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Original Article

Analysis of spatiotemporal changes of the human-water relationship using water resources constraint intensity index in Northwest China

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ABSTRACT

Water resources constraint intensity (WRCI) refers to the conflict degree between water scarcity and human activities. We provide a comprehensive dynamic assessment index system for WRCI, which is composed of three primary indicators (natural endowment, exploitation and utilization degree, exploitation and utilization efficiency of water resources) and nine secondary indicators. After ascertaining the thresholds and grading standards for each specific indicator and their integrated indexes according to the experience of developed countries and regions, we employ an Analytic Hierarchy Process (AHP) model reformed by entropy technology to calculate their weights, and establish a multi objective fuzzy membership function to calculate the normalized values. Subsequently, we use the statistical data of 51 prefecture level regions in Northwest China during 2000–2014 to analyze the spatiotemporal changes of WRCI and its primary and secondary indicators. The results show that WRCI in the whole region of Northwest China belonged to the less strong or weak constraint type during the period. However, Northwest China was confronted with great disparity in human-water relationship according to the temporal and spatial changes of WRCI and its primary and secondary indicators. About 1/3 of prefecture level regions belonged to the strong and very strong constraint type. About 1/3 belonged to the less strong constraint type. Only about 1/3 belonged to the weak and very weak constraint type. The framework provides a relatively absolute evaluation of the conflict degree between the human-water systems. It might help to scientifically understand the spatiotemporal features of the relationship between water scarcity and human activities for Northwest China, and also has the potential for application in other areas and scales for monitoring and comparison purposes in space and over time.

1. Introduction

Water is a kind of important and strategic resources for socio-economic development and eco-environmental protection (Bao and Fang, 2012; Zuo et al., 2016). Due to climate variability and change, explosive increase of population, widespread economic growth, rapid urbanization and industrialization, low efficiency of water consumption, improper water management and insufficient water storage infrastructure, arid and semi-arid regions are challenged by water scarcity with disastrous consequences, including river and lake drying, land degradation, biodiversity loss, ecological migration, living standard declining, etc. (Martin-Carrasco et al., 2013; Karkra et al., 2016a,b; Chitsaz and Azarnivand, 2017). Water scarcity and related eco-environmental issues have become key factors to restrict socio-economic development (Rijsberman 2006; Bao and Fang, 2007; Fang et al., 2007; Kumar et al., 2015, 2017). The conflicts between water scarcity and human activities have aroused worldwide concerns (Ragab and Prudhomme, 2002; Jiang, 2009; Liu et al., 2017a).

To assess the relationship between water scarcity and human activities, many scholars have provided a huge amount of single or comprehensive indicators and indexes (Ding et al., 2014; Gain and Giupponi, 2015; s et al., 2015,b; Kumar et al., 2016a,b). Each of them has been defined under different assumptions or conditions. Therefore, its applicability may be limited, and there is not a unique indicator suitable for all areas of study (Pedro-Monzonís et al., 2015).

As for single indicators, Water Stress Index (WSI) and Water Exploitation Index (WEI) have been widely used. Water Stress Index (WSI) was defined as average per capita water availability per year, with a threshold set at 1000 cubic meters per person per year (Falkenmark et al., 1989). Water Exploitation Index (WEI) was defined as the percentage of freshwater withdrawal with respect to the long-term mean annual freshwater resources, with a threshold set exceeding

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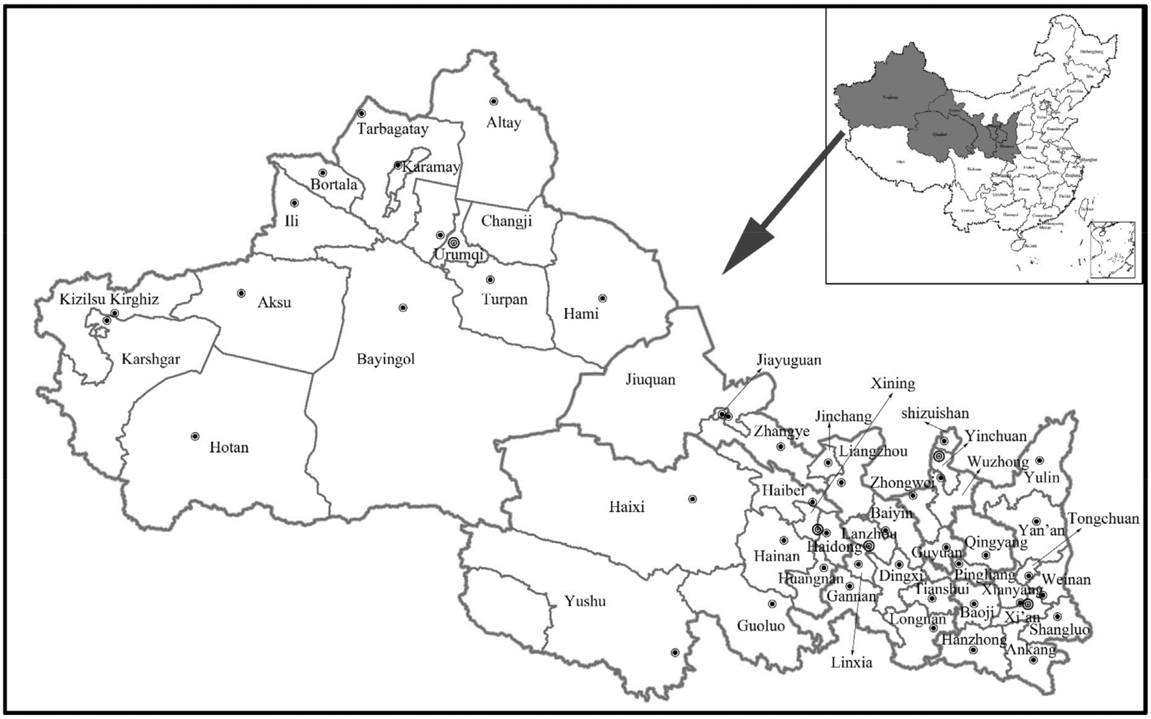

Fig. 1. Location and its prefecture level regions in Northwest China.

40% (EEA, 2005; Vörösmarty et al., 2005). With deep research of these two indicators, the detailed grading standards of the thresholds have been gradually improved according to practical situations (Jia et al., 2002; Fensholt and Sandholt, 2003; Pedro-Monzonís et al., 2015; Li et al., 2017; Wu et al., 2017; Simha et al., 2017). Though these single indicators are concise and clear for macro-scale assessment, they cannot reveal all aspects of the relationship between water scarcity and human activities. For example, where the average per capita water availability per year is large, the average per acre water availability per year may be small, and the Water Exploitation Index may be large. Therefore, the human-water relationship cannot be measured only by one or two simple indicators. A comprehensive system of indicators should be developed (Jia et al., 2002).

As for comprehensive indicators, the most commonly approaches are the Water Poverty Index (WPI) (Sullivan, 2002; Sullivan et al., 2003), the Integrated Water Stress Index (Jia et al., 2002; Liu et al., 2017a), the Water Scarcity or Shortage Index (Zeng et al., 2013; Liang et al., 2013), the Water Resources Carrying Capacity Index (Wang et al., 2005; Gong and Jin, 2009), the Water Security Index (Xia and Zhu, 2002; Jia et al., 2015) and the Human-Water Harmony Index (Ding et al., 2014). For example, the Water Poverty Index (WPI) is one of the most representative indicators to address and combat water problems and disparities. It highlights the strong link between water provision and poverty alleviation and holistically describes the water situation with five key components: resource, access, use, capacity and environment. The above composite indexes are calculated by the standardized values of the specific indicators and their weights. In general, methods for calculating the standardized values include target normalization, Z-score normalization, ratio normalization, and unit equivalence normalization (Pollesch and Daleb, 2016). Methods for calculating the weights include statistical-based methods (objective) and participatory-based methods (subjective) (OECD, 2008), such as the principal component/factor analysis (PCA/PFA), the objective/subjective dynamic weight method, the revised Simos' procedure, the Delphi method, and the Analytic Hierarchy Process (AHP) (Sutadian et al., 2017). All methods for calculating the standardized values and their weights have their own advantages and drawbacks (OECD, 2008; Pollesch and Daleb, 2016; Sutadian et al., 2017; Pires et al., 2017). The best choice depends on the indicators which are under consideration and the preferences of the decision maker (Gain and Giupponi, 2015). Moreover, when applied to the specific Chinese situations, the above composite indexes need to incorporate both social and culture characteristics (Ding et al., 2014). Therefore, the integrated assessment of human-water relationship according to Chinese regional situations and the proposed objectives is currently an urgent need in water resources management (Bao and Fang, 2009; Ding et al., 2014).

In this study, we provide a comprehensive dynamic assessment of the human-water relationship using water resources constraint intensity index for Northwest China, a region where water resources utilization has reached or exceeded its threshold and scarce water resources can constrain the socio-economic development (Cai, 2008; Bao and Fang, 2009). Firstly, we select nine frequently used statistical indicators to construct an integrated indicator system to assess water resources constraint intensity, which is defined as the conflict degree between water scarcity and human activities. Secondly, we ascertain the thresholds and grading standards for each specific indicator and their integrated indexes. Thirdly, we employ an Analytic Hierarchy Process (AHP) model reformed by entropy technology to calculate their weights. Fourthly, we establish a multi objective fuzzy membership function to calculate the standardized values. Finally, we use the statistical data of 51 prefecture level regions in Northwest China during 2000–2014 to calculate the WRCI and its primary and secondary indicators, and analyze the spatiotemporal changes. It might help to scientifically understand the spatiotemporal features of the relationship between water scarcity and human activities for Northwest China, and also provides an effective assessment method for Chinese regional situations.

2. Materials and methods

2.1. Study area

Northwest China, traditionally including the provinces of Shaanxi, Gansu, Qinghai and the autonomous regions of Xinjiang and Ningxia,