Environmental Science and Policy 89 (2018) 41–48

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

An interdisciplinary framework for the protection of karst aquifers

Katarina Kosič Ficco[a,b,*], Ira D. Sasowsky[c]

[a] University of Nova Gorica, Postgraduate Program of Karstology, Nova Gorica, Vipavska 13, 5000 Nova Gorica, Slovenia
[b] Department of Conservation and Recreation, Natural Heritage, Karst Protection Program, 8 Radford Street, Suite 102, Christiansburg, VA 24073, USA
[c] University of Akron, Department of Geosciences, Ohio, USA

ARTICLE INFO

Keywords:
Karst aquifer
Protection
Management
Interdisciplinary framework
Cooperation

ABSTRACT

Karst aquifer assessment and management demand site-specific approaches due to their varying character and susceptibility to contamination. This hampers adoption of sustainable protection policies and management practices for these valuable water resources, which currently remain disjointed. Existing methodologies and guidelines can be confusing, and interjurisdictional protection is hampered due to lack of cooperation between involved parties, and differences in legislative systems. By adopting unified procedures and steps, these issues could be solved. Therefore, a new interdisciplinary framework for karst aquifer protection and management is proposed, which can be used regardless of the legislative system, terrain, and hazards. This K-framework provides guidelines for carefully structured cooperation between domains that, are or need to be, involved in karst aquifer protection, e.g. karst scientists, other scientists, policy-making bodies, the public, and various stakeholders. The presented framework is based on levels of knowledge that each of these parties can contribute to the process, and can be used for developing site-specific assessment guidelines for karst aquifers as well as protection policies on the national and international levels. By following the straightforward guidelines provided in this framework, management and protection of karst aquifers can be assured without major changes to existing methodologies and legislative practices.

1. Introduction

Approximately 75% of European Union (EU) residents depend on groundwater for their water supply (Stevanović et al., 2016; Chen et al., 2017), along with 40% in the United States of America (USA) (Alley et al., 1999). Overall, karst aquifers, flowing through dissolution conduits in carbonate rock, provide 25% of the world's drinking water (Ford and Williams, 2007). Thus, protection and preservation of these resources is critical for countries worldwide.

Unfortunately, karst aquifers are highly susceptible to contamination and deterioration from overexploitation, lack of self-cleaning mechanisms, and poorly defined watersheds (Gunn, 2007; van Beynen, 2011; Parise, 2014; Stevanović, 2015). Additionally, their character varies between regions, which hampers their evaluation and prevents generalizing of preservation and protection approaches. Therefore, their protection is frequently neglected and/or not fully addressed.

There have been numerous discussions and proposals on how to combine scientific findings related to karst terrains and aquifers with environmental policies in order to assure more comprehensive and coherent protection measures for these resources (van Beynen and Townsend, 2005; Zhou and Beck, 2008; van Beynen, 2011; van Beynen et al., 2012; Krešić, 2013; De Waele et al., 2015; Ravbar and Šebela, 2015). However, karst aquifer preservation through the regulatory system is a complex process in which the involvement of specific domains is frequently ineffective or even neglected. Cooperation can be assured with inclusion of various domains, including scientists, policy-making bodies, stakeholders (e.g. governmental and private environmental agencies), and the public.

The goal of this study is to develop an interdisciplinary framework that enables enhanced management and protection of karst aquifers without substantial changes to existing methodologies and legislative practices. The framework is based on dividing these domains into various levels of knowledge about karst and defining their involvement in the process of karst aquifer protection and management, thereby assuring inclusion and information gathering from all impacted parties.

The framework in this study was created following the "levels of knowledge" approach developed by Bouma (2006) for hydropedology. This was accomplished by analyzing several aspects of existing karst aquifer protection and management. Two domains, policy-making bodies and scientists, and the obstacles that they are facing when trying to implement and shape environmental protection policies, were studied. Then, existing methods for protection of natural resources and,

* Corresponding author at: 8140 Cumberland Gap Rd., New Castle, VA, 24127, USA.
E-mail addresses: katarina.kosic@dcr.virginia.gov (K. Kosič Ficco), ids@uakron.edu (I.D. Sasowsky).

https://doi.org/10.1016/j.envsci.2018.07.005
Received 15 January 2018; Received in revised form 14 May 2018; Accepted 7 July 2018
1462-9011/ © 2018 Elsevier Ltd. All rights reserved.

consequently, karst aquifers, in the USA and the EU were analyzed in order to identify both the shortcomings and the positive aspects of existing approaches. Based on these analyses, three important aspects were identified: 1) inclusion of karst scientists and the public; 2) cooperation between various domains and stakeholders; and, 3) exchange of information among these domains. The final step was developing an interdisciplinary framework that would incorporate all of these findings and could assure inclusion of all domains based on their contribution to the process.

2. The functioning and protection of karst aquifers

Karst aquifers are characterized by heterogenous systems of conduits, fractures and fissures where groundwater follows preferential paths along fractures and bedding planes. Flow paths are mainly developed by dissolution of the rock and are subject to changes, in both time and space. Karst aquifers are also anisiotropic, meaning that their flow path is directionally dependent on the structure of solution openings and fractures which enable groundwater to move horizontally or vertically (Klimchouk, 2000; Culver and White, 2005; Ford and Williams, 2007; Goldscheider and Drew, 2007).

Contaminants reach karst aquifers through percolation of surface and meteoric waters underground. Recharge and storage influence the residence time of water in the aquifer (Fig. 1), as there are different ages of water that are present (soil water, old, mixed water, and fresh water). Flushing of these waters during a rain event depends upon the amount of precipitation and the structure of the system (Perrin et al., 2003; Ford and Williams, 2007; Knez et al., 2011). Thus, understanding recharge and storage is extremely important to evaluate contamination processes and hence develop suitable protection measures. Karst groundwater storage depends upon (1) the properties of soil; (2) the structure of the vadose and phreatic zones (Fig. 1); and (3) recharge (Perrin et al., 2003; Knez et al., 2011).

2.1. Vulnerability and protection of karst aquifers

Contaminants are detained and accumulate in these systems, with sporadic onward flushing toward springs (Knez et al., 2011), depending on the (1) structure of the system, (2) hydrological conditions, and (3) the nature of the contaminant (Perrin et al., 2003; Goldscheider and Drew, 2007; Knez et al., 2011). Contaminant residence times in the aquifer can be determined by analyzing the residence time of groundwater in the system if the contaminants are miscible/soluble or share similar physical characteristics with water. New water can be rapidly introduced in the system through direct recharge (Fig. 2). In this case the water and potential contaminants are introduced directly to the phreatic zone. However, depending upon the structure of the system, the water and contaminants can be detained in the system and slowly seep toward the spring. For example, Fig. 1A illustrates a void where old water was completely substituted by mixed water through a rain event, while Fig. 1B shows a void where the mixed waters are still displacing the old water through small fissures. In the last two cases, slight changes in groundwater chemistry, while not immediately and dramatically evident, may become so later (Urich, 2002). It is therefore important to address both point and non-point contamination sources (Kosič et al., 2015).

Properly mapping karst watersheds helps predict the transmission of contaminants through the aquifer. However, these watersheds can extend over vast areas that are difficult to delineate, since they rarely correlate to surface drainages (Krešić, 2013; Parise, 2014). Crossing surface water divides is caused by piracies and spillover routes, which enable groundwater to travel unpredictably through the aquifer (Culver and White, 2005).

There are many examples where contaminants have been unexpectedly detected at remote locations from their sources. Some have had deleterious, even fatal consequences (Imes and Emmett, 1994; Ford and Williams, 2007; Knez et al., 2011; van Beynen, 2011). Aquifer delineation and monitoring of discharge identify pathways for the contamination of groundwater and springs, and prevent such accidents. Due to the dependence of aquifer discharge on precipitation, water quality monitoring must be event based. Additionally, understanding of the recharge and watershed prior to implementation of hazardous activities is critical to assure that monitoring stations are present at all springs and wells being used as water sources.

On final note, remediation is greatly hampered once the contaminants reach groundwater in karst conduits (León and Parise, 2009; Knez et al., 2011) Therefore, legislative measures that implement remediation instead of prevention are inadequate for karst aquifer protection.

3. Methods

A framework that incorporates scientific and socio-political aspects was developed by combining analyses of scientific as well as legislative practices regarding karst aquifer protection. The main factors hindering the implementation of coherent protection policies were identified by: (1) analyzing the main obstacles that the two primary domains (policy-making bodies and scientists) face while trying to propose appropriate measures, (2) analyzing the current status of environmental protection in the USA and the EU, and (3) presenting cases of karst assessment in the USA prior to initiating construction projects in order to illustrate the importance of including karst scientists and the public domain in the processes. Conclusions derived from these analyses enabled development of an interdisciplinary framework for management and protection of karst aquifers.

4. Results and discussion

4.1. Scientific and policy-making domains and environmental legislation

Various domains and stakeholders have different incentives for dealing with water resources. Scientists develop suggestions and methods for protection measures through studies, research, monitoring, etc., while policy-making bodies, e.g. the political and legislative domains, are generally aiming to assure preservation of these resources through legislative mechanisms. Each domain encounters different issues while pursuing their mandate.

The scientific domain faces (1) lack of background data while trying to assess a resource; (2) lack of scientists for a specific field, e.g. taxonomists, karst experts (van Beynen and Townsend, 2005; North et al., 2009); and (3) inadequate implementation of legislation (Zagmajster et al., 2016).

Policy-making bodies, on the other hand, need to garner public support in order to effectively implement policies (Wan et al., 2017). Therefore, they need to adopt strategies that will be sustainable, cost-effective, appealing to the public and stakeholders, and applicable at various levels, including the international ones. Adopting inefficient or ineffective policies leads to loss of public trust. Additionally, it risks public health and safety, endangers natural resources, and impacts the economy of the country/region.

Choosing the most appropriate approach is challenging. Non-scientific stakeholders can have difficulties understanding proposed methods. Consequently, the scientific findings may not be appropriately comprehended and placed in a broader context, while assessing their functionality. This happens especially while working in interdisciplinary teams and international panels (Bouma, 2006). The process is additionally hampered by the variety of solutions which stakeholders can choose from, which can delay the process of policy-making and can be misused as a tool for interest-oriented decisions from legislative bodies (Robertson and Hull, 2003; Rayner, 2006; Holmes and Clark, 2008; De Santo, 2017).

In their effort to jointly assess and develop sustainable

Download English Version:

https://daneshyari.com/en/article/7465616

Download Persian Version:

https://daneshyari.com/article/7465616

Daneshyari.com