Stoch Environ Res Risk Assess (2005) 19: 158–171
DOI 10.1007/s00477-004-0223-3

ORIGINAL PAPER

Ho-Wen Chen · Ni-Bin Chang · Daigee Shaw

Valuation of in-stream water quality improvement via fuzzy contingent valuation method

Published online: 3 February 2005

Abstract Society benefits from rivers in many aspects. To the extent of water resources management, one of the salient issues is that the social benefit of in-stream water quality improvements is often difficult to be quantified for possible cost justification in many water pollution control programs. The difficulties arise from that many service flows of water quality are not channelled through the market system to consumers and producers. With different socio-economic structures, such valuation could be even more challenging when taking river basins with low-income level into account. Recent advances in fuzzy set theory provide a germain insight to viewing the in-stream water quality as a kind of fuzzy resource due to varying awareness of the quality of life. This paper provides a technical analysis using the fuzzy contingent valuation mothod (FCVM) to value in-stream water quality improvements in terms of three fuzzy resources from aesthetic to recreational, and to ecological aspects. Traditional CVM may allow interest groups or affected parties to join and present a more flexible asset assessment with respect to the prescribed environmental features in the river corridor. Yet the FCVM provides a mechanism that lies in providing a mapping (via fuzzy set theory) from a survey of respondents' valuation of subjective assessments of water quality into objective economic measures in terms of water quality parameters that management can more directly manipulate. With this new tool, the traditional CVM assessment outputs in a well-developed river basin may even lead to derive a simular valuaton function in a form of a regression equation in a developing river basin where the incme level is relatively low. As part of the sustainablity analysis basin wide, a case study in Taiwan showed that such effort may provide supportive information for cost benefit analysis in many water pollution control programs corresponding to different temporal and spatial scales.

Keywords Contingent valuation method · Fuzzy sets theory · Water resources management · Water quality management · Environmental economics

H.-W. Chen
Department of Environmental Engineering and Management, Chaoyang University of Technology, Taichung, Taiwan, Republic of China

N.-B. Chang (✉)
Department of Environmental Engineering, Texas A&M University-Kingsville, Kingsville, TX, 78363, USA
E-mail: NChang@even.tamuk.edu

D. Shaw
Institute of Economics, Academia Sinica, Taipei, Taiwan, Republic of China

Introduction

Society benefits from rivers in many aspects, such as irrigations, water supply, hydropower generation, etc. Traditional cost benefit analysis exhibits a unique scheme to providing essential economic justification for most water resources planning and management projects. In the past, differing water quality standards in most countries were established for classified water bodies taking into consideration their specific use that creates social value for the public. Most water pollution control programs mainly focus on the systematic assessment of the efficiency and reliability of the infrastructure utility to meet the goals of prescribed water quality standards. One of the salient issues is that the social benefit of in-stream water quality improvements is often difficult to be quantified for possible cost justification in many water pollution control programs. The implied economic values (i.e., benefit) of recreational, aesthetic, and ecological aspects of water bodies along the river corridor were not even deemed critical or even overlooked in traditional profile of cost benefit analyses. This is much due to that many service flows of water quality are not channelled to consumers and producers through the market system. Previous valuation of water quality management programs simply assesses their financial outlays derived from the market without regard to possible non-market benefits and costs. Such cost benefit analysis associated with water quality management programs might be defective without considering monetary values for the non-market environmental resources or service flows. As a result, the pricing of water resources or water quality could be further undervalued resulting in the possible abuse of those resources. In an attempt to seek broader values for all possible river uses in the context of environmental valuation, such implied economic values are viewed vital for the evaluation of a variety of basin-scale water pollution prevention and mitigation programs.

In the absence of ownership and efficient pricing, special techniques are required to place consumer preferentences for natural resources and environmental goods and services on common ground. Considerable advances have been made in the theories and methodologies of estimating non-market values of environmental and resource service flows. The direct method includes travel cost method (TCM), random utility model (RUM), and hedonic price method (HPM). Travel cost and the random utility models are based on expenditures and travel behavior for recreational opportunities. Hedonic price methods decompose market prices of goods to extract embedded values for related environmental attributes. Experimental method was also designed for eliciting consumer preferences indirectly, either by using hypothetical settings, called contingent valuation method (CVM), or by constructing a market where none existed (Freeman 1993; Lipton et al. 1995). In the earlier stage, TCM and HPM that are based on assumptions of some kind of substitute or complementary relationship between the environmental service and marketed goods are used most often. However, indirect techniques, such as CVM, that rely on observable behavior to deduce how much something is worth to an individual even though it is not traded in market, has the advantages of easy-to-perform. Many CVM studies are related to in-stream water resources. Farber (1988), Burrows and House (1989), Smith and Davies-Colley (1992), and Goffe (1995) discussed the public's perception of water quality in rivers and coastal wetland systems with respect to the suitability for recreational use by a contingent valuation approach. Gregory and Davis (1993) and Willis and Garrod (1993) valued the perception of riverscape aesthetics and landscape in their respective study. Kwak and Russell (1994) and Press and Soderqvist (1998) valued the improvement of drinking water quality. Shaw et al. (1998, 1999) conducted the cost benefit analysis based on the water quality improvements in a river basin and presented an initial CVM assessment scheme with regard to non-market environmental resources. Critiques on CVM show some controversial insights with regard to this survey-based technique for estimating the nonmarket benefits of environmental goods and services (Vossler and Kerkvliet 2003). For example, gross measurement error might be introduced from mid-points in the double-bounded dichotomous choice answers and double-bounded approaches are heavily criticized by a number of sources for creating a kind of endogenity or starting point bias (Cameron and Huppert 1989). Cameron et al. (2002) started with finding alternative non-market value-elicitation methods using a common underlying indirect utility function. It may be that only the unique approach that is requiring the fuzzy set mapping may help to jump through a lot of hoops that we otherwise wouldn't have to (Zadeh 1965).

This paper provides a technical analysis using the fuzzy contingent valuation mothod (FCVM) to value in-stream water quality improvements in terms of three fuzzy resources from aesthetic to recreational, and to ecological aspects. While traditional CVM provides a procedure to allow interest groups or affected parties to join and present a more flexible asset assessment viewpoints with respect to those designated aspects in a high-income river basin, application of environmental valuation techniques may be expensive and benefit transfer offers a lower cost alternative to performing a full-scale study for any particular use in a low-income river basin (Lipton et al. 1995). However, comparative appraisal between different basins with differing social traits and economic development levels can be made possible in terms of population density, educational level, income level, and recreational demand based on a benefit transfer procedure develped in this paper. The fuzzy clustering approach can then provide a mechanism that lies in providing a mapping (via fuzzy set theory) from a survey of respondents' valuation of subjective assessments of water quality, no matter if they have been transferred, into objective economic measures in terms of water quality parameters that management can more directly manipulate. The following case study in Taiwan deomnstrates the application potential.

Study objectives

Use of fuzzy set theory to capture the imprecision embedded in the environmental quality management had received wide attention in the 1990s (Sii et al. 1993; Deshpande et al. 1996; Chang and Wang 1996; Chang et al. 1997; and Chang and Lu 1997). It was found effective to supplement the traditional CVM for advanced valuation of environmental resources (Smith 1994). Yet the question remained is "what would be an appropriate way to extrapolate the appraisal information gained from consumers' side for advanced analysis using fuzzy set theory?" Thus, the first study objective in this paper is to use traditional CVM to expedite a complete assessment in a well-developed river basin. Secondly, for those river basins with relatively low-income level and different social traits, the residents might not be so sensitive to environmental quality before having had a water pollution prevention and mitigation program fulfilled. This does not imply those people living in low-income river basins have no right to enjoy the same level of environmental quality as those living in high-income river basins. Over the last decade, however, attention to the impact of environmental pollution on particular segments of our society has been steadily growing to meet the goal of environmental justice (US EPA 2002). This could require employing fair treatment for people of all races, cultures, and incomes, regarding the development of environmental laws, regulations, and policies (US EPA 2002). The second question of interest is "to what extent can this information derived from high-income river basins be applied to those low-income river basins?" The possibility of "benefit transfer" becomes a critical issue that is worthy of a further assessment in the context of environmental justice. Thus, the second study objective in this paper is to design a procedure to fuifilling such a "benefit transfer." By using fuzzy clustering approach, the final objective would be placed upon finding out the linkage between willingness to pay (WTP) for fuzzy resources and objective economic measures in terms of water quality parameters that management can more directly manipulate. Fuzzy resources mentioned in this paper might include supplying finfish and shellfish for sport (fly fishing) or commercial fishers to harvest; providing a spot for swimming, water skiing, kayaking or boating for people to increase life quality; and presenting riverscape beauty for tourists to ease the tension in daily life. Hence, it is expected that the programs of in-stream water quality improvements applicable to promote aesthetic, recreational, and ecological benefits should be uniquely appreciated by using the implied economic value derived by the FCVM.

Case study

Methodology

The first stage analysis in the integrated assessment in this case study started with conducting a double-bounded referendum contingent valuation survey and a travel cost survey in the Dan-Shui River Basin, North Taiwan where the local communities are deemed sensitive to environmental quality (Shaw et al. 1999). This area, located at the center of Taipei metropolitan region, has experienced a thorough implementation of both water pollution control measures and flood-proofing programs for the promotion of the quality of life in the past few decades.

First, for the contingent valuation survey, Shaw et al. (1999) asked survey respondents to state their WTP for several constructed scenarios of water quality improvements in the river system.There are four levels of water quality, i.e., that the water is boatable, fishable, swimmable and drinkable.Second, the travel cost survey collects such information as the names of recreational sites along the rivers visited in 1994, the number of trips made to each site in 1994, travel time, on-site time, travel vehicle, transportation costs, entrance fee, food and accommodation expenditure, and the number of accompanied persons under 12 of age. Shaw et al. (1999) developed an expenditure difference approach that links the two data sets together and estimated parameters and their standard errors of the WTP function for water quality improvements and the trip demand function simultaneously.

This paper use the simultaneously estimated functions for Dan-Shui River to estimate the use value and the nonuse value of water quality improvements in the Tseng-Wen River Basin by applying the benefit function transfer method. The idea of benefit function transfer is similar to the standard demand forecasting. Once the demand function is estimated, i.e., once the marginal effects of demand factors are estimated, we can predict the level of consumption by substituting the values of the factors into the estimated demand model. We first collect information such as education, sex, income, travel cost, etc. about a representative person living in different cities in the South, and then, substitute the information into the estimated functions of Dan-Shui River in the North and obtain his use value and the nonuse value of water quality improvements in the Tseng-Wen River Basin. Figure 1 exhibits the geographical location of these two river basins.

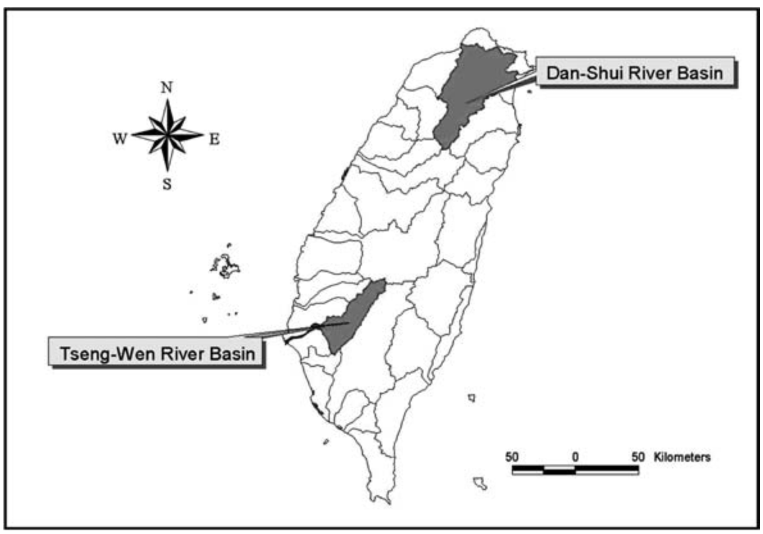


Fig. 1 The two river basins applied in this analysis

Membership functions required in fuzzy set theory were derived in the second stage to illustrate the subjective feeling of the possible monetary values for the achievable water quality standards in accordance with the aesthetic, recreational, and ecological benefits under uncertainty.The associated attributes of the use value and the nonuse value of water quality improvements in the Tseng-Wen River Basin estimated by the benefit function transfer in the first stage convey reliable signals of appraisal condition throughout the fuzzy clustering process.These estimates of the use value and the nonuse value can be analyzed, transformed, and utilized via the fuzzy clustering analysis to conduct a mapping in the Tseng-Wen River Basin, South Taiwan. Such information may support deriving a representative regression equation for further appraisal of relevant water quality management programs in the Tseng-Wen River Basin, South Taiwan where the residents are not so sensitive to environmental quality at present. Such a transfer from a high-income river basin in North Taiwan to a low-income river basin in South Taiwan should be based on locally applicable metrics in terms of population structure, educational level, income level, etc.. It is believed that the resulting derivation of such a value function for the in-stream water quality improvements should be applicable in assessing water pollution prevention and mitigation programs when we are able to factor socio-economic variations into the decision analysis matrix.

Overall, there are three non-trival steps required to get from the underlying study results to the desired output of beneficial valuation. One step is to connect the technical water quality measures to the use-descriptors (boatable, fishable, swimmable, drinkable) of the CVM questionnaire in a high-income river basin. The second is to translate the stated WTP for improvements in quality into WTP for levels of quality. And the third is to estimate a basin-dependent regression equation that includes enough explanatory variables in the sense that variations in WTP across respondents are to some large extent explained statistically in a low-income river basin. The way fuzzy set theory involves in this analysis is that WTP information expressed in terms of dollar value can be analyzed and utilized via the fuzzy clustering analysis in step 1 leading to derive a representative regression equation in the end for further appraisal in a river basin with low-income level. If we intend to transfer the benefit information to a new setting, socio-economic relationships have to be factored into the FCVM decision analysis independently up front rather than explicitly expressed as explanatory variables in the final regression equation. The following sections describe the study area, relevant rationale, procedures, and final results.

Study areas

With an area of 2,726 sq km, the Dan-Shui River Basin is the largest river basin in North Taiwan. The Dan-Shui River is composed of four tributaries, including: the Da-Han River, the Xin-Dain River, the Jing-Mei River, and the Keelung River, running from the surrounding mountains through the Taipei basin before reaching the ocean. Figure 2 addresses the general situation of the Dan-Shui River system. The Da-Han River and Dan-Shui River are generally regarded as the integrated main stream in many management practices. The extended length of the main stream is about 159 km. The Shi-Men Reservoir and Fei-Cui Reservoir are two important reservoirs that maintain the water supply for over six million population living in this river basin. The residents living in Taipei metropolitan region have been facing flooding impacts when typhoon and unusual

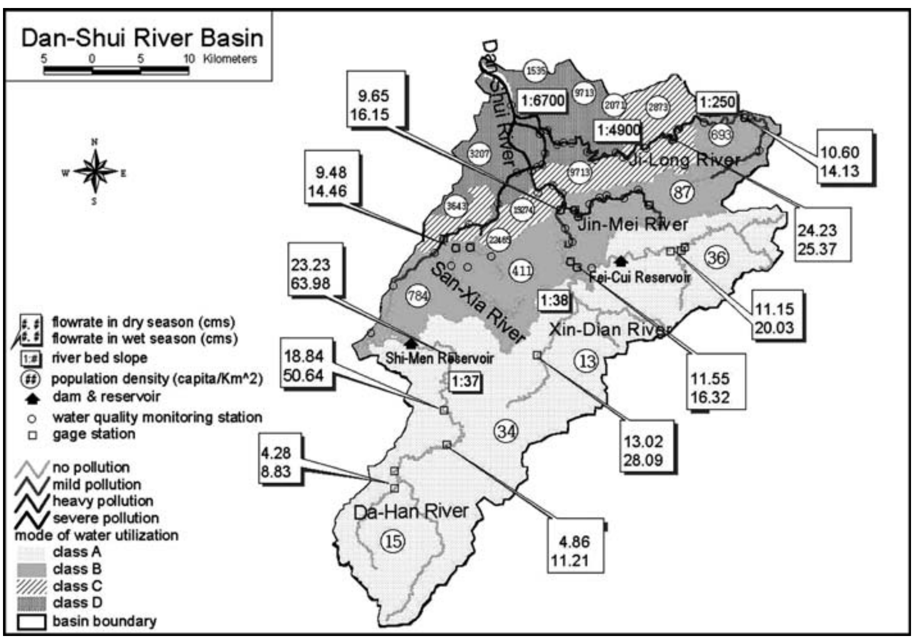


Fig. 2 The current situation of the Dan-Shui River Basin

storm periodically assault this island. Besides, the middle and downstream areas in the Dan-Shui River system have a long history of higher BOD_5 due to inadequate disposal of industrial effluents and domestic wastewater discharges in 1970s and 1980s.

Since 1960, the government has constructed many infrastructures such as walls, levees, etc. and the conservation of partial flood plain to mitigate the hazards of flooding. This flood-mitigating project was finished in 1997. The total nominal cost was around NT$100 billion (US$3.7 billion). In 1987, the government launched another large-scale project related to building a series of sewer system, coastal wastewater treatment plant, and ocean outfall facilities to control water pollution in this river system. The first phase of the project, which nominally cost NT$40 billion (US$1.48 billion), had the goal of preventing the downstream river water from becoming oxygen-deficient. Such goal was primarily fulfilled in 1997. An interceptor system along the river reaches in the Taipei metropolitan region and a centralized wastewater treatment and ocean disposal system were planned, built, and commissioned stepwise in the last fifteen years. The second phase of the project, which will cost another NT$40 billion (US$1.48 billion) up to the year 2003, requires meeting the water quality standards for the entire region of Dan-Shui River. In any circumstances, the Dan-Shui Rive Basin fosters the city of Taipei that plays the most important role in supporting economic, political, financial, and cultural activities in this country.

The Tseng-Wen River Basin, located in South Taiwan, is a narrow and steep watershed. The main stream in this river system is 138 km in length and drains towards the South Taiwan Strait (showed in Fig. 3). The entire watershed area of this river basin is 1,176 sq km, in which the Tseng-Wen Reservoir watershed covers 481 sq km. The average slope of this river basin is about 1/57. The Tseng-Wen Reservoir is a multipurpose reservoir that is designed for flood control, hydroelectric power generation, irrigation, water supply, recreation, and flow augmentation. It is located in the middle stream area of the Tseng-Wen River system. Three smaller reservoirs in the river basin surround this area. The Wu-San-Tou Reservoir, a separate impoundment connected with the Tseng-Wen Reservoir by a tunnel, performs short-term water storage for agricultural irrigation around the national largest irrigation area in southern Taiwan—the Chia-Yi and Tainan Counties. Because of insufficient stream flows, extremely uneven rainfall, and seasonal run-off and pollution from residential and pig farming effluents, the water supply for several coastal cities is facing a severe challenge.

Contingent valuation survey for river basin in North Taiwan

Contingent valuation method can be designed to ask for people's WTP for improvements in water quality from the level of respondent perceived to currently exist, to the next highest one on the "water quality ladder." The purpose of the CVM survey is to keep the record of a sample of respondents' revealed and stated preferences and their socio-economic characteristics. To increase the survey reliability, collectting a WTP database in terms of various respondents' backgrounds and characteristics, such as income, age, educational experiences, attitude and knowledge, and water resource's attributes, would

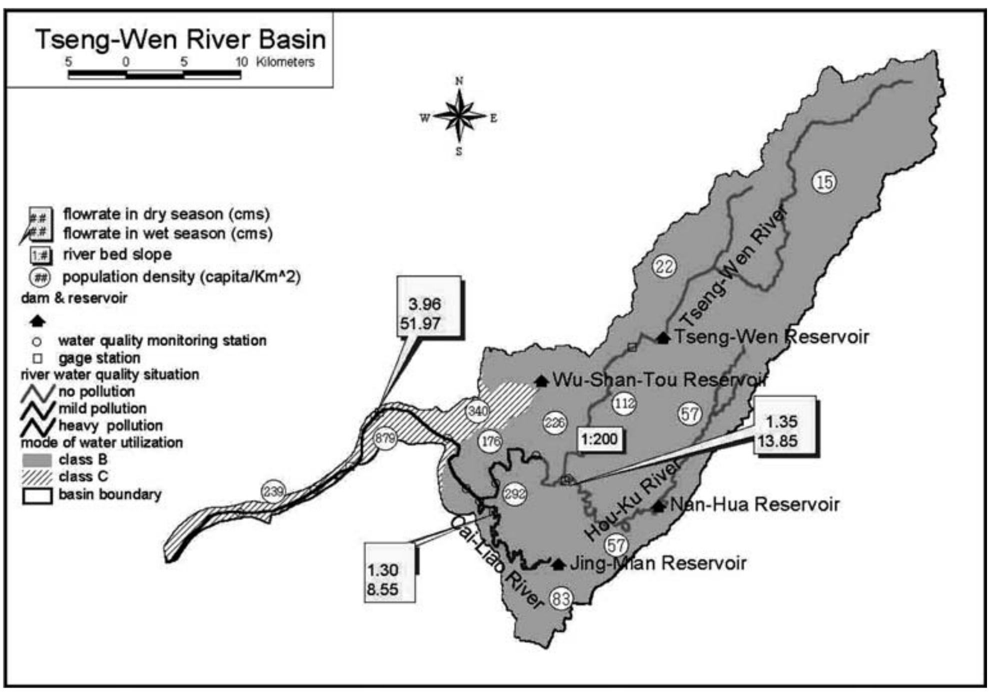


Fig. 3 The current situation of the Tseng-Wen River Basin

become essential. The implied economic value can then be retrieved directly in relation to the improved riverscape and water environment based on some socio-economic variables.

This study differs from previous ones in that we allowed respondents to define the water quality of the river that they were going to value, while previous studies described water quality for the respondent; i.e., instead of using an objective water quality, we used residents' perceptions of water quality in modeling their choices. We defined water as boatable when the respondent would not worry about the harm to his/her health if he/she happened to fall into it for a short time while boating or sailing, though it may not be fishable, swimmable or drinkable. The implied economic value for a boatable environment therefore can be portrayed by that people would likely be WTP some non-zero amount just to get from a situation that the river were anaerobic much of the time and so constituted a nuisance for a substantial area to the level of aerobic conditions/boatable water. Water is fishable when game fish can live in it and when the respondent would eat the fish caught in the water without worrying about endangering his/her health. Water is swimmable when the respondent would feel safe when swimming in it. Water is drinkable when the respondent would drink boiled river water.

In early 1995, we successfully conducted a mail survey of 978 residents over 13 years of age in the Taipei metropolitan region (Shaw et al. 1998). In the beginning the questionnaire is designed to ask the respondents to define water quality for two out of the four tributaries in the Dan-Shui River Basin that he/she was concerned with most. There were four levels of water quality considered in which the water is boatable, fishable, swimmable, and drinkable following the convention of several previous water quality CVM studies (Michell and Carson 1989). Survey respondents were asked to state their preferences concerning those scenarios. One special feature of our CVM survey is that we allow respondents to define the water quality of the river that they were going to value. Thus, the proposed survey was designed to derive people's WTP for water quality improvements (i.e., the implied economic value or indirect benefit) through their subjective choices or behaviors based on different scenarios. Instead of using an objective water quality standards applied by the government agency, respondent's perceptions of water quality can be directly defined in modeling their choices. These perceptions of water quality in terms of the attainable water uses in the river system include boatable, fishable, swimmable and drinkable possibilities.

A specific CVM question we asked was: ''In order to improve the quality of the downstream water of the river you are concerned with most, from boatable (fishable, swimmable) to fishable (swimmable, drinkable), are you willing to pay certain amount of money annually for the government to control water pollution in the Dan-Shui River?'' The respondents were randomly assigned a version of three bid values from a list of ten versions as shown in Table 1. The first bid value is the starting WTP bid for the first question. Right after the first question, the respondents were offered a second bid value which was higher than the first starting value if his/her answer to the first question was a yes, or lower if the first answer was a no. This is the so-called double-bounded referendum CV question or referendum CV with a follow-up question. The ranges of the ten values are determined based on one pre-test survey and one focus group discussion. However, since only two respondents having answered the questionnaire believed that the water was drinkable, this level of water quality was dropped during our analysis.

As to the WTP, on average, the annual implied economic value varies with respect to differing water quality improvement and could be summirized in Table 2. It worths about US$56.7 in 1995 as the water quality improves from a boatable level to a fishable level per person. Multiplying this value of WTP by the current population in this region (6,278,000 persons) gives US$355.8 million. However, it increases significantly to US$93 as the water quality improves from a fishable level to a swimmable level. Multiplying this value of WTP by the current population of Taipei metropolitan region (6,278,000 persons) gives US$583.8 million.

Table 1 A set of bid values of WTP for water quality improvements associated with the ten scenarios designed in the questionnaire (NT$)

Water quality improvement scenarios	Boatable to fishable	Fishable to swimmable	Swimmable to drinkable
1	(50,100,30)	(50,100,30)	(50,100,30)
2	(70,250,50)	(70,250,50)	(70,250,50)
3	(200,500,150)	(200,600,150)	(200,600,150)
4	(400,800,300)	(500,1000,400)	(500,1000,400)
5	(600,1200,400)	(800,1500,500)	(800,1500,500)
6	(1000,2000,500)	(1200,2500,600)	(1200,2500,600)
7	(1700,2500,1000)	(2000,3000,1200)	(2000,3000,1200)
8	(2500,3000,1500)	(3000,5000,1700)	(3000,5000,1700)
9	(3000,5000,2500)	(5000,7000,3000)	(5000,7000,3000)
10	(5000,7000,3000)	(7000,9000,5000)	(7000,9000,5000)

Note:
1. The first number in parentheses is the starting WTP bid value; and the second value is asked if the answer to the first question was a yes, or the third value was asked if the answer to the first question was a no
2. The currency ratio is 29NT/1*US* in 1997

Table 2 Estimated WTP under different levels of water quality improvements in the Dan-Shui River Basin

Levels of water quality improvements	Ecological conservation	Boatable to fishable	Fishable to swimmable	Swimmable to drinkable
Dan-Shui River	500	1,265	1,214	1,187
Kee-Lung River	450	995	955	934
Xin-Dain River	600	1,422	1,364	1,334
Da-Han River	750	1,635	1,569	1,534

The currency ratio is 29 NT/ 1*US* in 1997

These two values are the aggregated annual willingness to pay for such two marginal water quality improvements in Taipei metropolitan region.

Overall, the empirical estimation results show that the use value becomes much bigger when the water quality improves to a higher level. In addition, the nonuse value makes up a big share of the total value of improving water quality, thus the nonuse value could be crucial for examining those projects which are aimed at improving the water quality of the four tributaries in the Dan Shui river system (Shaw et al. 1999). The estimation function for WTP in the Dan-Shui River Basin could be formulated in Eq. 1 by using socio-economic conditions as variables, in which *t*-values are presented in parentheses below parameters, in which Edu is the number of years studying in schools; Work stands whether people employed or not and 1 means people who employed and 0 otherwise; Famsize is the numbers of persons in a family; Fincome is total income for a family each year; Travel is ravel frequency for a family in one year; Car means the numbers of car owned by a family; Sex stands whether is male or not and 1 means male and 0 female. The numbers marked in parenthesis below are all *t*-values in statistics that explain all repressors are statistically significant in this regression analysis.

$$\begin{aligned} \mathrm{WTP} = & \underset{(25.33)}{6.49} - \underset{(-2.57)}{0.008} \times \mathrm{Age} - \underset{(-1.77)}{0.129} \times \mathrm{Sex} \\ & + \underset{(2.18)}{0.028} \times \mathrm{Edu} + \underset{(1.27)}{0.106} \times \mathrm{Work} - \underset{(-1.05)}{0.022} \times \mathrm{Famsize} \\ & + \underset{(4.62)}{0.248} \times \mathrm{Car} + \underset{(6.16)}{0.058} \times \mathrm{Travel} + \underset{(3.80)}{2.05 \times 10^{-7}} \\ & \times \mathrm{Fincome} \end{aligned} \quad (1)$$

In an attempt to extend such research outcome to a developing river basin, the Tseng-Wen River Basin, additional considerations with respect to the differences of population structure, educational level, and income level are required. This paper use the simultaneously estimated functions for Dan-Shui River to estimate the use value and the nonuse value of water quality improvements in the Tseng-Wen River Basin by applying the benefit function transfer method which is a benefit transfer, as defined by Boyle and Bergstrom (1992), is the transfer of existing estimates of non-market values to a new study that is different from the study for which the values were originally estimated. Various benefit transfer methods have been proposed. In general all the proposed methods fall into four categories: direct benefit transfer, benefit function transfer, meta analysis benefit transfer, and preference calibration benefit transfer. Among them, benefit function transfer is to, instead of applying directly the mean value, use the estimated model for the study site and substitute conditions of the policy site into the model to derive the relevant benefit estimates for the policy site. The majority of benefit transfer studies concentrates on validating or improving this transfer method (e.g., Loomis 1992; Luken et al. 1992; McConnell 1992; Downing and Ozuna 1996; Kirchhoff et al. 1997; Bergstrom et al. 2001; Morrison 2002; Barton 2002). Table 3 is the socio-economic information pertaining to both of the Dan-Shui River Basin and Tseng-Wen River Basin, which collected for the purpose of proceeding benefit transfer. The final results of benefit transfer are described in Table 4.

Fuzzy clustering analysis for a river basin in South Taiwan

The next step in FCVM is to provide a mechanism that lies in providing a mapping (via fuzzy set theory) from a survey of respondents' valuation of subjective assessments of water quality into objective economic measures in terms of water quality parameters that management can more directly manipulate. The incorporation of the fuzzy clustering technique for proper classification is essential. Fuzzy clustering technique is one of the main focuses in pattern recognition (Trauwaert et al. 1991; Kamel and Selim 1994). It has been applied to improve the efficiency of image processing in remote sensing (Shih and Chen 1994; Kreinovich et al., 1998; and Eom 1999), the classification for climate pattern (McBratney and Moore 1985), the evaluation of the provenance of

Table 3 Socio-economic conditions in the Dan-Shui River Basin and Tseng-Wen River Basin

Items for benefit transfer	Dan-Shui River Basin	Tseng-Wen River Basin
Age (year)	34.82	31.48
Sex[a]	0.51	0.52
Education(year)	13.18	8.89
Work[b]	0.61	0.45
Fincome (NT$/year)	9,007,380	753,606
Famsize (capita)	4.52	3.96
Car	0.82	0.42
Travel (frequency/year)	6.88	6.88

[a]male is equal to 1 and female is equal to 0
[b]1 stand for person who has a job and 0 otherwise

Table 4 Estimated WTP under different levels of water quality improvements in the Tseng-Wen River Basin

Levels of water quality improvements	Ecological conservation	Boatable to fishable	Fishable to swimmable	Swimmable to drinkable
WTP (NT$/capita-year)[a]	500	1,297	1,597	3,243

[a]The currency ratio is 29 NT/ 1*US* in 1997

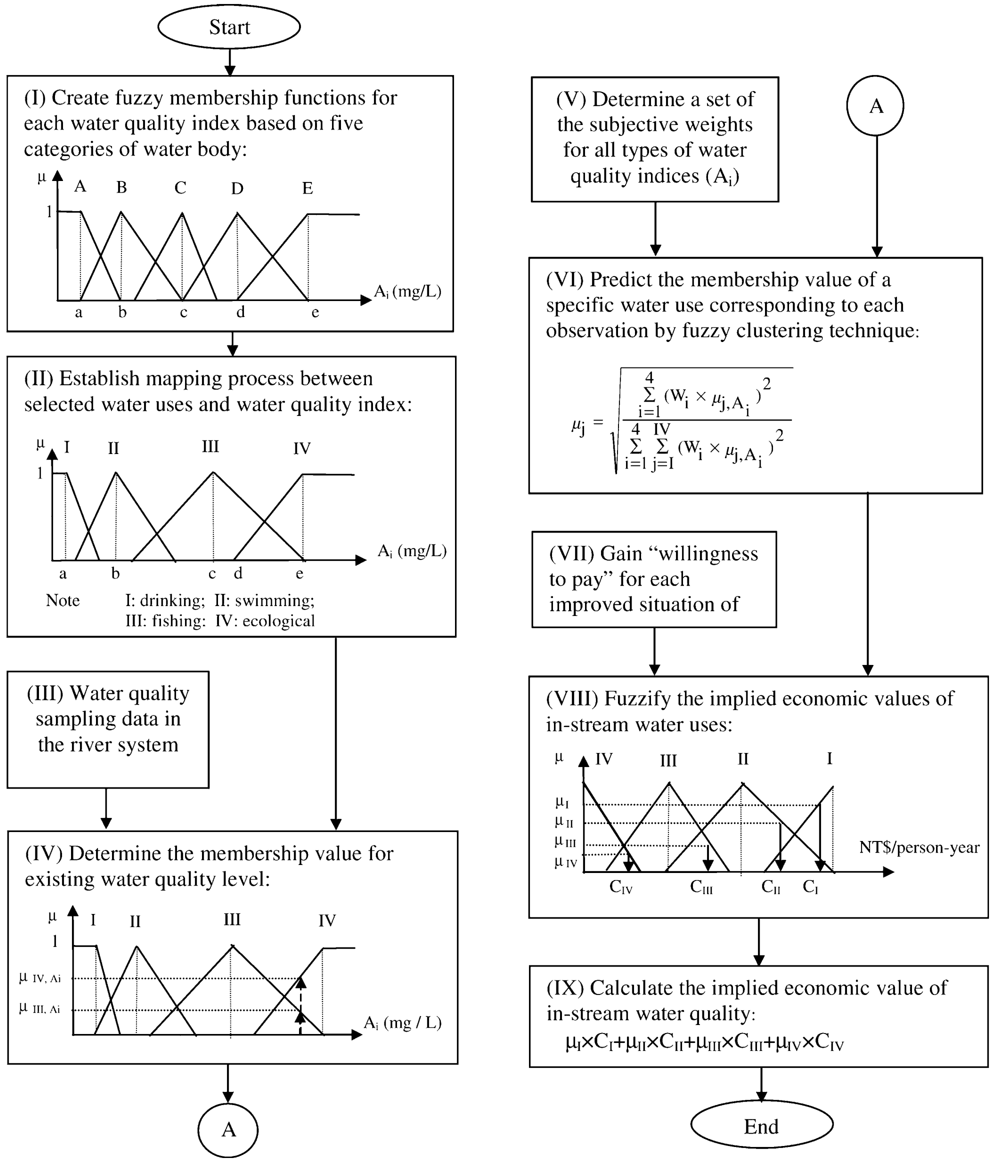
glacial till (Granath 1984), and environmental management (Tao and Xinmiao 1998 and Xu et al. 2001). The WTP for environmental and resource service flows solicited by CVM were traditionally formulated as a function of a number of social-economic factors, including the age, income, gender, education, etc. (Shaw et al. 1999). Seldom of them were directly related to the categories of classification of water uses. Therefore, such an environmental valuation is less applicable in environmental management programs. Besides, uncertainties may arise from their subjective perceptions of water quality and usefulnesses of water body with respect to water quality standards. In an attempt to address the uncertainties involved in CVM, however, the contingent valuation survey and fuzzy clustering analysis must be combined together to evaluate the implied economic value with respect to the in-stream water quality improvements. This paper therefore develops an innovative approach by integrating fuzzy clustering technique (Heinonen and Herve 1994) with traditional CVM technique for advanced assessment. When there is a need of processing benefit transfer, comparable socio-economic relationsahips between river basins can be factored into the decision analysis matrix of FCVM so that variations in WTP due to variations in terms of income, education, and others could be captured.

Figure 4 delineates the flowchart or the analytical scheme of FCVM for a possible appraisal. With such a flowchart, it would be easier to understand the logics or ideas of how can the value of in-stream water quality improvements be mapped into the domain of attainable water uses by those selected water quality indices or parameters and then be quantified via the information of consumer's WTP for those indirect beneficial uses. The designed analytical scheme here is to identify the value of in-stream water quality improvements in terms of four water quality indices corresponding to four types of attainable water uses that was officially being classified into five categories (i.e., from A to E in Taiwan) for various purposes in a river system. The water quality indices to be considered consist of the 5 days Biochemical Oxygen Demand (BOD_5), Dissolved Oxygen (DO), and Suspend Solid (SS) and colon bacillus (E-Coli), while the types of water uses applied are comprised of drinking, swimming, fishing, and ecological conservation in this analysis. Table 5 lists the official classification of water body in Taiwan, in which each category (i.e., from A to E in Taiwan) is designated for several particular levels of attainable water uses being defined by a set of predetermined water quality indices.

The proposed analytical scheme first requires identifying membership functions for the illustration of water body category with respect to each selected water quality index, as indicated by step (I) in Fig. 4. Use of fuzzy membership function to ease the distinction between different categories provides a smooth transition (Chang et al. 2001). Linkages can then be made between the multiple uses of in-stream water and the corresponding water quality standards. It lies to design a mapping via a fuzzy reasoning process that connects those water quality indices, such as BOD_5, SS, DO, and colon bacillus, to different water uses directly, as shown by step (II) in Fig. 4. In an attempt to quantify the value of in-stream water in the study area of a river system, a sampling campaign is required to gather those essential observations and generate the membership values corresponding to various water uses based on each set of observations. The steps (III) and (IV) in Fig. 4 address such actions. Thus, based on the concept of fuzzy classification, a site situation of quality existing in a river system might be differentiated by a combination of several membership values for various water uses instead of a single value for a unique water use. At this moment, decision-makers or planners could assign an individual weight for each of the water quality index to reflect the relative significance of them so that the aggregate membership value of a specific water use for a particular observation becomes predictable. An aggregate membership value for a specific water use in terms of all water quality indices for a particular observation can be defined by a fractional formula, as shown by step (V) in Fig. 4. The acquired aggregate effect of all water quality indices for a specific type of water use is then available for the subsequent integration with the information of consumer's WTP. Final appraisal of the implied economic value of in-stream water quality improvements may be expressed as the summation of all the multiplication between the aggregate membership value for each specific water use and the associated consumer's WTP under a fuzzy environment. The steps from (VI) to (VIII) in Fig. 4 delineate such a mathematical manipulation.

The fuzzy clustering technique applied above becomes applicable for the prediction of the implied economic value of in-stream water quality improvements at this stage. A series of fuzzy membership functions were constructed and used sequentially to illustrate the fuzzy relationships between the subjective perception of the water quality improvements with respect to aesthetic, ecological, and recreational uses

Fig. 4 The fuzzy CVM algorithm for the prediction of the implied economic values



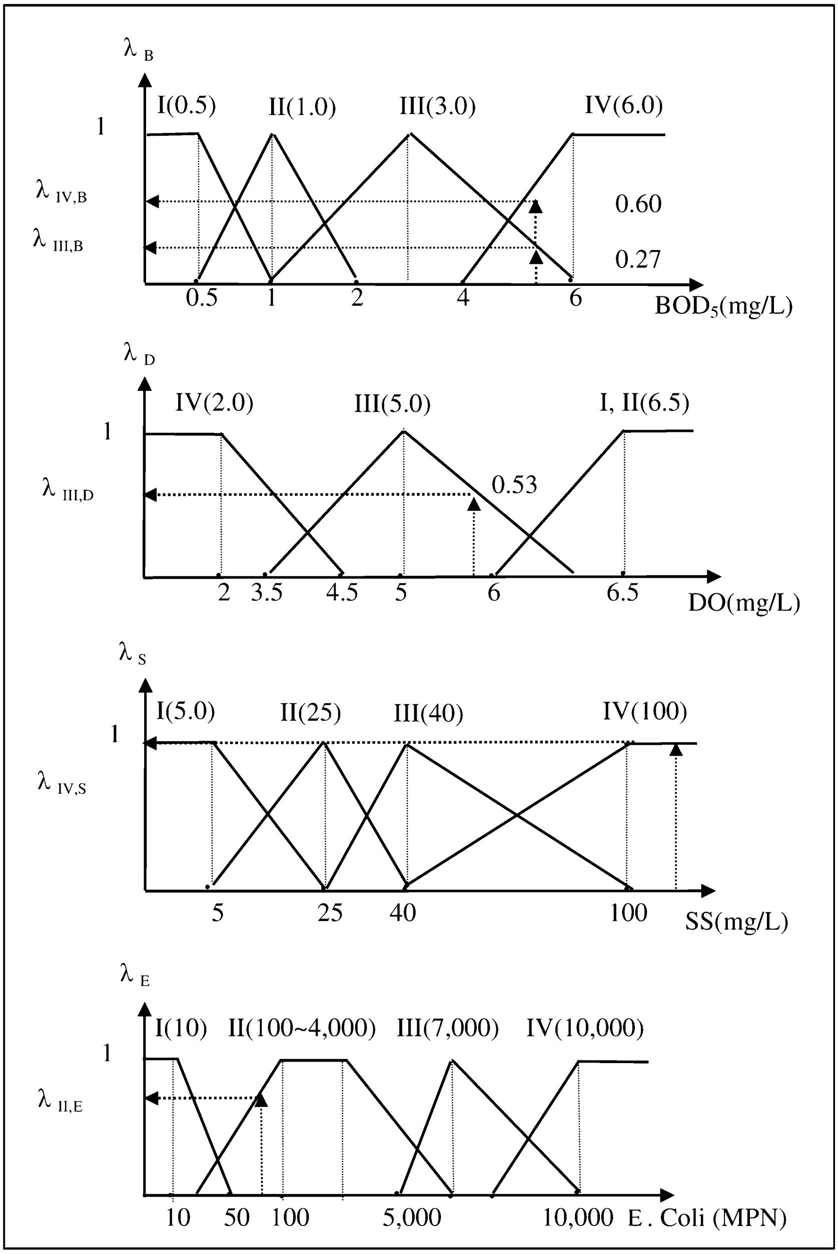
and the associated consumer's WTP for a specified water quality level. The derivation of implied economic value for aesthetic, ecological, and recreational uses is equivalent to designing a mapping mechanism between the consumer's WTP and existing water quality levels associated with those selected site situations. Figure 5 describes the membership functions applied in the FCVM.

Table 5 The water quality standards applied in all river systems in Taiwan

Class	A	B	C	D	E
Utility (Standard)	1.Public water supply (primary level) 2.Swimming	1.Public water supply (secondary level) 2.Fishery (primary level)	1.Public water supply (third level) 2.Fishery (secondary level) 3.industry water supply (primary level)	1.Irrigation 2.Industrial water supply (secondary level)	Environmental protection
Item					
	6.5~8.5	6.0~9.0	6.0~9.0	6.0~9.0	6.0~9.0
DO, mg/L	> 6.5	> 5.5	> 4.5	> 2.0	> 2.0
Coliform, MPN/100 ml	< 50	< 5000	< 10000	–	–
BOD_5 (20°C), mg/L	< 1	< 2	< 4	–	–
SS, mg/L	< 25	< 25	< 40	< 100	–

DO dissolved oxygen; *BOD_5* biochemical oxygen demand; *SS* suspended solids

Fig. 5 The membership functions defined for performing fuzzy CVM analysis



Note : I:drinkable; II:swimmable; III:fishable; IV:ecological conservation

Derivation of a beneficial valuation function

Based on the data set collected, Table 6 lists the information required to support the regression analysis. Figure 6 addresses the scatter plot of those predicted samples. Performing a regression analysis that relates values and objective characteristics may generate the following equations, which can be applicable for future water quality management program. The data set applied for the prediction of the implied economic values includes estimated WTP, BOD_5, DO, SS, and E-Coli. Based on different combination of endogenous variables included in the regression analysis, they can be derived in Eq. 2 as below:

$$\begin{aligned}\mathrm{P(NT\$\ /capita\text{-}year)} = {} & \underset{(8.65)}{1971} + \underset{(6.76)}{205.7} \times [\mathrm{DO}] \\ & - \underset{(-9.26)}{306.3} \times \mathrm{Ln}[\mathrm{BOD_5}] \\ & + \underset{(-2.07)}{0.55} \times [\mathrm{SS}] - \underset{(-1.90)}{0.33} \times [\text{E-Coli.}]\end{aligned} \qquad (2)$$

in which P is the implied economic value of in-stream water quality in the river system per capita-year. The numbers marked in parenthesis below are all t-values in statistics that explain all repressors are statistically significant in this regression analysis. The adjusted R^2 of regression function is 0.88.

Table 6 The database for prediction of the implied economic value of in-stream water quality in the Tseng-Wen River Basin

Item No.	DO (mg/L)	BOD (mg/L)	SS (mg/L)	E-Coli. (colonies/100 ml)	Benefit (NT$/capita-year)
1	1.0	6.3	120	12,000	0
2	4.0	6.3	120	12,000	84
3	1.0	5.0	60	9,000	206
4	6.2	6.3	120	12,000	467
5	4.0	5.0	60	9,000	470
6	3.0	6.3	80	5	843
7	6.2	5.0	60	9,000	954
8	5.5	6.3	5	800	997
9	1.0	1.5	36	3,000	1,025
10	5.5	5.0	5	9,000	1,082
11	1.0	3.2	60	6,000	1,123
12	3.0	5.0	5	7,000	1,128
13	5.5	3.2	25	6,000	1,282
14	3.0	3.2	25	60	1,360
15	6.2	3.2	36	6,000	1,467
16	3.0	1.5	36	2,000	1,506
17	1.0	0.7	23	60	1,513
18	4.0	3.2	60	6,000	1,544
19	5.5	1.5	36	3,000	1,560
20	7.0	6.3	120	800	1,694
21	4.0	1.5	36	3,000	1,727
22	7.0	3.2	36	6,000	2,032
23	3.0	0.2	120	9,000	2,258
24	6.2	1.5	23	3,000	2,507
25	3.0	0.7	60	5,000	2,508
26	7.0	5.0	60	9,000	2,509
27	1.0	0.2	3	5	2,639
28	5.5	0.7	60	10	2,798
29	7.0	1.5	23	3,000	2,915
30	5.5	0.2	120	5	2,945
31	4.0	0.7	23	60	2,973
32	6.2	0.7	3	60	3,360
33	7.0	0.7	3	10	3,390
34	6.2	0.2	80	5	3,428
35	4.0	0.2	3	5	3,494
36	7.0	0.2	80	5	3,505

The currency ratio is 29 NT/1*US* in 1997

The aggregated implied economic value or benefits gained from a water pollution control and/or flood-proofing program may become available once the population living in a river basin is available. However, to ease the application, a simplified formula as shown in Eq. 3 can be derived in terms of BOD and DO only, as listed below. Decision makers could also adjust variables in regression function according to their available quality information in their monitoring plan.

$$P(\text{NT\$ /capita - year}) = \underset{(8.65)}{1199} + \underset{(6.76)}{217} \times [DO] \underset{(-9.26)}{-692} \times \text{Ln}[BOD_5] \quad (3)$$

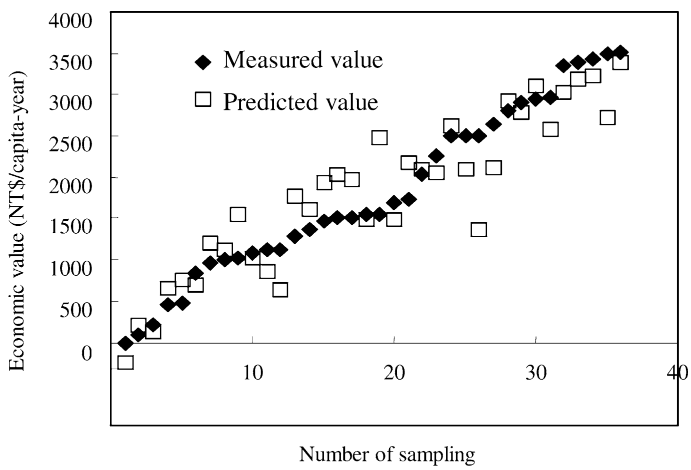


Fig. 6 The derivation of implied economic value via regression analysis

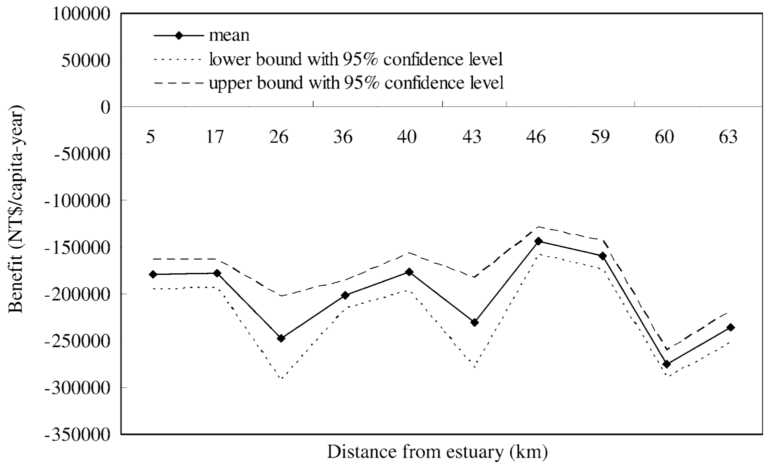


Fig. 7 The distribution of in-stream value in dry season for Tseng-Wen River Basin

in which the numbers marked in parenthesis below are all *t*-values in statistics that explain all repressors are statistically significant in this regression analysis. The adjusted R^2 of regression function is 0.83.

Overall, the fuzzy set theory was presumably used to map from the respondents subjective assessments into the objective measures that management can now directly address. Both equations in above enable us to assess the monetary value associated with proposed BOD-DO relationship in the Tseng-Wen River system so as to justify upcoming engineering efforts in various water pollution control programs. The more the population involved in a river basin, the higher the total impact of the non-market values would be. The provision of such a beneficial valuation function for the appraisal of river water quality may eventually lead to support evaluation of versatile multi-disciplinary and multi-objective water quality management programs in the future.

Valuation of in-stream in Tseng-Wen River basin

A Monte-Carlo simulation practice can be used to demonstrate how to use these Eqs. in 2 and 3 to assess the implied economic value based on the environmental monitoring data of in-stream water quality. The water year in a hydrological sense can be divided into two seasons. The wet season generally covers the time period from May to October, the remainder time period is the dry season. Though the mean annual rainfall in the Tseng-Wen River basin is close to 3,000 mm, over 90% of which appears in the wet season. Differing hydrologic situations make water quality trun out to be dramatically different during dry and wet seasons. In order to realize the in-stream values of the Tseng-Wen River Basin from spatial and temporal aspects, water quality data pertaining to the Tseng-Wen River Basin from 1992 to 2002 is collected and Monte-Carlo simulation is conducted.

Eq. 3 is selcted as a tool in this Monte-Carlo simulation practice with respect to several monitoring stations located at downstream areas. Before Monte-Carlo simulation is performed, correlation coefficients matrix among variables and probaility distriution function for each variable are defined according to the water quality data collected. Therefore, the spatial and temporal framework could be immerged into the procedure of random sampling. The results of Monte-Carlo simulation are shown in Figs. 7 and 8. They seem to imply that serious water pollution makes the implied economic value of in-stream water quality negative ubiquitously in the past decade and variabilities appear aparantly between dry and wet seasons. This might provide some feedbacks to upstream reservoir operation.

Final remarks

Natural systems provide human society many tangible and intangible items. In the area of environmental service and valuation, a contemporary scientific challenge is to determine the socio-economic value of human dependence on natural system and to ensure how the interaction of human and natural processes may affect both the capacity of natural system and the quality of life (National Science Foundation 2003). However, present water quality management and planning practices still focus on utilizing environmental assimilative capacity and the maintenance of officially required water quality standards for different attainable water uses. It usually takes only the economic value into account that reflect the financial outlay in the current market system without regard to the benefits and costs of those non-marketed goods and services. As a result, such assessment cannot effectively capture non-market values or the environmental costs and benefits for future generations. To the extent of the value of water quality improvement, however, it requires developing advanced and improved methodology in the environmental economics and management regime.

The FCVM in this study provides a mechanism that lies in providing a mapping (via fuzzy set theory) from a survey of respondents' valuation of subjective assessments of water quality into objective economic measures in terms of water quality parameters that management can more directly manipulate. It unambiguously bridges a gap in the nexus of environmental impact assessment,

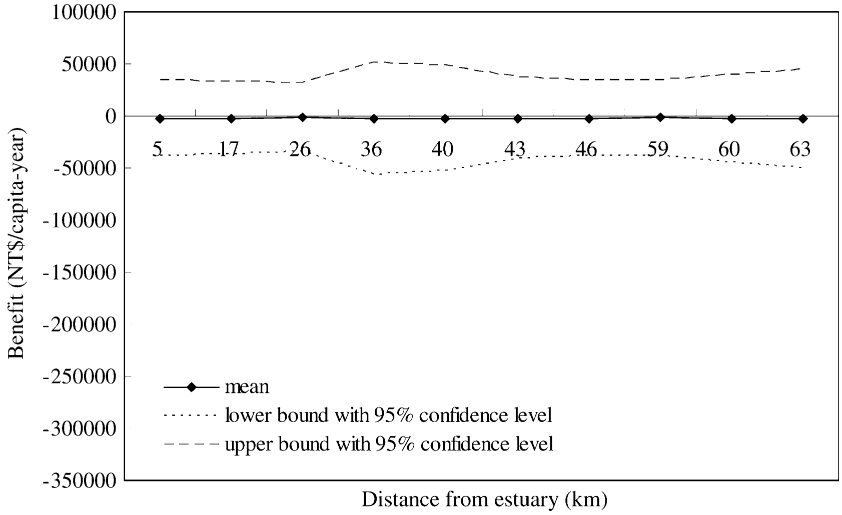


Fig. 8 The distribution of in-stream value in wet season for Tseng-Wen River Basin

value engineering, resources economics, and cost benefit analysis. The case study evaluates those non-marketed values relevant to the in-sterm water quality improvements via comparing the sample results to the undertaken water quality standards associated with water quality indices of concern. It leads to summarize sveral individual water quality parameter values for an integrated appraisal using the fuzzy clustering process eventually. The indirect benefits related to aesthetic, recreational, and ecological aspects therefore become predictable and transferrable based on the fuzzy information of WTP. Differing social traits and economic levels in different river basins can be taken into account under such a fuzzy reasoning process. The information summarized from the final regression analysis clearly shows that the total benefits of the in-stream water quality improvements are proportional to the number of residents living in that area that are influenced by the in-stream water quality. Final appraisal of the variability of implied economic value of in-stream water quality may become achievable via the use of Monte-Carlo simulation. Such an effort may provide additional strengths to reinforence the current cost benefit analysis for promoting water pollution control programs basin wide. With such assessment, it is anticipated that the marketplace could serve as the setting for maintenance and protection of the natural environment if implied economic values of environmental systems have been established. The integration of such information with a multi-objective decision analysis for a waste load allocation planning in the Tseng-Wen River Basin that is designed to provide a balanced watershed-based permitting procedure will be the future work.

References

Barton DN (2002) The transferability of benefit transfer: contingent valuation of water quality improvements in Costa Rica. Ecol Eco 42(1–2):147–164

Bergstrom JC, Kevin JB, Poe GL (eds) (2001) The economic value of water quality. In: New horizons in environmental economics, Elgar, Northampton Mass

Boyle KJ, Bergstrom JC (1992) "Benefit transfer studies: myths, pragmatism, and idealism. In: Water resources research, vol. 28, No. 3, pp 657–663

Burrows AM, House MA (1989) Public's perception of water quality and the use of water for recreation. In: Laikari H (ed) River basin management-V. Pergamon Press, London, pp 371–379

Cameron TA, Huppert DD (1989) OLS versus ML estimation of non-market resource values with payment card interval data. J Environ Eco Manag 17:230–246

Cameron TA, Poe GL, Ethier RG, Schulze WD (2002) Alternative non-market value-elicitation methods: are the underlying preferences the same? J Environ Eco Manag 44(3):391–425

Chang NB, Chen HW (2001) Identification of river water quality by fuzzy synthetic evaluation approach. J Environ Manag 64:1–13

Chang NB, Lu HY (1997) A new approach for long term planning of solid waste management systems using fuzzy global criterion. J Environ Sci Health A32(4):1025–1047

Chang NB, Wang SF (1996) Managerial fuzzy optimal planning for solid waste management systems. J Environ Eng ASCE 122(7):649–658

Chang NB, Chen YL, Wang SF (1997) A fuzzy interval multi-objective mixed integer programming approach for the optimal planning of metropolitan solid waste management system. Fuzzy Sets Syst 89(1):35–60

Deshpande AW, Raje DV, Khanna P (1996) Fuzzy description of river water quality. In: Proceedings of EUFIT'96, ELITE Foundation, Promenade 9, 52076, Aachen, Germany, pp 1795–1801

Downing M, Ozuna T Jr (1996) Testing the reliability of the benefit function transfer approach. J Environ Eco Manag 30:316–322

Eom KB (1999) Fuzzy clustering approach in unsupervised sea-ice classification. Neurocomputing 25:149–166

Farber S (1988) The value of coastal wetlands for recreation: an application of travel cost and contingent valuation methodologies. J Environ Manag 26:299–312

Freeman AM (1993) The measurement of environmental and resource values. Resources for the Future, Washington DC

Goffe PL (1995) The benefits of improvements in coastal water quality: a contingent approach. J Environ Manag 45:305–317. DOI: 10.1006/jema.1995.0078

Granath G (1984) Application of fuzzy clustering and fuzzy classification to evaluate the provenance of glacial till. Math Geol 16(3):283–301

Gregory KJ, Davis RJ (1993) The perception of riverscape aesthetics: an example from two hampshire rivers. J Environ Manag 39:171–185. DOI: 10.1006/jema.1993.1062

Heinonen P, Herve S (1994) The development of a new water quality classification system for Finland. Water Sci Tech 30(10):21–24

Kamel MS, Selim SZ (1994) New algorithms for solving the fuzzy clustering problem. Pattern Recog 27(3):421–428

Kirchhoff S, Colby BG, LaFrance JT (1997) Evaluation the performance of benefit transfer: an empirical inquiry. J Environ Eco Manag 33(1):75–93

Kreinovich V, Nguyen HT, Starks SA, Yam Y (1998) Decision making based on satellite images: optimal fuzzy clustering approach. Proc IEEE Conf Decision Contr 4:4246–4251

Kwak SJ, Russell CS (1994) Contingent valuation in Korean environmental planning: a pilot application to the protection of drinking water quality in Seoul. J Environ Eco Manag 4:511–526

Lipton DW, Wellman KF, Sheifer IC, Weiher RF (1995) Economic valuation of natural resources—a handbook for coastal resources policymakers. In: NOAA Coastal Ocean Prpgram Decision Analysis Series No. 5, NOAA Coastal Ocean Office, Silver Spring, p 131

Loomis JB (1992) The evolution of a more rigorous approach to benefit transfer. Water Res Res 28(3):701–705

Luken RA, Reed Johnson F, Kibler V (1992) Benefits and costs of pulp and paper effluent controls under the clean water act. Water Res Res 28(3):665–674

McBratney AB, Moore AW (1985) Application of fuzzy sets to climatic classification. Agric Forest Meteorol 35:165–185

McConnell KE (1992) Model building and judgment: implication for benefit transfers with travel cost models. Water Res Res 28(3):695–700

Michell RC, Carson R (1989) Using surveys to value public goods: the contingent valuation method. Resources for the Future, Washington DC

Morrison M (2002) Choice modeling and tests of benefit transfer. Am J Agric Eco 84(1):161–170

National Science Foundation (2003) Complex environmnetal systems: sciences for earth, life, and society in the 21th Century. NSF advisory Committee for Environmental Research and Education, USA

Press J, Soderqvist T (1998) On estimating the benefits of groundwater protection: a contingent valuation study in Milan.In: Swanson T, Vighi M (eds) Regulating Chemical Accumulation in the Environment, Chap 6 Cambridge University Press, Cambridge

Shaw D, Chen YL, Tsai LH (1998) Valuing the improvements in the water quality of and the scenery surrounging the Tamshui River system in Taiwan. Taipei Economic Inquiry 35(1):29–60

Shaw D, Chen YL, Lin YM (1999) An alternative approach to combining revealed and stated preference data: valuing water quality of the river system in Taipei. Environ Eco Policy Studies 2(2):97–112

Shih FY, Chen GP (1994) Classification of landsat remote sensing images by a fuzzy unsupervised clustering algorithm. Inf Sci Appl 1:97–116

Sii HI, Sherrard JH, Wilson TE (1993) A water quality index based on fuzzy sets theory. In: Proceedings of 1993 Joint CSCE-ASCE National Conference on Environmental Engineering, Montreal, pp 1727–1734

Smith PN (1994) Applications of fuzzy sets in the environmental evaluation of projects. J Environ Manag 42:365–388. DOI: 10.1006/jema.1994.1078

Smith DG, Davies-Colley RJ (1992) Perception of water clarity and color in terms of suitability for recreational use. J Environ Manag 36:225–235

Tao Y, Xinmiao Y (1998) Fuzzy comprehensive assessment, fuzzy clustering analysis and its application for urban traffic environment quality evaluation. In: Transportaion Research, Part D: Transport and Environment, vol 3, pp 51–57

Trauwaert E, Kaufman L, Rousseeuw P (1991) Fuzzy clustering algorithms based on the maximum likelihood principle. Fuzzy Sets Syst 42:213–227

United States Environmental Protection Agency (USEPA) (2002) http://www.epa.gov/swerosps/ej/

Vossler CA, Kerkvliet J (2003) A criterion validity test of the contingent valuation method: comparing hypothetical and actual voting behavior for a public referendum, J Environ Eco Manag 45(3):631–649. DOI: 10.1016/S0095

Willis KG, Garrod GD (1993) Valuing landscape: a contingent valuation approach. J Environ Manag 37:1–22. DOI: 10.1006/jema.1993.1001

Xu H, Liu D, Wu H (2001) Environmental regionalization for the management of township and village enterprises in China. J Environ Manag 63:203–210. DOI: 10.1006/jema.2001.0449

Zadeh LI (1965) Fuzzy Sets. Inf Contr 8:338–353