago, other operators include the Empresa de Servicios Públicos de Heredia (ESPH S.A.) and the Junta Administrativa del Servicio Eléctrico Municipal de Cartago (JASEC S.A.). At the local level, many small administrative entities are distributed across the country, especially in rural areas; they are called Asociaciones Administradoras de los Sistemas de Acueductos y Alcantarillados Comunales (ASADAS) or Administrative Committees of Rural Water Systems (Guzmán-Arias and Calvo-Alvarado, 2013). In order to operate, ASADAS must first be endorsed by AyA, comply with AyA's guidelines and the Law of Associations No. 218. According to Astorga (2010), the number of water supply operators in Costa Rica is ~2,300, which results in a high percentage of access to drinking water of adequate quality for Costa Rica's population of 91.2% (PEN, 2016).

Despite the excellent water access in Costa Rica, infrastructure problems are constantly threatening the quality of the water used for consumption. For example, only 21% of the pipelines that are supplying 73% of the population have occasional water quality monitoring by AyA (de Albuquerque, 2009; Bower, 2014), even though Costa Rica's most recent drinking water regulation (No. 38924-S, published in January 2015) includes maximum limits for total pesticides, organochlorine pesticides, 29 organic compounds (including hydrocarbons), and 25 inorganic species that include heavy metals. Groundwater in the Central Valley is at high risk for pollution because of the overuse of agrochemicals and the uncontrolled use of septic tanks, which has increased the amount of nitrate present in some aquifers (Reynolds-Vargas *et al.*, 2006; Guzmán-Arias and Calvo-Alvarado, 2013). In Guanacaste, the natural presence of arsenic compounds in drinking water above 10 μg/L presents another risk of water pollution (Mora-Alvarado *et al.*, 2015). Overall, wastewater sanitation is a major problem in Costa Rica. Most sewage is treated at the source (i.e., homes, industry, and hotels) either by a small wastewater treatment plant or through septic systems (Bower, 2014); however, only ~25% of the population is connected to sewage systems and only ~4% has appropriate treatment (Guzmán-Arias and Calvo-Alvarado, 2013). As a result, the rivers located in the Central Valley, especially those inside the Río Virilla Basin, are severely contaminated. The extent of this contamination is affecting the coastal water and littoral ecosystems across the country (García *et al.*, 2006).

The above described water resources context indicates that an analysis of the spatial distribution of the types and causes of WC in Costa Rica would be very useful to untangle the relationships between water resources, institutions, and society. Geographical information systems (GIS) offer powerful tools for compiling, visualizing, and analyzing potential indicators of WC, and they have the capability to incorporate physical and socioeconomic data (Yoffe *et al.*, 2004). GIS analysis could also provide opportunities to reveal the main features of conflicts in local communities (Rivera *et al.*, 2016). Therefore, we combined information about the occurrence of WC, available at government and media records, with hydro-meteorological and climate information to analyze the aforementioned relationships using a spatial distribution analysis.

Data Sources of WC

Information for the analysis of WC was derived from governmental agencies and media (i.e., newspaper) archives for the time period 2005–2015. Two institutions were included in the analysis: the Environmental Administrative Tribunal (Tribunal Ambiental Administrativo [TAA]), which has the exclusive task of investigating suspected violations of environmental legislation and the Constitutional Court of Costa Rica, also known as Sala IV, which oversees the protection of the fundamental rights specified in the Constitution of Costa Rica. The information existing at Sala IV was accessed using an online information system (Sala Constitucional de Costa Rica: https://www.poder-judicial.go.cr/salaconstitucional), while the Document and Information Center for Social Sciences (CIDCSO) of the National University of Costa Rica was used to access the records of the TAA (http://www.cidcso.una.ac.cr/tribunal). Since 2013, the Ministry of the Environment and Energy, which is responsible for management, protection, and monitoring of public water resources, administers the Integrated Processing System for Environmental Claims (Sistema Integrado de Trámite y Atención de Denuncias Ambientales [SITADA]). SITADA is an official website (http://www.minae.go.cr/denuncias-publico) where environmental complaints can be presented by the country's residents. This online platform is expected to allow a better definition of environmental issues and to improve the reviewing and processing of the information reported by the country' residents. It should facilitate the interaction of the country's residents with governmental agencies and offices. Residents may decide to submit their identity as public or confidential. However, each record must be entered along with complete personal information (i.e., full name, identification number, phone number, address, and email). In this study, we used the records available at Sala IV and TAA because they provided a better description of the conflicts during the selected time period.

Information from the media archives was obtained from a national newspaper in Costa Rica (La Nación: http://www.nacion.com). As shown by De Stefano *et al.* (2010), the analysis of water events reported in the news offers useful documentation about the level of cooperation/conflict around water resources and can be used as an indicator of relations between water-sharing actors. Information related to demographic and social indicators in Costa Rica was gathered from Programa Estado de la Nación (PEN) (http://www.estadonacion.or.cr), a research program on sustainable human development which belongs to the National Council of Rectors (Consejo Nacional de Rectores [CONARE]) formed by the public universities of Costa Rica.

The climate variability analysis was based on monthly precipitation and monthly SST anomalies records. Precipitation data were retrieved from the National Meteorology Institute of Costa Rica (IMN) database (http://www.imn.ac.cr). SST anomalies values were reported by National Oceanic and Atmospheric Administration in the eastern tropical Pacific Ocean El Niño 3.4 (http://www.cpc.ncep.noaa.gov/data/indices/sstoi.indices). We also included information related to the incidence of HME, namely flooding, droughts, landslides, thunderstorms, and avalanches registered between 2005 and 2015. This information was accessed using the Disaster Effects Inventory System (DesInventar: https://online.desinventar.org).

Data Analysis

We used data integration in the analysis of WC to illustrate and cross-validate the information related to the occurrence of the WC (Fielding, 2012). The information collected from the government and media sources was combined to create a database of WC. First, each conflict was georeferenced and assigned to the corresponding municipality. Second, each reported WC was classified into a particular type using the set of cataloging terms used by the Constitutional Court of Costa Rica and the TAA from the following categories: agriculture, chemical accidents, construction, groundwater damage, hydropower, industrial, irrigation, livestock activities, mining, protected area violations, sewage, silviculture, solid waste, transboundary conflict, wastewater, water infrastructure, and water extraction. This approach is similar to the one used by Torre *et al.* (2014) and Rivera *et al.* (2016) to analyze conflicts using media information and legal records, respectively. Third, WC were further categorized into the following causes: drought, flooding, groundwater pollution, groundwater recharge area damage, illegal extraction, coastal pollution, navigation, protected areas invasion (i.e., transgression of the boundaries of protected areas to exploit water resources), physical breakage, shortage, spills, surface water pollution, and unidentified causes. These causes were derived from a description of the nature of the conflict and the parties involved based on the information in the public archives or provided by the media source. Table 1 lists the criteria used to assign each WC to a type or cause, although for some conflicts it was not possible to identify an underlying cause. We decided to assign each conflict to only one type or cause because in most of the available records the information provided was not detailed enough to expand the analysis to multiple types or causes. It was not possible to reconcile conflicts reported in the government and media conflicts, so we analyzed government and media conflicts separately.

A spatial distribution analysis was conducted using the Atlas of Costa Rica 2008 database (ITEC, 2008). This analysis was done by constructing a geographic projection of the WC data across the Costa Rican territory in order to identify the intensity of the occurrence of WC (i.e., the number of conflicts per municipality) between 2005 and 2015 (Costumero *et al.*, 2017; Ide, 2017). The distribution analysis was also applied to contrast the water availability within the boundaries of the municipalities of Costa Rica, the incidence of HME, and the occurrence of WC. We used the estimated mean annual runoff for each municipality of Costa Rica (Sánchez-Murillo and Birkel, 2016) as a proxy for water availability. The mean runoff values were sampled and calculated in ArcGIS 10.4 (ESRI, Redlands, California) using the nearest neighbor tool and the raster information developed at a 100 m^2 grid resolution (Sánchez-Murillo and Birkel, 2016).

Statistical Analysis

The statistical analysis was carried out using aggregated data by municipalities with reported WC. WC affecting more than one municipality were assigned to each municipality involved in the conflict. The types and causes of conflicts were ranked based on the percentage of contribution to the total and were ordered from largest to smallest percentages. The types and causes with the largest percentages were summed until they reached a contribution of 75% or more of the total and were then grouped into the “major type” or “major cause” category.

We first applied a bivariate analysis using the number of conflicts as response variable. An exploratory Spearman’s correlation analysis ($p = 0.05$) was performed using the types and causes of conflicts identified in each municipality, the social and demographic conditions, the incidence of HME, and the water availability as independent or explanatory variables. The social and demographic conditions included the following variables: total population, population density, the human development index (HDI), the material well-being index (MWI), and the human poverty index (HPI). The HDI was calculated as the geometric mean of the following normalized indices: life expectancy at birth, mean years of schooling, expected years of schooling, and the gross net income per capita. HDI values are in the range 0–1, with low values associated with low human development and high values with high human development. The HPI was calculated by combining four indices: probability at birth of not surviving to age 60, percentage of adults lacking functional literacy skills, percentage of population below income poverty line, and the rate of long-term unemployment. This index is expressed as a percentage of the population living under poverty conditions, with low values referring to low poverty conditions and high values to high poverty conditions. The MWI was calculated using the residential electricity consumption per capita adjusted to the time period 2001–2004 (Shakelford *et al.*, 2016). The HPI values are in the range 0–1, with low values associated with low material well-being and high values with high material well-being. HME and water availability were included in the analysis as the sum of HME and the mean runoff at each municipality.

A simple linear correlation analysis was used to estimate the possible influence of climate variability (e.g., precipitation variability or SST anomalies in El Niño 3.4) on the incidence of HME and WC in the Central Valley metropolitan area. This region was selected because of its demographic and economic importance in Costa Rica. An analysis of variance (ANOVA) was used to contrast the temporal variation

TABLE 1. Description of the Criteria Used to Classify WC by Type and Cause as Reported between 2005 and 2015.

Criteria	Number of Conflicts (% of contribution)	Description[1]
Types of WC		
Agriculture	17 (2.4)	WC related to agricultural activities (e.g., use of fertilizers and pesticides)
Chemical accidents	10 (1.4)	WC related to accidents involving chemicals products affecting water bodies
Construction[2]	76 (10.6)	WC related to the construction of new infrastructure, both private and public, affecting water resources
Groundwater damage	9 (1.3)	WC that damaged groundwater systems (e.g., recharge areas)
Hydropower	11 (1.5)	WC linked with the development and operation of hydropower projects
Industrial	2 (0.3)	WC related to specific industrial activities affecting water resources
Irrigation	5 (0.7)	WC linked with the use of water for irrigation
Livestock activities	12 (1.7)	WC related to contamination of water resources by livestock activities
Mining	7 (1.0)	WC linked with exploitation of minerals (e.g., limestone) or illegal gold extraction
Protected area violations	39 (5.4)	WC generated by affectation of water resources located inside of protected areas
Sewage[2]	74 (10.3)	WC linked to the management of untreated domestic or municipal wastewater affecting water bodies
Silviculture	4 (0.6)	WC associated with silviculture or alleged deforestation
Solid waste	17 (2.4)	WC related to poor management of solid and municipal waste
Transboundary conflicts	1 (0.1)	It refers to the transboundary conflict between Costa Rica and Nicaragua on the San Juan River
Wastewater[2]	119 (16.6)	WC mainly related to poor management of treated wastewater (mainly industrial) affecting water bodies
Water infrastructure[2]	291 (40.5)	WC connected with poor maintenance of water infrastructure (e.g., pipelines, drinking water facilities) or damage to water infrastructure
Water extraction	25 (3.5)	WC linked with alleged illegal water extraction
Causes of WC		
Drought	5 (0.7)	WC caused by a deficit in the water availability (i.e., drinking water) due to decreased precipitation amounts
Flooding[3]	81 (11.3)	WC triggered by flooding events caused mainly by intense precipitation events
Groundwater pollution[3]	74 (10.3)	WC associated with contamination of groundwater systems but not caused by spills
Groundwater recharge area affectation	3 (0.4)	WC mainly triggered by construction of private infrastructure, near to recharge areas, but not located inside protected areas
Illegal extraction	26 (3.6)	WC which were effectively caused by illegal water extraction in protected areas
Coastal pollution	3 (0.4)	WC caused by contamination of water resources located in coastal regions (e.g., mangrove ecosystems)
Navigation	1 (0.1)	This is the main cause linked with the transboundary conflict between Costa Rica and Nicaragua on the San Juan River
Physical breakage[3]	67 (9.3)	WC caused by damage to existing water infrastructure due to poor maintenance or after HME
Protected areas invasion	10 (1.4)	Affectation of water bodies located inside protected areas, but not caused by water extraction
Shortage[3]	98 (13.6)	WC caused by unanticipated shortage of drinking water or during long time periods
Spill[3]	173 (24.1)	WC caused by spills of sewage, industrial wastewater, chemicals, solid waste lixiviates into water bodies
Surface water pollution[3]	74 (10.3)	WC affecting surface water systems, but not caused by spills
Unidentified causes	104 (14.5)	WC that were assigned to a type of conflict but without a specific cause

Notes: WC, water conflicts; HME, hydro-meteorological events.
Types of conflicts were categorized according to Costa Rica's Constitutional Court catalog. Causes of conflicts were identified using the description provided by the archives or media records. Each conflict was assigned to only one type or cause because in most of the available records the information provided was not detailed enough to expand the analysis to multiple types or causes.
[1]The categorization scheme used to create this table is based on the catalog of the Constitutional Court of Costa Rica as described in the Data Analysis section.
[2]Major types of WC: construction, sewage, wastewater, and water infrastructure (78%).
[3]Major causes of WC: flooding, groundwater pollution, physical breakage, shortage, spill, and surface water pollution (79%).

(i.e., yearly changes) of the main types, causes, and classes of HME with the observed changes in El Niño 3.4 (a reliable predictor of "wet" and "dry" years in Costa Rica) and the precipitation anomalies in the Central Valley (Alfaro, 2002; Saénz and Durán-Quesada, 2015). A Dixon's Q test (p = 0.05) was also used to identify if some types or causes of conflicts were significantly greater in some municipalities or years.

We applied a multivariate analysis based on hierarchical cluster analysis. The cluster analysis was applied to establish the relationship among the most important types and causes of WC (explanatory variables). The complete linkage method and the Euclidean distance between variables were selected to construct the clusters (Lance and Williams, 1967) using the Minitab software v.17 (Minitab Inc., State College, Pennsylvania). The number of clusters was determined using a minimum similarity level of 68%, which is equivalent to a 68% of probability (1σ). We also applied a multiple linear regression (MLR) model using the social and demographic conditions, and the number of HME in order to identify the major drivers of WC across the country. The results of the correlation analysis using the number of conflicts, the social and demographic conditions, and the number of HME were used to identify possible collinearity issues between the independent variables and results were reported as a correlation matrix. The forward selection stepwise regression method was selected to incorporate the factors in the model, using the adjusted coefficient of determination (adj R^2) as a variables-selection criterion.

RESULTS

Spatial Overview of WC

The number of WC in Costa Rica reported by the government and the media was 448 and 271, respectively, for a total number of 719 conflicts reported between 2005 and 2015 (Figure 2). Overall, of 448

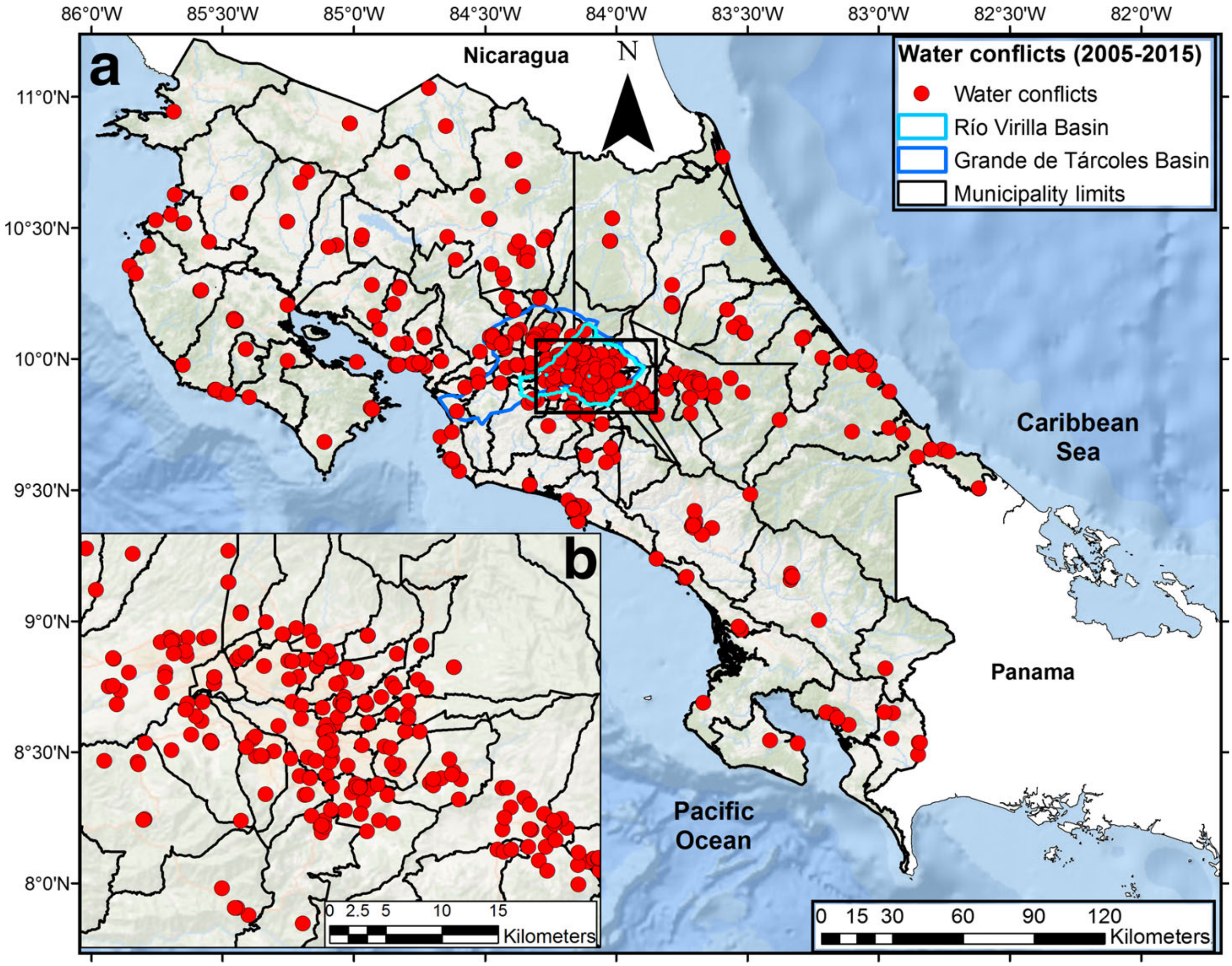

FIGURE 2. (a) Spatial Distribution of Historical WC in Costa Rica Reported between 2005 and 2015. Municipalities are denoted by black polygons. The Río Virilla Basin and the Grande de Tárcoles Basin are identified by light blue and blue polygons, respectively, in the middle of the map. (b) Zoomed in on rectangle in (a), showing the distribution of WC in the municipalities located in the metropolitan area.

conflicts reported by the government, 421 official court cases (94%) were found; 54% of the official court cases were between private individuals and governmental institutions, and 27% between private individuals and commercial entities. The remaining official records (19%) were conflicts among private individuals only.

The spatial distribution of WC in Costa Rica shows that the Central Valley and the coastal zones of the country are the main locations where conflicts occurred (Figure 2a and 2b). Based on the total number of conflicts, we classified, however, the Central Valley of Costa Rica as the main "hot spot" of WC due to the relatively high density of conflicts identified in this region. Nevertheless, we cannot exclude the possibility that this high density of conflicts is related to the better accessibility of the metropolitan population to governmental institutions, for example, court offices. Sixty-eight percent of the conflicts occurred in municipalities situated in this central region, based on the number of conflicts separately reported by the media and the government (Figure 2b). These conflicts occurred mainly inside the Río Virilla Basin, located within the Grande de Tárcoles Basin (Figure 2a). At the local level, 25 municipalities were above the 75th percentile of the total WC reported between 2005 and 2015 (i.e., 10 or more WC) according to governmental and media archives. Together, these municipalities experienced 457 WC during this time period, representing 63% of the conflicts between 2005 and 2015. Out of the 25 municipalities, 12 are located inside the Central Valley, whereas 13 are mainly located in peripheral areas (Figure 2a and 2b). The municipalities located in the Central Valley that reported the greatest number of conflicts were San José, Alajuela, and Desamparados with 45, 36, and 28 WC reported between 2005 and 2015, respectively, while San Carlos, Puntarenas, and Limón were the municipalities situated outside the Central Valley that reported the greatest number of conflicts, with 32, 30, and 27 conflicts, in that order.

Types and Causes of WC

The types of WC reported both by the government and the media were mainly related to construction, sewage, wastewater, and water infrastructure (Table 1). Together, these types of WC accounted for 78% of the conflicts. Among these types of conflicts, water infrastructure contributed 40.5% of the conflicts. The most common causes involved in the occurrence of WC were flooding, groundwater pollution, physical breakage, water shortage, spills (including both sewage and wastewater), and surface water pollution, which together contributed to 79% of the identified causes. Of these causes, the spills contributed to 24% of the conflicts. WC caused by drought events contributed to 0.7% of the total. Between 2005 and 2015, 22 drought events were reported, representing ~2% of the 919 HME recorded in the same period. These drought events were also reported at the end of the study period (e.g., 18 events in 2014 during El Niño 2014–2016) and were located mainly in the Pacific domain of the country (~68%). Therefore, we cannot ignore the influence that such drier-than-normal periods may have on the occurrence of WC, because they usually last from months to years. Overall, the major classes of HME found in the Disaster Effects Inventory System (DesInventar) were flooding, heavy precipitation events, and flash floods, contributing to 92% of the 919 HME registered between 2005 and 2015.

Overall, the distribution of types and causes of WC across the municipalities of Costa Rica were relatively equitable with some exceptions that were identified using the Dixon's Q test. In San Jose and Alajuela, which are the municipalities with the greatest number of conflicts, namely 45 and 36 conflicts (Table 2), the water infrastructure-related conflicts were significantly greater than in the rest of the municipalities ($p = 0.040$ and 0.010, respectively). These conflicts contributed to 75% and 58% of the conflicts registered in these municipalities, respectively. Moreover, WC caused by spills (both of wastewater and sewage) were significantly greater in Alajuela and San Ramon (with 17 reported conflicts, as shown in Table 2) than in the rest of the municipalities ($p = 0.021$ and 0.010, respectively). The contributions of the conflicts caused by spills were 36% and 28% of the conflicts found in these municipalities, respectively. Due to the limited information provided mainly by the media archives, it was not possible to assign a specific conflict's cause to 15% of the WC (see Table S1). The media appeared to be more attracted to report on conflicts caused by water shortage (42%) and broken pipes (22%).

Social Conditions, Water Availability, HME, and WC in Costa Rica

Based on the social conditions prevailing in the municipalities in the time period 2005–2015 and the mean water availability in the Costa Rican watersheds, the metropolitan area and the Grande de Tárcoles Basin are the most affected areas of the country in terms of WC. Of the 25 municipalities that reported at least 10 WC in the time period 2005–2015 (Table 2), the municipalities located in the metropolitan area (12 municipalities) have the best social conditions in Costa Rica in terms of human

TABLE 2. Ranking of Municipalities Based on the Number of WC Reported between 2005 and 2015.

Municipality	Code	WC	% of Major Types of WC[1]	HME	Population (inhabitants)	Population Density (inhabitants/km^2)	HDI[2]	HPI (%)[3]	MWI[4]	Q (mm)
San José[5]	62	45	96	16	331,019	7,419	0.769	12.0	0.546	588
Alajuela[5]	4	36	92	19	289,451	745	0.773	12.5	0.532	1,784
San Carlos	60	32	63	23	181,648	54	0.749	18.5	0.476	2,312
Puntarenas	58	30	73	17	128,501	70	0.738	20.2	0.522	841
Desamparados[5]	20	28	93	19	230,770	1,951	0.753	12.8	0.484	672
Limón	39	27	59	15	97,661	55	0.726	20.5	0.422	2,223
Cartago[5]	16	25	92	17	156,325	543	0.819	12.1	0.610	994
Siquirres	72	22	32	13	62,086	72	0.753	20.6	0.507	2,620
Pérez Zeledón	55	18	78	17	141,383	74	0.736	25.0	0.399	2,049
San Ramón	66	17	88	15	87,481	86	0.777	14.1	0.449	2,037
Turrialba	77	16	75	19	73,276	45	0.761	13.4	0.482	2,198
Nicoya	48	15	93	12	53,212	40	0.790	23.7	0.532	907
Santa Cruz	69	14	64	13	61,706	47	0.785	23.7	0.549	780
Heredia[5]	32	13	85	13	133,614	473	0.860	11.8	0.705	3,398
Paraíso[5]	53	13	92	14	59,861	145	0.791	12.7	0.573	2,779
Carrillo	15	12	67	10	40,558	70	0.765	22.9	0.536	668
Tibás[5]	75	12	75	11	80,743	9,907	0.712	12.2	0.497	686
Belén[5]	12	11	73	9	25,024	2,060	0.920	11.9	0.857	747
Santa Ana[5]	67	11	91	12	55,733	907	0.944	12.1	1.000	646
Barva[5]	11	10	100	9	43,110	801	0.821	12.2	0.597	1,681
Escazú[5]	23	10	90	11	65,925	1,911	0.930	12.2	1.000	541
Garabito	26	10	90	11	22,118	70	0.747	20.1	0.533	996
La Unión[5]	36	10	80	15	105,194	2,347	0.845	11.7	0.637	829
Palmares	52	10	60	8	38,014	999	0.770	12.7	0.467	711
Talamanca	73	10	80	10	38,216	14	0.634	21.3	0.309	2,022
Aguirre	3	9	78	15	30,098	55	0.764	20.3	0.514	2,723
Aserrí[5]	8	9	78	16	60,082	360	0.749	13.2	0.459	1,159
Goicoechea[5]	27	9	78	9	130,854	4,154	0.774	12.0	0.527	1,059
Moravia[5]	45	9	89	13	60,217	2,104	0.850	11.8	0.687	1,606
Pococí	57	9	67	14	137,809	57	0.725	20.4	0.401	3,444
Grecia	29	8	88	10	86,385	218	0.756	14.3	0.480	2,511
Oreamuno[5]	49	8	75	11	47,550	236	0.826	12.2	0.668	2,476
Osa	51	8	75	15	30,089	16	0.803	25.6	0.639	1,781
Alajuelita[5]	5	7	100	12	86,397	4,081	0.676	12.7	0.396	591
Coronado[5]	81	7	86	10	67,139	302	0.798	12.5	0.613	3,029
Golfito	28	7	71	18	42,516	24	0.755	24.9	0.463	2,670
Liberia	38	7	86	13	68,785	48	0.768	22.2	0.558	624
Mora[5]	44	7	57	9	28,700	177	0.826	13.7	0.626	1,018
Santo Domingo[5]	70	7	100	10	46,161	1,858	0.851	11.7	0.678	935
Buenos Aires	13	6	67	11	49,397	21	0.693	25.6	0.263	1,699
Cañas	14	6	17	10	30,415	45	0.739	22.2	0.496	601
Corredores	17	6	100	13	48,909	79	0.727	24.5	0.402	2,763
Curridabat[5]	19	6	100	11	75,582	4,739	0.807	11.8	0.701	798
El Guarco[5]	22	6	83	8	43,882	262	0.825	12.3	0.642	1,007
San Isidro[5]	61	6	100	8	21,712	805	0.891	12.4	0.806	1,557
San Pablo[5]	64	6	100	8	29,869	3,967	0.827	12.0	0.661	887
Santa Bárbara[5]	68	6	100	10	39,231	737	0.795	12.3	0.570	1,707
Acosta	2	5	40	10	20,962	61	0.744	14.9	0.415	1,536
Jiménez	34	5	40	8	16,028	56	0.717	13.5	0.413	2,641
Naranjo	47	5	80	12	45,592	360	0.762	13.6	0.435	1,228
Orotina	50	5	80	9	21,772	153	0.788	20.2	0.595	997
Poás[5]	56	5	40	10	31,121	421	0.742	13.2	0.457	1,655
Puriscal	59	5	100	13	35,841	65	0.767	14.5	0.441	1,480
Sarapiquí	71	5	40	13	70,299	33	0.679	20.1	0.358	2,968
Tarrazú	74	5	80	6	17,634	59	0.693	13.5	0.339	2,805
Alvarado[5]	7	4	75	7	14,715	182	0.788	13.4	0.536	1,231
Bagaces	10	4	50	7	21,936	17	0.740	23.5	0.480	583
Flores[5]	25	4	75	9	23,106	3,320	0.801	12.0	0.622	927

(continued)

TABLE 2. (continued)

Municipality	Code	WC	% of Major Types of WC[1]	HME	Population (inhabitants)	Population Density (inhabitants/km^2)	HDI[2]	HPI (%)[3]	MWI[4]	Q (mm)
Matina	41	4	100	14	42,958	56	0.645	20.8	0.270	2,389
Montes de Oca[5]	42	4	75	9	61,032	4,026	0.802	11.7	0.701	959
Upala	79	4	75	10	49,697	31	0.651	19.9	0.312	1,158
Zarcero	6	4	75	10	13,396	86	0.745	14.1	0.473	2,399
Abangares	1	3	33	11	19,081	28	0.770	24.4	0.528	763
Atenas[5]	9	3	100	9	27,451	216	0.856	13.6	0.627	705
Hojancha	33	3	67	6	7,685	29	0.808	24.6	0.542	982
Montes de Oro	43	3	33	7	13,421	55	0.756	20.3	0.541	1,436
Parrita	54	3	67	11	17,949	37	0.756	20.1	0.468	1,716
Coto Brus	18	2	100	10	43,811	47	0.669	27.3	0.297	2,047
Esparza	24	2	100	8	34,862	161	0.771	20.0	0.519	1,124
Guatuso	31	2	0	10	17,780	23	0.670	20.1	0.318	1,896
Los Chiles	40	2	0	4	29,390	22	0.617	20.0	0.265	1,197
Nandayure	46	2	100	12	11,525	20	0.733	25.0	0.415	805
San Rafael[5]	65	2	50	13	51,028	1,055	0.829	12.0	0.696	1,669
Tilarán	76	2	50	11	20,883	33	0.793	23.4	0.543	1,515
Turrubares	78	2	100	12	6,355	15	0.805	15.1	0.446	1,133
Valverde Vega	80	2	100	11	20,728	172	0.717	14.2	0.408	2,771
La Cruz	35	1	0	7	24,083	17	0.651	24.2	0.286	606
San Mateo	63	1	100	3	6,701	53	0.835	20.2	0.562	1,046
Dota	21	0	0	7	7,606	19	0.701	14.7	0.323	1,916
Guácimo	30	0	0	13	49,373	86	0.670	20.6	0.363	3,211
León Cortés	37	0	0	5	12,910	107	0.690	14.5	0.328	1,073
Median		6	78	11	43,110	86	0.765	14.5	0.514	1,231
25th Percentile		4	63	9	22,118	47	0.733	12.4	0.415	887
75th Percentile		10	92	13	66,229	592	0.803	20.6	0.600	2,086

Notes: HDI, human development index; HPI, human poverty index; MWI, material well-being index; Q, runoff.
The number of HME recorded in this period is also shown. The demographic and social indicators for each municipality correspond to those updated as 2014–2015. Mean runoff values were interpolated using the municipality limits shown in Figure 1.
[1]Calculated using the sum of conflicts related to infrastructure, wastewater, construction, and sewage divided by the total of WC.
[2]Low values are associated with low human development and high values with high human development.
[3]HPI is reported as the percentage of the population living under poverty conditions. Low values indicate low percentage of poverty conditions and high values high percentage of poverty conditions.
[4]Low values associated with low material well-being and high values with high material well-being.
[5]Municipalities located in the metropolitan area.

development, material well-being, and human poverty, and concentrate the majority of the population of the country. For example, the HDI values in the metropolitan area are between 0.712 and 0.944, with HPI values in the range 0.484–1.000. In the other 13 municipalities, located outside the Central Valley, the HDI and HPI values were in the range 0.634–0.791 and 0.309–0.549, respectively.

In terms of water availability, and based on the mean annual runoff estimated by Sánchez-Murillo and Birkel (2016), the Grande de Tárcoles Basin was the most affected watershed with 319 conflicts registered (Figure 3a). With the exception of the municipalities located in the Pacific domain (Figure 3a) that have an average runoff of <1,122 mm/yr, the municipalities within the Grande de Tárcoles Basin are ranked as having the lowest mean runoff (<1,704 mm/yr, see Figure 3b). The next most affected region was the eastern side of the Central Valley (Caribbean domain) (Figure 3a), where some smaller municipalities have a mean runoff of <2,286 mm/yr (Figure 3b).

The incidence of WC was also compared with the amount of HME reported across the country. The incidence of these events was mainly related to the occurrence of flooding, which represents ~75% of the total. Events caused by thunderstorms and landslides contributed to ~16% of the total. In general, the occurrence of HME in Costa Rica in the period 2005–2015 was relatively homogenous (Figure 4a). In the metropolitan area, the number of HME fluctuated between 9 and 19 events per municipality, whereas in the municipalities located outside the Central Valley, the number of events was in the range 8–19 per municipality, with exception of San Carlos where 23 events were reported. As shown in Figure 4b, the majority of the WC were reported in municipalities that registered 10–14 events (40%) and 15–19 events (40%).

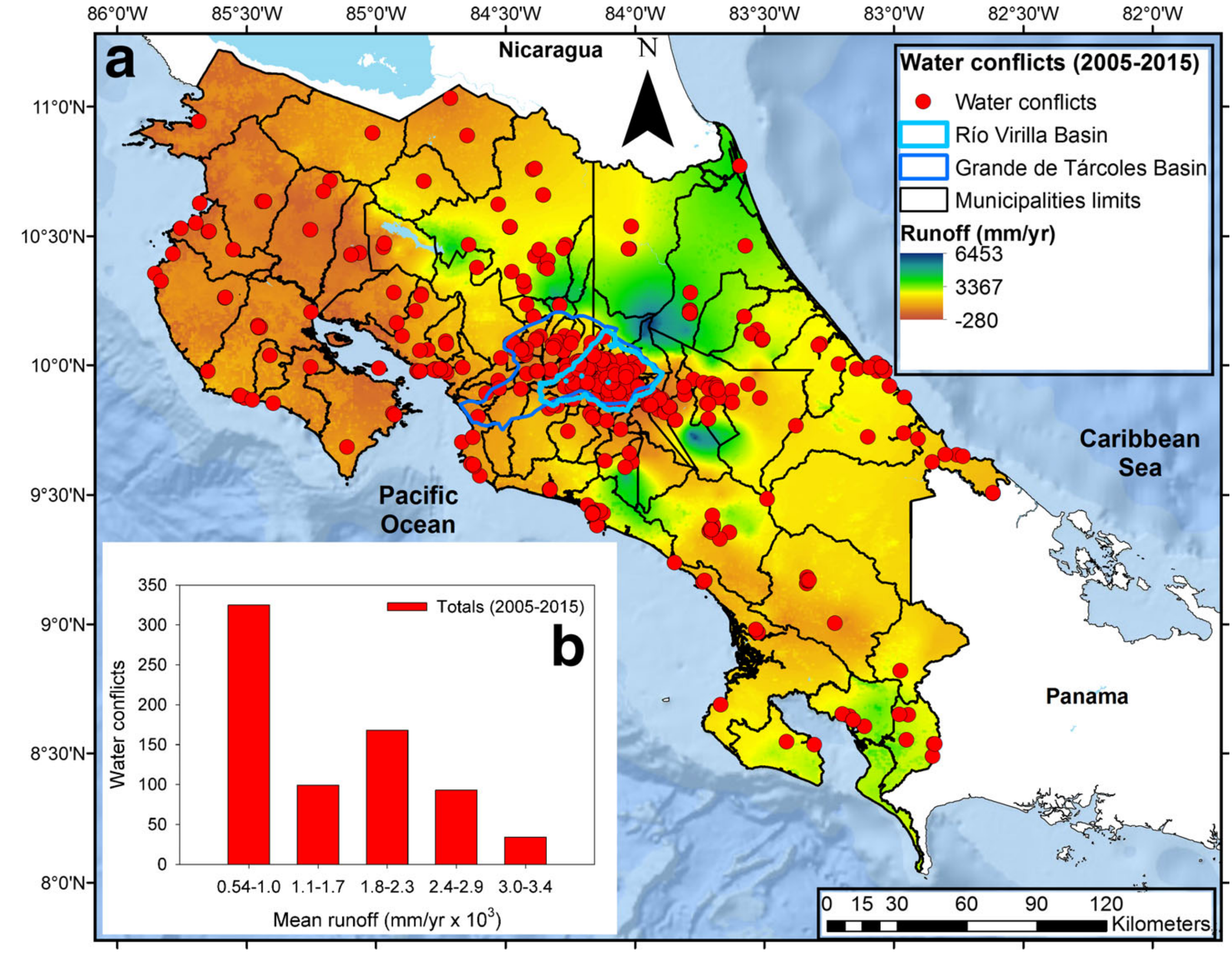

FIGURE 3. (a) Spatial Distribution of WC and the Mean Annual Runoff Calculated by Sánchez-Murillo and Birkel (2016). The Río Virilla Basin and the Grande de Tárcoles Basin are highlighted by the light blue and blue polygons, respectively. (b) Bar graph showing the distribution of WC in relation to the mean annual runoff values (mm/yr) as reported by Sánchez-Murillo and Birkel (2016). Mean runoff was interpolated using the limits of each municipality (black polygons).

Cluster and MLR Analysis

The correlation analysis performed using the types and causes of conflicts identified in 78 municipalities (no conflicts were reported in Dota, Guácimo, and Leon Cortés, see Table 2) demonstrates that the major causes of WC are strongly and significantly correlated with the major types of conflicts. For example, water infrastructure-related conflicts were significantly correlated with causes of conflicts like flooding (r = 0.705, p < 0.001), infrastructure damage (r = 0.635, p < 0.001), and water shortage (r = 0.644, p < 0.001). WC caused by spills were significantly correlated with types like sewage (r = 0.707, p < 0.001) and construction activities (r = 0.794, p < 0.001). The hierarchical cluster analysis shows that these types and causes of conflicts can be grouped into three major clusters (Figure 5). The first cluster includes the conflicts caused by flooding that originated from groundwater and surface water pollution, which were also associated with construction activities and sewage problems. The second cluster includes conflicts related to water shortage caused by physical breakage. The third cluster includes wastewater-related conflicts that are mainly caused by unregulated spills. The major conflict type, infrastructure, seems to be more difficult to associate with a specific cause because of two reasons: (1) ~14% of these conflicts have no identified cause and (2) the most important causes, namely flooding, physical breakage, and

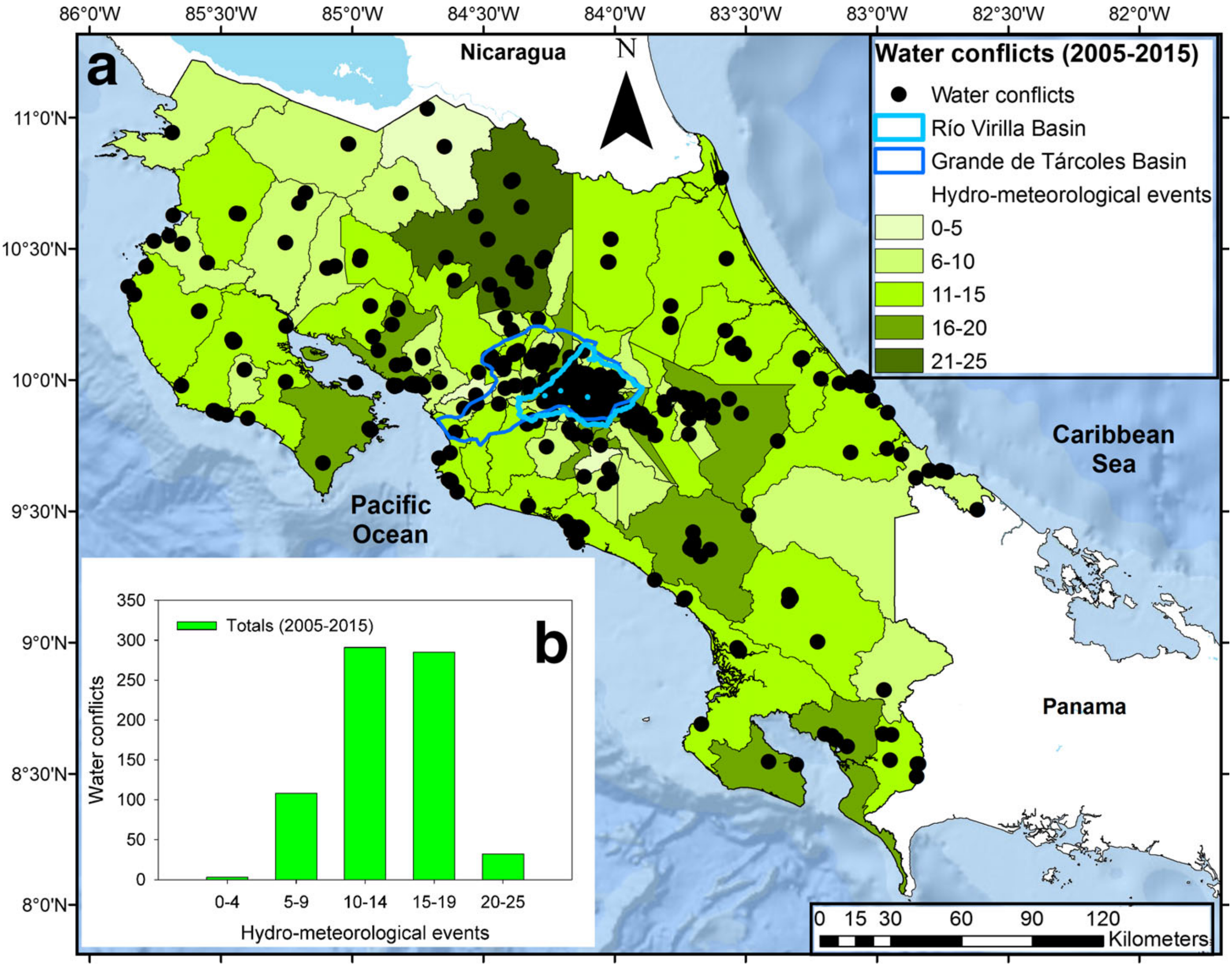

FIGURE 4. (a) Spatial Distribution of WC and the Sum of HME Reported for Each Municipality (black polygons) between 2005 and 2015. (b) Bar graph showing the distribution of WC in relation to the number of HME. Each category was calculated using the sum of conflicts reported within the limits of each municipality (black polygons).

shortage, are equally distributed with percentages of contribution around 26%.

As shown in Table 3, WC reported between 2005 and 2015 are significantly correlated at $p = 0.001$ with the number of HME ($r = 0.568$, $p < 0.001$) and the population in the municipalities ($r = 0.740$, $p < 0.001$). Relatively weak, but still significant correlations at $p = 0.05$ were also found between WC and the population density ($r = 0.341$, $p = 0.0024$), the MWI ($r = -0.237$, $p = 0.037$), and the HPI ($r = 0.224$, p=0.049). Although the HME were mainly associated with episodes linked with increased precipitation amounts, we also recognize that more information is needed to assess the influence of high-impacting HME like drought. Such HME may have a great impact in the occurrence of WC in climate-sensitive regions like the Pacific region of Costa Rica.

As shown in Figure 6, the best performing MLR model included only two variables: POP and HME. This two-parameter MLR model resulted in variance inflation factors of 1.74 for both variables and 76.6% overall explained variance for the number of WC reported in each municipality. We further tested the model performance using the regression residuals histogram shown in the inset of Figure 6. The distribution of the residuals nearly follows the normal distribution ($p = 0.043$), with a mean value of -0.023 ± 4.060 (1σ).

WC: Climate Variability, Temporal Trends, and HME

In the metropolitan area of Costa Rica, the incidence of HME between 2005 and 2015 correlated

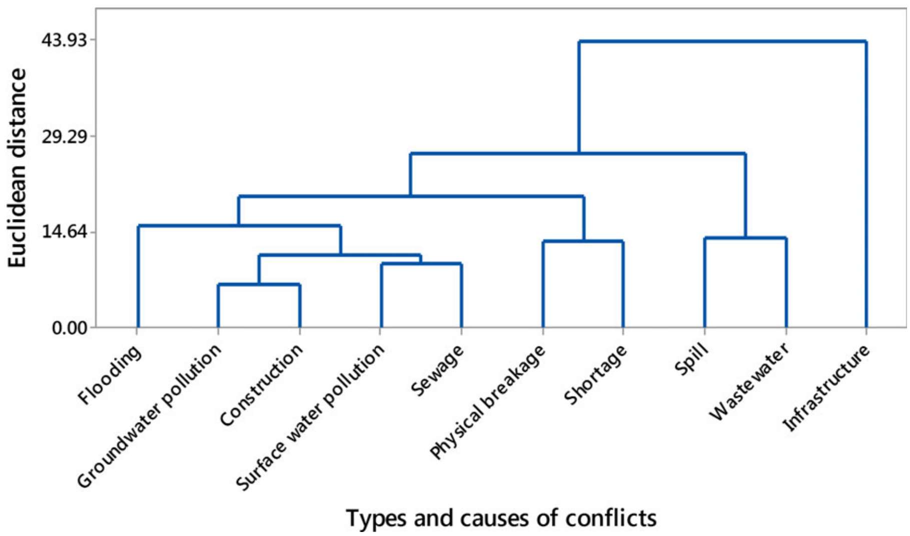

FIGURE 5. Hierarchical Cluster Constructed Using the Types and Causes of WC Identified in 78 Municipalities and Reported between 2005 and 2015. The vertical axis represents the Euclidean distance calculated with the method of complete linkage (Lance and Williams, 1967).

TABLE 3. Spearman's Rank Correlation Matrix Using WC in Combination with HME and Social Indexes.

	HME	POP	POP-d	HDI	MWI	HPI	Q
WC	0.589**	0.740**	0.341*	0.147	−0.237*	0.224*	−0.00142
HME		0.651**	0.00674	−0.0822	0.0559	−0.0804	0.221
POP			0.411**	0.0218	−0.300*	0.0952	0.0341
POP-d				0.491**	−0.854**	0.554**	−0.225*
HDI					−0.548**	0.915**	−0.248*
MWI						−0.567**	0.126
HPI							−0.316*
Q							

Notes: POP, population; POP-d, population density.
Calculations were made using aggregated data at municipality level.
$^*p < 0.05$. $^{**}p < 0.001$.

significantly with the precipitation anomalies recorded in this region. Moreover, the temporal variation of WC observed in the municipalities of Costa Rica that reported WC can be described using the major types and causes of conflicts and the major classes of HME. As shown in Figure 7a, in the study period, three warm phases were identified in the El Niño 3.4 region: 2006–2007, 2009–2010, and 2014–2016. These last two warm periods were associated with moderate and very strong El Niño conditions, respectively. Also, three cold phases were recorded in this region of the Pacific Ocean: 2007–2008, 2010–2011, and 2012–2013, one of them associated with a moderate La Niña 2007–2008.

The influence of the changes in the conditions of the El Niño 3.4 region on the precipitation pattern, and the occurrence of HME in the metropolitan area of Costa Rica is shown in Figure 7b. We used normalized precipitation anomalies because they are useful to assess the influence of positive and negative changes in the precipitation patterns associated with the ENSO cycles and can effectively describe the influence of such changes when drought or high precipitation amounts are registered. In the metropolitan region, the average precipitation amount in the study period was 1,696 ± 336 mm (1σ). It is clear that during years when warm conditions were prevalent in the El Niño 3.4 region, the precipitation anomalies in the Central Valley were negative, indicating a reduction in the precipitation amount that fell in this region, whereas when the conditions in the El Niño 3.4 region were colder than usual, the precipitation amounts increased in the metropolitan area. A significant correlation between the precipitation anomalies and the number of HME was also found ($r = 0.670$, $p = 0.021$).

As shown in Figure 8, the number of WC (as grouped by major types and causes) reported per year

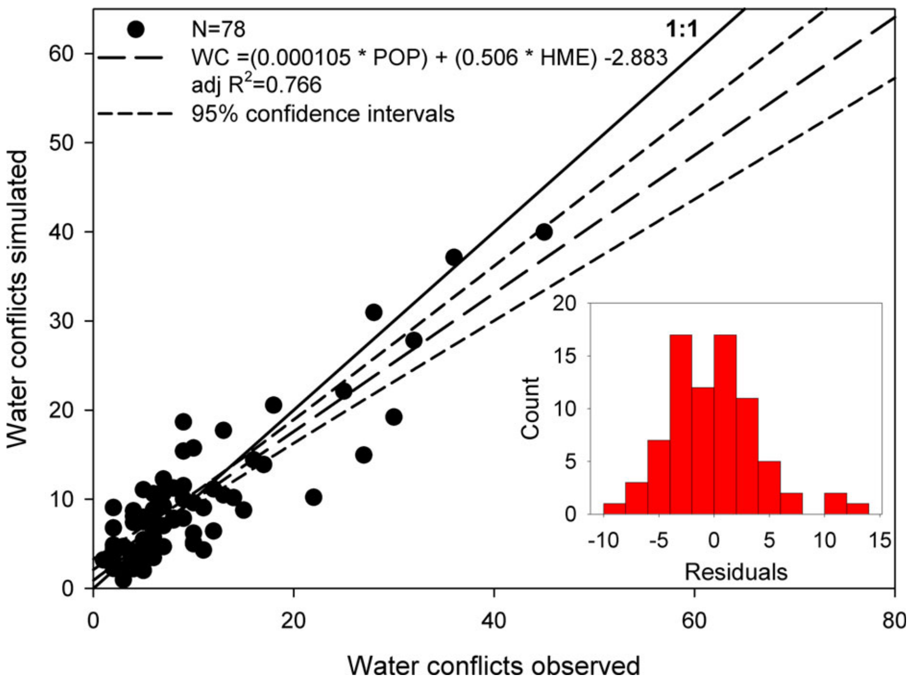

FIGURE 6. Scatterplot Showing the Relationship between the Observed and Simulated WC, Calculated Using Multiple Linear Regression Analysis (N = 78). The 95% confidence intervals of the regression model are also shown. The inset graph shows the distribution of the regression residuals with skewness and kurtosis values of 0.644 and 1.097, respectively.

was relatively constant throughout the study period, with the exception of the conflicts reported in 2007 during the La Niña event, when 148 conflicts were registered in the country of which 80 occurred in the metropolitan area (54%). Using Dixon's Q test, we identified that the 2007 WC related to wastewater were significantly greater than the other types of conflicts at $p = 0.05$ ($p = 0.001$) and contributed to 43% of the total conflicts. These WC were caused by spills that were also significantly greater ($p = 0.004$) than the other causes (45% of total). Additionally, an increase in the incidence of conflicts caused by flooding and physical breakage of ~27% was observed when positive precipitation anomalies were registered in comparison with other periods in the Central Valley. Using a one-way ANOVA, we also found that the differences in the mean values among the major types (51 ± 28 conflicts per year) and causes of WC (52 ± 27 conflicts per year), and the major classes of HME (77 ± 26 events per year), are not statistically significant at $p = 0.05$ ($p = 0.058$), which is in agreement with the previously reported correlation analysis where a strong correlation between WC and HME was reported (see Table 3). Therefore, the use of this hydro-meteorological information, for example by trained personnel, could help in the definition of better management actions as WC could be used as indicators of areas of greatest vulnerability to climate variability.

DISCUSSION

Costa Rica reported 719 conflicts related to water resources, with an average of one to two conflicts per week, between 2005 and 2015, based on the records available in the government and media databases. If we compare this number of WC with other Latin-American countries such as Chile, with ~1,000 conflicts in 34 years (Rivera *et al.*, 2016), Costa Rica experienced ~2.5 times more WC per year than Chile. However, these conflicts can be classified as low intensity conflicts, with ~60% related to legal and official court cases (Kuzdas *et al.*, 2016b). In the Central Valley, the number of reported WC was the greatest and therefore can be considered the main "hot spot" of conflicts. However, the peripheral municipalities, located mainly in the coastal areas of the Pacific and Caribbean regions, also suffered a considerable number of conflicts, which are comparable with the number of conflicts that were registered in the metropolitan area.

Overall, the incidence of conflicts is mainly related to the state of the water infrastructure across the country, which can explain the distribution of conflicts among the different parties (i.e., private individuals, private companies, and the government) where only 19% of the conflicts were among private individuals. In a country where water access cannot be considered a limitation (PEN, 2016), it seems that access

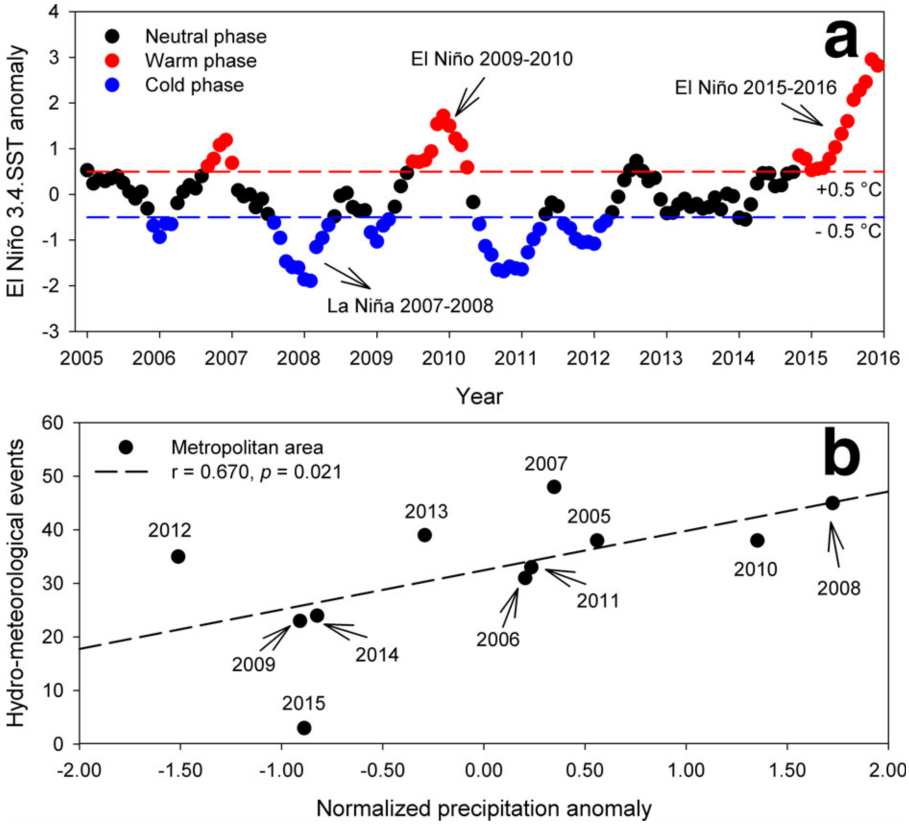

FIGURE 7. (a) Sea Surface Temperature Anomalies in the El Niño 3.4 Region between 2005 and 2015. The moderate events of La Niña 2007–2008, El Niño 2009–2010, and the very strong El Niño 2014–2016 are highlighted with red circles. (b) Scatter plot showing the significant relationship (p = 0.021) between the total number of HME reported in the metropolitan area and the precipitation anomalies recorded in the study period.

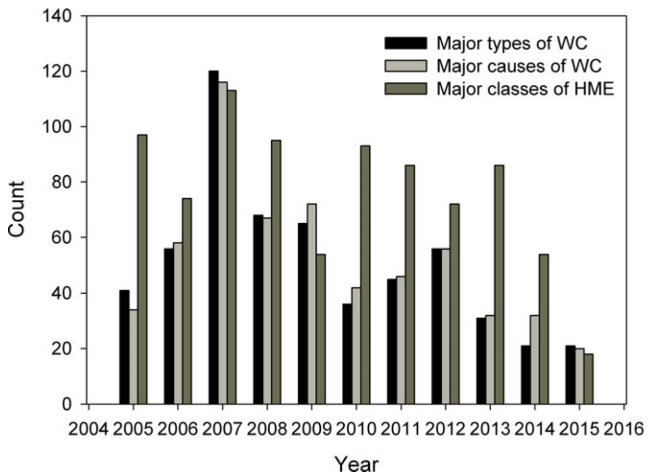

FIGURE 8. Temporal Variation of the Occurrence of Major Types and Causes of WC in Relation to Major Classes of HME. Major types of WC include construction, sewage, wastewater, and water infrastructure-related conflicts (78% of the total). Major causes of WC were flooding, groundwater pollution, physical breakage, shortage, spills of sewage, spills of wastewater, and surface water pollution (79% of the total). Major classes of HME include flooding, heavy precipitation events, and flash floods (92% of the total).

to water infrastructure of good quality is a major restriction. When this condition cannot be fulfilled, contamination problems affecting groundwater and surface water systems due to construction activities and sewage spills appear as the main causes of conflicts, followed by conflicts caused by flooding and water shortage due to physical breakage. This situation adds pressure to the institutions dealing with water management as the probability of facing problems with water quality and quantity will increase over time if the water infrastructure is not updated. There is also lack of available scientific information to manage the quantity and quality of the water delivered to the population, which has historically restricted the development of sustainable water plans that take into account the demand vs. availability and quality of water (de Albuquerque, 2009; Bower, 2014; Babcock *et al.*, 2016). Therefore, our findings confirm that Costa Rica can be considered an economically water-stressed country as reported by the United Nations (WWAP, 2012), because its infrastructure cannot efficiently supply water and sanitation as illustrated by the high number of WC related and caused by infrastructure problems (~80%).

A closer look at the incidence of WC across the municipalities reveals that the intensity of conflicts' occurrence (i.e., number of conflicts per municipality) can be explained using a linear model that includes two variables: the municipalities' population and the number of HME per municipality. In terms of social conditions, a relatively weak correlation between WC, population density, the MWI, and the HPI was found, which seems to be related to relatively good and homogenous social conditions reported for the country in the period 2005–2015 (Hidalgo and Alfaro, 2012). Finally, climate variability, namely, the changes in the precipitation patterns, seems to have influenced an increase in HME (e.g., in the metropolitan area), and thus, the occurrence of WC. This influence of precipitation patterns was also observed when the temporal variation of major types and causes of WC was compared with the temporal changes in the number of HME. A clear pattern of the influence of climate variability on the incidence of these conflicts emerged especially when positive changes or anomalies in the precipitation regime were registered during La Niña episodes. These changes added pressure on the water infrastructure located mainly in the Central Valley that resulted in an increase in the number of WC. For example, spills of wastewater were significantly greater ($p < 0.05$) than the other types or causes of WC during La Niña 2007. Also, an increase of ~27% in the occurrence of conflicts related to flooding and physical breakage was registered in the Central Valley.

The results of this study have several potential implications for water resources management in Costa Rica. First, there is a need to recognize that reducing the risks of water-related conflicts requires reducing the pressures on water resources that contribute to economic, social, political, and environmental disruptions (Gleick, 2014). In Costa Rica, the current situation is prone to conflicts due to the increasing societal pressure for access to water infrastructure of good quality. The statistical analyses presented in this paper suggest that there is a relationship between the major types and causes of conflicts, all of them related to poorly maintained systems of water supply and sanitation infrastructure. Traditionally, governments in both developed and developing countries have struggled to finance infrastructure management. Local traditionally centralized governance systems (e.g., municipalities) have received significantly less resources and support from the central government in recent decades, which in some cases has led to operationally fragmented systems with isolated actors and vague accountability mechanisms, which allow for risk of conflict (Kuzdas *et al.*, 2016b). In developing countries, people still lack access to safe water and improved sanitation (Hallegatte *et al.*, 2017). In Costa Rica, 60% of the poulation depends mainly on the water resources provided within two watersheds (i.e., the Grande de Tárcoles Basin and the Río Virilla Basin), and therefore, an important short-term goal for the municipalities located in the Central Valley and the metropolitan area is to update this water infrastructure. Second, regulatory and management policies related to water are necessary to guarantee long-term sustainable water access and use. As recognized by Bower (2014), the large number of national and municipal agencies dealing with water creates confusion in roles and responsibilities. To deal with these impediments, WC literature has proposed to use water management plans that incorporate the natural boundaries of watersheds as organizational units in order to clarify the sharing of water resources and responsibilities among the municipalities (Yoffe *et al.*, 2004; Priscoli and Wolf, 2009), and to handle more effectively the occurrence of WC (Rivera *et al.*, 2016). Costa Rica's water management strategies were developed under a fragmentized institutional framework. For example, institutions like AyA, and more recently ESPH and JASEC, have played important roles in the definition of water and sanitation strategies, but the municipalities historically have had the jurisdiction on the management and maintenance of local water supply and sanitary services, generally with a minimum level of quality and efficiency (Bower, 2014). Therefore, to deal with the duplication of responsibilities and lack of coordination, the new and updated legislation could incorporate bigger management units based on the limits of watersheds in order to group those municipalities that share water resources and need to develop truly integrated water supply and sanitation plans. Third, there is still a high degree of uncertainty regarding water supply and use of groundwater reserves because of inadequate regulatory policies and poor water governance (Biswas and Tortajada, 2010; Kuzdas *et al.*, 2014, 2016b; Schulz *et al.*, 2017). This is especially true if the increasing and unsustainable demand for water resources related to real estate and construction development in Costa Rica is taken into account (de Albuquerque, 2009). Therefore, regulatory guidelines have to be updated in order to establish clear policies and institutional functions, to establish acceptable fees and sanctions for water use or contamination across the country, and to provide appropriate distribution and management of water.

While an international debate over the role of climate in WC is ongoing, and, in turn, the possibility of providing scenarios of future conflict patterns in a changing climate is still an academic exercise (Salehyan, 2008; Raleigh and Kniveton, 2012; Ide, 2017), our results suggest that climate variability (i.e., changes in the precipitation patterns and the resulting HME) is an important factor that must be taken into consideration for effective management of water resources in the Central Valley of Costa Rica. The increase in the number of conflicts reported in years with positive precipitation anomalies identifies a relationship of the water infrastructure located in the metropolitan area during intensified rainfall events, caused mainly by the occurrence of flooding (Bower, 2014). Thus, the societal response to such events must be acknowledged by governmental institutions, especially by municipalities located in the metropolitan area, where it seems that these conflicts are more likely to occur. To date, there are insufficient human and technical resources at most governmental institutions, including municipalities (Bower, 2014). These institutions need to change traditional methods of planning and incorporate personnel trained in the use of hydroclimate information in their management actions. Although scientific information such as the three-month El Niño forecasts provided by the IMN is available to most governmental institutions, it appears that its use is still ineffective or nonexistent (Babcock *et al.*, 2016). Therefore, WC may be useful as indicators of areas of greatest water vulnerability by linking conflicts, use of water resources, and the impact of anthropogenic activities on the environment (Mason *et al.*, 2009).

CONCLUSIONS

In this work, we analyzed 719 WC registered between 2005 and 2015. These conflicts occurred mainly between private individuals and the government and were mostly located in the Grande de Tárcoles Basin. The incidence of conflicts was strongly related to the state of the water infrastructure inside the metropolitan area of the Central Valley. When access to water infrastructure of good quality was not possible, contamination problems due to physical breakage of pipelines and wastewater spills were the main causes of conflicts, followed by conflicts caused by flooding and water shortage. A linear model including two variables: municipality population and the number of HME explained ~76% of the variance observed in the occurrence of WC in 78 municipalities of Costa Rica. There was also a weak influence of the social conditions of the municipalities located in the metropolitan area and the rest of the country on the incidence of all WC. Climate variability or the changes in the precipitation patterns of the Central Valley were significantly correlated with the occurrence of HME like flooding in this region. During La Niña episodes, the observed positive changes or anomalies in the precipitation patterns put additional pressure on the water infrastructure, mainly located in the Central Valley that resulted in an increase in the number of WC, especially those related to spills and physical breakage. Therefore, this region can be considered as climate vulnerable in terms of the incidence of WC.

Our results indicate the urgent need to develop updated economic, regulatory, and management policies related to water in Costa Rica, and also to designate funding to implement these updated management plans and then enforce major changes to the traditional water governance across the country. We suggest that new management instruments and strategies incorporate the natural boundaries of watersheds as organizational units. The incorporation of trained personnel and the use of available scientific hydroclimate information are needed to clarify the sharing of water resources and the responsibilities among local governments. In the municipalities located in the Central Valley, WC could be used as indicators of areas of the greatest water vulnerability by linking the climate variability context, and the access to good quality water infrastructure.

SUPPORTING INFORMATION

Additional supporting information may be found online under the Supporting Information tab for this article: Water conflicts database.

ACKNOWLEDGMENTS

This work was supported by the World Bank and National University of Costa Rica partial PhD scholarship to GEH in the Climate Change and Natural Resource Management doctorate program at DOCINADE (San José, Costa Rica). GEH and RSM also acknowledge support from the National University of Costa Rica Research Council.

LITERATURE CITED

Alfaro, E.J., 2002. Some Characteristics of the Annual Precipitation Cycle in Central America and Their Relationships with Its Surrounding Tropical Oceans. *Tópicos Meteorológicos y Oceanográficos* 9:88–103.

Alpízar-Rodríguez, F., 2012. ¿Democracia ecológica? Las instituciones, la participación política y las contiendas por el agua en Costa Rica (1821–2010). Ph.D. Thesis, Universidad Complutense de Madrid, Madrid, Spain.

Arnell, N.W., 2004. Climate Change and Global Water Resources: SRES Emissions and Socio-Economic Scenarios. *Global Environmental Change* 14:31–52. https://doi.org/10.1016/j.gloenvcha.2003.10.006.

Ashton, P.J., 2002. Avoiding Conflicts over Africa's Water Resources. *Ambio* 31:236–242. https://doi.org/10.1579/0044-7447-31.3.236.

Astorga, Y., 2010. Gestión del Recurso Hídrico y Uso del Agua. Decimosexto Informe Estado de la Nación. San José, Programa Estado de la Nación, San José, Costa Rica.

Babcock, M., G. Wong-Parodi, M.J. Small, and I. Grossmann, 2016. Stakeholder Perceptions of Water Systems and Hydro-Climate Information in Guanacaste, Costa Rica. *Earth Perspectives* 3: 1–13. https://doi.org/10.1186/s40322-016-0035-x.

Bernauer, T., T. Böhmelt, and V. Koubi, 2012. Environmental Changes and Violent Conflict. *Environmental Research Letters* 7:015601. https://doi.org/10.1088/1748-9326/7/1/015601.

Biswas, A.K., 2008. Integrated Water Resources Management: Is It Working? *International Journal of Water Resources Development* 24(1):5–22. https://doi.org/10.1080/07900620701871718.

Biswas, A.K. and C. Tortajada, 2010. Future Water Governance: Problems and Perspectives. *International Journal of Water Resources Development* 26(2):129–139. https://doi.org/10.1080/07900627.2010.488853.

Blomquist, W., M. Ballestero, A. Bhat, and K.E. Kemper, 2007. Costa Rica: Tárcoles Basin. *In*: Integrated River Management through Decentralization, K.E. Kemper, W. Blomquist, and A. Dinar (Editors). Springer, New York City, New York, pp. 149–165. https://doi.org/10.1007/978-3-540-28355-3_8.

Bogardi, J.J., D. Dudgeon, R. Lawford, E. Flinkerbusch, A. Meyn, C. Pahl-Wostl, K. Vielhauer, and C. Vörösmarty, 2012. Water Security for a Planet Under Pressure: Interconnected Challenges of a Changing World Call for Sustainable Solutions. *Current Opinion in Environmental Sustainability* 4:35–43. https://doi.org/10.1016/j.cosust.2011.12.002.

Bower, K., 2014. Water Supply and Sanitation of Costa Rica. *Environmental Earth Science* 71:107–123. https://doi.org/10.1007/s12665-013-2416-x.

Costumero, R., J. Sánchez, A. García-Pedrero, D. Rivera, M. Lillo, C. Gonzalo-Martín, and E. Menasalvas, 2017. Geography of Legal Water Disputes in Chile. *Journal of Maps* 13(1):7–13. https://doi.org/10.1080/17445647.2016.1252803.

CTI-Agua (Comité Técnico Interinstitucional para estadísticas del Agua), 2015. Datos e indicadores claves para la gestión integrada del recurso hídrico (GIRH). Ministerio de Ambiente y Energía (MINAE), Instituto Nacional de Estadísticas y Censos (INEC), Sistema Nacional de Información Ambiental (SINIA), Dirección de Agua, San José, Costa Rica.

de Albuquerque, C., 2009. Promotion and Protection of All Human Rights, Civil, Political, Economic, Social and Cultural Rights, Including the Right to Development. Report of the independent expert on the issue of human rights obligations related to access to safe drinking water and sanitation. Addendum Mission to Costa Rica. Report to the United Nations General Assembly A/HRC/12/24/Add.1.

De Stefano, L., P. Edwards, L. de Silva, and A.T. Wolf, 2010. Tracking Cooperation and Conflict in International Basins: Historic and Recent Trends. *Water Policy* 12:871–884. https://doi.org/10.2166/wp.2010.137.

Fielding, N.G., 2012. Triangulation and Mixed Methods Designs: Data Integration with New Research Technologies. *Journal of Mixed Methods Research* 6:124–136. https://doi.org/10.1177/1558689812437101.

Funder, M., S.M. Cold-Ravnkilde, and I. Peters-Ginsborg, 2012. Addressing Climate Change and Conflict in Development Cooperation: Experiences from Natural Resource Management. Danish Institute for International Studies, Report 2012:04, Copenhagen, Denmark, pp. 9–13.

García, V., J. Acuña-González, J.A. Vargas-Zamora, and J. García-Céspedes, 2006. Calidad bacteriológica y desechos sólidos en cinco ambientes costeros de Costa Rica. *Revista de Biología Tropical* 54:35–48.

Gleick, P.H., 2014. Water, Drought, Climate Change, and Conflict in Syria. *Weather, Climate and Society* 6:331–340. https://doi.org/10.1175/WCAS-D-13-00059.1.

Guzmán-Arias, I. and J.C. Calvo-Alvarado, 2013. Planning and Development of Costa Rica Water Resources: Current Status and Perspectives. *Tecnología en Marcha* 26:52–63. https://doi.org/10.18845/tm.v26i4.1583.

Hallegatte, S., A. Vogt-Schilb, M. Bangalore, and J. Rozenberg, 2017. Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters. Climate Change and Development Series. International Bank for Reconstruction and Development/The World Bank. Washington, D.C.

Hidalgo, H.G. and E.J. Alfaro, 2012. Some Physical and Socio-Economic Aspects of Climate Change in Central America. *Progress in Physical Geography* 36:379–399. https://doi.org/10.1177/0309133312438906.

Hidalgo, H.G., J.A. Amador, E.J. Alfaro, and B. Quesada, 2013. Hydrological Climate Change Projections for Central America. *Journal of Hydrology* 495:94–112. https://doi.org/10.1016/j.jhydrol.2013.05.004.

Ide, T., 2017. Research Methods for Exploring the Links between Climate Change and Conflict. *WIRES Climate Change* 8:e456. https://doi.org/10.1002/wcc.456.

ITEC (Instituto Tecnológico de Costa Rica), 2008. Atlas de Costa Rica. Escuela de Ingeniería Forestal. Cartago, Costa Rica. Digital Atlas, ITEC, Cartago, Costa Rica.

Kuzdas, C., B.P. Warner, A. Wiek, R. Vignola, M. Yglesias, and D.L. Childers, 2016a. Sustainability Assessment of Water Governance Alternatives: The Case of Guanacaste Costa Rica. *Sustainability Science* 1:231–247. https://doi.org/10.1007/s11625-015-0324-6.

Kuzdas, C., B. Warner, A. Wiek, M. Yglesias, R. Vignola, and A. Ramírez-Cover, 2016b. Identifying the Potential of Governance Regimes to Aggravate or Mitigate Local Water Conflicts in Regions Threatened by Climate Change. *Local Environment* 21:1–22. https://doi.org/10.1080/13549839.2015.1129604.

Kuzdas, C. and A. Wiek, 2014. Governance Scenarios for Addressing Water Conflicts and Climate Change Impacts. *Environmental Science and Policy* 42:181–196. https://doi.org/10.1016/j.envsci.2014.06.007.

Kuzdas, C., A. Wiek, B. Warner, R. Vignola, and R. Morataya, 2014. Sustainability Appraisal of Water Governance Regimes: The Case of Guanacaste, Costa Rica. *Environmental Management* 54:205–222. https://doi.org/10.1007/s00267-014-0292-0.

Lager, T. and M. Wikström, 2007.Polluted Domestic Water in Costa Rica: An Analysis from a Technical and an Economic Perspective. Degree Thesis in Economics, Department of Economics, Sveriges Lantbruksuniversitet, Uppsala, Sweden.

Lance, G.N. and W.T. Williams, 1967. A General Theory of Classificatory Sorting Strategies: 1. Hierarchical Systems. *The Computer Journal* 9:373–380. https://doi.org/10.1093/comjnl/9.4.373.

Mason, S.A., T. Hagmann, C. Bichsel, E. Ludi, and Y. Arsano, 2009. Linkages between Sub-National and International Water Conflicts: The Eastern Nile Basin. *In*: Facing Global Environmental Change: Environmental, Human, Energy, Food, Health and Water Security Concepts, H.G. Brauch, J. Grin, C. Mesjasz, H. Krummenacher, N.C. Behera, B. Chourou, U. Oswald-Spring, P.H. Liotta, and P. Kameri-Mbote (Editors). Springer-Verlag, Berlin, Germany, pp. 325–334.

Mora-Alvarado, D., A. Urbina-Campos, and H. Chamizo-García, 2015. Ecological Study on Chronic Kidney Disease and Arsenic in Drinking Water in Districts of Guanacaste. *Tecnología en Marcha* 28:102–115. https://doi.org/10.18845/tm.v28i2.2337.

Oki, T. and S. Kanae, 2006. Global Hydrological Cycles and World Water Resources. *Science* 313:1068. https://doi.org/10.1126/science.1128845.

Pahl-Wostl, C., K. Conca, A. Kramer, J. Maestu, and F. Schmidt, 2013. Missing Links in Global Water Governance: A Processes-Oriented

Analysis. *Ecology and Society* 18(2):33. https://doi.org/10.5751/ES-05554-180233.

PEN (Programa Estado de la Nación), 2015. Vigésimo Primer Informe Estado de la Nación en Desarrollo Humano Sostenible. Programa Estado de la Nación, San José, Costa Rica.

PEN (Programa Estado de la Nación), 2016. Vigésimo Segundo Informe Estado de la Nación en Desarrollo Humano Sostenible. Programa Estado de la Nación, San José, Costa Rica.

Priscoli, J.D. and A.T. Wolf (Editors), 2009. Managing and Transforming Water Conflicts. International Hydrology Series with Cambridge University Press, Cambridge, United Kingdom.

Raleigh, C. and D. Kniveton, 2012. Come Rain or Shine: An Analysis of Conflict and Climate Variability in East Africa. *Journal of Peace Research* 49(1):51–64. https://doi.org/10.1177/0022343311427754.

Ramírez-Cover, A., 2008. Conflictos socioambientales y recursos hídricos en Guanacaste; una descripción desde el cambio en el estilo de desarrollo (1997–2006). *Anuario de Estudios Centroamericanos* 33–34:359–385.

Reynolds-Vargas, J., J. Fraile-Merino, and R. Hirata, 2006. Trends in Nitrate Concentrations and Determination of Its Origin Using Stable Isotopes (^{18}O and ^{15}N) in Groundwater of the Western Central Valley, Costa Rica. *Ambio* 35:229–236. https://doi.org/10.1579/05-R-046R1.1.

Rivera, D., A. Godoy-Faúundez, M. Lillo, A. Alvez, V. Delgado, C. Gonzalo-Martín, E. Menasalvas, R. Costumero, and A. García-Pedrero, 2016. Legal Disputes as a Proxy for Regional Conflicts over Water Rights in Chile. *Journal of Hydrology* 535:36–45. https://doi.org/10.1016/j.jhydrol.2016.01.057.

Saénz, F. and A.M. Durán-Quesada, 2015. A Climatology of Low Level Wind Regimes over Central America Using a Weather Type Classification Approach. *Frontiers in Earth Science* 3:1–18. https://doi.org/10.3389/feart.2015.00015.

Salehyan, I., 2008. From Climate Change to Conflict? No Consensus Yet. *Journal of Peace Research* 45(3):315–326. https://doi.org/10.1177/0022343308088812.

Sánchez-Murillo, R. and C. Birkel, 2016. Groundwater Recharge Mechanisms Inferred from Isoscapes in a Complex Tropical Mountainous Region. *Geophysical Research Letters* 1–10, https://doi.org/10.1002/2016GL068888.

Schulz, C., J. Martin-Ortega, K. Glenk, and A.A.R. Ioris, 2017. The Value Base of Water Governance: A Multi-Disciplinary Perspective. *Ecological Economics* 131:241–249. https://doi.org/10.1016/j.ecolecon.2016.09.009.

Segura-Bonilla, O., 2002. Agenda Ambiental del Agua en Costa Rica. *Revista Geográfica de América Central*, 40(I–II):39–49.

Shakelford, A., F. Ramírez-Hernández, K. Brade-Jiménez, J. Madrigal-Pana, P. Omodeo- Cubero, G. Mora-Muñoz, G. Mata-Marín, D. Mora-Díaz, and D. Ramírez-Chaves, 2016. Atlas del Desarrollo Humano Cantonal de Costa Rica 2016: Proyecto "Informe Nacional de Desarrollo Humano." Programa de las Naciones Unidas para el Desarrollo/Universidad de Costa Rica.

Stahl, K., 2005. Influence of Hydroclimatology and Socioeconomic Conditions on Water-Related International Relations. *Water International* 30:270–282. https://doi.org/10.1080/02508060508691868.

Torre, A., R. Melot, H. Magsi, L. Bossuet, A. Cadoret, A. Caron, S. Darly, P. Jeanneaux, T. Kirat, and H.V. Pham, 2014. Identifying and Measuring Land-Use and Proximity Conflicts: Methods and Identification. *Springer Plus* 3:1–26. https://doi.org/10.1186/2193-1801-3-85.

Wang, L., L. Fang, and K.W. Hipel, 2008. Basin-Wide Cooperative Water Resources Allocation. *European Journal of Operational Research* 190(3):798–817. https://doi.org/10.1016/j.ejor.2007.06.045.

Waylen, M.E., 1996. Interannual Variability of Monthly Precipitation in Costa Rica. *Journal of Climatology* 9:2606–2613. https://doi.org/10.1175/1520-0442(1996) 009<2606:IVOMPI>2.0.CO;2.

Wolf, A.T., S.B. Yoffe, and M. Giordano, 2003. International Waters: Identifying Basins at Risk. *Water Policy* 5:29–60.

Woodhouse, P. and M. Muller, 2017. Water Governance — An Historical Perspective on Current Debates. *World Development* 92:225–241. https://doi.org/10.1016/j.worlddev.2016.11.014.

WWAP (World Water Assessment Programme), 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. UNESCO, Paris, France.

Yoffe, S., G. Fiske, M. Giordano, M. Giordano, K. Larson, K. Stahl, and A.T. Wolf, 2004. Geography of International Water Conflict and Cooperation: Data Sets and Applications. *Water Resources Research* 40:W05S04. https://doi.org/10.1029/2003wr002530.