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ARTICLE

Assessing the Economic Value of Improvement in Water Quality and Aquatic Ecosystem Services Resulting from Ecological Stream Restoration in South Korea

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ABSTRACT

Urbanization and environmental degradation have led to significant declines in water quality and aquatic ecosystem health, highlighting the urgent need for effective restoration efforts. This study applies an integrated analysis approach to estimate the economic value and benefits of improvements in water quality and aquatic ecosystem services resulting from the Ecological Stream Restoration Project. Using survey data analyzed through the choice experiment (CE) method, we assessed respondents' preferences for various ecosystem services, including water-friendly services, ecological functions, water-level control, and water-quality purification. Three empirical analysis models—the Conditional Logit Model (CLM), Nested Logit Model (NL), and Error Component Logit Model (ECL)—were applied, with the ECL model identified as the most suitable for this study. From the physical impact assessment, we derived compensating variations to estimate the annual economic benefits of the project. The estimated annual economic value of water quality improvement due to the Anyangcheon Ecological Stream Restoration Project ranged from approximately KRW 10.54 billion to KRW 21.44 billion, while the economic value of aquatic ecosystem improvement was estimated to range from KRW 6.05 billion to KRW 12.30 billion annually. This study provides analytic framework that can inform future ecological restoration projects and sustainable water management policies.

Keywords: Ecological Stream Restoration; Non-Market Valuation; Choice Experiment; Ecosystem Services, Integrated Environmental And Economic Analysis

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1. Introduction

Ecological stream restoration projects aim to restore the ecological health of streams where water quality has deteriorated or habitats for aquatic species have been damaged. Water quality and stream ecosystem services are critical components in creating an environment where humans and nature can coexist, playing a key role in enhancing not only the environmental value of streams but also their social and economic value. Clean water quality maintains the ecological functions of streams and provides a healthy habitat for various species. Additionally, aquatic ecosystem services improve human quality of life by offering benefits such as biodiversity conservation, climate change mitigation, and recreational spaces. These ecosystem services may not be easily quantified in monetary terms, but their impact on local communities and the national economy is substantial.

In this context, ecological stream restoration projects go beyond simple water management or physical restoration to create an environment where humans and nature can thrive together through improvements in water quality and ecosystem recovery. Today, urbanization and climate change have led to significant degradation of stream ecosystems, particularly in urban areas, making this a major concern[1–3]. As a result, ecological stream restoration projects have become essential environmental policies to address these issues and promote sustainable water management and ecosystem service enhancement[4, 5]. Restoration projects offer several benefits. First, improving water quality and restoring ecosystems can enhance the environmental value of the stream[6]. Second, restored streams provide recreational spaces for citizens, improving their well-being[7]. Third, streams that have regained their natural characteristics enhance resilience to natural disasters such as floods and play a crucial role in adapting to climate change[8]. Fourth, restored streams enhance scenic value, contributing to the revitalization of local economies[9].

Since the 1960s in South Korea, various stream management projects, such as straightening rivers and constructing artificial embankments, have been implemented to promote industrialization. While these efforts maximized water usage and flood prevention functions, they caused changes in aquatic ecosystems, reducing biodiversity and ecological health, which significantly lowered the environmental value of streams[10]. As awareness grew of the need to restore damaged streams to their natural state, South Korea's ecological stream restoration projects evolved from pollution control efforts initiated in 1987[11, 12]. Initially, the primary focus was on improving water quality, but since 2002, the projects expanded into "natural stream restoration projects" aimed at restoring ecological health[11]. By 2009, the projects had developed into today's "ecological stream restoration projects," focusing on ecosystem restoration[11]. These projects aim to restore the natural functions of streams by recreating habitats, ensuring both longitudinal and lateral connectivity, and achieving natural flood control stability[11]. Ecological stream restoration projects seek to improve both aquatic ecosystem health and human quality of life. The diverse ecosystem services provided through these projects hold economic and social value. Research to measure the economic value of such non-market goods and services has been increasing, with choice experiments (CE) widely used to estimate environmental values and the public's willingness to pay (WTP).

Barak and Katz[13] analyzed public preferences for in-stream and riparian restoration in Israel to evaluate the economic value of stream restoration projects. Using choice modeling, they investigated how much additional tax the public would be willing to pay for these two types of restoration. Respondents showed a higher preference for riparian restoration and indicated an average willingness to pay an additional $66 per household per year. Moreover, the greater the awareness of stream restoration, the higher the WTP. Kunwar et al.[14] estimated local residents' perceptions and WTP for river restoration projects in Nepal's Danda Basin. Using a discrete choice experiment, they examined the impact of various restoration attributes—such as water quality improvement, ecosystem restoration, and scenic improvement—on residents' preferences. Respondents considered water quality improvement the most important factor and preferred river restoration managed by local communities rather than the government. Spatial heterogeneity was also observed, with urban residents showing a higher WTP for restoration projects compared to rural residents. Chen et al.[15] applied a discrete choice experiment to analyze differences in preferences for river restoration in Guangzhou, China, and Brussels, Belgium. While residents of both cities recognized the ecological benefits of river restoration, Guangzhou residents showed greater uncertainty due to scale heterogeneity and were more sensitive to costs, whereas Brussels residents placed higher value on biodiversity and visual naturalness. Brouwer et al.[16] also used a choice experiment to compare the benefits of river restoration projects in Austria, Hungary, and Romania within the Danube River Basin. The results showed that all three countries had a positive preference for water quality improvement, though flood risk reduction was more important in Austria than in Hungary and Romania. Chen and Cho[17] assessed the impact of environmental information disclosure on public participation and preferences for urban river restoration in Shaoguan, China, through a discrete choice experiment. Passive information disclosure successfully increased public participation, and simply providing information increased support for river restoration. However, active information disclosure increased uncertainty about restoration, reducing participation. The study also highlighted heterogeneity in public preferences for restoration, with some individuals being less sensitive to costs, while others responded more to costs than to specific attributes.

This study evaluates the impact of the Anyangcheon Ecological Stream Restoration Project on water quality and aquatic ecosystems and estimates its economic value. The objectives of the study are as follows. First, to assess the social benefits of the restoration project by estimating the economic value of changes in water quality and aquatic ecosystems resulting from the project. Second, to demonstrate the policy relevance of similar ecological stream restoration projects through this analysis and provide foundational data for decision-making processes. While previous studies have mainly analyzed preferences for specific elements of ecological restoration, such as water quality improvement, flood control, or scenic improvement, this study evaluates both water quality improvement and aquatic ecosystem health, providing a comprehensive analysis of ecosystem service changes and their economic value. Additionally, this study applies integrated environmental and economic analysis, a method that quantifies the monetary value of physical environmental changes, such as water quality or habitat quality. This re-emphasizes the economic and environmental importance of ecological stream restoration projects and provides practical insights for sustainable urban stream management.

2. Study Area

The study area, Anyangcheon, is a major stream flowing through Seoul and Gyeonggi Province in South Korea and is one of the main tributaries of the Han River (see **Figure 1**). It has a basin area of 286 km^2 and a stream length of 32.5 km, making it the second-largest tributary of the Han River after Jungnangcheon. The Anyangcheon basin encompasses 14 local governments, including 7 cities in Gyeonggi Province and 7 districts in Seoul, with a population of approximately 3.5 million people[18]. Since the 1970s, industrialization and urbanization have led to the increase of factories and population concentration, resulting in pollution from industrial wastewater and domestic sewage[18]. To address this issue, Anyang City began constructing sewage treatment facilities and installing water purification systems in 1986, which led to some improvements in water quality. However, significant fluctuations in water quality persisted, resulting in poor living conditions for native flora and fauna, and the loss of the stream's functions as a habitat and recreational space for citizens[18]. In response, Anyang City established the "Anyangcheon Restoration Master Plan" in the 2000s, aiming to improve water quality, secure water flow, maintain the natural stream, and restore the ecosystem. Anyangcheon was selected as the study area because it is one of the urban streams where the ecosystem has been severely damaged by urbanization and industrialization. Additionally, as an important recreational and environmental resource for residents of Seoul and the surrounding metropolitan area, the stream offers a valuable case for analyzing the impact of such restoration projects on the quality of life of citizens.

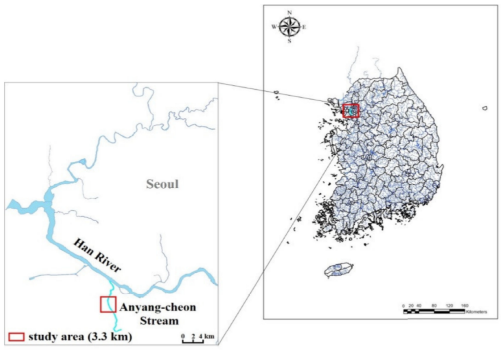

Figure 1. Study area: Anyangcheon stream. Source:[19].

3. Materials and Methods

3.1. Survey Outline

This study utilizes data from the "National Survey on Management and Improvement of Water Quality" conducted by Ahn et al.[20] to evaluate the economic value of the Anyangcheon Ecological Stream Restoration Project. The survey aimed to assess the public's awareness and preferences regarding major ecosystem services of the four major rivers in South Korea (Han River, Nakdong River, Geum River, and Yeongsan River) and estimate the value of changes in the quality of individual ecosystem services through a discrete choice experiment (CE). The survey was conducted with 3,000 households residing in or using the four major river basins in South Korea. It was commissioned to Korea Data World Co., Ltd., a professional survey agency, and conducted using an online survey method. The margin of error was ±1.79 percentage points at a 95% confidence level, and the sample design was based on population-proportional allocation using August 2017 population data. The survey was conducted over 14 days, with a preliminary survey from September 27 to 29, 2017, and the main survey from October 10 to 20, 2017. Respondents evaluated their preferences for various ecosystem service attributes, including water quality, aquatic ecosystems, hydrological functions, and water level control, and expressed their willingness to trade off these services against water use charges. For this study, the responses of 1,500 households in the Han River basin, where Anyangcheon is located, were used. The choice experiment data were re-estimated to fit the purpose of this study, and based on the estimation results, the social benefits of improvements in water quality and aquatic ecosystems resulting from the ecological stream restoration project were calculated.

The aim of this study is not to estimate the total value of all services provided by the Ecological Stream Restoration Project, but rather to estimate the value of the key attributes: water quality and aquatic ecosystems. Therefore, choice experiment data from a case study were used. The survey was designed to understand the general public's awareness and preferences regarding the services (functions) provided by the four major rivers, rather than analyzing the impact of a specific policy or project. In other words, the survey data from Ahn et al.[20] were conducted independently as a case study, excluding the effects of specific policies, which ensures the objectivity of the research findings.

Figure 2 illustrates the benefit assessment procedure used in this study, which is based on survey results from 1,500 households residing in the Han River. The Iraqi River Water Quality Index (IRWQI) was applied to measure water quality, and the Hydraulic Habitat Suitability (HHS) Index was used to assess aquatic ecosystems. To derive the unit value for changes in water quality and aquatic ecosystem indexes, the pre-project water quality and aquatic ecosystem index values were compared with those after the project. The final benefits were estimated by converting the derived willingness to pay (WTP) into an annual WTP and applying the total number of households benefiting from the ecological stream restoration project.

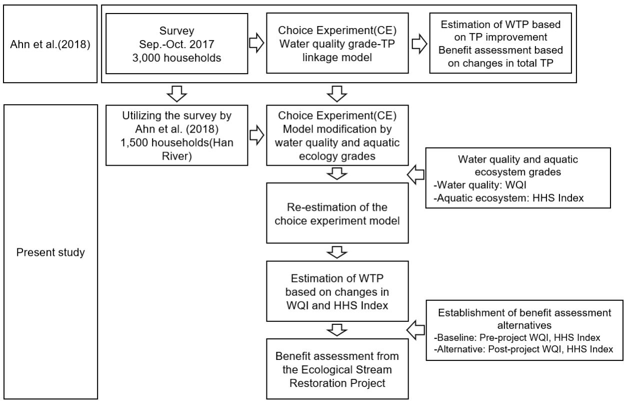

Figure 2. Benefit assessment procedure. Source: [21].

3.2. Choice Experiment Design

The Choice Experiment (CE) is a method that presents respondents with various scenarios of qualitative changes in river environments due to restoration projects and measures their preferences for each scenario. This approach allows for the estimation of the public's WTP for changes in each ecosystem service attribute. In this study, water-friendliness, ecological functions, water-level control, and water-quality purification were set as the main attributes, and water use charges were applied as the trade-off element for these services. The choice experiment is effective as it simulates a consumer's decision-making process in selecting between various goods in a market, thus guiding respondents to make a choice[22–24]. For the experiment design, the pivot-style design was applied, which reflects respondents' prior experiences and presents more realistic scenarios[25]. In other words, the current levels of each attribute as perceived by the respondents are set as the reference alternative, and by altering these levels, hypothetical alternatives are designed and presented as choice options. Respondents then choose their preferred alternative[26]. **Table 1** shows the definition, levels, and change levels for each attribute.

In order to more accurately capture respondents' preferences, it is important to design the choice experiment so that respondents can easily understand the information related to attributes, attribute levels, and changes in attribute levels[27]. This ensures that they can fully comprehend the available alternatives and select the one they prefer most. **Table 2** provides the definitions of each grade of water quality standards presented during the survey.

Table 1. Definition of the attributes and levels used in CE.

Attribute	Definition	Attribute Levels	Change
Water-friendliness	• Accessibility and familiarity with the river and surrounding streams • Riverside parks, walking trails, ecological streams, sports facilities, ecological learning experiences, ecological tourism, etc.	Very poor Poor Fair Good Very Good	One level down No change One level up
Aquatic ecosystem	• Degree of eco-friendliness perceived in the river and surrounding stream ecosystems • Ecosystem diversity, ecological habitats, ecological connectivity, etc.	Very poor Poor Fair Good Excellent	One level down No change One level up
Water level	• Perceived water level in the river and major streams • Water level suitable for recreational activities (e.g., swimming) during the season from June to September	Very low Low Fair High Very high	One level down No change One level up
Water quality	• Perceived water quality in the river and surrounding streams • Suitability for swimming, fishing, and the degree of pollution	Very poor Poor Fairly poor Fair Fairly good Good Very Good	Two levels down One level down No change One level up Two levels up
Cost	• Water use charge that the household pays to protect water quality in water supply source	KRW 170/m^3	30% down 15% down No change 15% up 30% up

Source: [20, 26].

Table 2. Definitions of water quality standards.

Grade	Definition
Very poor	Water heavily polluted with almost no dissolved oxygen, making it uninhabitable for fish.
Poor	Water contains pollutants that deplete excessive amounts of dissolved oxygen, indicating a poor ecosystem where fish are rarely observed. It is not unpleasant for everyday activities such as walking and can be used as industrial water after special purification.
Fairly poor	Water contains pollutants that deplete a considerable amount of dissolved oxygen, indicating an ecosystem that can be used for agricultural purposes but requires advanced purification for industrial use.
Fair	Water contains a moderate level of pollutants that deplete dissolved oxygen, representing a general ecosystem. It can be used as domestic water after advanced purification and as industrial water after general purification.
Fairly good	Water contains some pollutants but has a relatively high level of dissolved oxygen, indicating a fairly good ecosystem. It can be used as domestic water or swimming water after general purification.
Good	Water has a high level of dissolved oxygen and is close to a clean state with almost no pollutants.
Very good	Water is rich in dissolved oxygen and free from pollutants, indicating a pristine ecosystem. It can be used as domestic water after simple purification.

Source: [20].

3.3. Empirical Model

This study employs three empirical analysis models: the Conditional Logit Model (CLM) for estimating preference consistency, the Nested Logit Model (NL) to account for correlations among choice alternatives, and the Error Component Logit Model (ECL) to address heteroscedasticity and improve estimation accuracy. The conditional indirect utility is derived when an individual decision-maker (i) selects one alternative (j) from among the available alternatives that maximizes their utility. It is composed of two parts, as shown in Equation (1). Here, $V_{i,j}$ represents the deterministic term that can be identified by the researcher, while $\varepsilon_{i,j}$ represents the unidentifiable part, which is the random component.

$$U_{i,j} = V_{i,j} + \varepsilon_{i,j} \tag{1}$$

In Equation (1), $V_{i,j} = \sum_k \beta_k X_{i,jk}$ is expressed as the random component, and $X_{i,jk}$ represents the set of attributes belonging to the selected alternative (j). β_k refers to the estimated coefficients for each attribute, including the Alternative Specific Constants (ASC). In the case of pivot-style choice experiments, ASC includes the dummy variable Sq (Status quo), which indicates the selection of the current alternative (i.e., the alternative 1 evaluated by the respondent). Sq is a variable that reflects whether the respondent prefers the current alternative over the hypothetical alternatives when all other attributes and conditions are equal. A positive sign (+) for this variable means that the respondent prefers the current alternative they evaluated, while a negative sign (-) indicates the opposite. Each respondent is presented with three alternatives ($j = 1,\ 2,\ 3$) and repeats the experiment ($n = 1, \ldots, 6$) six times, with different choice scenarios. In this case, Equation (1) can be reformulated as Equation (2). One important point to note in Equation (2) is that the identifiable part of the utility function ($U^i_{1,n}$) for the respondent's evaluated alternative is expressed as V^i_1 rather than $V^i_{1,n}$. This is because the levels (values) of individual attributes do not change during the six repeated choice experiments for each respondent.

$$\begin{aligned} U^i_{1,n} &= V^i_1 + \varepsilon^i_{1,n} \\ U^i_{2,n} &= V^i_{2,n} + \varepsilon^i_{2,n} \\ U^i_{3,n} &= V^i_{3,n} + \varepsilon^i_{3,n} \end{aligned} \tag{2}$$

While Equation (2) serves as the basis for the CLM, Hess and Rose[25] pointed out econometric issues that may arise when using data generated by pivot design. As mentioned, the levels of attributes included in the reference alternative (the alternative evaluated by the respondent) remain constant throughout the repeated choice experiments for the same respondent. This suggests that the basic assumption regarding the error term in the CLM model may be violated. To rephrase, there is a high likelihood that the hypothetical alternatives (alternatives 2 and 3) will be highly correlated, which could violate the assumption of Independent and Identically Distributed (IID) error terms[28]. These econometric issues can be resolved by applying the ECL[26]. Therefore, in this study, both the CLM and ECL models were estimated. The ECL model controls for heteroscedasticity by incorporating alternative-specific variance into the error term of Equation (2), as shown in Equation (3).

$$\begin{aligned} U^i_{1,n} &= V^i_1 + \sigma_1 \varphi^i_{1,n} + \varepsilon^i_{1,n} \\ U^i_{2,n} &= V^i_{2,n} + \sigma_2 \varphi^i_{2,n} + \varepsilon^i_{2,n} \\ U^i_{3,n} &= V^i_{3,n} + \sigma_3 \varphi^i_{3,n} + \varepsilon^i_{3,n} \end{aligned} \tag{3}$$

In Equation (3), ($j = 1,\ 2,\ 3$) represents the standard deviation, which is the estimated coefficient related to the variance of each alternative, and $\varphi^i_{j,n}$ is the error component that follows a standard normal distribution ($\varphi^i_{j,n} \sim$ N[0,1])[28]. To estimate the model based on Equation (3), the σ_j with the smallest variance among the three σ_j must be identified and set to 0.

4. Results

4.1. Estimation Results

This study redefined the econometric analysis model based on the physical environmental impact results of[19] by incorporating the concept of integrated environmental and economic analysis. To estimate the model for individual attribute variables, including water quality and aquatic ecosystem variables, we modified V_{ij} of Equation (3) as shown in Equation (4) to account for the grade-specific model of each attribute.

$$\begin{aligned} V_{ij} = sq &+ \textstyle\sum_k \beta_{k_{re}} k_{reij} + \sum_k \beta_{k_{bio}} k_{bioij} \\ &+ \textstyle\sum_k \beta_{k_{wl}} k_{wlij} + \sum_z \beta_{z\_wq} z\_wq_{ij} \\ &+ \beta_{cost} Cost_{ij} \end{aligned} \tag{4}$$

Here, sq represents the variable for ASC, which is set to 1 for the respondent's evaluated alternative and 0 for the other hypothetical alternatives. re denotes water-friendliness, bio represents the aquatic ecosystem, wl stands for water level, wq signifies water quality, and $cost$ refers to water charges. $k(vgood,\ good,\ nor,\ bad,\ vbad)$ indicates the corresponding grade among the five grades for the water-friendliness, aquatic ecosystem, and water level attributes (see **Table 3**). Similarly, $z(vgood,\ good,\ 1good,\ nor,\ 1bad,\ bad,\ vbad)$ represents the corresponding grade among the seven grades for the water quality attribute. In this study, to account for the nonlinear effects of categorical data, we estimated the model by treating each attribute level as a dummy variable for each grade, as shown in Equation (4), rather than treating the levels as continuous variables.

The CLM, NL, and ECL models were estimated using NGENE 6.0, and the coefficients for each model were derived through maximum likelihood estimation or simulated maximum likelihood estimation. The estimation results are shown in **Table 4**. In all models, most of the estimated coefficients had signs consistent with expectations and showed statistical significance within the 5% level. Regarding the statistically significant variables, the fact that the sq variable was estimated with a positive (+) sign can be interpreted as a preference for the current alternative (the respondent's evaluated alternative) over hypothetical alternatives, all other conditions being equal. The estimated coefficients for the grade-specific dummy variables of each attribute can be interpreted by comparing them to the reference variable[28]. For example, the coefficients for the variable $vgood_{re} \sim bad_{re}$ related to water-friendliness were all positive (+), indicating that as the level of water-friendliness improved compared to the reference variable $vbad_{re}$, the respondent's utility increased, positively influencing the choice of alternatives. Other variables can be interpreted similarly. On the other hand, the cost-related variable $cost$ showed a negative (-) impact, meaning that as the water use charges increased, the respondent's utility decreased.

Table 3. Variables and Definitions Used in the Econometric Analysis Model.

Variable	Definition
sq	1: Current alternative (respondent's evaluated alternative) 0: Other alternatives
vgood_re	Water-friendliness. 1: very good, 0: Otherwise
good_re	Water-friendliness. 1: good, 0: otherwise
nor_re	Water-friendliness. 1: fair, 0: otherwise
bad_re	Water-friendliness. 1: poor, 0: otherwise
vbad_re	Water-friendliness. 1: very poor, 0: otherwise
vgood_bio	Aquatic ecosystem 1: very good, 0: otherwise
good_bio	Aquatic ecosystem 1: good, 0: otherwise
nor_bio	Aquatic ecosystem 1: fair, 0: otherwise
bad_bio	Aquatic ecosystem 1: poor, 0: otherwise
vbad_bio	Aquatic ecosystem 1: very poor, 0: otherwise
vgood_wl	Water level. 1: very high, 0: otherwise
good_wl	Water level. 1: high, 0: otherwise
nor_wl	Water level. 1: fair, 0: otherwise
bad_wl	Water level. 1: low, 0: otherwise
vbad_wl	Water level. 1: very low, 0: otherwise
vgood_wq	Water quality. 1: very good, 0: otherwise
good_wq	Water quality. 1: good, 0: otherwise
lgood_wq	Water quality. 1: fairly good, 0: otherwise
nor_wq	Water quality. 1: fair, 0: otherwise
lbad_wq	Water quality. 1: fairly poor, 0: otherwise
bad_wq	Water quality. 1: poor, 0: otherwise
vbad_wq	Water quality. 1: very poor, 0: otherwise
cost	KRW 170/m^3

Table 4. Estimation Results of CLM, NL, and ECL Models.

	Choice Model					
Model	**CLM**		**NL**		**ECL**	
Vriable	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
sq	0.5201***	0.0329	0.7004***	0.1043	0.7212***	0.0357
vgood_re	0.9098***	0.0889	1.1064***	0.1517	0.8436***	0.0975
good_re	0.7983***	0.0744	0.9725***	0.1303	0.7335***	0.0792
nor_re	0.7148***	0.0703	0.8510***	0.1114	0.7070***	0.0715
bad_re	0.1915***	0.0684	0.2644***	0.0882	0.1468**	0.0715
vbad_re	reference		reference		reference	
vgood_bio	0.4755***	0.0906	0.6208***	0.1291	0.6549***	0.1053
good_bio	0.4474***	0.0663	0.5872***	0.1035	0.6090***	0.0712
nor_bio	0.4473***	0.0628	0.5401***	0.0886	0.6001***	0.0649
bad_bio	0.0344	0.0601	0.0684	0.0723	0.0718	0.0651
vbad_bio	reference		reference		reference	
vgood_wl	0.2179***	0.0801	0.2827***	0.0958	0.1257	0.0875
good_wl	0.1694***	0.0629	0.2180***	0.0759	0.1417**	0.0677
nor_wl	0.2099***	0.0588	0.2596***	0.0714	0.1844***	0.0618
bad_wl	0.1073**	0.0539	0.1500**	0.0617	0.0511	0.0554
vbad_wl	reference		reference		reference	
vgood_wq	1.1924***	0.0781	1.5166***	0.1952	1.4112***	0.0762
good_wq	1.0033***	0.0640	1.2508***	0.1581	1.2019***	0.0656
lgood_wq	0.9566***	0.0549	1.1689***	0.1308	1.1316***	0.0499
nor_wq	0.7624***	0.0561	0.9118***	0.1073	0.9343***	0.0548
lbad_wq	0.1412***	0.0548	0.2322***	0.0814	0.2110***	0.0586
bad_wq	0.0714	0.0594	0.1203	0.0755	0.1008	0.0658
vbad_wq	reference		reference		reference	
cost	−0.0011***	0.0003	−0.0014***	0.0004	−0.0023***	0.0003
IV parameters						
Branch1			1.0	fixed		
Branch2			1.2324***	0.1276		
σ1					1.3976***	0.0483
σ2					1.1781***	0.0609
LL	−8810.48		−8808.58		−8344.84	
Pseudo R^2	0.109		0.075		0.156	

Note: ***, ** indicate statistical significance at the 1% and 5% levels, respectively.

The NL model allows for the correlation of error terms among hypothetical alternatives (alternatives 2 and 3) by grouping them in the same nest. In the NL model estimation, the current alternative was assigned to Branch 1, and the hypothetical alternatives (alternatives 2 and 3) were assigned to Branch 2. The estimated coefficients of the NL model showed little difference from the CLM model in terms of statistical significance or the magnitude of the coefficients. However, the IV parameter for Branch 2 was estimated to be greater than 1. According to Hensher et al.[29], this violates the assumption of global utility maximization. One possible solution to this problem would be to reassign the alternatives to a new nesting structure. However, in this study, since there is only one current alternative and two hypothetical alternatives, it is not feasible to reorganize the nesting structure. Therefore, considering the NL model results for further analysis may not be appropriate.

To estimate the ECL model, the alternative with the smallest variance among the three alternatives must be identified[30]. Preliminary analysis revealed that the current alternative (the respondent's evaluated alternative) had a smaller variance than the hypothetical alternatives, so the standard deviation of the error term for the current alternative was normalized to 0. When comparing the ECL model estimation results with the CLM model, there were some changes in the magnitude and statistical significance of the coefficients for each attribute. For example, $vgood_{wl}$ and bad_{wl} were statistically significant in the CLM model but no longer statistically significant in the ECL model. Additionally, the statistical significance of some variables decreased. Notably, the magnitude of the cost variable increased by more than double (in absolute terms).

The estimated coefficients related to the variance of hypothetical alternatives 2 and 3, σ_1 and σ_2, were both statistically significant and had positive signs. The estimated coefficient values for σ_1 and σ_2 were 1.3976 and 1.1781, respectively, indicating that while the variance of the current alternative $\frac{\pi^2}{6}$ remains constant, the variance of hypothetical alternatives 2 and 3 is larger, as indicated by $\frac{\pi^2}{6} + 1.3976^2$ and $\frac{\pi^2}{6} + 1.1781^2$. When comparing the statistical fit between the ECL and CLM models, the ECL model, which accounts for heteroscedasticity among potential choice alternatives, was found to be more suitable. The Pseudo R^2 was also higher for the ECL model (0.18) compared to the NL model (0.156). Overall, these findings suggest that the choice of model can influence the estimated coefficients, which in turn can affect the benefit calculations based on those coefficients. Therefore, when analyzing pivot-style data, it is important to consider models that can control for potential biases.

4.2. Benefit Analysis

In this section, the economic value of improvements in water quality and aquatic ecosystem levels (grades) resulting from the Anyangcheon Ecological Stream Restoration Project is estimated, and the benefits are calculated by considering the final beneficiaries. According to Choi and Choi [19], when water quality changes were categorized into grades using both the CCME WQI and IRWQI methodologies, both methods showed a two-level improvement in water quality due to the ecological stream restoration project (**Table 5**). **Table 6** presents the changes in weighted usable area for target fish species before and after the restoration. The results indicate that the ecological stream restoration significantly improved habitat availability for the target species [19].

The benefit calculation alternatives are shown in **Table 7**. The water quality grade before the restoration project (in 2001) was evaluated as 'fairly poor' according to the integrated water quality index (IRWQI), while the current grade (in 2018) after the project was evaluated as 'fairly good,' indicating a two-grade improvement. For the aquatic ecosystem, the HHS Index assessment estimated that the grade improved from 'poor' before the project to 'fair' in 2018, indicating a one-level improvement. The ECL model was used for the benefit analysis.

Table 5. WQI Before and After the Ecological Stream Restoration Project.

Method	**WQI Grade (Score)**		
	Before (2001)	**After (2006)**	**Present (2018)**
CCME WQI	Marginal (55.59)	Good (88.56)	Good (87.67)
IRWQI	Poor (49.53)	Good (77.81)	Good (76.53)

Source: [19].

Table 6. Target species and their weighted usable Area and hydraulic habitat suitability.

Target Fish Species	**Total Area (m^2)**	**Weighted Usable Area (m^2)**		
		Before (2001)	**After (2006)**	**Present (2018)**
Zacco koreanus	144,047	5,844	10,317	10,003
Zacco platypus		6,653	9,693	9,433
Coreoleuciscus splendidus		1,542	3,684	3,781
Pungtungia herzi		6,430	10,622	11,054
Acheilognathus yamatsutae		9,902	18,432	16,041
Total Weighted Usable Area		30,371	52,748	50,312
HHS Index		21.08% (low)	36.62% (medium)	34.93% (medium)

Source: [19].

Table 7. Benefit calculation alternatives.

Category	**Details**	
Analysis Method	Benefits from changes in water quality and aquatic ecosystem grades due to the Ecological Stream Restoration Project	
Water Quality	IRWQI grade	
	Before(2001)	After(2018)
	fairly poor	fairly good
Aquatic Ecosystem	HHS Index	
	Before(2001)	After(2018)
	Poor	fair
Benefit Analysis Model	ECL Model	

Source: [20].

Based on the physical impact assessment results of the Anyangcheon water quality and aquatic ecosystem following the Ecological Stream Restoration Project, the benefits were estimated using the compensating variation (CV) concept in Equation (5). In Equation (5), β_{1good_wq} and β_{1bad_wq} represent the estimated coefficients from the ECL model related to the 'fairly good water quality level' and 'fairly poor water quality level,' respectively, while β_{nor_bio} and β_{bad_bio} represent the estimated coefficients for the 'fair aquatic ecosystem function' and 'poor aquatic ecosystem function' variables, respectively.

$$\begin{aligned} CV_{water\ quality} &= -\frac{(\beta_{1good\_wq} - \beta_{1bad_{wq}})}{\beta_{cost}} \\ CV_{aquatic\ ecosystem} &= -\frac{(\beta_{nor\_bio} - \beta_{bad\_bio})}{\beta_{cost}} \end{aligned} \quad (5)$$

The results of the estimated annual benefits from improvements in water quality and aquatic ecosystem levels are shown in **Table 8**. The benefit estimation process is explained as follows. First, the WTP (KRW/m^3/household) was derived using the coefficients estimated from the ECL model. To convert this into the monthly WTP (KRW/month/household), the average monthly water usage per household in the Han River basin (approximately 20 m^3) was considered. While previous studies typically use 12 months to calculate the annual WTP (KRW/year/household), Ahn et al.[31] applied an empirical conversion factor of 5.9 months based on the environmental value database (DB). This study applied both methods, referencing Ahn et al.[31], to estimate the annual WTP (KRW/year/household). Finally, the number of households in Anyang City was considered as the beneficiary group for the improvements in water quality and the aquatic ecosystem resulting from the Anyangcheon Ecological Stream Restoration Project. This is because the middle section of Anyangcheon, which is the focus of this study, belongs to Anyang City, and according to Anyang City's "Anyangcheon Restoration Master Plan"[18], the Ecological Stream Restoration Project was targeted at residents within the Anyangcheon basin.

The estimated annual benefits from water quality improvements were approximately KRW 21.44 billion using the general conversion method (12 months) and approximately KRW 10.54 billion using the conservative conversion method (5.9 months). For the aquatic ecosystem, the annual benefits were estimated at approximately KRW 12.30 billion with the 12-month method and KRW 6.05 billion with the 5.9-month method. The values estimated in this study represent the benefits accruing to beneficiaries over one year. However, considering that the benefits from water quality and aquatic ecosystem improvements due to the Ecological Stream Restoration Project continue to accrue each year, the estimates derived in this study are significant.

Table 8. Estimated Annual Benefits from Improvements in Water Quality and Aquatic Ecosystem Grades.

Category	WTP (KRW/m^3/household)	WTP1) (KRW/month/household)	WTP(A) (×12;KRW/year/household)	WTP(B)2) (×5.9;KRW/year/household)	Number of Households (C)	Annual Benefit (A×C; billion KRW)	Annual Benefit (B×C; billion KRW)
Water Quality	400.2	8,005.0	96,059.5	47,229.2	223,172	214.4	105.4
Aquatic Ecosystem	229.7	4,594.3	55,132.2	27,106.7	223,172	123.0	60.5

Note: 1) WTP (KRW/month/household) = WTP (KRW/m^3/household) × 20 m^3 (the average monthly water usage per household in the Han River basin).
2) To calculate the annual WTP, a conversion factor of 5.9, derived from the environmental value database, was applied to the WTP (KRW/month/household) value.

5. Discussion

This study provides a comprehensive economic assessment of the Anyangcheon Ecological Stream Restoration Project by quantifying the value of improvements in water quality and aquatic ecosystem services. Leveraging survey data from Ahn et al.[20] and applying CE methods, this study evaluated the public's preferences for key ecosystem service attributes such as water-friendliness, ecological functions, water level control, and water quality purification. Through the choice experiment design, water use charges were used as the primary trade-off element, allowing the study to capture the monetary value that respondents assign to each improvement in ecosystem services. This approach offers valuable insights into public perception and willingness to pay for ecological restoration, which is critical in understanding the social demand for ecosystem service improvements.

The study's use of multiple benefit analysis models, including the CLM, NL, and ECL, provides a robust foundation for the valuation of non-market ecosystem services. Among these, the ECL model emerged as the most suitable, as it accounts for preference heterogeneity and allows for a more precise capture of individual variability in choices. This choice model's robustness reflects the complexity of environmental choices where respondents may have varying degrees of preference strength and trade-offs based on factors like environmental awareness, personal value systems, and prior experience with environmental services. By using a sophisticated model that incorporates these nuances, the study yields a more realistic and comprehensive valuation of the ecosystem benefits derived from restoration projects, which has implications for the application of economic valuation in environmental policymaking.

The findings highlight that the public places significant value on qualitative improvements in ecosystem services provided by the restoration project. Specifically, the annual economic benefits from water quality improvements were estimated to range between KRW 10.54 billion and KRW 21.44 billion, and the benefits from aquatic ecosystem enhancements were estimated to range from KRW 6.05 billion to KRW 12.30 billion annually. These values underscore the economic importance of the Anyangcheon Ecological Stream Restoration Project beyond its environmental benefits, showing that such projects are perceived as valuable public investments. This economic valuation aligns with global trends that prioritize ecosystem service improvements within urban and environmental planning, as well as with initiatives aimed at integrating natural capital considerations into national accounts. By emphasizing the economic returns associated with ecological restoration, this study reinforces the notion that environmental investments, particularly in urban areas, yield tangible benefits for both nature and society.

The study also underscores the critical role of post-evaluation in environmental policy and project implementation. Post-evaluation involves analyzing the differences between anticipated and realized benefits after a project's completion, which is essential for evaluating the effectiveness of the project and identifying areas for potential improvement. Such evaluations provide a mechanism for validating whether the environmental and economic benefits predicted during the planning phase have been achieved, and they enable policymakers to make data-driven adjustments in future projects. Through post-evaluation, decision-makers can assess the project's long-term impacts on water quality and aquatic ecosystems, verify its sustainability, and refine approaches to maximize its effectiveness. This feedback loop is especially valuable in environmental policymaking, where outcomes may vary significantly based on contextual factors, including geographic location, local ecological conditions, and community engagement.

The application of integrated environmental and economic analysis, as utilized in this study, adds further value by providing a quantitative foundation for policy development. By estimating the economic value of physical environmental changes, such as improvements in water quality and habitat quality, the study offers policymakers a robust tool for cost-benefit analysis. This type of analysis is instrumental in justifying public expenditures on ecological restoration and provides policymakers with a clear basis for understanding the economic returns of environmental interventions. The choice of compensating variation as a valuation metric enhances the utility of this analysis, as it translates non-market environmental benefits into economic terms that are directly applicable in resource allocation decisions.

However, the study's focus on a single case—Anyangcheon—limits the generalizability of its findings. While the results provide strong evidence for the economic and environmental value of ecological restoration in this context, it is essential to conduct comparative studies across different regions to validate these findings more broadly. Different ecological characteristics, socioeconomic factors, and urban pressures may influence the outcomes of restoration projects, and understanding these variations is key to developing adaptable and region-specific policies. Future studies that analyze multiple cases could reveal patterns and factors that influence the success of restoration projects, offering a more comprehensive understanding of how diverse contexts shape restoration outcomes.

Additionally, the study highlights the importance of accounting for long-term influences, such as urban expansion and climate change, in evaluating the economic value of restoration projects. Urbanization can intensify pressures on water quality and ecosystems by increasing pollution levels, altering natural hydrological patterns, and generating increased runoff. Similarly, climate change presents a significant risk to water quality and ecosystem stability, with potential impacts ranging from extreme weather events to changes in precipitation patterns. Restoration projects that incorporate adaptive management strategies and long-term resilience planning can better withstand these dynamic environmental influences. Addressing these factors in future studies can ensure that the economic value of restoration projects is preserved over time, making them sustainable investments in urban resilience.

In summary, this study contributes to a growing body of research on the economic valuation of ecosystem services, demonstrating that ecological restoration projects like the Anyangcheon Ecological Stream Restoration Project provide substantial societal, environmental, and economic benefits. By emphasizing the value of integrated environmental and economic analysis, this study offers policymakers a framework for assessing the multifaceted impacts of ecological restoration, supporting the development of policies that prioritize sustainable water and ecosystem management in urban settings. This focus on long-term adaptability and public value positions ecological stream restoration as a critical component of urban sustainability, balancing the needs of human development with environmental stewardship.

6. Conclusion

In conclusion, this study quantitatively evaluated the economic benefits provided by the Anyangcheon Ecological Stream Restoration Project, affirming its positive impact on both local residents and the environment. The results demonstrate that ecological stream restoration projects offer substantial environmental benefits and play a key role in improving quality of life and fostering sustainable urban environments. This study's findings serve as valuable foundational data for future restoration planning and implementation, offering insights for formulating long-term environmental policies that support ecological restoration.

To build on these findings, future research should undertake comparative studies of ecological stream restoration projects across different regions to derive more generalized policy insights. Such research will allow policymakers to adapt restoration approaches based on the unique ecological characteristics of each region. Furthermore, analyzing the influence of long-term factors, such as urban expansion and climate change, on the economic value of restoration projects is essential. Climate change poses a significant threat to water quality, aquatic ecosystems, and water resources, making it crucial to develop adaptive policies that address these dynamic influences.

Ultimately, this study reinforces the value of ecological stream restoration projects not only for environmental enhancement but also as key contributors to resilient and sustainable urban planning. By emphasizing the economic and social benefits of ecosystem service improvements, this study highlights the importance of integrated environmental and economic approaches in crafting effective water management and urban development policies.

Author Contributions

Conceptualization, H.N.K.; methodology, H.N.K.; data analysis, H.N.K.; validation, H.N.K.; writing, H.N.K.; reviewing, H.N.K.; supervision, H.N.K.; investigation, H.R.; writing, H.R.; reviewing, H.R.; editing, H.R. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest

The authors declare no conflict of interest.

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