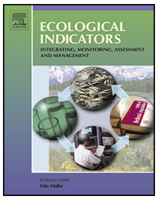
Ecological Indicators 75 (2017) 164–181

Contents lists available at ScienceDirect

Ecological Indicators

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



Original Articles

The weighted groundwater health index: Improving the monitoring and management of groundwater resources

Kathryn L. Korbel*, Grant C. Hose

Department of Biological Sciences, Macquarie University, New South Wales 2109, Australia

ARTICLE INFO

Article history:
Received 21 July 2015
Received in revised form
24 November 2016
Accepted 25 November 2016
Available online 30 December 2016

Keywords:
Groundwater
Stygofauna
Ecosystem health
Biomonitoring
Groundwater assessment

ABSTRACT

Increased global demand for groundwater has resulted in the need to measure and monitor this resource. Rather than monitoring groundwater simply though water chemistry and levels, which provides a 'snap-shot' of the conditions at any given time, a more holistic approach to managing groundwater resources and their changes over time is needed. Korbel & Hose (2011) introduced the first structured framework for measuring groundwater health – the Groundwater Health Index (GHI). This multimetric, two-tiered framework uses biotic and abiotic components of the groundwater ecosystem to measure and identify ecosystem health. The framework can be used to classify impacted from non-impacted groundwaters, however it has certain limitations. With increased research and associated knowledge of groundwater ecosystems in recent times, it is now timely to attempt to build on the GHI framework.

This paper refines and improves the GHI by incorporating a weighting system to account for natural factors contributing to variations in biotic distribution and is tested on data within four geologically similar alluvial aquifers in intensively irrigated agricultural areas of New South Wales and Queensland, Australia. Using a combination of microbial, stygofaunal, water chemistry and environmental indicators, the 'weighted GHI' framework was able to discriminate three distinct ecosystem health classifications; that of 'similar to reference'(displaying reference-like condition) 'mild deviation from reference' (sites failing to meet between 2 and 3 benchmarks) and 'major deviation from reference' (sites with more than four benchmarks exceeded). The framework indicated that groundwater health deviated from reference condition in all four catchments studied, with irrigated sites consistently displaying deviations from reference ecosystem health. Tier 2 benchmarks were set using results from the Gwydir River, and were tested on the adjacent Namoi River catchment, the Condamine and Lower Macquarie catchments. Results indicated that ecosystem health benchmarks may be associate with aquifer typology, rather than being applicable only for local areas.

1. Introduction

The growing pressures on aquifers for water supply and the impact of human activities (Di Lorenzo et al., 2014; Griebler and Lueders, 2009) has led to a worldwide push to monitor groundwater quality (e.g. CRC, 2004; EU Groundwater Directive 2006/118/EC). In Australia, as in many jurisdictions globally, legislation and government policies are requiring the monitoring and assessment of groundwater and dependent ecosystems (e.g. DNR, 2003a, 2003b), including, in places, the establishment of biological indicators (NGC, 2004a, 2004b). While techniques to assess the health and condition of surface waters are well established (e.g. Chessman, 1995; Simpson et al., 2000; Wright et al., 1998), the same cannot be said for groundwater ecosystems.

Despite the potential for using bioindicators to measure groundwater health (Bauld, 1996; Griebler et al., 2014; Malard et al., 1996 Malard et al., 1996), few studies have utilised such indicators (e.g. Marmonier et al., 2013; Mermillod-Blondin et al., 2013). Hahn (2006) provided the first predictor of groundwater faunal composition, the Groundwater Fauna Index, based on hydrological exchange within aquifers, and others have attempted to predict groundwater diversity (e.g. Stoch et al., 2009) however such predictive tools focus on biological structure or integrity and so, do not reflect the more holistic notion of ecosystem health (Boulton 1999). The relative paucity of research may reflect the difficulties associated with sampling and analysis of groundwater ecosystems (Hahn, 2002; Korbel et al., 2013a), and the limited knowledge of

---

* Corresponding author.
E-mail address: Kathryn.Korbel@mq.edu.au (K.L. Korbel).

http://dx.doi.org/10.1016/j.ecolind.2016.11.039
1470-160X/

groundwater ecosystem functioning including their response to environmental change (Stein et al., 2012).

Korbel and Hose (2011) introduced a tiered framework for assessing groundwater ecosystem health, which culminated in the Groundwater Health Index (GHI). The framework is a two tiered assessment approach, using biotic and abiotic attributes of groundwater ecosystem to set benchmarks which, by way of comparison, provide an indication of ecosystem health. Tier 1 benchmarks were based on generic attributes of groundwater ecosystems and so are potentially applicable to groundwater ecosystems worldwide. Tier 2 benchmarks were established using data from local reference sites, and accordingly may have limited applicability beyond the region from which benchmarks were established. The GHI could effectively discriminate disturbed from undisturbed sites however, its ability to classify sites in terms of ecosystem health was limited.

The GHI was originally applied to assess sites under irrigated and non-irrigated agricultural lands. Differences in groundwater biota and water quality under different agricultural landuses have been widely demonstrated (Bolger and Stevens, 1999; Korbel et al., 2013a; Schmidt et al., 2007), with changes to biota occurring in response to altered hydrological connectivity (between surface and groundwater) and increases in nutrient and agrochemical concentrations in the groundwater as a result of infiltration of irrigation water. These processes have been identified as threats to groundwater quality and ecosystem health (Böhlke, 2002; Hose, 2005; Humphreys, 2009; Korbel et al., 2013b), and have been associated with shifts towards increased overall biotic abundance and changes in community structure, such as decreased relative abundance of obligate groundwater taxa and decreases in proportions of crustaceans (see Korbel and Hose, 2011).

With relatively subtle changes occurring in groundwater ecosystems due to moderate nutrient enrichment or disturbance, it can be difficult to distinguish disturbed sites from those with a fauna that may be naturally rich or abundant. Recent advances in the understanding of groundwater ecosystem structure and function in response to natural factors such as dissolved oxygen concentration, geology, tree roots, hydrological exchange and climate (Graillot et al., 2014; Hahn, 2006; Jasinska and Knott, 2000; Korbel and Hose, 2015; Schmidt and Hahn, 2012), have the potential to increase the discriminatory power of the GHI and in this paper we aim to improve the GHI by incorporating such knowledge of groundwater ecosystems and their response to natural and anthropogenic factors.

Specifically, the aims of this study are 1) to improve the existing GHI framework by incorporating new knowledge of groundwater ecosystem functioning and biotic distribution; 2) to classify sites based on their ecosystem health status; and 3) to test the improved weighted groundwater health index (wGHI) framework across new sites in the catchment where it was developed (the Gwydir) and within three other catchments (Namoi, Condamine and Lower Macquarie) of similar typology and geological history.

2. Study region

The study was conducted in the Gwydir, Namoi and Macquarie River catchments in Western New South Wales (NSW) and the Condamine River catchment in South-Western Queensland, Australia, over a period of 8 years (Fig. 1). In general terms, all four catchments have similar geological formations (sand, silt and gravels), underlying areas of geologically younger alluvium (Barrett, 2009; Carr and Kelly, 2010; Giambastiani and Kelly, 2010; Queensland Government, 2012). Sampling was restricted to the upper unconfined alluvial aquifers in all catchments, with depths of 10–38 m.

The Gwydir and Namoi catchments both consist of the 'Narrabri' formation and experience similar rapid recharge of groundwater after rainfall, indicating high hydroconnectivity to the surface (Kelly et al., 2012; Menció et al., 2013). Sampling in the Condamine catchment was limited to the Condamine River alluvium, and the Macquarie catchment was restricted to the Lower Macquarie alluvium, both consisting of layers of fine to course sands, silt and gravels, with layers of clay (Giambastiani and Kelly, 2010; Queensland Government, 2012). Hydraulic conductivity of the aquifers is thought to be comparable between all four catchments (Barrett, 2009; CSIRO, 2007; Dafny and Silburn, 2014).

A pilot study (used for reference site selection) consisted of sampling 15 sites within the Gwydir River catchment around the township of Moree (29°28′S, 149°54′E, population 7720; ABS, 2011; Fig. 1). After the conclusion of the pilot study, a total of twenty-five wells were sampled from the shallow alluvial aquifer in the Gwydir River catchment in August 2007, February/March 2008, February 2010, August 2010, February 2015 and September 2015. Due to sampling conditions and access, not all wells were sampled on all occasions. A further 15 wells from the adjacent Namoi River catchment, near the township of Wee Waa (30°12′S, 149°26′E, population 1653; ABS, 2011), were sampled in August/September 2007 and February/March 2008. A prolonged drought in the region ended in 2010, resulting in the Gwydir catchment being sampled during and after drought conditions. All Namoi catchment sites were sampled during drought conditions.

The Macquarie River catchment (Central −Western NSW) and the Condamine catchment in Queensland were sampled in December 2014 and September 2015. Coincidently, this was also in a period of drought. The Condamine catchment is located approximately 180 km to the north of the Gwydir catchment, near Toowoomba (27°33′S, 151°93′E, population 161,970; ABS, 2011) in southern Queensland. Fifteen sites within the shallow alluvial aquifers, west and south of Toowoomba were sampled in this study. Ten sites in the lower Macquarie River catchment, located 300 km south of the Gwydir catchment, were sampled around the township of Narromine (32°13′S, 148°14′E, population 6854; ABS, 2011). Samples were taken from the shallow (10–35 m depth) aquifers in areas where the geology was very similar to the other three catchments.

2.1. Landuses

Agriculture is the main industry in all four catchments, with irrigated cotton being the largest financial contributor to the Namoi and Gwydir catchments (ACG, 2010), and a dominant landuse in the Condamine (MDBA, 2015) and lower Macquarie catchments (Green et al., 2011). Other landuses include grazing and both dryland and irrigated cropping (e.g. sorghum, lucerne, mung beans) and, consequently, all catchments have been extensively modified for agriculture. Groundwater is widely used for irrigation and stock in all four catchments, with irrigation activities undertaken for over 50 years (Carr and Kelly, 2010; Giambastiani and Kelly, 2010; Kelly et al., 2012). Declining groundwater levels and pesticide contamination have been linked to irrigation in the Gwydir and Naomi catchments (Barrett, 2009; Carr and Kelly, 2010; Muschal and Cooper, 1998) and groundwater extraction in the Condamine catchment is believed to contribute to declining water levels (MDBA, 2012, 2015). Sites were categorised into one of three land uses; irrigated cropping, mixed landuse and grazing (following Korbel et al., 2013a).

2.1.1. Irrigated cropping

'Irrigated cropping' landuse classification was dependent on irrigated infrastructure (e.g. canals/trenches, irrigation and/or groundwater pumps) being clearly visible. Cotton growing in all catchments involves the addition of fertilisers in late winter and then periodic inundation of fields with a combination of