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Spatiotemporal variation of watershed health propensity through reliability-resilience-vulnerability based drought index (case study: Shazand Watershed in Iran)

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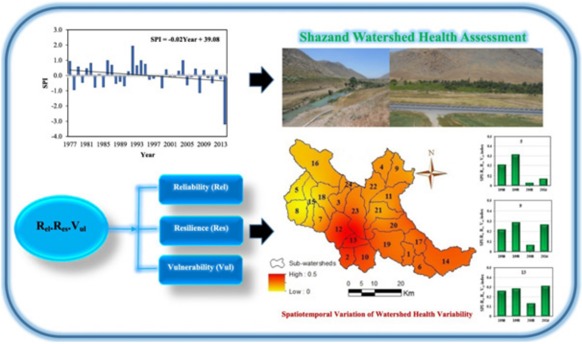
HIGHLIGHTS

- SPI is a key watershed health assessment criterion.
- R_{el} $R_{es}V_{ul}$ framework was conceptualized for SPI.
- Spatiotemporal variations of SPI-R_{el} $R_{es}V_{ul}$ watershed health index was proved.
- The weak response type of the sub-watersheds to climate condition was obtained.

GRAPHICAL ABSTRACT



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ABSTRACT

Quantitative response of the watershed health to climate variability is of critical importance for watershed managers. However, existing studies seldom considered the impact of climate variability on watershed health. The present study therefore aimed to analyze the temporal and spatial variability of reliability (R_{el}), resilience (R_{es}) and vulnerability (V_{ul}) indicators in node years of 1986, 1998, 2008 and 2014 in connection with Standardized Precipitation Index (SPI) for 24 sub-watersheds in the Shazand Watershed of Markazi Province in Iran. The analysis was based on rainfall variability as one of the main climatic drivers. To achieve the study purposes, the monthly rainfall time series of eight rain gauge stations distributed across the watershed or neighboring areas were analyzed and corresponding SPIs and R_{el} $R_{es}V_{ul}$ indicators were calculated. Ultimately, the spatial variation of SPI oriented R_{el} $R_{es}V_{ul}$ was mapped for the study watershed using Geographic Information System (GIS). The average and standard deviation of SPI-R_{el} $R_{es}V_{ul}$ index for the study years of 1986, 1998, 2008 and 2014 was obtained 0.240 ± 0.025, 0.290 ± 0.036, 0.077 ± 0.0280 and 0.241 ± 0.081, respectively. In overall, the results of the study proved the spatiotemporal variations of SPI-R_{el} $R_{es}V_{ul}$ watershed health index in the study area. Accordingly, all the sub-watersheds of the Shazand Watershed were grouped in unhealthy and very unhealthy conditions in all the study years. For 1986 and 1998 all the sub-watersheds were assessed in unhealthy status. Whilst, it declined to very unhealthy condition in 2008 and then some 75% of the watershed ultimately referred again to unhealthy and the rest still remained under very unhealthy conditions in 2014.

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1. Introduction

The global climate is changing (Kim and Chung, 2014). Change in rainfall as a driving force is one of the most critical factors determining the overall impact of climate change. However, rainfall is one of the foremost drivers of soil erosion by water. Hence, it is a major concern in soil conservation (Mengistu et al., 2016; Panagos et al., 2015; Sadeghi and Hazbavi, 2015; Brevik, 2013; Hazbavi and Sadeghi, 2013).

Watersheds are dynamic biophysical landscape constructs that are driven by hydrological imperative (Falkenmark, 2003). The watershed conditions are strongly controlled by climate (long-term) and weather (short-term), hydrologic conditions, biotic/abiotic interactions and land uses. There is a belief among many scientists (e.g., Parkes et al., 2008 and Hazbavi and Sadeghi, 2016) that global climate changes will create "hydrological imperatives" and influence global precipitation patterns, altering both the amount of precipitation received and the distribution of precipitation (Brevik, 2013; IPCC, 2007) that require adaptation and management on a variety of scales. Effective watershed governance links health and sustainability with the concept of watersheds as ecosystems (Parkes et al., 2008).

In recent years, due to the effect of climate change, drought studies are getting special attention (e.g., Li et al., 2016; Kumar et al., 2016; Paulo et al., 2016). Drought is characterized by below-average water availability (Kumar et al., 2016). It is often associated with large socio-economic losses and damages to natural ecosystems leading to several environmental losses briefly are reflected in lowering quality and quantity of ecosystem services (Wilhite and Vanyarkho, 2000). On the other hand, rainfall anomalies in the more assessments of drought have characterized by Standardized Precipitation Index (SPI) as a probabilistic means of it (Keyantash and Dracup, 2002). The most recent report of the World Meteorological Organization (WMO) indicates that the SPI is the most prominent and primary meteorological index used (WMO, World Meteorological Organization, 2016). This index compares very favorably against several other "drought" indices (Giddings et al., 2005; Keyantash and Dracup, 2002). The SPI has been employed to examine numerous questions such as, drought, teleconnections with large scale circulatory systems, floods and crop yields (Giddings et al., 2005). McKee et al. (1993) developed the SPI to categorize observed rainfall as a standardized departure with respect to a rainfall probability distribution function. It indicates how precipitation for any given duration (e.g., one month, two months, etc.) at a particular observing site compares with the long-term precipitation record at the same site of the same duration (Edwards and McKee, 1997). Accordingly, different steps of time spans were applied to compute the SPI to facilitate the assessment of the effects of a precipitation deficit on different water resources components (soil moisture, groundwater, stream flow, reservoir storage) (Mashari Eshghabad et al., 2014).

Several attempts have been made in the past to analyze the appropriateness in describing the drought characteristics for a particular region (e.g., Bandyopadhyay and Saha, 2016; Li et al., 2016; Kumar et al., 2016; Paulo et al., 2016; Xu et al., 2011; Jamshidi et al., 2011; Giddings et al., 2005; McKee et al., 1993) using the SPI. In addition, previous studies typically focused on the spatiotemporal trend analysis of the SPI (e.g., Wang et al., 2016; Rahmat et al., 2012; Tabari et al., 2011; Bonaccorso et al., 2003), future change analysis of the SPI (Bachmair et al., 2016; Rhee and Cho, 2016), investigating the relationship between the SPI and some remote sensing data (Damavandi et al., 2016; Owrangi et al., 2011). However, the SPI characterizing by risk assessment indicators viz. reliability (R_{el}), resilience (R_{es}), and vulnerability (V_{ul}), as the first attempt, has not been carried out or documented yet. The risk indicators including R_{el} $R_{es}V_{ul}$ can help watershed managers understand the behavior of the SPI changes and relate it to watershed health status. The watershed health may have several connotations. Here, the main focus was on the watershed health assessment based on important dynamic index of standardized precipitation and its spatiotemporal variation. The US EPA has proposed the use of integrated assessments of watershed health to assist managers with identifying healthy watersheds and prioritizing candidate watersheds for protection and restoration (EPA, Environmental Protection Agency, 2014). A key component of watershed health is the ability to withstand, recover from, or adapt to natural and anthropogenic disturbances. However, healthy watersheds are naturally dynamic and often depend on recurrent natural disturbances to maintain their health (EPA, Environmental Protection Agency, 2012). Watershed health assessment (WHA) is therefore supposed as an appropriate conjunct approach between watershed research and management (Hazbavi and Sadeghi, 2016).

Since a system failure should be simultaneously characterized by its R_{el} $R_{es}V_{ul}$ characteristics, a compound framework has to be used for comprehensive assessment of watershed health to a specific criterion like climatic variables. It is also a fundamental concept for developing new ways to assess and manage environmental resources (Suo et al., 2008). Application of R_{el} $R_{es}V_{ul}$ indicators in ecology (Walker et al., 2004; Naeem, 1998; Loucks, 1997; Holling, 1973) and hydrology (Asefa et al., 2014; Mondal et al., 2009; Kundzewicz and Laski, 1995; Hashimoto et al., 1982) was well documented. In addition, during last few years the R_{el} $R_{es}V_{ul}$ indicators have been employed by Sood and Ritter (2011) for watershed sustainability, Hoque et al. (2016, 2014, 2013, 2012) for water quality substances and by Chanda et al. (2014) and Maity et al. (2013) for Drought Management Index (DMI). Recently, a potential method of assessing watershed health with respect to hydrological responses was documented by Hazbavi and Sadeghi (2016). However, the application of R_{el} $R_{es}V_{ul}$ indicators coupled with the SPI has not been practically applied for the assessment of temporal and spatial variability of watershed health. Based on reviewing of the literature, it is very high important to investigate the watershed responses in respect to climate change. Since the climate change has the potential to disrupt and modify hydrological regimes and thus affects watershed health, it is very high essential to understand the response of the watershed system using this probabilistic framework in respect to SPI variation as a state-of-the-art method for assessing climatic variability. Hence, the present research attempted to expand the scope of the concept of R_{el} $R_{es}V_{ul}$ framework for the assessment of watershed health with the help of dynamic phenomenon of precipitation under governing changing climate. The results of the study reflect the general effectiveness of precipitation factor on changing watershed health. It, itself, helps managers and decision makers plan appropriately and adopt their adaptive approaches. Toward this attempt, the present research characterized the R_{el} $R_{es}V_{ul}$ indicators for the SPI and developed a SPI-R_{el} $R_{es}V_{ul}$ index for a semi-arid watershed located in central Iran for four node years of 1986, 1998, 2008 and 2014.

2. Materials and methods

2.1. Study area

The present research was performed as a case study in the Shazand Watershed (ca. 1740 sq. km.) of south west of Markazi Province, Iran. It lies between the north latitudes 33° 44′42″ to 34° 12′ 13″ and east longitudes of 49° 04′ 15″ to 49° 52′ 12″ which is shown in Fig. 1. The Shazand Watershed is a part of Sareband mountainous City and located in a distance of 40 km from southwest of Arak City, capital of Markazi Province, and in the vicinity of Hamadan and Lorestan Provinces. The area underlying mainly by karst formation and therefore is important in terms of water resources (Yousefirad, 2005). Of total area, 50.15% includes highlands with hard formations and the rest 44.85% contains alluvial sediments and/or sub-mountain screes. According to Darabi et al. (2014), the Shazand Watershed has been divided into 24 sub-watersheds/inter-basins (Fig. 1). The mean annual precipitation in the watershed is about 420 mm, with a moderate semi-arid to cold semi-arid climate (Davudirad et al., 2016; Sadeghi and Hazbavi, 2016). During recent years, the Shazand Watershed experienced a huge development in