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Beyond aquifer boundaries: unveiling the multi-dimensional value of groundwater management in Jeju, Korea

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ABSTRACT

This paper presents a comprehensive analysis of groundwater valuation in Jeju Island, Korea, which relies heavily on groundwater resources. The research addresses the limitations of conventional valuation methodologies that often undervalue groundwater management and ignore spatial heterogeneity. We employ three non-market valuation aggregation methods: local benefit, national benefit, and a combined heterogeneous benefit approach. The heterogeneous benefit approach divides the population into groups based on their distinct groundwater valuations and then consolidates their willingness to pay. Using a contingent valuation method, we analyze survey data from 542 respondents in Jeju and 1,000 respondents nationwide to capture the comprehensive value of improving groundwater quality, considering both local and non-local dependencies. Results show that national benefits exceed local benefits by a factor of 21.4, and this disparity increases to 21.6 when spatial heterogeneity is included. These findings highlight a significant underestimation in previous studies focusing solely on local beneficiaries. Our approach enhances understanding of the varied values attributed to groundwater by different populations, providing crucial insights for sustainable water resource management

Key words: Jeju groundwater, Spatial heterogeneity, Groundwater valuation, Population of beneficiaries, Extent of market

HIGHLIGHTS

- It introduced three non-market valuation aggregation methods to capture comprehensive groundwater value in Jeju.
- It shows the difference between national and local benefits.
- It highlights the need for sustainable groundwater management policies that consider diverse beneficiary populations.
- It provides a framework for evaluating groundwater quality improvements in other regions dependent on groundwater resources.

1. INTRODUCTION

The increasing global challenges related to water management over the past century underscore the importance of accurate valuation of this critical resource. Rapid population growth, economic activities, and climate change have led to heightened seawater intrusion, accelerated groundwater depletion, and escalated water pollution (Esteban & Albiac, 2011). These issues are particularly profound in regions such as islands, where reliance on groundwater is significant, and unique ecosystem characteristics – such as isolation, vulnerability, and limited

connectivity – exacerbate these challenges. Hence, estimating the true value of groundwater management, a common pool resource, is critical for devising sustainable policies.

Aggregate benefit estimates can vary significantly depending on how the market extent is defined and whether heterogeneous spatial patterns are accounted for. The estimated value often hinges more significantly on the definition of the extent of the market than the estimates of mean willingness to pay (WTP) (Smith, 1993). Accurately defining the market extent is challenging, with various methodologies employed, such as distance decay (Pate & Loomis, 1997; Hanley *et al.*, 2003; Bateman *et al.*, 2006; Schaafsma *et al.*, 2012) and geopolitical threshold effects (Johnston & Duke, 2009; Brouwer *et al.*, 2010). While our study defines the market extent at a national level, we will also illustrate differences in benefit estimates when narrowing the extent to the aquifer boundary, highlighting the impact of market extent on groundwater valuation.

Despite a well-defined market extent, consideration must also be given to the spatial patterns within this extent. Most stated preference (SP) studies have implemented random sampling from a target population, often neglecting spatial dimensions, overlooking these patterns can result in biased or inefficient estimations (Anselin, 2001; Glenk *et al.*, 2020). A failure to account for this spatial diversity can lead to an underestimation of welfare when aggregating WTP values across regions (Brouwer *et al.*, 2010). Our study scrutinizes the variability in how Jeju groundwater is perceived as a resource across different regions.

We employ three distinct non-market valuation aggregation methods to provide a comprehensive understanding of the heterogeneous regional values ascribed to groundwater quality improvements. The first method appraises local benefits within the aquifer area, a technique frequently used in groundwater valuation studies (Sun *et al.*, 1992; Jordan & Elnagheeb, 1993; Bergstrom & Dorfman, 1994; Bergstrom *et al.*, 2004; Abedi *et al.*, 2014; Tentes & Damigos, 2015; Vo & Huynh, 2017). Previous studies on Jeju groundwater have been similarly limited to the aquifer area, potentially underestimating the broader benefits for the entire population (Shin *et al.*, 2011; Park & Lee, 2022).

SP studies on cultural heritage, in contrast, have explored various market extents, reflecting diverse economic values. Some studies focus solely on local residents (Santagata & Signorello, 2000; Whitehead & Finney, 2003; Barrena *et al.*, 2014), while others target tourists and visitors (Boxall *et al.*, 2003; Apostolakis & Jaffry, 2005). Additionally, some studies include both local residents and tourists (Tuan & Navrud, 2007; Báez & Herrero, 2012), and others concentrate on the domestic population (Maddison & Mourato, 2001; Kim *et al.*, 2007). This varied market scope provides a comprehensive understanding of the economic value of cultural heritage, reflecting both local impacts and broader societal benefits.

In contrast to cultural heritage, groundwater valuation is often limited to aquifer boundaries, even though groundwater can also hold natural heritage value. Most studies have confined groundwater valuation to local residents within the aquifer area. However, Azzopardi *et al.* (2023) highlight that people do not distinguish between cultural heritage and natural heritage, recognizing that the environment itself holds heritage value. Just as a forest can hold significant meaning beyond being a collection of trees, natural elements like beaches, coves, and rivers are considered cultural heritage.

This implies that while cultural heritage encompasses national pride and value to tourists, it is inconsistent to limit the evaluation of natural resources like water strictly within their ecological boundaries. It is crucial to identify, evaluate, and understand the relationships between heritage values for effective environmental management, and integrate these values into legal and voluntary governance processes. Bridging these fields can promote more effective and integrated participatory management (Azzopardi *et al.*, 2023).

Two key reasons justify a broader population of users for Jeju groundwater. The first is Jeju Island's status as an iconic tourism resource in Korea, with tourists attributing recreational or option value to the island's ecosystem. The second reason involves the extensive use of the island's groundwater beyond its geographical boundaries.

Mainland residents are indirect users, as they also consume Jeju Island's groundwater. Samdasoo, a bottled spring water sourced from Jeju, is the country's top-selling mineral water brand, claiming 44.2% of the Korean bottled water market (Kim, 2022). Thus, Jeju's groundwater valuation must consider the entire Korean population as the extent of the market.

Our second approach estimates national benefits by sampling a nationally representative group and extrapolating the mean WTP to the country's total households. While this approach addresses the limitations of the localized approach by appropriately defining the extent of the market, it might overlook the spatial heterogeneity. For Jeju residents, groundwater is more than a source; it is a pillar of sustainability, integral to their daily lives and future aspirations. It is the sole water source that sustains crucial industries such as agriculture and livestock, supplying water for consumption and various daily activities. Conversely, mainland residents may ascribe different values to Jeju's groundwater, which include option value as a tourism resource, bequest value for future generations, and altruistic value, along with its indirect use value through the consumption of Samdasoo. Therefore, our research assumes that spatial heterogeneity discretely varies between Jeju and mainland Korea. Disregarding these spatial data patterns could lead to biased and inefficient estimations of benefits (Anselin, 2001).

The third approach aggregates heterogeneous benefits. This methodology seeks to address the limitations of the second approach, particularly in its representation of our population of interest, Jeju, which constitutes only 1.3% of the national population. Over-sampling from Jeju Island's population could address this, but it may also result in a lack of national representation in the sample. Hence, we propose separate benefit evaluations for mainland and island populations before aggregation. This approach not only ensures an accurate representation of diverse perspectives but also offers a comprehensive estimate of the benefits associated with groundwater.

Our empirical findings reveal that national benefits surpass local benefits by a factor of 21.4 and, when considering the combined heterogeneous benefit, this ratio escalates to a factor of 21.6. These findings imply a significant underestimation of benefits in previous studies that focused solely on the aquifer area.

This research contributes to the existing body of literature in two significant ways. First, it offers an approach to the valuation of natural resources by incorporating spatial heterogeneity into the analysis. While previous studies on the valuation of water resources often overlooked the influence of spatial dimensions in determining the market extent, our research recognizes that perceptions and valuations of a resource can significantly vary across regions. This unique perspective encourages a more nuanced understanding of resource valuation, enabling policymakers to devise more effective and regionally tailored strategies for sustainable resource management.

Second, our research introduces and demonstrates a three-pronged approach to aggregate benefit estimations. By simultaneously considering local, national, and spatially heterogeneous benefits, we not only capture a more comprehensive view of the values attributed to groundwater quality improvements but also overcome the limitations of previous valuation methods that focused too narrowly on one segment of the population. This holistic methodology serves as a useful framework for future studies aiming to comprehensively evaluate the benefits of resource management, particularly in areas where resources transcend local boundaries and impact wider populations.

The remainder of this paper is organized as follows: Section 2 reviews Jeju, the study area. Section 3 outlines the methodology, followed by the presentation and examination of empirical results in Section 4. Finally, Section 5 concludes with findings and policy implications.

2. STUDY AREA

Jeju Island, the largest island in Korea, is a volcanic island situated in the southwest of the Korean Peninsula and has an area of 1,850 km^2. Home to approximately 700,000 people and attracting around 14 million tourists per

year, the main industries on the island include tourism, agriculture, livestock farming and fisheries (Jeju Statistics Portal n.d.). Resulting from volcanic activities, Jeju Island showcases a diverse array of distinctive volcanic formations. The island boasts around 360 small volcanic bodies and, beneath the earth's surface, approximately 160 lava tubes are dispersed, representing a rarity in global geological features. The exceptional value of Jeju Island has been recognized through three prestigious awards bestowed by United Nations Educational, Scientific and Cultural Organization (UNESCO). Its journey commenced in 2002 with the designation as a biosphere reserve, followed by the esteemed title of a World Natural Heritage site in 2007 (UNESCO, 2018; n.d.). Subsequently, in 2010, it received certification as a Global Geopark (Yonhap News, 2010). UNESCO's triple crown solidifies Jeju Island's status as a 'treasure island of environmental assets'.

Jeju Island, formed through various volcanic activities, predominantly consists of highly permeable basalts, enabling rain and stream waters to easily permeate into the basalts. This unique geological feature allows water to gradually flow within accessible and exploitable aquifers, resulting in an abundant groundwater supply but limited surface water resources (Won *et al.*, 2006; Kwon *et al.*, 2022). As a consequence, Jeju Island lacks perennial streams and heavily relies on groundwater as its primary water source. Groundwater plays a critical role, providing 97.2% of the island's water supply and 97.6% of agricultural water, earning it the reputation of being the 'water of life' (Jeju Special Self-Governing Province, 2020). Currently, Jeju Island is equipped with approximately 5,987 wells for groundwater extraction (Jeju Special Self-Governing Province, 2023) (Figure 1). These hydrological characteristics contrast with the Korean mainland, where crystalline granitic and metamorphic rocks yield limited groundwater but facilitate excellent surface runoff (Won *et al.*, 2006). Therefore, water management strategies must be specifically tailored to address the unique conditions of Jeju Island.

However, Jeju is currently exposed to risks that jeopardize the sustainability of its groundwater resources. The risks include seawater intrusion, water contamination, and declining groundwater levels brought on by climate change and over-exploitation (Chang *et al.*, 2020; Kwon *et al.*, 2022). Currently, 89.9% of the amount of

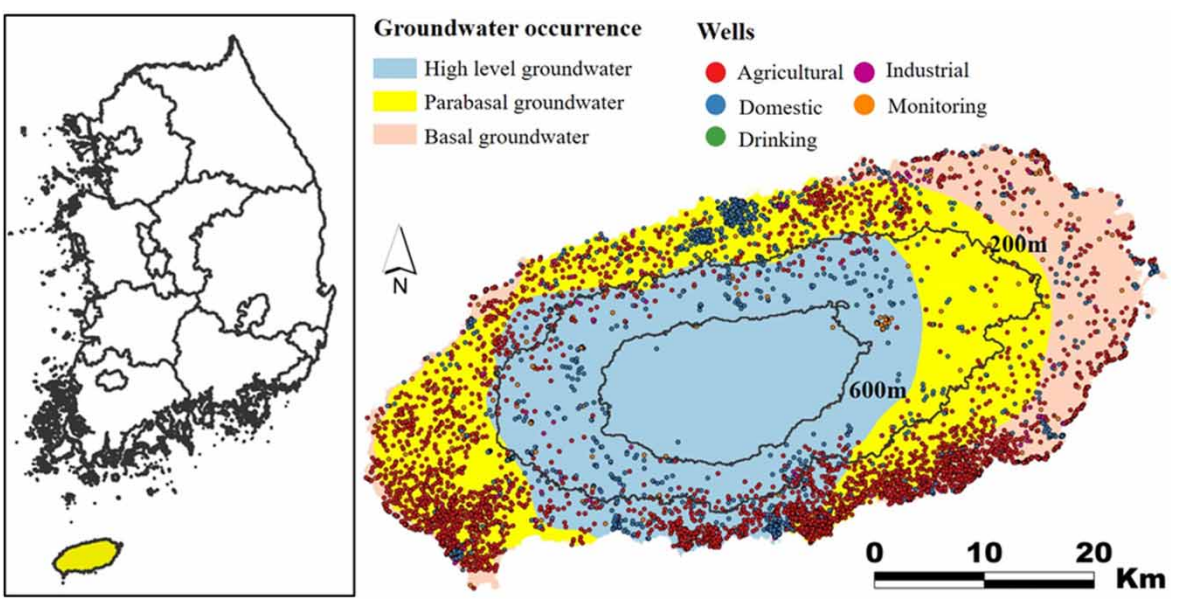

Fig. 1 | Hydrogeological properties of Jeju.

sustainable groundwater use has been developed, and specific areas such as Aewol (364%) and Hankyung (254%) have exceeded the allowable limit (Jeju Special Self-Governing Province, 2022).

This study specifically focuses on the issue of nitrate-nitrogen contamination, which has emerged as the greatest threat to the sustainability of Jeju groundwater. Rapid urbanization and population growth have led to increased discharge of domestic wastewater and livestock manure and the subsequent use of agricultural fertilizers and liquefied manure. This, in turn, has resulted in nitrate-nitrogen contamination of groundwater (Jeju Special Self-Governing Province, 2022). These environmental challenges tend to be more prominent in specific regions, underscoring the need for targeted interventions and effective management strategies to mitigate their detrimental effects. Figure 2 provides a visual representation of groundwater contamination levels in Jeju Island, depicting the concentrations of nitrate nitrogen, hydrogen ions, and chloride. The western region, characterized by a high density of livestock manure discharge facilities and intense agricultural activity, shows particularly high nitrate-nitrogen levels due to the use of chemical fertilizers and pesticides. The region also displays heightened pH levels. In the eastern and western coastal areas, significantly affected by seawater intrusion, the levels of chloride ions are notably high (Jeju Special Self-Governing Province, 2022).

Jeju Island has undertaken several proactive measures to manage and conserve its groundwater resources. One example is the expansion of the special management area for groundwater resources, which imposes restrictions on private groundwater development activities. Furthermore, the island has established a real-time observation system to monitor groundwater levels and quality. In addition, the implementation of rainwater utilization facilities and grouting projects aims to effectively manage and protect groundwater resources (Jeju Special Self-Governing Province, 2020).

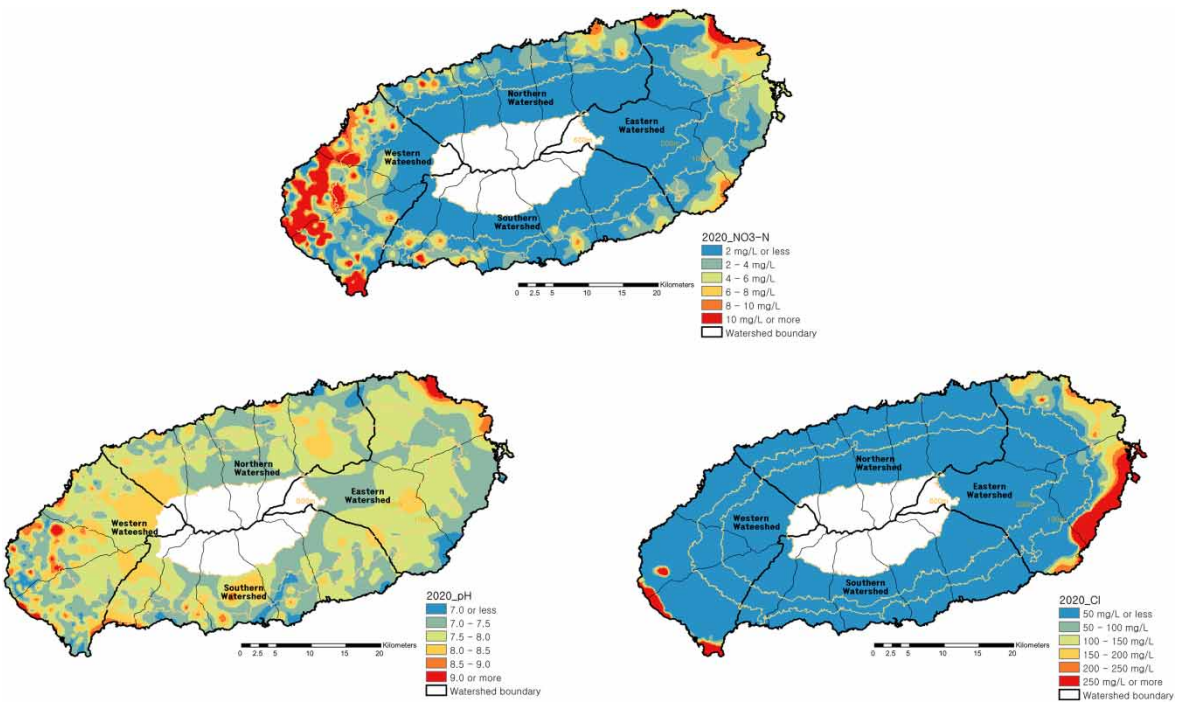

Fig. 2 | Spatial distribution of contamination in Jeju groundwater.

Many regions worldwide heavily rely on groundwater as a critical water source, but they are confronted with significant environmental challenges. This study holds great significance as it is expected to provide valuable policy implications for the sustainable management of groundwater, not only in Jeju Island but also in other regions across the globe. By analyzing the specific case of Jeju Island and valuing its groundwater management, this research can offer insights and lessons that can be applied to address similar challenges faced by other regions.

3. MATERIALS AND METHODS

3.1. Survey procedure

Our research design involved two contingent valuation surveys with varying geographic coverage. The first survey focused on the population of Jeju Island, while the second spanned the entire South Korean populace (Table 1). Both surveys were carried out in 2022, targeting individuals aged between 20 and 69 years. There was an interval of approximately 7 months between the two survey periods. By conducting these surveys within the same calendar year, we sought to minimize the impact of external influences on WTP, such as economic fluctuations or shifts in public sentiment over time. Additionally, to mitigate the potential seasonal effects on WTP, we purposefully avoided the Korean summer rainy season (June–September). This season often sees a surge in water-borne diseases and increased groundwater pollution due to substantial rainfall (Woo *et al.*, 2001). During this period, both nitrate-nitrogen concentrations and public consciousness about water quality typically peak. Following careful evaluation, we concluded that the biases resulting from temporal and seasonal differences would likely be insignificant. Nonetheless, we acknowledge the potential for unobserved biases stemming from the different survey periods as a study limitation.

The questionnaire was developed with inputs from economists and non-market valuation experts, and vetted through a peer-review process. Their expertise guided economic valuation, virtual market scenario formation, and payment methodologies. Between March and April 2022, we conducted three focus group interviews

Table 1 | Survey overview.

	Local survey	National survey
Population	Residents in Jeju Island	Residents all over Korea
Survey period	Late April to early May, 2022	December, 2022
Sampling method	Quota sampling in respect of age, region, and gender	
Sample size	542	1,000
Protesters	78 (14.4%)	400 (40%)
Survey mode	Web-based survey	
Elicitation method	Single-bounded dichotomous choice model	
Payment vehicle	Tax ('Charge for Improving Groundwater Quality in Jeju Island')	
Valued goods	Groundwater quality improvement in Jeju Island	
Level of change	The groundwater quality consistently meets the standards for annual average concentrations of nitrate nitrogen.	
Bid offered	KRW 3,000, 5,000, 8,000, 10,000, 15,000, 30,000 (USD 2, 4, 6, 8, 12, 23)	

Note: 1. USD 1 = KRW 1,291 (IMF, 2022). 2. Dollar conversion is represented by rounding to the first decimal place.

(FGIs) with local residents of Jeju Island to determine specific details such as payment vehicles, payment frequency, and scenario descriptions. A preliminary survey involving 40 participants was executed to assess WTP, utilizing open-ended questions, and we established six offered bids within the 15–85% range of the WTP distribution. The first survey in Jeju was performed from late April to early May 2022, employing a quota sampling method that considered the population, gender, and age distribution in each region of Jeju Island.

We planned a second survey subsequent to the first, acknowledging that the market extent for Jeju Island's groundwater might extend beyond the island and cover the whole of South Korea. The second study used the same questions as the previous survey and included 1,000 participants from around the nation. With specific alterations indicated in Section 3.2, the scenario only needed to be slightly modified to better fit the national context. The national survey was conducted in December 2022.

3.2. Questionnaire design

The questionnaire was structured into three parts: perceptions, WTP, and socio-economic characteristics. The perception section varied between local and national surveys. In the local survey, Jeju residents were asked about their perception of groundwater contamination and the need for water quality improvement on Jeju Island. The national survey, meanwhile, inquired about respondents' frequency of visiting Jeju Island and the consumption of Samdasoo, bottled water from Jeju's springs.

The second part presented the WTP scenario, depicting groundwater contamination in Jeju through a map of nitrate nitrogen, hydrogen ion, and chlorine concentrations. A proposed policy suggested installing pollution prevention facilities to meet groundwater quality standards. Respondents were asked if they would accept an 'annual charge for improving Jeju's groundwater quality,' emphasizing its collective responsibility. Each respondent was randomly assigned one of six bids, with a follow-up question offering a higher or lower amount based on their initial response. However, to avoid potential violations of incentive compatibility, the analysis was restricted to the first responses using a single-bounded dichotomous format (Johnston *et al.*, 2017). It is important to note that in our web survey format, respondents were not made aware that they would be asked multiple valuation questions. As per guidelines of Arrow *et al.* (1993), a reminder of limited household income was included.

Local and national surveys necessitate adjustments to the scenarios to align with the respective sample contexts, but excessive scenario adjustments can potentially yield disparate WTP results. Thus, we minimized scenario adjustments. In the national questionnaire, two adjustments were made. First, the national survey questionnaire included information stating that 'Jeju Island, being a volcanic island, has limited river development, and nearly 100% of its water source relies on groundwater.' During the FGI, it was evident that Jeju residents were already well-informed about this aspect and, therefore, was omitted from their survey. However, in the national survey, we included information about Jeju's unique hydrogeology and exclusive reliance on groundwater because mainlanders were less likely to be aware of these characteristics.

Second, the statement that Jeju residents also contribute taxes was additionally included in the national survey questionnaire to address potential protests from mainland respondents about contributing to a project benefiting Jeju Island. This approach was inspired by the Exxon Valdez oil spill contingent valuation method (CVM) study, which addressed similar concerns by assuring respondents that oil companies would cover part of the cost through a special tax on their corporate profits (Carson *et al.*, 1992).

Similarly, our survey included information to assure respondents and enhance the acceptability of the funding scenario: 'Jeju Island and its residents contribute a substantial amount in taxes; however, these funds alone are insufficient for the Jeju groundwater quality improvement project.' This aimed to prevent rejection of the premise that mainland respondents should contribute.

Our reviewer thoughtfully suggested the possibility that informing respondents about the significant contributions of Jeju residents might lead mainlanders to perceive the payment as a donation or a top-up for existing available funds, potentially resulting in a lower WTP. This is an intriguing research question, as respondents might feel less compelled to pay if they believe existing contributions already address the problem. Whether this phenomenon occurred is a topic worth exploring in future research through experiments or other methods. While our study cannot definitively determine this, we acknowledge the possibility and consider our estimates conservative if this phenomenon occurred.

3.3. Econometric model

We estimated the average WTP for groundwater quality improvement in Jeju Island using the utility difference model proposed by Hanemann (1984). Below, we introduce the econometric model applied in this study.

Let $G(B;\theta)$ be the cumulative distribution function with the parameter θ. The probabilities of answering 'no' and 'yes' to the proposed WTP can be, respectively, expressed as:

$$\Pr(\text{no}|B) = \Pr(\text{WTP} < B) = G(B;\theta), \tag{1}$$

$$\Pr(\text{yes}|B) = \Pr(\text{WTP} \geq B) = 1 - G(B;\theta), \tag{2}$$

when B_i represents the amount offered to the respondent i, the log-likelihood function for N respondents is as follows:

$$\ln L = \sum_{i=1}^{N} \{I_i^Y \ln[1 - G(B_i;\theta)] + I_i^N \ln G(B_i;\theta)\}, \tag{3}$$

I_i^Y and I_i^N are the indicator functions, defined as:

$$\begin{cases} I_i^Y = 1, & \text{if response of respondent } i = \text{yes}, \quad 0 \quad \text{otherwise} \\ I_i^N = 1, & \text{if response of respondent } i = \text{no}, \quad 0 \quad \text{otherwise} \end{cases}. \tag{4}$$

The estimation was conducted using the probit model, assuming that the error terms of $G(B;\theta)$ follow a normal distribution.

3.4. Aggregation methods

In estimating the total economic value, we employed three different methodologies reflecting distinct market extents. First, *local benefit*: This method is a conventional approach typically used in groundwater valuation studies and concentrates on the area where the groundwater aquifer is located. Here, we multiplied the mean WTP, derived from the Jeju sample, by the number of households in Jeju, thereby estimating the benefits of groundwater quality improvement within the local region.

Second, *national benefit*: We explored a scenario with a nationwide market extent, using the results from the national survey. The mean WTP of the national sample was multiplied by the total number of households in the country to estimate the national benefits of improving groundwater quality.

Third, *combined heterogeneous benefit*: This combined heterogeneous approach accounts for the heterogeneous values across different regions. It calculates the total economic value by adding two components:

Benefit of Jeju residents: This is calculated by multiplying the mean WTP in Jeju by the number of households in Jeju.

Benefit of mainland residents: This is obtained by multiplying the mean WTP of the national sample, excluding Jeju residents, by the number of households in the mainland of Korea.

We can express the three aggregation methods using the following formula:

$$\begin{cases} I_i^J = 1, & \text{if} \quad \text{living area of respondent } i = \text{Jeju}, \quad 0 \quad \text{otherwise} \\ I_i^M = 1, & \text{if} \quad \text{living area of respondent } i = \text{Mainland}, \quad 0 \quad \text{otherwise} \end{cases}. \tag{5}$$

First, the aggregated WTP of Jeju is calculated as:

$$\text{aggWTP}_{\text{Jeju}} = \sum_{i=1}^{n} I_i^J \overline{\text{WTP}_J}, \tag{6}$$

where n represents the total population of South Korea.

Second, the aggregated national WTP is calculated as:

$$\text{aggWTP}_{\text{National}} = \sum_{i=1}^{n} (I_i^J + I_i^M) \overline{\text{WTP}_{J+M}} = n * \text{WTP}_{J+M}. \tag{7}$$

Third, the aggregated combined heterogeneous WTP is calculated as:

$$\text{aggWTP}_{\text{Combined}} = \sum_{i=1}^{n} (I_i^J \overline{\text{WTP}_J} + I_i^M \overline{\text{WTP}_M}). \tag{8}$$

4. RESULT

4.1. Sample characteristics

Upon assessing whether the samples from both surveys adequately represented their respective populations, we found that the samples demonstrated satisfactory representativeness. Tables comparing the sample and population are provided in Appendices A and B. Of the 1,000 respondents in the national survey, only 9 were residents of Jeju Island, which aligns with the fact that Jeju residents constitute only 1.3% of the total population of Korea.

4.1.1. Summary statistics

Table 2 presents the summary statistics of the local and national surveys. Gender, education level, number of household members, income level, and interest in the water environment were investigated in both surveys. A 5-point Likert scale was used to measure the level of interest in water quality, with a score of 4 or higher indicating an interest in the water environment (coded as '1') and lower scores suggesting a lack of interest (coded as '0').

There were several differences between the two surveys. First, while the Jeju Island survey collected age data in group form, the national survey obtained the exact age as a direct response, which we believed would yield more meaningful insights.

Furthermore, the Jeju survey incorporated additional variables specific to the context of Jeju Island. These included the respondents' estimated direct contribution to Jeju's water pollution on a 5-point Likert scale and the number of years they had lived on the island. Lower scores indicated minimal or no contribution, whereas scores of 3 or higher indicated some level of involvement. This variable is intended to explore the relationship between perceived contributions to pollution and WTP, based on the polluter pays principle.

Table 2 | Summary statistics.

	Local survey ($N = 542$)			National survey ($N = 1,000$)		
Variable	**Mean**	**SD**	**Min–Max**	**Mean**	**SD**	**Min–Max**
Female	0.53	0.50	0–1	0.48	0.50	0–1
Age				45.95	12.35	20–69
Age in 20s	0.17	0.38	0–1			
Age in 30s	0.20	0.40	0–1			
Age in 40s	0.25	0.43	0–1			
Age in 50s	0.25	0.44	0–1			
Age in 60s	0.12	0.33	0–1			
Undergraduate or higher education	0.64	0.48	0–1	0.86	0.35	0–1
No. of family members	3.08	1.33	1–7	2.78	1.24	1–6
Income						
Less than KRW 300,000	0.29	0.45	0–1	0.22	0.42	0–1
KRW 300,000–499,000	0.32	0.47	0–1	0.30	0.46	0–1
KRW 500,000–699,000	0.23	0.42	0–1	0.24	0.43	0–1
KRW 700,000 or more	0.15	0.36	0–1	0.23	0.42	0–1
Years of residence in Jeju	32.78	18.77	0.8–70			
Score of interest in water quality environment	3.73	1.03	1–5	3.88	0.77	1–5
'I have contributed to the deterioration of groundwater quality.'	0.60	0.49	0–1	National survey excluding Jeju residents ($N = 991$)		
No. of visits to Jeju within the past 3 years				1.46	1.98	0–20
'Tourists have contributed groundwater pollution in Jeju Island.'				0.77	0.42	0–1
'I drink Samdasoo at least once a month.'				0.25	0.43	0–1

The national survey incorporated three additional variables designed to explore connections between individuals living outside Jeju Island and the island itself. First, we asked about the number of visits to Jeju Island within the past 3 years. Second, we used a 5-point Likert scale to evaluate how they perceive visitors' impact on groundwater contamination in Jeju Island. Scores of 4 or higher indicated belief in a significant impact from tourists, while lower scores suggested a minimal impact. This variable aimed to identify if a sense of responsibility as mainland residents increased their WTP. Lastly, we included the consumption of Samdasoo, a bottled mineral water sourced from Jeju Island springs, as a variable, querying whether respondents consumed it at least once a month. These three variables sought to uncover characteristics associated with a higher WTP among respondents living outside Jeju Island. We calculated descriptive statistics using a sample that excluded the nine Jeju residents from the national survey.

4.1.2. Protest responses

Respondents indicating no benefit from improved groundwater quality could be understood to have a true WTP of zero. However, it is essential to distinguish these from respondents who stated a zero WTP due to concerns about

the reliability of policy options, fairness of the payment method, or the payment vehicles, despite potentially deriving some benefits from groundwater quality improvement. These respondents, identified as protesters, should not be interpreted as having a true zero WTP. They instead should be eliminated from the sample used to calculate the average WTP. Respondents who stated that they were unwilling to pay the suggested amount were asked a follow-up question: 'Would you be willing to contribute even a penny to this project?' To discern between protest and true zero bids from those indicating no intention to pay, we used additional questions (Table 3). To mitigate potential order effects, all responses to these questions were randomly presented, except for 'others', which consistently appeared as the final choice.

During the identification of protest responses, item 12 was adjusted to fit the local context for both the local and national surveys. To ensure a conservative estimate of WTP and avoid overestimation, all 'other responses' were considered as zero WTP responses. The local survey identified 77 protesters, making up roughly 14.2% of the total sample, while the national survey found 400 protesters, representing about 40% of the sample. Given that the average protest rate for CVM studies on environmental resources in Korea is 30.5%, our study demonstrates a protest rate that is approximately 10% age points higher (Kim & Oh, 2011). Over half of the protesters in the national sample expressed the view that 'Jeju Island should pay'. This response can be interpreted in two ways. First, respondents might have believed that regional jurisdiction should manage the issue effectively and fairly. Second, the response aligns with the polluter pays principle, suggesting that residents significantly contributing to pollution should bear the responsibility of addressing it. Intriguingly, in the national sample, only about 12% of respondents indicated a true zero WTP. This empirical evidence underscores the broader beneficiary

Table 3 | Identification of zero bids.

Items			Local survey ($N = 542$)		National survey ($N = 1,000$)	
			Freq.	%	Freq.	%
Zero WTP	1	I do not have enough money to pay the levy.	14	46.43	31	25.20
	2	Improving water quality is not important to me or is not the subject of my interest.	3	14.29	5	4.07
	3	There are already enough alternative facilities or methods to substitute the water quality improvement project.	6	21.43	12	9.76
	4	Our society faces more pressing issues than groundwater quality improvement.	2	7.14	9	7.32
	5	My household does not benefit from the water quality improvement project.	3	10.71	37	30.08
	6	Others	0	0	29	23.58
	Total		28	100	123	100
Protest bids	7	Insufficient information to form a judgment.	4	5.19	14	3.50
	8	I lack trust in the government's business plan.	3	3.90	24	6.00
	9	The improvement in groundwater quality is unlikely to be significant.	4	5.19	9	2.25
	10	I believe this problem should be resolved using the taxes or resources I have already contributed.	50	64.94	143	35.75
	11	Alternative approach needed for water quality improvement.	1	1.30	0	0.00
	12–1	The polluter should bear the cost, not me.	16	20.78	.	
	12–2	Jeju Island (Local Government, Jeju Island Residents) should pay.	.		210	52.50
	Total		77	100	400	100

spectrum for groundwater quality improvement, extending beyond local residents of the aquifer area. Thus, these findings substantiate the argument for expanding the beneficiary area to a nationwide scale.

4.2. WTP for improving groundwater quality in Jeju

We used a probit model to estimate the annual WTP for each sample. The analysis revealed a significant difference between the WTP values in the Jeju region and the nationwide values. Specifically, the annual WTP per household in the Jeju region was calculated to be Korean Won (KRW) 26,664, which is approximately 3.6 times higher than the nationwide WTP of KRW 7,479. Excluding the sample of 9 Jeju residents from the national sample slightly reduced the mean WTP to KRW 7,306 (Table 4).

To construct a robust measure of uncertainty, we calculated a 95% confidence interval using the Krinsky & Robb (1986) method. This technique employs a Monte Carlo simulation approach that uses the asymptotic property of the maximum likelihood estimator. Specifically, we conducted 50,000 bootstrapping iterations to ensure a reliable estimate of the WTP.

4.3. Total economic value for different extents of market

Our comparative analysis of the benefits calculated via various methodologies revealed a distinct variation. Specifically, the national benefit was found to be 21.4 times greater than the local benefit (Table 5). Furthermore, the method of combining heterogeneous benefits yielded the highest value, resulting in an annual benefit that was 21.6 times greater than those derived from approaches exclusively focused on water quality improvement in Jeju Island.

These findings underscore that previous studies that merely calculated the benefits within Jeju Island have significantly underestimated the benefits. This underestimation arises from the fact that Jeju Island's groundwater is

Table 4 | Mean WTPs of different samples.

	Local survey	National survey	National survey excluding Jeju residents
Annual mean WTP	KRW 26,664 (USD 20.65)	KRW 7,479 (USD 5.79)	KRW 7,306 (USD 5.66)
95% C.I.	[21,798, 35,839]	[3,610, 10,520]	[3,316, 10,271]

Note: USD 1 = KRW 1,291 (IMF, 2022).

Table 5 | Aggregated benefits.

	(1) Local benefit	(2) National benefit	(3) Combined heterogeneous benefits
Annual mean WTP	KRW 26,664	KRW 7,479	Jeju: KRW 26,664 Mainland: KRW 7,306
Population (No. of households)	311,355	23,705,814	Jeju: 311,355 Mainland: 23,394,459
Annual benefit	KRW 8.3 billion (USD 6.43 million)	KRW 177.3 billion (USD 137.3 million)	KRW 179.2 billion (USD 138.8 million)
Extent of market	Jeju Island	Korea	Korea
Spatial dimension		X	O

Note: 1. For the number of households, we utilized the Ministry of Public Administration and Security's 2022 annual statistics on 'Resident Registration Population and Household Status'. 2. USD 1 = KRW 1,291 (IMF, 2022).

not only sold and distributed nationwide but also because of the island's high touristic appeal, both of which extend the beneficiary group beyond the island.

We also found that assuming uniform benefits across the entire country can lead to underestimation or overestimation of the actual value. This discrepancy is evidenced by the difference between the national benefit and the combined heterogeneous benefits, even though this gap is relatively small. The most accurate estimation of benefits is attainable by acknowledging the distinct values held by residents within the aquifer area and nonresidents and subsequently aggregating their respective benefits.

Nonetheless, owing to constraints in cost and time, it may not always be feasible to segregate beneficiaries based on their value attributes and execute separate surveys in CVM studies. Our research illustrates that the divergence between national and combined heterogeneous benefits is substantially smaller than that between local and combined heterogeneous benefits. Consequently, when it is impractical to conduct surveys with an adequate number of respondents both within and outside the aquifer areas, taking into account the entire beneficiary group could provide a more precise estimate of the true value.

4.4. Factors affecting WTP for groundwater quality improvement

We used a probit model to scrutinize the determinants of WTP for both Jeju residents and mainland residents (Table 6). Model (1) consists of 464 observations, excluding protesters from the Jeju sample. Model (2) includes 592 observations, excluding Jeju residents and protesters from the national sample. In both models, the coefficients of the bid variable are significantly and negatively associated with WTP at a 99% confidence level. This supports the basic tenet that the probability of a 'yes' response diminishes as the proposed amount escalates.

Model (1) revealed that individuals in their 50s have a significantly higher WTP compared to those in their 20s, though the number of years living in Jeju did not significantly impact WTP. Higher-income groups demonstrated a markedly elevated WTP relative to the lowest income group. Respondents expressing interest in the water environment manifested a significantly higher WTP at a 99% confidence level, suggesting a profound valuation of groundwater quality improvement. We also found that individuals who believe they contribute to Jeju's groundwater contamination have a significantly higher WTP compared to those who do not share this belief.

In model (2), we considered age as a continuous variable, and the impact of its squared term was also inspected. Both the linear squared terms of age were significant at the 99% confidence level, with the squared term showing a positive coefficient, indicating a downward convex parabolic relationship. By identifying the vertex through differentiation, we discovered that mainland residents' WTP decreases until age 48.37 and then increases thereafter. The number of family members, which was not significant in model (1), exhibited a positive and significant effect in model (2). Unlike in the case of Jeju residents, income level no longer showed significance for mainland residents. Just like model (1), mainland residents with an interest in the water environment showed a higher WTP. Individuals who believe tourists impact groundwater pollution also show higher WTP.

We also estimated the impact of the number of visits to Jeju Island over the past 3 years, considering both linear and squared terms. A significantly negative coefficient for the squared term indicated an upward convex quadratic relationship. The vertex, ascertained through differentiation, was calculated as 6.41, suggesting that WTP increases as the number of visits to Jeju Island grows, but beyond 6.41 visits, WTP starts to decrease. This may be explained by the stronger attachment to Jeju Island's natural environment and groundwater that develops with increased visits, assigning them a higher value. However, those visiting Jeju Island excessively, likely for business or work, may experience a diminished attachment to the Jeju environment or groundwater.

The variable with the highest coefficient and statistical significance was whether individuals consume Samdasoo. Mainland residents who purchase and drink Samdasoo at least once a month exhibit a higher WTP for Jeju

Table 6 | Factors affecting WTP.

	(1) Jeju residents (obs = 464)		(2) Mainland residents (obs = 592)	
Variable	**Coef.**	**S.E.**	**Coef.**	**S.E.**
Bid	−0.00***	0.00	−0.00***	0.00
Female	0.08	0.14	−0.09	0.11
Age			−0.12***	0.03
Age^2			0.00***	0.00
Age in 20s	ref.			
Age in 30s	−0.00	0.22		
Age in 40s	−0.07	0.21		
Age in 50s	0.41*	0.24		
Age in 60s	0.26	0.30		
Undergraduate or higher education	0.17	0.15	−0.28	0.17
No. of family members	−0.07	0.06	0.09*	0.05
Income				
Less than KRW 300,000	ref.		ref.	
KRW 300,000–499,000	0.35*	0.18	0.10	0.17
KRW 500,000–699,000	0.43**	0.21	0.10	0.19
KRW 700,000 or more	0.48**	0.23	0.10	0.20
Years of residence in Jeju	0.00	0.00		
Interest in water quality environment	0.24***	0.07	0.26***	0.08
'I have contributed'	0.34**	0.14		
'Tourists have contributed'			0.36**	0.15
No. of visits to Jeju			0.16***	0.05
$(\text{No. of visits to Jeju})^2$			−0.01**	0.00
'I drink Samdasoo'			0.57***	0.12
constant	−0.44	0.33	1.19	0.78
Log-likelihood	−235.88	−346.50		
Prob > Chi^2	0.00	0.00		
Pseudo R^2	0.14	0.15		

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

groundwater quality improvement compared to those who do not. This finding highlights a significantly higher WTP among individuals living outside Jeju who recognize and appreciate the use value of Jeju's groundwater.

5. DISCUSSION AND CONCLUSION

This study aimed to capture the heterogeneous values attributed to Jeju's groundwater by varying populations and areas. Utilizing the CVM, we integrated the spatial dimension into our sampling methodology. Remarkably, we identified the maximum benefit with the implementation of the combined heterogeneous benefit approach. This

approach, acknowledging the unique value attributes of the diverse beneficiary populations, delivered a benefit 21.6 times larger than the previous studies employed with an exclusive focus on Jeju's aquifer area.

We observed significant differences in the WTP for groundwater between residents of Jeju and mainland Korea, with Jeju residents showing a WTP of approximately 3.6 times higher. This disparity can be attributed to spatial heterogeneity, including distance and availability of substitutes. Jeju residents, living closer to the groundwater, exhibited a higher WTP due to a heightened sense of ownership or responsibility (Hanley *et al.*, 2003; Bateman *et al.*, 2006), whereas mainland residents had lower WTP due to increased costs associated with distance, including higher travel costs and opportunity costs (Pate & Loomis, 1997; Hanley *et al.*, 2003; Bateman *et al.*, 2006) and availability of alternative water sources (Brouwer *et al.*, 2010; Schaafsma *et al.*, 2012; Logar & Brouwer, 2018).

Patrick *et al.* (2014) explored how framing water management issues at different scales and levels affects perceptions of justice. From an ecological perspective, managing groundwater resources within the ecosystem's boundaries, as in the case of Jeju Island, appears appropriate. However, from an economic and social perspective, the framing changes. Mainland residents, who are both consumers and contributors to pollution, should also bear responsibility. Excluding them from responsibility could be perceived as unjust. This suggests that previous water management practices may have overly relied on an ecological framing, neglecting broader economic and social contexts.

The study emphasizes the importance of considering the perspectives of different stakeholder units in water resource management. The significantly higher national benefits found in our study indicate that improving groundwater quality enhances the overall public welfare of Koreans all across the country. This finding supports the use of national funds for groundwater quality improvement projects rather than relying solely on local budgets. Jeju can leverage government initiatives and support from the Ministry of Environment to address groundwater quality issues, with our research providing empirical evidence for such policy moves.

Our research underscores that previous studies, by overlooking these disparate perspectives, may have significantly underestimated the actual value of managing Jeju Island's groundwater. In a world facing escalating water management challenges, it is crucial to address the distinct needs of regions heavily reliant on groundwater, such as islands. Inaccurate estimation of groundwater value can lead to inappropriate resource allocation and underinvestment, threatening long-term utilization, water security, community welfare, and cultural heritage.

To guide policymakers, we suggest the following steps:

Regional and national collaboration: Encourage collaboration between regional and national governments to fund groundwater management projects, highlighting the broader benefits that extend beyond regional boundaries.

Including spatial heterogeneity in valuation: Consider spatial heterogeneity in valuation techniques, taking into account varying WTP among different populations to ensure equitable benefits and contributions.

Comprehensive stakeholder engagement: Engage a broad spectrum of stakeholders, such as locals, national beneficiaries, and foreign organizations. Identifying different viewpoints and making sure that all pertinent stakeholders participate in and gain from groundwater management projects can be accomplished with the aid of this inclusive strategy.

Moreover, these insights should not be confined to Jeju Island alone but have global implications. Even nonresidents often highly value the ecological assets of various regions and may indirectly benefit from their ecosystem services. For example, assessing the value of water resources in iconic American vacation spots like Guam or Hawaii solely based on the residents' perspectives would significantly underestimate their worth. Groundwater provides 99% of Hawaii's domestic water and about 80% of Guam's total water supply, making

the sustainability of these groundwater resources critical to the islands' overall sustainability (United States Geological Survey n.d.; Jocson *et al.*, 2002).

Globally, there are numerous instances where groundwater is recognized as an ecologically vital resource, with various stakeholders striving to protect and manage it. Socio-economic changes and climate change intensify the importance of groundwater management. Future policy decisions should consider the socio-economic extent of the market, rather than simply defining it by aquifer boundaries, to address potential injustices and ensure comprehensive resource management.

In conclusion, accurate valuation of groundwater management is crucial for ensuring the long-term availability and quality of groundwater and promoting environmental health and social well-being. By acknowledging broader benefits and responsibilities that extend beyond local boundaries, we can develop more equitable and effective groundwater management strategies. This comprehensive approach enhances the sustainability of vital resources like Jeju's groundwater and ensures fair distribution of benefits across regions and populations. Our findings advocate for a balanced groundwater policy considering both local and national interests, contributing to more inclusive and just environmental governance. Future studies should continue exploring innovative methods to achieve a more precise understanding of groundwater's true value with spatial heterogeneity, contributing to more sustainable practices and policies worldwide.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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