Ecological Indicators 88 (2018) 292–304

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Economic valuation of groundwater protection using a groundwater quality ladder based on chemical threshold levels

Roy Brouwer[a,b,*], Carlos Miraldo Ordens[c], Rute Pinto[a,d], M. Teresa Condesso de Melo[e]

[a] University of Waterloo, Canada
[b] Swiss Federal Institute for Aquatic Science and Technology (Eawag), Zürich, Switzerland
[c] University College London Australia, Adelaide, South Australia, Australia
[d] MARE, Faculty of Sciences and Technology, University of Coimbra, Portugal
[e] CERIS, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal

ARTICLE INFO

Keywords:
Groundwater quality ladder
Natural background levels
Contingent valuation
European Groundwater Directive

ABSTRACT

Improving groundwater quality is expected to yield direct use benefits to society (e.g. clean and safe drinking water) and groundwater dependent ecosystems. Ten years after the adoption of the European Groundwater Directive (GWD), policymaker and public understanding of the societal value of groundwater protection is still rather limited. This is partly due to the invisible and intangible nature of groundwater resources and the sheer lack of valuation studies. This study contributes to the limited number of groundwater valuation studies in Europe by estimating the public benefits from improved groundwater quality in the Aveiro Quaternary Aquifer (AQA) in Portugal. This is the first and only economic valuation study of groundwater in Portugal. In order to communicate the various benefits provided by groundwater resources in easy understandable terms to lay people, and to assess public perception and willingness to pay (WTP) for groundwater protection, a groundwater quality ladder was developed based on the threshold values proposed in the GWD. The ladder reflects the different use and non-use values of groundwater quality improvements and accounts for natural background levels of chemicals in groundwater. The large-scale survey targets a representative sample of residents in the AQA. Split samples are used to assess the impact of framing groundwater protection in a broader regional water resources management context, giving part of the sample furthermore time to think about their WTP for the different groundwater threshold levels. Although use values dominate public WTP for the different groundwater threshold values, substantial non-use values are also found. Public WTP is considerable, varying between 20 and 30% over and above the current water bill residents pay for safe drinking water quality and natural background levels, respectively. Giving respondents time to think and framing groundwater protection as part of the improvement of all water resources in the region results in a more conservative WTP estimate. Public WTP is higher for better informed private well owners in rural areas. Aggregated across the entire aquifer the estimated total economic value is 1.5 million euros annually for safe drinking water quality and 3.5 million euros annually for groundwater containing natural background levels only.

1. Introduction

Groundwater resources are subject to increasing pressures, from both point- and diffuse-pollution sources. As a result, hazardous chemicals that infiltrate the aquifers from domestic and industrial sources, and fertilisers and pesticides from farms accumulate in the groundwater (e.g. Panno et al., 2006; Pedreira et al., 2015). In addition, also climate change is expected to significantly increase the vulnerability of these aquatic resources (Woldeamlak et al., 2007). Groundwater quality changes pose a significant threat to dependent ecosystems (Eamus et al., 2015), long-term aquifer sustainability (Werner et al., 2011), human health (Cabral Pinto et al., 2017) and to social and economic activities that rely on the groundwater resources (Bergstrom et al., 1996; Kløve et al., 2011). As a result, in 2006 the European Union adopted and implemented the European Groundwater Directive (GWD) 2006/118/EC, a 'daughter' directive of the Water Framework Directive (WFD) 2000/60/EC, to protect groundwater bodies. In order to achieve this, the chemical status of groundwater bodies has to be determined and threshold values have to be established to guarantee the protection of human health and the environment (Hinsby et al., 2008). However, these threshold values can only be identified after assessment of the groundwater's natural background levels (NBLs) of the chemicals involved. Groundwater bodies may

* Corresponding author at: Department of Economics and the Water Institute, University of Waterloo, 200 University Avenue West, Waterloo, ON, N2L 3G1, Canada.
E-mail addresses: rbrouwer@uwaterloo.ca (R. Brouwer), c.branco@ucl.ac.u (C.M. Ordens), rutepinto@ci.uc.pt (R. Pinto), teresa.melo@tecnico.ulisboa.pt (M.T. Condesso de Melo).

https://doi.org/10.1016/j.ecolind.2018.01.041
Received 12 September 2017; Received in revised form 18 January 2018; Accepted 21 January 2018
1470-160X/

naturally contain a range of chemicals, depending on the natural characteristics of the aquifers, such as their geological and geographical features, flow paths and chemicals' residence times (e.g. Edmunds et al., 2003; Ducci et al., 2016; Cidu et al., 2017). Only after the assessment of these NBLs and the definition of threshold values, regulatory measures can be implemented effectively.

Besides the importance of reaching good chemical status for groundwater bodies, the GWD also recognizes the need to balance the costs of groundwater protection policies with the environmental and socio-economic benefits generated by these resources. Previous studies have shown that the identification of groundwater benefits and their associated values is essential to effectively communicate their importance to users and decision-makers (e.g. McClelland et al., 1992; Koundouri et al., 2013a). Groundwater provides a large number of services that are of value to humans. Direct uses of groundwater include extraction for drinking water, irrigation or industrial production. Groundwater may also have non-use value if people that are currently not using the resource place a value on its continued existence or pristine state. In addition, people that currently do not use groundwater might place a value on having the option to use it in the future, or for it to be available to future generations. Evaluation of the trade-offs necessary to allocate these limited available groundwater resources in an efficient and sustainable manner between competing demands requires the consideration of their economic value.

Some values associated with groundwater may be directly observable in well-functioning markets, for instance if water users pay a fee for the quantity of water they extract. Often, however, groundwater values are not observable and can only be estimated using non-market valuation methods. Among the available valuation techniques, stated preference methods have been used for valuing both use and non-use benefits of water resources (e.g. Johnston et al., 2003). One of the most used methods in this context are contingent valuation (CV) surveys to assess public perception and valuation of groundwater quality improvements (e.g. Poe et al., 2001; Hérivaux and Rinaudo, 2016). This method has been applied to address several groundwater quality issues, including the estimation of the environmental costs associated with groundwater quality changes (White et al., 2001; Tentes and Damigos, 2012), including non-use values to inform policy for example in the context of the EU WFD (e.g. Hasler et al., 2005; Martínez-Paz and Perni, 2011), to improve drinking water quality (e.g. Khan et al., 2014), or to inform groundwater remediation projects (e.g. Stenger and Willinger, 1998; Rinaudo and Aulong, 2014).

Despite the importance of groundwater for successful integrated water resources management, a WFD requirement, the number of economic valuation studies focusing on groundwater protection is very limited, also in Portugal. In fact, no such studies exist and the study presented here, although carried out immediately following the adoption of the GWD in 2006, is the first and only one as far as we know. The values obtained in 2006 are still highly relevant now to inform policy and decision-making, and serve as a benchmark for future groundwater valuation studies in Portugal. The limited number of stated preference studies related to water carried out in Portugal all focus on surface water. In a choice experiment, Katayama et al. (2009) analysed farmers' willingness to pay (WTP) in the Guadiana basin, a transboundary river in southwest Portugal, for water supply policies, considering the effects of a large dam construction (the Alqueva dam). Guimarães et al. (2011) used CV surveys to estimate local residents' WTP to improve water quality in the Guadiana estuary. Pinto et al. (2016) conducted a large-scale CV study in the Mondego catchment in the north-western part of Portugal, focusing on WTP of local residents to improve water quality levels of the basin and the estuary separately to good ecological status as required by the WFD. Roebeling et al. (2014 and 2016) assessed the non-market values of water quality improvements in the Minho catchment in northern Portugal and in a sub-catchment of the Vouga river, but borrowed values from the international literature to approximate these values.

The main objective of this study is to add to the empirical evidence base of the societal value of groundwater protection in Portugal and Europe. Although carried out in 2006 following the adoption of the GWD, the study follows a state-of-the-art design (Bateman et al., 2002; Johnston et al., 2017) and tests a number of relevant methodological issues, including the effect of framing groundwater protection in a wider water resources management context, sensitivity to scope, giving respondents time to think and comparing the effect of different survey administration procedures. Although a lot of attention has been paid to the water quality ladder developed by Resources for the Future for surface water quality (e.g. Brouwer et al., 2009), no such ladder exists for groundwater, and this study is hence the first study, as far as we know, that applies such a ladder in this particular context, accounting for groundwater resources' NBLs. This study is furthermore considered relevant since it incorporates social dimensions, through the involvement of local communities and groundwater end users, into hydrogeological research and groundwater management, which has become increasingly important (Re, 2015).

2. Methodology

2.1. Survey design and main hypotheses

Public WTP for groundwater protection was estimated through a large-scale CV survey in the Aveiro Quaternary Aquifer (AQA) region. Respondents were asked for their WTP for different groundwater threshold values. Two different questionnaire versions were used, differing in how the WTP questions were framed. One version asked respondents to value all surface and groundwater resources in their region first, followed by the value they attach to the protection of the groundwater body only. The other version asked respondents to value the AQA directly. This leads to our first hypothesis related to the framing of the WTP question for groundwater protection, where we undertook a systematic comparison between the values that inhabitants give to nested goods, considering all surface and groundwater resources in their region (*allwater*) with the values attributed to groundwater protection only (*groundwater*):

$$H_1: WTP_{allwater} < WTP_{groundwater} \quad (1)$$

Following similar embedding procedures followed elsewhere in the literature (e.g. Brouwer and Slangen, 1998; Powe and Bateman, 2004), our a priori expectation is that the mean stated WTP values for groundwater will be significantly lower when elicited as part of a bigger whole.

Our second hypothesis was that if respondents are given more time to think, they will state WTP values that are lower than those from respondents who are not given extra time to think. This was tested by leaving the questionnaire behind in respondents' home and picking it up after a few days (e.g. Ethier et al., 2000; Cook et al., 2007, 2012). Respondents were either selected on a random next- to-pass basis in the main streets of villages and towns in the region, and interviewed face-to-face on the spot by trained enumerators, or they were contacted in their home by interviewers who went door-to-door, explained the questions in the questionnaire and left the questionnaire with respondents to fill out on their own before it would be picked up again at a predetermined time by the interviewer (respondents were given either 1, 2, 3, 4, 5, 6 or 7 days to complete the survey).

Based on previous studies, our a priori expectation is that mean WTP will be lower if respondents are given time to think over the questions on their own in their home without any time pressure and limited interviewer bias:

$$H_2: WTP_{home} < WTP_{face-to-face} \quad (2)$$

In order to estimate WTP for groundwater quality improvements, a water quality ladder (Fig. 1A) was created. In a first step, current groundwater quality levels were described to respondents, identifying