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A simple approach to assess water scarcity integrating water quantity and quality

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ABSTRACT

Water scarcity has become widespread all over the world. Current methods for water scarcity assessment are mainly based on water quantity and seldom consider water quality. Here, we develop a simple approach for assessing water scarcity considering both water quantity and quality. In this approach, a new water scarcity index is used to describe the severity of water scarcity in the form of a water scarcity meter, which may help to communicate water scarcity to a wider audience. To illustrate the approach, we analyzed the historical trend of water scarcity for Beijing city in China during 1995–2009. The results show that Beijing made a huge progress in mitigating water scarcity, and that from 1999 to 2009 the blue and grey water scarcity index decreased by 59% and 62%, respectively. These achievements were made through great efforts of water-saving measures and wastewater treatment. Despite this progress, we demonstrate that Beijing is still characterized by serious water scarcity due to both water quantity and quality. The water scarcity index remained at a high value of 3.5 with a blue and grey water scarcity index of 1.2 and 2.3 in 2009 (exceeding the thresholds of 0.4 and 1, respectively). As a result of unsustainable water use and pollution, groundwater levels continue to decline, and water quality shows a continuously deteriorating trend. To curb this trend, future water policies should further decrease water withdrawal from local sources (in particular groundwater) within Beijing, and should limit the grey water footprint below the total amount of water resources.

1. Introduction

Water is the basic natural resources for the development of human society, as well as for the survival of ecosystems (Oki and Kanae, 2006; Vörösmarty et al., 2010). With rapid socio-economic development, conflicts between water demand and supply have become more intense; water has become a bottleneck for the sustainable development of more and more countries and regions. Water scarcity assessment has become a hot research topic in the field of hydrology and water resources (Vörösmarty et al., 2000; Oki and Kanae, 2006).

There are four main approaches for water scarcity assessment (Table 1). The Falkenmark index (Falkenmark et al., 1989), Criticality ratio (Alcamo et al., 2000) and IWMI indicator (Seckler et al., 1998) are easy to apply, but they focus on water quantity and neglect water quality and the contribution of green water (Savenije, 2000). Water poverty index (Sullivan, 2002) considers both quantity and quality, but is too complex to calculate and, moreover, hard to explain. There is a clear need for a water scarcity indicator that integrates all water resources, water use and environmental impacts, but such an approach should be simple enough to apply with easily available input data and should be transparent so as to allow easy interpretation.

Water quality or water pollution is rarely regarded as an important factor in the water scarcity assessment (Oki and Kanae, 2006; Vörösmarty et al., 2010). Currently, almost all widely used methods for water scarcity assessment focus on the quantity of freshwater resources but pay little attention to water quality. However, water pollution has become a key factor influencing sustainable development in many countries. In China, according to the *Environmental Quality Standards for Surface Water* of China, 41% of river length and 42% of lake area did not meet general acceptable water quality standards in 2009 (MWRC, 2009). Without considering water quality, water scarcity is often underestimated. In China, water quality is assessed based on a comparison of key pollutant concentrations with water quality standards. Nowadays, more and more researchers call for an integrated water scarcity assessment that combines both water quality and quantity (Xia et al., 2005; Wang et al., 2006). Despite of this, the integration of water quality in water scarcity assessment is still

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Table 1
Main approaches for water scarcity assessment.

Approach	Main method for water scarcity assessment	Indicator threshold	Main inputs	Advantage	Disadvantage	Level of complexity	Main references
Falkenmark index (water stress index)	WSI = *WA*/*P* WSI: water stress index (m^3/cap/year) WA: water availability P: population	Water stress: WSI = 1000–1700 Water scarcity: WSI = 500–1000 Absolute scarcity: WSI < 500	(a) Water availability (b) Population	(a) The data are easily available. (b) The meaning is easy to understand.	(a) Not consider water quality. (b) Not reflect the contribution of water infrastructure to the release of water scarcity. (c) Not show the difference in water demand due to different climate conditions and lifestyle.	Low	Falkenmark et al. (1989); Ohlsson and Appelgren (1998); Savenije (2000)
Criticality ratio (CR)	CR = *W*/*WA* CR: criticality ratio W: water withdrawal WA: water availability	No water stress: CR = 0–0.1 Low water stress: CR = 0.1–0.2 Mid water stress: CR = 0.2–0.4 High water stress: CR = 0.4–0.8 Very high water stress: CR > 0.8	(a) Water withdrawal (b) Water availability	(a) The data are easily available. (b) The method makes a relationship between annual water supply and human demand.	(a) Not consider water pollution-induced scarcity. (b) Not include society adaptive capacity.	Low	Alcamo et al. (2000); Vörösmarty et al. (2000); Oki and Kanae (2006); Raskin et al. (1997)
IWMI indicator	WS = PWS/UWS UWS: utilizable water supply PWS: primary water supply	Physical water scarcity: WS ≥ 60% (the region will not be able to meet water demand in future) Economic water scarcity: WS < 60%, IPWS ≥ 25% (the region has sufficient water resources, but would have to make significant investment to make these resources available to people) Little or no water scarce: WS < 60%, IPWS < 25%	(a) Utilizable water supply (b) Primary water supply (c) Population (d) Water resources (e) Society's adaptive capacity	(a) The method considers water availability for human. (b) The method considers water demands based on consumptive water use. (c) The method takes into account society's adaptive capacity.	(a) The input data are enormous, complex and hard to collect. (b) Expert judgments are needed. (c) This approach is often practical for assessment at a country level, but not at a lower spatial level.	High	Seckler et al. (1998)
Water poverty index	$WPI = \frac{\sum_{i=1}^{n} w_i X_i}{\sum_{i=1}^{N} w_i}$ WPI: water poverty index value X_i: component *i* of the WPI structure (assessment as %) w_i: weight applied to the component *i*.	The lowest possible level of water poverty: WPI = 100 Level of water poverty: 0 < WPI < 100 the highest possible level of water poverty: WPI = 0	(a) Water resources: physical availability of both surface and groundwater (b) Water access: human access to water (c) Capacity: effectiveness of people's ability to manage water (d) Water use: different uses of water (e) Environment: evaluation of aquatic ecosystem completeness	Consider five dimensions: access to water; water quantity, quality and variability; water uses; water management capacity; and environmental aspects.	(a) The input data are enormous, complex and hard to collect. (b) Expert judgments are needed. (c) The meaning of this index is hard and complex to understand.	High	Sullivan (2002); Sullivan et al. (2003)