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Review

Groundwater vulnerability to climate change: A review of the assessment methodology

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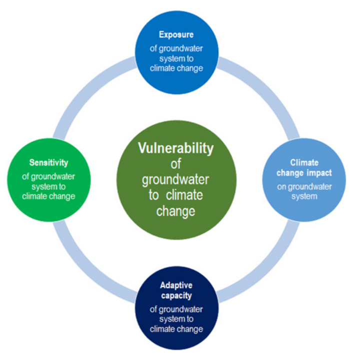
HIGHLIGHTS

- Presents a comprehensive review on methodologies for groundwater vulnerability assessment to climate change.
- Highlights the research gaps, including role of adaptive capacity in overall vulnerability.
- Proposes a new integrated methodology to assess vulnerability of groundwater resources to climate change.

GRAPHICAL ABSTRACT



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ABSTRACT

Impacts of climate change on water resources, especially groundwater, can no longer be hidden. These impacts are further exacerbated under the integrated influence of climate variability, climate change and anthropogenic activities. The degree of impact varies according to geographical location and other factors leading systems and regions towards different levels of vulnerability. In the recent past, several attempts have been made in various regions across the globe to quantify the impacts and consequences of climate and non-climate factors in terms of vulnerability to groundwater resources. Firstly, this paper provides a structured review of the available literature, aiming to critically analyse and highlight the limitations and knowledge gaps involved in vulnerability (of groundwater to climate change) assessment methodologies. The effects of indicator choice and the importance of including composite indicators are then emphasised. A new integrated approach for the assessment of groundwater vulnerability to climate change is proposed to successfully address those limitations. This review concludes that the choice of indicator has a significant role in defining the reliability of computed results. The effect of an individual indicator is also apparent but the consideration of a combination (variety) of indicators may give more realistic results. Therefore, in future, depending upon the local conditions and scale of the study, indicators from various groups should be chosen. Furthermore, there are various assumptions involved in previous methodologies, which limit their scope by introducing uncertainty in the calculated results. These limitations can be overcome by implementing the proposed approach.

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Contents

1. Introduction

Groundwater is a valuable resource for healthy living, ecosystems and sustainable development. At the global scale, it supplies one-third of total water withdrawal to cater for nearly 85 and 50% of rural and urban needs, respectively (Kumar and Shah, 2006). It is available in large reservoirs underneath the earth's surface that provide access or buffer storage during periods of shortage from surface resources (Lapworth et al., 2013). This ability further increases its importance at regional (e.g., Asia, Africa, Central and South America) as well as at national level, more specifically in semiarid countries.

Groundwater satisfies the drinking water requirements of about 2.5 billion of the global population (WHO (World Health organization), 2014). It also serves to sustain baseflow in wetlands, lakes and rivers during periods of low or no precipitation. Despite these indispensable contributions to human welfare and natural ecosystems, the resource is being developed in a haphazard manner, leading to its depletion and degradation. Climate variability/change has further worsened the situation by changing groundwater recharge in terms of timing, duration and magnitude (Hiscock et al., 2012; Taylor et al., 2012).

Since the beginning of the modern era, there has been an increasing threat to the quantity and quality of groundwater both from climatic and non-climatic factors solely and jointly. The former is associated with changes in climate over the twentieth century. During the latter part of twentieth century, air and ocean temperatures have escalated giving rise to hot days, hot nights and heat waves. Similarly, average precipitation totals have increased over high latitudes and decreased over subtropical, middle and lower latitudes (Bates et al., 2008). Precipitation intensity, duration and frequency are also likely to change. As projected by various studies, these trends will continue during the twenty-first century (Bates et al., 2008). The aforementioned changes have impacted on groundwater recharge (Okkonen and Kløve, 2011), sea levels and snow packs, which are key processes for the sustainability of groundwater resources (Taylor et al., 2012). It is likely that groundwater vulnerability will increase if the change in climate continues at current trends (IPCC, 2007). The non-climatic factors have the propensity to stress groundwater include population growth, urbanisation, deforestation and industrialisation, as well as increasing demands from the domestic and agriculture sectors, amplified by climate change (Mato, 2002; Taylor, 2014; Van der Gun, 2012). In some situations, the impact of non-climatic factors dominates those of climatic factors (Scanlon et al., 2007).

From the perspective of translating the impact information into relevant policy formulation and practice guidelines, it is imperative to assess groundwater vulnerability to climate change. This is because knowledge of its vulnerability can help explore the risks posed by climate change and identify/develop/implement feasible adaptation measures. Groundwater vulnerability to climate change refers to its sensitivity to current and potential threats from climatic stressors. It is a function of exposure, sensitivity and adaptive capacity (Fig. 1), representing the level up to which a system cannot withstand the potentially damaging impact of climate change. Exposure is the change in climate stimuli to which a system is exposed. Whereas sensitivity refers to the degree of impact on a system as a result of exposure to climate related stimuli, which is an intrinsic property. Adaptive capacity, on the other hand, is its ability to adjust to the potential damaging impacts of climate change. Therefore, groundwater reservoirs with insufficient capacity to withstand damaging impacts are vulnerable to climate change (IPCC, 2007; Vrba and Zaporozec, 1994).

To date, a number of investigations have been undertaken at different geographical locations and at different spatial scales to assess the vulnerability of groundwater resources to direct and indirect impacts of climate change. It is generally agreed that global climate change is posing a great challenge on human and natural systems (IPCC, 2007). As a result, there has been an increasing demand for dependable methods to assess the relative vulnerability of systems to likely impacts of climate change (Carter et al., 2007). However, as vulnerability to climate change is highly dependent on the context and scale, varying