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Changeability of reliability, resilience and vulnerability indicators with respect to drought patterns

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A B S T R A C T

Climate-related extremes such as droughts have led to significant impacts on some watersheds. To assess watershed health and develop effective management plans, information about the function and structure of the watersheds in the context of their climatic response, especially to take into account rainfall anomalies and climate change adaptation, is needed. Integration of climatic variables with reliability, resilience and vulnerability (RRV) indicators, is a novel approach for generating this information. This study investigated the behavior of RRV indicators with respect to rainfall variability and drought patterns for three watersheds governed by different climates. Reliability was defined as the probability of a watershed to be in the range of satisfactory Standardized Precipitation Index (SPI) values. Resilience was indicated as the speed of recovery from an unsatisfactory condition. Vulnerability was defined as a function of the exposure of a watershed to climate change and variation using the SPI. The study areas were the Foyle Watershed in Northern Ireland (temperate oceanic, Cfb), the Xarrama Watershed in Portugal (Mediterranean hot summer, Csa) and the Shazand Watershed in Iran (moderate to cold semi-arid (Bsk). Based on the SPI pattern of each watershed, the SPI of −0.1 for the Foyle and Xarrama watersheds and +0.1 for the Shazand Watershed was selected as the drought threshold. The drought based RRV index was subsequently calculated from long-term (1981–2012) RRV indicators, resulting in means of 0.52 ± 0.25, 0.53 ± 0.21 and 0.30 ± 0.18 for the three watersheds, respectively. These means reflect the status of the watersheds in terms of climatic conditions, which was moderate dry (0.41–0.60) for the Foyle and Xarrama watersheds and dry (0.21–0.40) for the Shazand Watershed. The temporal trend of the drought based RRV index was found to be non-significantly increasing (P-value > 0.52) for the Foyle and Xarrama watersheds and non-significantly decreasing for the Shazand Watershed (P-value > 0.48). The vulnerability indicator and drought based RRV index were significantly (p-value = 0.00) affected by the climatological gradient. The results of the conceptual framework linked to statistical trends can provide researchers, policy makers, and land managers a more comprehensive base to assess variability of watershed health and design drought management plans.

1. Introduction

Recent changes in climate have widespread impacts on human and natural systems (IPCC, 2014). Among other things, climate change has the potential to disrupt and modify hydrological regimes and thus affect watershed conditions and associated management approaches (Sood and Ritter, 2011; IPCC, 2014; Teegavarapu, 2017; Zareian et al., 2017; Herath and Hasanov, 2017). Increases in the frequency or intensity of ecosystem changes such as droughts have been detected in many parts of the world and are, in some cases, attributed to climate change (IPCC, 2014).

Droughts are considered to be one of the world's costliest natural disasters affecting a variety of sectors (Esfahanian et al., 2017) and rainfall, or lack thereof, is a factor in their occurrence. Climate change has been recognized to impact rainfall patterns in various low to medium latitude mid-continental regions and in already arid areas in around the world (McMichael et al., 2003). Hence, quantifying rainfall patterns and variability has been an area of increasing interest for many

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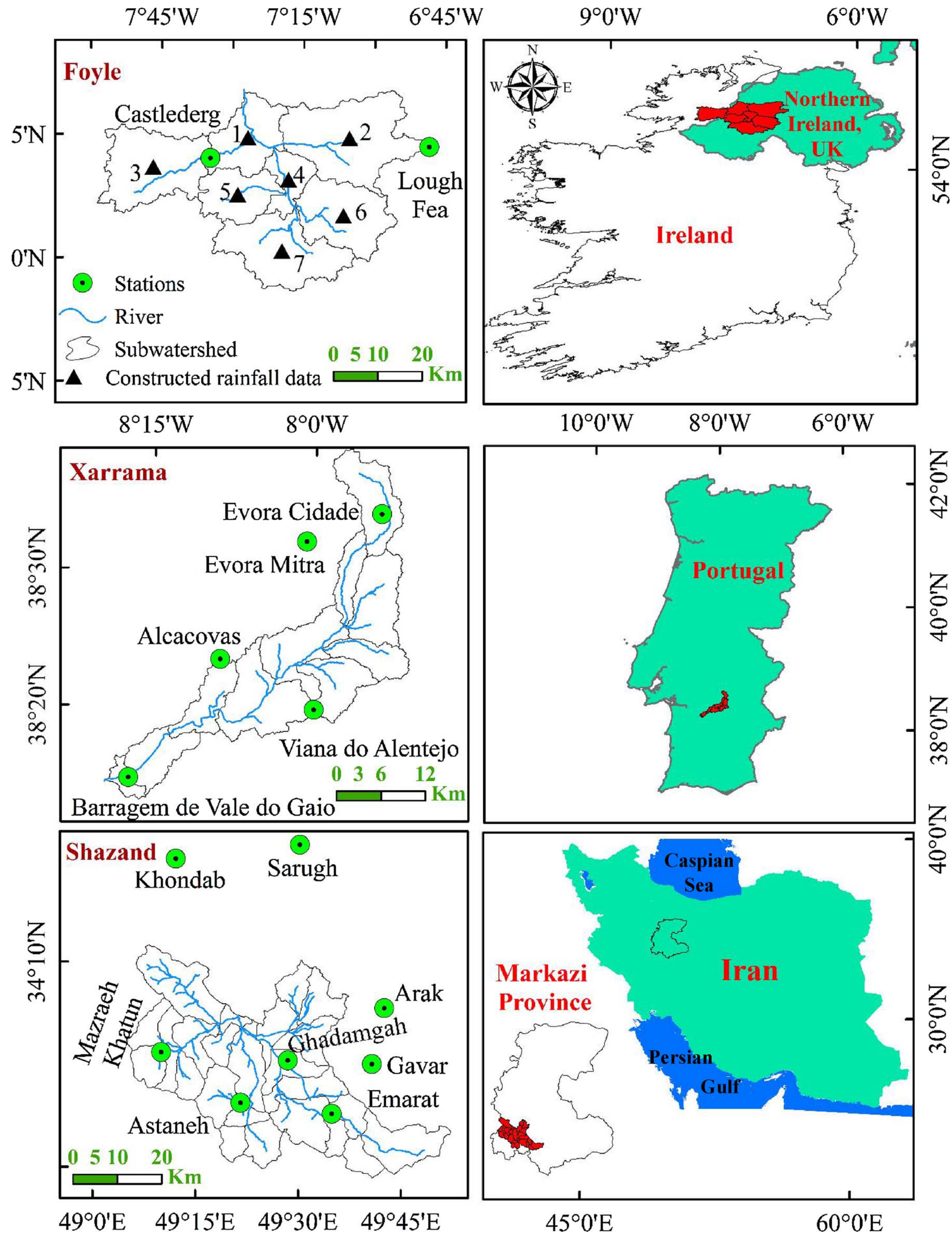

Fig. 1. General view and main characteristics of study watersheds.

researchers studying droughts. Additionally, adaptation to future severe droughts requires insight into the drivers of the drought and its possible impacts (van Dijk et al., 2013).

The reliability-resilience-vulnerability framework (RRV) was initially elaborated by Hashimoto et al. (1982) to describe the performance of a multipurpose reservoir system. Each complement criterion (i.e., reliability, resilience and vulnerability) assesses different aspects of the watershed system. Reliability measures the frequency or probability of the watershed being in a satisfactory state during the total data period. Resilience measures how quickly, on average, a system rebounds to a satisfactory state after reaching an unsatisfactory state. It accounts for the number of rebounds as a percentage of total unsatisfactory study time. Vulnerability assesses how severe the unsatisfactory state is or the factors that caused it. Assessing these metrics (Asefa et al., 2014) provides insight into system performance in changing or varying climatic conditions. The ability of RRV analysis to distinguish trends using long term data is well documented for water resources systems (Hashimoto et al., 1982; Maier et al., 2001; Kjeldsen