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Article

Sustainable Water Infrastructure Asset Management: A Gap Analysis of Customer and Service Provider Perspectives

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Abstract: The ultimate goal of urban water infrastructure asset management may be sustainable water supply with satisfaction for customers. In this work, we attempted to evaluate the gaps between the perspectives of customers and service providers in Korea's water infrastructure asset management. To evaluate the customers' perspective, a hierarchical questionnaire survey was conducted to estimate the weights of influence for six customer values and their attributes on Korean water utility management. To evaluate the service providers' perspective, an AHP (Analytic Hierarchy Process) analysis was performed to estimate the weights of influence for the customer values and their PIs (performance indicators). The gap analysis results show that customers place higher value on customer service satisfaction (emotion and information) than do the service providers (managers), whereas the managers place more value on affordability than do the customers. The findings from this work imply that improving customer service is effective in satisfying the desirable water LOS (level of service) for customers. Recommendations have also been provided for administrators and engineers to develop integrated decision-making systems that can reflect customer needs regarding the improvement of their water infrastructure asset management. The findings from this work may be helpful for the Korean government and water supply utilities in improving the sustainability of their water infrastructure asset management.

Keywords: water asset management; Gap analysis; LOS (level of service); PIs (performance indicators); customer value

1. Introduction

Sustainability may be one of the key goals of water infrastructure asset management. To make water infrastructure asset management sustainable, it is necessary not only to reduce maintenance costs but also to improve user satisfaction. Asset management in the water sector is an emerging concept that has been adapted from many successful applications in the management of other infrastructure assets, such as the transportation sector and power plants [1]. Many studies regarding water and wastewater asset management have focused on cost-effective and preventive management using risk-based methods [2–4], cost-benefit methods [5,6], and GIS-based asset data integrations [7]. In the past, some research into the methodology of evaluating the levels of service (LOSs) from the customer's perspective has been performed [8–10].

According to the overall asset management process suggested by the New Zealand NAMS (National Asset Management Steering) group, the starting point of strategic planning for asset management is to determine the LOSs that are currently provided [11,12]. Defining the current LOS provisions and setting performance targets play an important role in planning asset management [12]. Schulting and Alegre [1] defined the asset management process as follows: "in addition to the key parameters 'performance-risk-costs' which represent the internal process of asset management in an organization, there are external factors/drivers including customers and regulatory bodies which will influence and set the boundaries for the overall balance between these parameters".

This definition suggests that a comprehensive approach is required to evaluate and set appropriate LOS provisions for water asset management. Understanding the needs of external stakeholders is an area that has not been extensively studied. Customer satisfaction evaluations have been mainly investigated in the marketing sector. However, in the water sector, current customer satisfaction analyses have been limited to a few areas of water quality [13,14] and the cost of water service [15,16], without a comprehensive assessment of its weights of influence in the context of other customer values.

Gap analysis is a useful tool that can help companies or utilities identify gaps between their current status and future goals [17]. In water asset management, gap analysis has been used to identify gaps among different water utilities and to set targets for managing water infrastructure through benchmarking [18–20]. Although several previous studies have addressed the issues regarding gaps between the perspectives of customers and service providers in other sectors (e.g., marketing, airports, and banks) [21–23], no such analysis has been reported in the water asset management field.

In our previous study, Han *et al.* [24] developed a new method to quantitatively evaluate customer needs in the Korean water and wastewater service utility sector (independent of the service provider's perspective) using six customer values: (1) sustainability, (2) affordability, (3) quality (functional performance), (4) health and safety, (5) reliability and responsiveness, and (6) customer service. The developed methodology for quantitatively assessing customer values allowed us to analyze the gaps between the perspectives of water service customers and providers in Korean water and wastewater infrastructure asset management. To compare the LOS evaluations from the customer's perspective to those from the provider's perspective, it is necessary to select and develop PIs to measure the provider's values that are equivalent to the six customer's values considered in the LOS evaluation of the customer's perspective [24] Although PIs [25–36] and methodologies [37–40] to measure water infrastructure asset management from the provider's perspective already exist, it is necessary to further investigate which PIs are suitable for comparison with LOS evaluations from the customer's perspective. Based on a literature review, the research objectives of this work were (i) to select and develop customer-based key performance indicators (KPIs) to evaluate water infrastructure asset management in Korea and (ii) to compare the LOS evaluations between the perspectives of customers and providers.

2. Research Approach and Methodology

The research methodology for comparing the LOS evaluations between the perspectives of customers and service providers is briefly shown in Figure 1. A wellbeing approach [12] has been adopted to analyze the LOS evaluations based on the aspects of environmental, economic, and social wellbeing, which are matched with the six customer values suggested in our previous study [24]. Accessibility to an unrestricted water supply in the community is not included in the six customer values according to our previous customer survey because the weight of influence of accessibility had the lowest customer value. The customer value definitions are obtained from the New Zealand asset management steering group [12]. The "environmental sustainability" value is defined as the quantity and quality of water resources that should be provided for present and future generations. The "affordability" value is defined as the water service level at the lowest possible cost. The "quality" value indicates the structural and functional stability and quality of the pipe system and water supply pressure. The "health/safety" value is defined as the availability of drinking water and the perspective on the risk to customer health and safety. The "reliability/responsiveness" value represents the reliable and responsive provisions of water services without inconvenience or interruption. The "customer service" value is defined as the availability of polite and transparent provisions regarding water services. To evaluate the six values from a provider's perspective, a triple bottom line (TBL) approach [38,39] was used in this study.

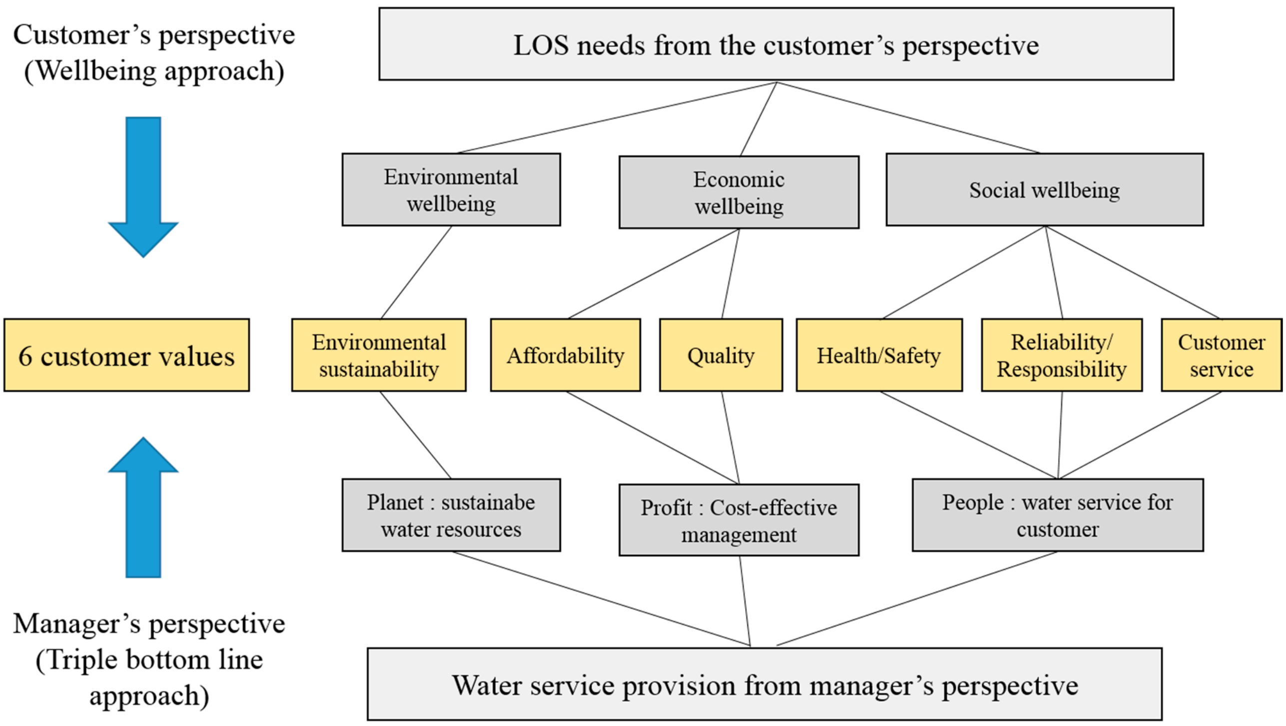

Figure 1. A schematic of the methodology used to compare the LOS evaluations between the perspectives of customers and providers (managers).

The LOS evaluations from the two perspectives were compared using the SERVPERF model [41]. Cronin and Taylor [41] proposed a performance-based methodology for measuring service quality (SERVPERF). They noted that the SERVPERF model was developed to resolve the difficulty in measuring the SERVQUAL scale based on the gap theory of Parasuraman *et al*. [21,42]. Compared with the SERQUAL Equation (1), the weighted SERVPERF equation proposed by Cronin and Taylor is expressed as Equation (2). They suggested that service quality is sufficient to measure only the performance that is perceived as having a direct relation to customer satisfaction [41].

$$Service\ Quality = (Performance - Expectations) \quad (1)$$

$$Service\ Quality = Importance\ (Performance) \quad (2)$$

To evaluate the customer values from the customer's perspective, the levels of customer value attributes (LCVAs) were defined, and their weights of influence were measured using hierarchical customer opinions based on surveys [24]. To evaluate the customer values from the service provider's perspective, KPIs were selected and developed as described below; their weights of influence were measured using the Analytic Hierarchy Process (AHP) to represent the opinion of water service experts. The weights of influence of the LCVAs and KPIs were compared to identify the gaps between the perspectives of the customers and providers regarding water infrastructure asset management. The methodology framework for the gap analysis conducted in this work is summarized in Figure 2.

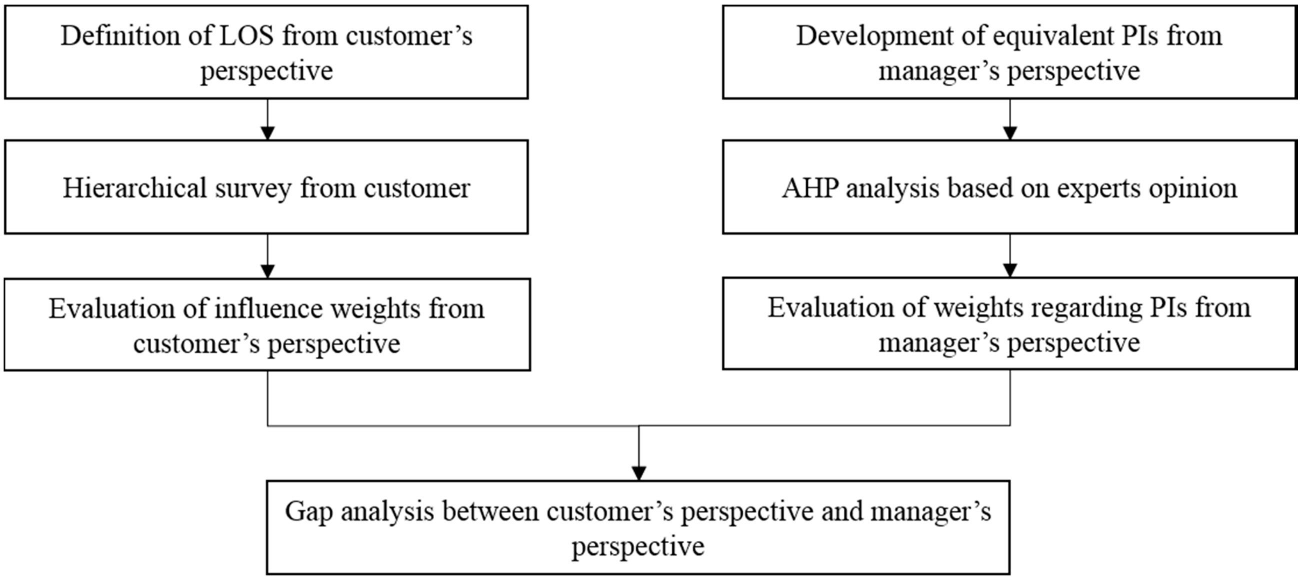

Figure 2. Scheme of the gap analysis between the perspectives of customers and managers on water infrastructure asset management.

3. LOS Evaluation from the Customer's Perspective

A new hierarchical survey method was developed in our previous study [24] to assess the response of customers regarding the LOSs for water utilities in Korea. Because it is difficult for general customers to understand the technical definitions of the customer values and their attributes and meanings in the LOS evaluations, it was necessary to stratify the survey questionnaire using simple to more complex questions. Questions regarding the LCVAs (levels of customer value attributes) were addressed first, followed by questions regarding the LOCVs (levels of customer values) and the LOWs (levels of wellbeing) (Figure 3). The answering system for the questionnaire was based on a seven-point Likert scale, *i.e.*, (1) "strongly disagree" (0 points), (2) "disagree" (16.7 points), (3) "disagree somewhat" (33.3 points), (4) "neutral" (50 points), (5) "agree somewhat" (66.7 points), (6) "agree" (83.3 points), and (7) "strongly agree" (100 points). An electronic survey was conducted via the Internet for 800 tap water customers from seven cities in Korea. When the customers were asked about water being "safe to drink", the concept of "safe to drink" included attributes regarding taste, color, and odor along with attributes regarding toxic chemicals and microbial hazards.

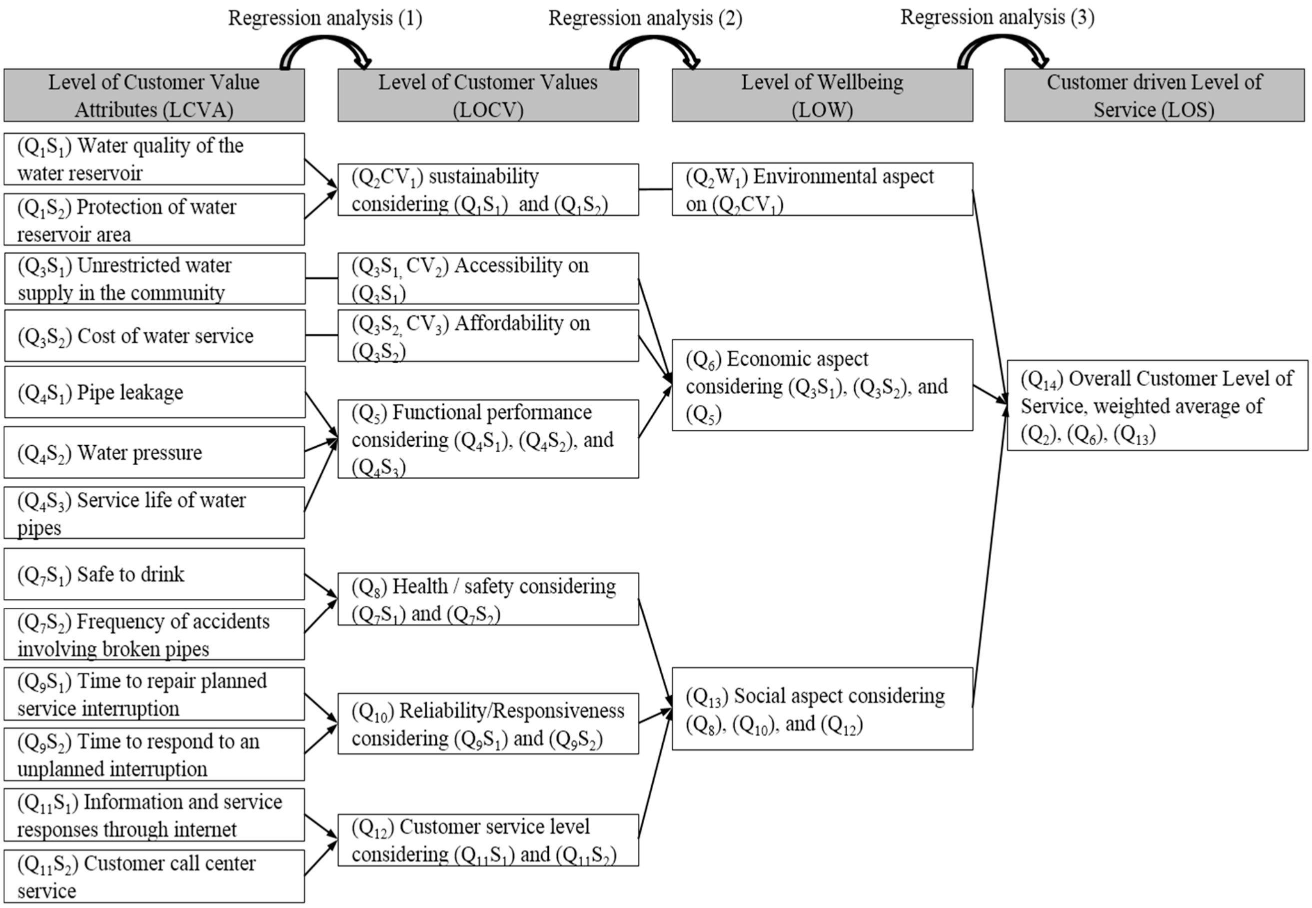

Figure 3. The hierarchical structure of the questionnaire used in the LOS evaluation from the customer's perspective [24].

The weights of influence between two adjacent levels were analyzed using multi-variant regression [43]. A standardized coefficient for the multi-variant statistical analysis (β) was used as the statistical indicator for the weight of influence. Based on the determined β values, the relative weight CVs (customer values) and CVAs (customer value attributes) were calculated (Table 1). For the LOCA, the relative weight of the 'customer service' factor was the highest (0.312) among the six CAs. For the LCVA, the relative weights of "information on Internet" and "customer call center service" (0.162 and 0.150, respectively) were higher than the other CVAs used in the analysis. Considering the fact that the "information on Internet" and "customer call center service" CVA factors are categorized into the "customer service" category for the LOCA, "customer service" was identified as the most influential CV factor in the LOS evaluation from the customer's perspective.

Table 1. The weights of influence (β) and relative weights of CVs and CVAs determined from the customer's perspective.

Factors	LOW (A)	LOCV (B)	LCVA (C)	Relative Weights of CVs ($= \frac{A \times B}{\sum A \times B}$)	Relative Weights of CVAs ($= \frac{A \times B \times C}{\sum A \times B \times C}$)
	β				
Level 1					
Environmental	0.131				
Economic	0.274				
Social	0.596				
Level 2-Environmental					
Sustainability	0.131	1		0.131	
Level 2-Economic					
Affordability	0.274	0.189		0.052	
Quality		0.810		0.222	
Level 2-Social					
Health/Safety	0.596	0.249		0.148	
Reliability/Responsiveness		0.227		0.135	
Customer service		0.524		0.312	
Level 3-*Sustainability*					
Water quality of water reservoir	0.131	1	0.449		0.059
Protection of water reservoir area			0.551		0.072
Level 3-*Affordability*					
Cost of water service	0.274	0.189	1		0.052
Level 3-*Quality(Physical)*					
Water losses	0.274	0.810	0.143		0.032
Water pressure			0.326		0.072
Useful life of water mains			0.531		0.118
Level 3-*Health/Safety*					
Safe to drink	0.596	0.249	0.754		0.112
Probability of pipe accidents			0.246		0.037
Level 3-*Reliability/Responsiveness*					
Time to respond to planned service interruption	0.596	0.227	0.297		0.040
Time to respond to unplanned interruption			0.703		0.095
Level 3-*Customer service*					
Information on internet	0.596	0.524	0.519		0.162
Customer call center service			0.481		0.150

4. LOS Evaluation from the Manager's Perspective

The procedure for evaluating the water supply utility LOSs from the water utility manager's perspective is shown in Figure 4.

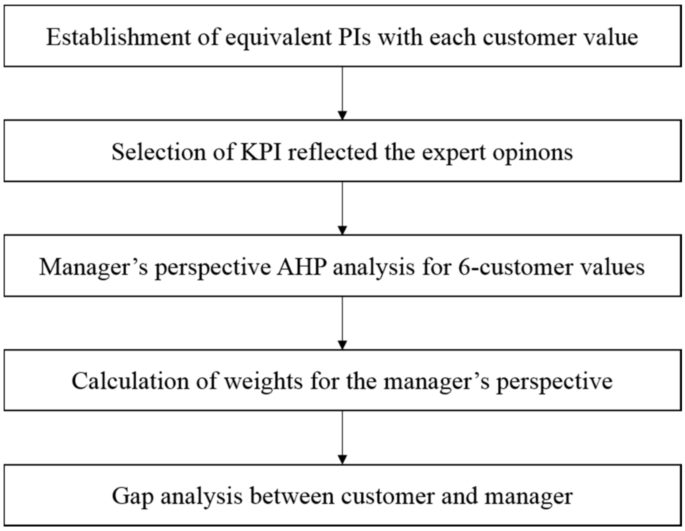

Figure 4. The evaluation process for the manager's perspective.

The AHP decomposes the decision problem into a hierarchy of sub-problems. The decision maker then evaluates the relative importance of its various elements via pairwise comparisons. The AHP converts those evaluations to numerical values (weights or priorities), which are used to calculate a score for each alternative [44]. Importance scales for pairwise comparison are shown in Table 2.

Table 2. Intensity of importance for pairwise comparison [44].

Linguistic terms (the comparison of A to B)	Score
Absolutely strong (AS)	9
Between AS and VS	8
Very strong (VS)	7
Between VS and FS	6
Fairly strong (FS)	5
Between FS and SS	4
Slightly strong (SS)	3
Between SS and E	2
Equal (E)	1
Between E and SW	1/2
Slightly weak (SW)	1/3
Between SW and FW	1/4
Fairly weak (FW)	1/5
Between FW and VW	1/6
Very weak (VW)	1/7
Between VW and AW	1/8
Absolutely weak (AW)	1/9

The hierarchy of the AHP analysis is presented in Figure 5. The advice from eight professional experts in the Korean water sector and information from selectively used literature from the IWA PI system and CARE-W rehab PIs were used in this study [26]. Level 1 is considered the strategic aspect and is equivalent to the LOW in the LOS evaluation from the customer's perspective. Levels 2 and 3 address tactical and operational aspects, respectively, and are equivalent to the LOCV and LCVA in the water infrastructure LOS evaluation from the customer's perspective. At the strategic level (Level 1), the three TBL goals (*i.e.*, planet, profit, and people) were selected as the major factors to be considered in the LOS evaluation from the water service provider's perspective. At the tactical level (Level 2), six factors that are equivalent to the six CVs were chosen for comparison with the weight of influence results from the analysis of the customer's perspective. At the operational level (Level 3), the KPIs for the planet ("environmental sustainability") and profit ("affordability" and "quality [physical]") goals were selected among the previously established PIs from the IWA PI system and the CARE-W rehab PIs [26]. Due to the unavailability of PI information, KPIs for the Level 1 objective for the customers' goals (the Level 2 objectives of "health/safety", "reliability/responsiveness", and "customer service") were newly developed in this work based on expert opinions.

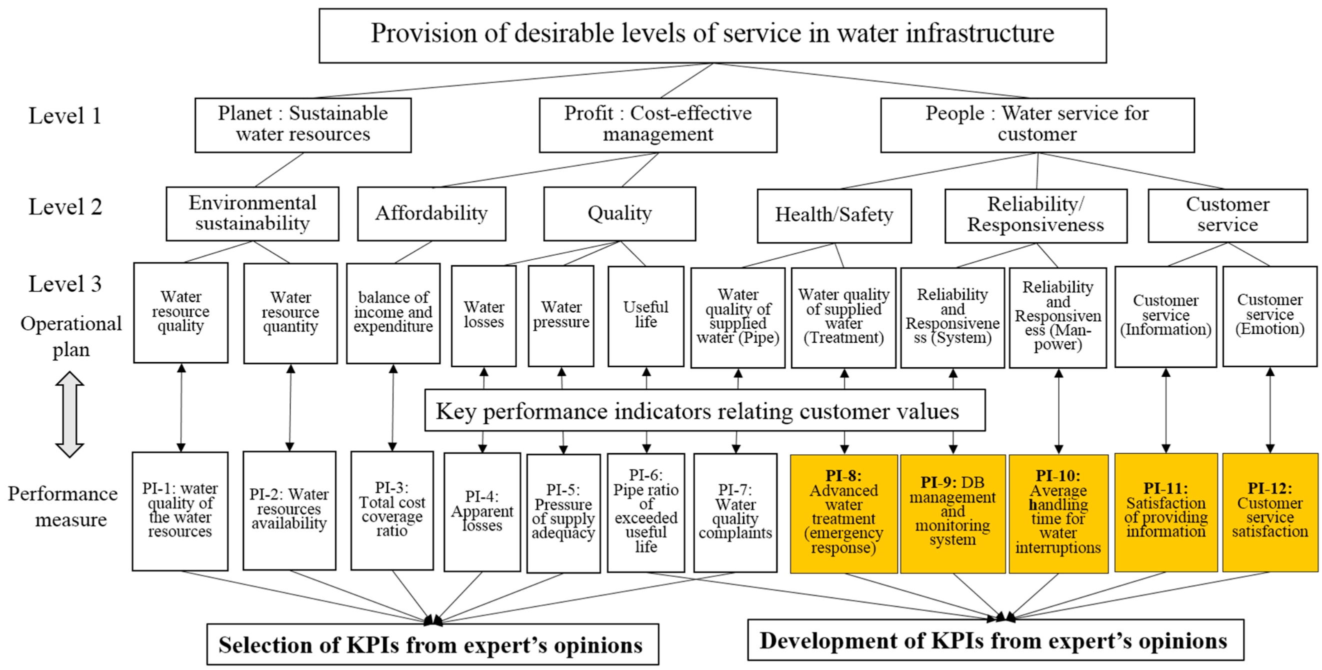

Figure 5. Hierarchy for LOS evaluation from the service provider's perspective and the KPIs for the six CVs.

Table 3. An example of a five-grade system for evaluating the PIs. (The example is for advanced water treatment for emergency management [PI-8]).

Grade	Description
1	Ultra-advanced purification technology application (membrane filtration), 100% automated WTP, expanded facilities for source water management, 100% compliance rate for the water treatment plant safety inspection
2	Advanced purification technology application, more than 80% automated WTP, 100% compliance rate for the water treatment plant safety inspection
3	More than 60% automated WTP, more than 80% compliance rate for the water treatment plant safety inspection
4	More than 40% automated WTP, more than 60% compliance rate for the water treatment plant safety inspection
5	Less than 40% automated WTP, less than 60% compliance rate for water treatment plant safety inspection

The new PIs were intended to be evaluated through rating scales. A five-grade system was developed to evaluate the new PIs based on the collected expert opinions. Advanced water treatment with emergency response capacity (PI-8) includes factors such as advanced water purification capacity, capacity for automatic facility operation, expanded capacity facilities for source water treatment, and safety of the water treatment plant (Table 3). The capacity of the database management and monitoring system (PI-9) refers to the use of a GIS-based management system, an adequate water distribution block system, a flow monitoring system, and a water metering automation system. With regard to the average handling time for water interruptions (PI-10), the results of the expert opinions indicated that Grade 1 is within 2.5 h, Grade 2 is within 5.6 h, and Grades 3, 4, and 5 are within 10.8, 24, and 40.7 h, respectively. According to a previous study [24], 5 h per year (46.6% of respondents) and 6–10 h per year (24.9% of respondents) were given as the accepted durations of water service disruptions for handling various incidents, such as freezing or pipe damage. The following satisfaction factors for providing information (PI-11) are considered: detailed water service information that contains the asset management goals for water utilities, water quality monitoring data in the water pipe network, the request process for all water service types, financial statements, statistics of water services, announcements regarding planned rehabilitation, database management for frequent complaints, provision of water charge calculation for each household, and bidding information. Customer service satisfaction (PI-12) includes items such as staff training for customer complaints (including complaint database management), the provision of tap water quality testing, and automatic meter reading that eschews visits to customers' homes to inspect water usage.

To assess the weights of influence for the water LOSs from the manager's perspective, a KPI-based AHP analysis was conducted [44]. This survey included eight experts: one professor, three researchers, and four public water utility managers. The collective working experience of the selected experts included more than 15 years in the water sector. As shown in Table 4, all PI weights of influence were derived using the AHP analysis results. Pairwise comparisons were used to evaluate the relative weights of the six CVs and their corresponding PIs. At the tactical level, the relative weights of the "affordability" and "quality" factors (0.317 and 0.204) were higher than those of the other CVs. Unlike the customer's perspective (Table 1), the "customer service" factor was considered the least influential factor from the provider's perspective. At the operational level PIs, the relative weight of the "total water cost coverage ratio" factor (0.317) was the highest among the PIs tested in the AHP analysis, whereas the customer service PIs (the "satisfaction with customer service on information" and "satisfaction with customer service on emotion" factors) were considered the least influential PIs from the provider's perspective.

Table 4. The weights of influence (β) and relative weights of the CVs and PIs determined from the AHP analysis of the service provider's perspective.

Factor	Strategic Level (A)	Tactical Level (B)	Operational Level (C)	Weights of CVs $(=\frac{A\times B}{\sum A\times B})$	Weights of PIs $(=\frac{A\times B\times C}{\sum A\times B\times C})$
Level 1					
Planet	0.114				
Profit	0.522				
People	0.365				
Level 2-Planet					
Sustainability	0.114	1		0.114	
Level 2-Profit					
Affordability	0.522	0.608		0.317	
Quality		0.392		0.204	
Level 2-People					
Health/Safety	0.365	0.453		0.165	
Reliability/Responsiveness		0.348		0.127	
Customer service		0.198		0.072	
Level 3-*Sustainability*					
Water resource quality	0.114	1	0.438		0.050
Water resource quantity			0.562		0.064
Level 3-*Affordability*					
Total cost coverage ratio	0.522	0.608	1		0.317
Level 3-*Quality(Pipe)*					
Apparent losses	0.522	0.392	0.239		0.049
Pressure of supply adequacy			0.485		0.099
Pipe ratio of exceeded useful life			0.276		0.056
Level 3-*Health/Safety*					
Water quality of supplied water from Pipe	0.365	0.453	0.633		0.105
Water quality of supplied water from treatment plant			0.367		0.061
Level 3-Reliability/Responsiveness					
System	0.365	0.348	0.597		0.076
Manpower			0.403		0.051
Level 3-*Customer service*					
Satisfaction with customer service on information	0.365	0.198	0.503		0.036
Satisfaction with customer service on emotion			0.497		0.036

5. The Gap Analysis Results between the Perspectives of Customers and Managers

The relative weights of the six CVs were compared between the perspectives of customers and managers (Figure 6). From the customer's perspective, the "customer service" CV factor was identified as the most influential. Moreover, from the provider's perspective, the "affordability" CV factor was found to be the most influential. Other CV factors (e.g., "sustainability", "quality", "health and safety", and "reliability and responsiveness") were insignificantly different between the perspectives of customers and managers. The results suggest the possible existence of significant gaps between customers' needs and managers' provision, and "customer service" and "affordability of cost" were identified as the customer values that had gaps between customers' needs and water utility provision.

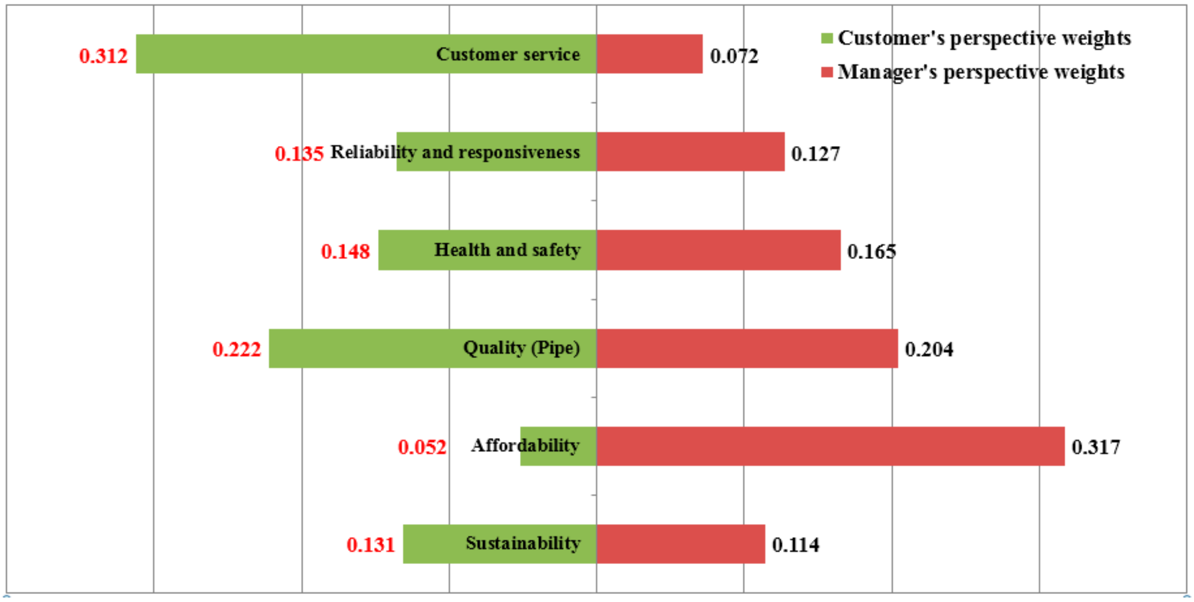

Figure 6. The gap analysis results between the perspectives of customers and managers on six CVs.

The gap analysis at Level 3 identified the CVAs and PIs with significant gaps between customers and service providers (Figure 7). The customers may place the highest values on satisfaction of customer service on emotion (relative influence weight = 0.150) and information (relative influence weight = 0.162), whereas the customer service attributes are given the lowest priority by water utility managers (corresponding relative weights = 0.036). Further, affordability was identified as the lowest priority by customers (relative influence weight = 0.052) but as the highest priority by managers (relative influence weight = 0.317). The results provide implications regarding what tactical and operational actions may be needed to improve customer satisfaction.

To improve customer service, information provision and the emotional aspect of contact with customers may have to be emphasized further in water utility management. Water service information includes announcements regarding water asset management planning, water quality monitoring data, and service. In other developed countries, such water service information is publicly available and reachable [45]; however, information on (i) water asset management planning and its evaluation outcomes and (ii) water quality monitoring data is often closed to the public or is unreachable in Korea. This lower public availability and reachability may cause citizens in many Korean cities to feel that the quality and price of tap water is not as good or reasonable as they expect them to be, even though the water quality and water infrastructure assets are scientifically monitored and externally evaluated by civilian experts with standards as high as those of other developed countries. There are some unique differences in water utility management in Korea compared with other countries. Most municipalities in Korea directly operate and manage water supply utilities, whereas water utilities are operated and managed mainly by private companies in European countries [46]. In addition, the managers of Korean water utilities often have non-engineering education backgrounds, and change jobs frequently in local government; these factors hinder the development of long-term credibility from citizens.

The findings from this work suggest that the difference in the perception of reasonably cost-effective and safe water service between Korean customers (citizens) and water service providers may have resulted from a lack of such information being provided to the customers. To address this issue, announcements of asset management planning and subsequent evaluation summaries, posts about water quality monitoring data on publicly available websites or social network systems (SNS), and periodic customer surveys can be effective tools for communication with customers. In addition, improving customer service is an effective way to increase customer satisfaction. Hunter Water in Australia reported that their customer and commercial development teams succeeded in achieving 94% customer satisfaction during the fiscal year 2009–2010 as a result of consistent commitment to customer service excellence [47]. A sufficiently large service staff and customer call service professionals with technical knowledge are required to address customers' questions and problems regarding the quality and price of water service. Customers' opinions on customer service must be regularly surveyed and evaluated, and the feedback should be reflected in improvements to customer service in terms of information provision as well as emotional aspects.

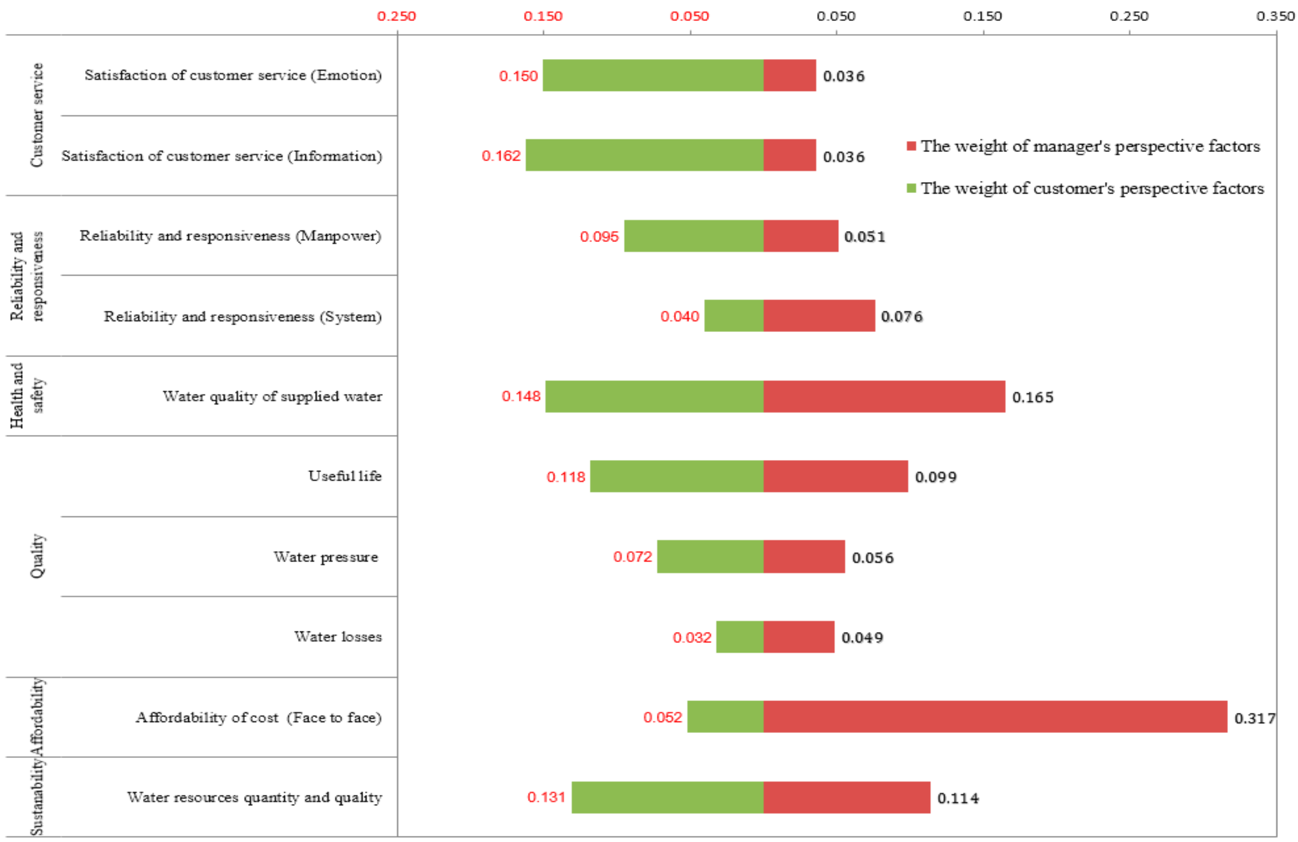

Figure 7. The gap analysis results between the perspectives of customers and managers on the water LOS.

6. Conclusions

Local administrators are interested in selecting the highest priority for a management area through a risk-based approach or by allocating additional funds for sustainable water management. However, in light of the results of this study, these actions may not represent the best approach for asset management. This study identified the gaps between customer needs and service provisions. The gap analysis results show that utility managers do not consider customer satisfaction, use information, and service-related emotions. This reflects the current problem of water infrastructure asset management in Korea. At the same time, the gap analysis results suggest that customer service improvement is an effective way to fill the gaps between the perspectives of customers and providers on water service.

To improve customer service, steps must be taken to increase the flow of information, particularly regarding water quality monitoring data, and reinforcement of staff training and education are recommended based on the results of gap analysis of the weights given to CVAs and PIs between the perspectives of customers and managers. The findings from this work may be useful in assisting local government administrators in making better decisions on water infrastructure asset management by integrating the perspectives of service providers and customers, and in turn may be helpful in improving the sustainability of water infrastructure asset management.

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Author Contributions

Sangjong Han and Hwankook Hwang developed the concept and conducted the surveys. Sangjong Han was the main writer of the manuscript. Seonghoon Kim analyzed the survey data. Gyu Seok Back developed the KPIs. Joonhong Park, as Sangjong Han's PhD dissertation advisor, edited the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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