Economic Analysis on Preference of Downstream Water Users to Ameliorate the Algae Bloom: Empirical Evidence from Korea

Yoon Lee[1] and Yongsuk Hong[2]

[1]Assistant Professor, Department of International Economics & Trade, Sunmoon University, Asan 336-708, Republic of Korea, email: lyoon21@sunmoon.ac.kr

[2](Corresponding Author) Assistant Professor, Program in Environmental Technology and Policy, Department of Environmental Engineering, Korea University, Sejong 339-700, Republic of Korea, email: yhong@korea.ac.kr

Abstract**:** *There are growing concerns on water quality degradation due to anthropogenic activities. Among many water quality problems, algae bloom at the reservoir-level could be one of the environmental catastrophes to prevent. To provide clean water to downstream, water suppliers and planners usually spend billions of public expenditure. This study tries to answer some fundamental research questions. Will it be worth to public for spending massive money to have clean water in already developed countries? How clean is acceptable to public? This study analysed downstream water users' preference to ameliorate water quality due to algae bloom during summer. Double bounded dichotomous choice survey method used to estimate willingness to pay to improve water quality of Paldang reservoir in Korea as a case study. The mean WTP based on predicted value from the probit model in this study was 1,981 won per household per month. The annual WTP was estimated at 137.9 billion won for Seoul metropolitan area.*

Keywords: *Consumer Preference, Probit Model, Willingness to Pay, Water Quality, Algae Bloom*

1. Introduction

There are growing concerns on deterioration of water quality due to anthropogenic activities that leads us current climate change. Water quality degradation can be monitored not only for the developing countries but also for developed ones. Among the many existing water quality problems, algae bloom at the reservoir-level during the summer could be a typical example that addressed upstream anthropogenic activities impacts environments as negative externalities. Since unusual high temperature in the summer along with drought increases a high probability of algae occurrence which is a major source of water quality degradation and extremely expensive to recover, especially it happens in drinking water purpose reservoir. For instance, during the spring 2007 in China, massive algae bloom broke out in Lake Taihu and became an environmental crisis which made a water supplier immediately cut tap water supply to several million residents in nearby region [1]. In addition, Paldang reservoir, main drinking water source for one half of entire Korean population, occasionally suffers from periodic algae bloom [2]. In this regards, anthropogenic disturbances including human expansion and agricultural development can affect sustain reservoir in many aspects. Whether it is direct sedimentation onto, or an increase in the turbidity of the water due to eutrophication, or increases in the total nutrients that enhance the growth of algae [3], all these have negative externalities of water supply management. Since algae bloom at the drinking water source is a catastrophic event, decision-makers should have solid and sound management of water supply. In economic sense, to solve aforementioned periodic events in reality, comprehensive analysis on costs and benefits of alternatives should be considered. The interaction, however, between ecological and economic process of algae dynamic is complex and water quality is non-market systems of public goods with no market price.

In 2012, the ministry of environment (MOE) of Korea announced an ambitious plan, 3rd phase of implementing total maximum daily load (TMDL) to grantee sound level of water quality in any given circumstances [4] that would need a massive amount of financial investment. Considering the mechanism of public water supply and dynamic of algae bloom, a number of fundamental research questions have been brought up immediately. To provide clean water to downstream, MOE planned to spend billions of public

http://dx.doi.org/10.17758/ERPUB.ER715221

expenditure. Will that be worth? What level of water quality would be acceptable to public? Will that be any preference deviation among water users? Or is it economically efficient way to spend money on water quality improvement? In the context of non-market valuation literature, there are a wide range of research that have assessed the impact of public water services, quantity- and quality-wise. One of the notable researches was done by Whittington et al. [5] that investigated the impact of water service improvement in southern Haiti using the contingent valuation survey methods and brought up that the contingent valuation method was feasible to calculate willingness to pay (WTP). North and Griffin [6], however, analysed water source as a housing perspective using the hedonic price method and concluded that policy of improving public water in a quality standpoint would be inappropriate. On the contrary to this, the contingent valuation method (CVM) conducted in Georgia by Jordan and Elnagheeb [7] concluded that the improvements in drinking water quality would be benefit to consumers. These inconsistent results may come from the lack of survey codification.

Recent research show better consistent results where the WTP for water quality improvement was significant and better off consumers [8], but we have not yet seen any literature investigating improvement of water quality related to periodic environmental catastrophic events such as algae bloom in summer where water demand is high. In this paper, we examined the stated preference of water users in downstream of the Paldang reservoir to address benefits of algae removal for ameliorating water quality. Our research analysis is based on double-bounded dichotomous choice (DBDC) survey data, similar to those done in environmental and resource economics literature [9-11]. The rest of the paper was organized as follows. Section 2 provides an overview of the theoretical approach to estimate the downstream water users' willingness to pay for the improvement of the water quality related to algae. Section 3 describes the survey design and data including the algae dynamic in Paldang reservoir. Section 4 presents empirical results from the case study. And the last section, we conclude the paper with a summary of the main findings and a brief policy suggestions.

2. Model Specification

To attempt valuing environment, the contingent valuation method (CVM) has remarkably evolved as a quintessential tool for estimating the conceptual demand curve of non-marketed goods [12]. Addressing stakeholders' willingness to pay (WTP) for a hypothetical commodity, the CVM attempts to generate points of the Total Value Curve (TVC). It is assumed that the individuals utility can be defined over a non-market good (Q_0) and Hicksian composite (Y), the TVC is the locus of all points for which $U(Q_0, Y) = U(Q_1, Y - WTP)$, where Q_1 denotes a change in the level of non-market good and WTP is the individual WTP for availing the proposed change [13].

Among the many ways to induce the WTP, we followed the double bounded dichotomous choice (DBDC), which has been highly recommended by [14, 15]. Unlike the singe bounded dichotomous choice, two sequences of bids are given and offered to the respondents in the DBDC questionnaire format. First, whether a respondent would be willing to accept or reject an initial bid; subsequently, a second bid is asked depending on the answer to the first bid from the respondent. In other words, a respondent is asked whether an initial bid B^1 is acceptable or not. If a respondent accepts an initial bid, the double of the first bid B^2 will be offered as a second bid ($B^1 < B^2$). If an initial bid B^1 is rejected, one half of the first bid B^3 will be offered ($B^1 > B^3$). Therefore, in this DBDC questionnaire format, there are four possible responses bundles in the data set: "yes-yes"; "yes-no"; "no-yes"; "no-no". The likelihoods of these responses are π^{yy}, π^{yn}, π^{ny}, π^{nn}, respectively [15].

Under the assumption of a utility maximizing respondent, for these likelihoods are as follows. In the first case, we have $B_i^1 < B_i^2$, and

$$\begin{aligned} \pi^{yy}(B_i^1, B_i^2) &= \Pr\left\{ B_i^1 \le WTP \text{ and } B_i^2 \le WTP \right\} \\ &= \Pr\left\{ B_i^1 \le WTP \middle| B_i^2 \le WTP \right\} \Pr\left\{ B_i^2 \le WTP \right\} \\ &= \Pr\left\{ B_i^2 \le WTP \right\} = 1 - G(B_i^2; \theta) \end{aligned} \tag{1}$$

where i is the number of respondent; $G(\bullet;\theta)$ is some statistical distribution functions with the parameter vector θ. Hanemann [16] pointed out that this statistical model can be interpreted as a utility-maximization response, where $G(\bullet;\theta)$ is the cumulative density function (CDF) of the individual's true maximum WTP. If we assume that $G(B)$ is the logistic CDF, it can be expressed as the logit model and if the lognormal or normal CDF were used in place of $G(B)$, this would be interpreted as the probit model.

In the second case when a "no" is followed by a "yes", we have $B_i^1 < B_i^2$ and

$$\pi^{yn}(B_i^1, B_i^2) = \Pr\left\{B_i^1 \le WTP \le B_i^2\right\} = G(B_i^2;\theta) - G(B_i^1;\theta) \tag{2}$$

When a "yes" is followed by a "no", the likelihood of this outcome can be expressed as follow.

$$\pi^{ny}(B_i^1, B_i^3) = \Pr\left\{B_i^3 \le WTP \le B_i^1\right\} = G(B_i^1;\theta) - G(B_i^3;\theta) \tag{3}$$

Finally, if answers from the respondent are both "no", then the likelihood can be rewritten as follow. It is noted that with $B_i^3 < B_i^1$, $\Pr\left\{B_i^3 \le WTP \middle| B_i^1 \le WTP \right\} \equiv 1$, then,

$$\pi^{nn}(B_i^1, B_i^3) = \Pr\left\{B_i^1 > WTP \text{ and } B_i^3 > WTP\right\} = G(B_i^3;\theta) \tag{4}$$

It is noted that the second bid allows us to place both an upper and a lower bound on the respondent's unobserved true WTP in Equation (3) and (4) while Equation (1) and (5) give us similar results to the single bound. When there are N number of respondents (i.e. $i = 1, \ldots, N$), the log-likelihood function takes the form as,

$$\ln L(\theta) = \sum_{i=1}^{N} \left\{ \begin{array}{l} d_i^{yy} \ln \pi^{yy}(B_i^1, B_i^2) + d_i^{yn} \ln \pi^{yn}(B_i^1, B_i^2) + d_i^{ny} \ln \pi^{ny}(B_i^1, B_i^3) \\ + d_i^{nn} \ln \pi^{nn}(B_i^1, B_i^3) \end{array} \right\} \tag{5}$$

where d_i^{yy}, d_i^{yn}, d_i^{ny}, and d_i^{nn} are indicator variables.

Assuming the logistic CDF of $G(B)$, when the WTP is bigger or equal to 0, the truncated mean of WTP (WTP^+) can be expressed as followed by Hanemann [17].

$$WTP^+ = 1/b \ln\left\{1 + e^a\right\} \tag{6}$$

where a is the estimated constant and b is the estimated coefficient on the bid variables.

In addition, the mean WTP (WTP^*) are given by the following equation.

$$WTP^* = a/b \tag{7}$$

It is necessary for us to analyze covariates to see how the socio-economic variables impact to the response. Thus, Equation (7) and (8) can be modified when we consider covariates.

$$WTP^+ = 1/b \ln\left\{1 + e^{(a + x_i'\beta)}\right\} \tag{8}$$

$$WTP^* = (a + x_i'\beta)/b \tag{9}$$

where x_i is the covariate vector for the respondents socio-economic characteristics, β is the parameter to estimate. Since the WTP is derived from the ML estimates of a and b, which are random variables. Moreover, their distribution solely depends on ML estimates; those are asymptotically normal with variance-covariance matrices. Followed by Park et al. [18], we applied Krinsky and Robb [19] simulation technique to obtain confidence intervals for the point estimates of WTP.

3. Application

3.1. Algae bloom at the Paldang Reservoir

Paldang reservoir is major drinking water source for approximately 20 million households in the Seoul metropolitan area in Korea. It is located in the middle of Kyunggi province and the eastern part of Seoul. The reservoir was constructed in 1974 for the multi-purpose of providing secure drinking water and generation hydro-power to Seoul metropolitan area. The water quality of the Paldang reservoir has been degraded due to liquid waste from manufacturing industry upstream and wastewater from livestock farming in the region [21]. It is well known that these non-point-source pollutions can accelerate algae bloom when it comes with high temperature.

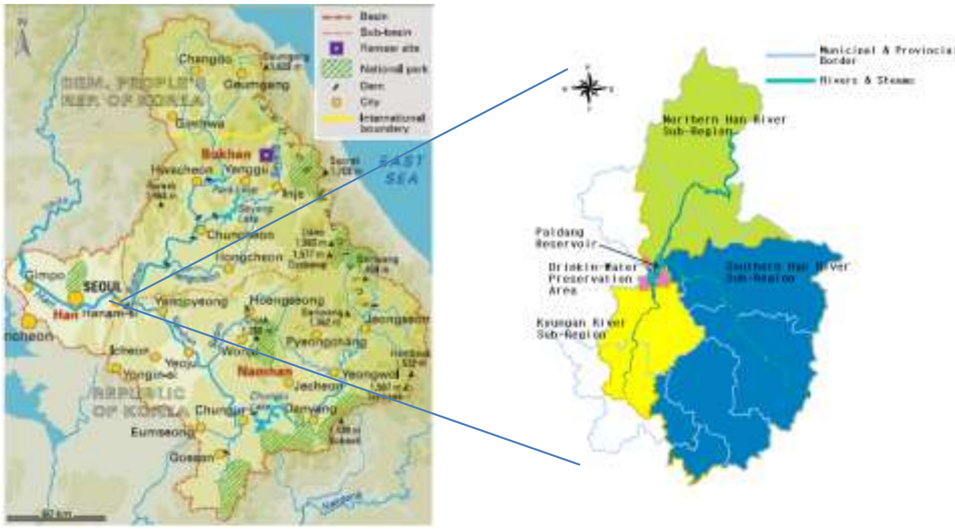

Fig. 1: Map of Paldang Reservoir (modified from [20])

MOE has been monitored algae bloom to ameliorate water quality since 1998 and invested massive amount of public expenditure, approximately 350 billion won (approximately 1,100 won equals 1 US dollar) per year up to 2015, to control such event. In spite of these efforts, algae bloom in the reservoir is still monitored and causes severe environmental damage. Figure 2 shows monitored algae bloom in 2014 summer.

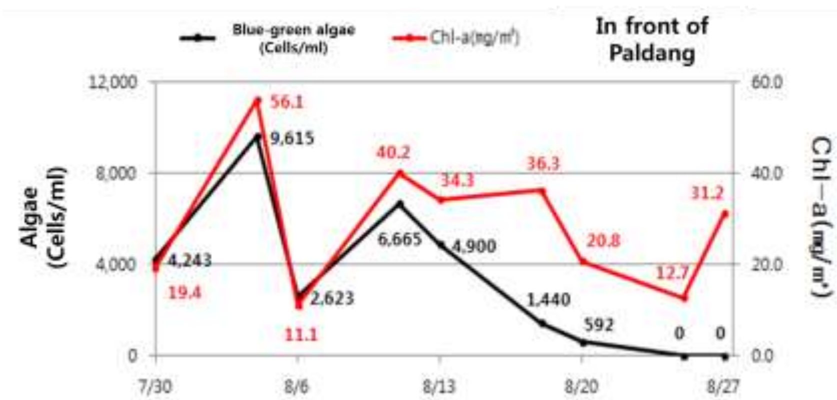

Fig. 2: Monitored Algae Bloom in Paldang [22]

3.2. Survey Design

The downstream household survey was designed to collect information on socio-economic characteristics of the respondents, their WTP for improving water quality of the drinking water due to Algae, their awareness and perception of the water quality of the Paldang reservoir, types of water source and use, household monthly income and education level. Pilot survey was conducted to test the survey instrument as a final step for designing the main survey questionnaire. This pre-test step used open-ended questionnaire to analyse the respondents' distribution of WTP. The main survey was conducted in the form of personal interview in August 2013 for 243 individuals who are at least 20 years old and also live in the Seoul metropolitan area where the downstream of Paldang reservoir for using this water source as a drinking purpose.

The procedure of personal interview provided specific information about the quality in Paldang reservoir and showed algae bloom due to eutrophication during the summer. For initial bids, 500 won/month/household, 1,000 won/month/household, and 2,000 won/month/household were used to collect double-bounded dichotomous choice data for WTP.

4. Empirical Results

A double-bounded dichotomous choice probit model was used to estimate the WTP for water quality improvement with considering algae bloom at the Paldang reservoir in Korea. Table 1 explains the variables used in the model and their general statistics such as the mean and standard error.

TABLE I: Variable Description and their Statistics

Variable	Description	Mean	Standard Error
Gender	1 if male; 2 otherwise.	1.50	0.500
Age	1 if above 20 below 30; 2 if above 30 below 40; 3 if above 40 below 50; 4 if above 50 below 60; 5 if above 60	1.88	1.118
Use	Source of household drinking water, 1 if tap water; 2 if boiled water; 3 if purified water; 4 if bottled water; 5 if undergrounded water	3.03	0.873
Quality	Perception of water quality in Paldang reservoir.	2.27	0.772
Job	1 if student; 2 if graduate student; 3 if farmer; 4 if self-employed; 5 if sale; 6 if engineer; 7 if business man; 8 if management; 9 if public officer; 10 if CEO; 11 if professional; 12 if housewife; 13 if no job	6.57	4.183
Edu	1 if middle school graduate; 2 if high school graduate; 3 if college attended; 4 if master or higher	2.76	0.643
House	Type of housing. 1 if apartment; 2 if condo or simillar; 3 if house; 4 otherwise	1.66	0.738
Fsize	Number of household	2.96	1.442
Income	1 if below 2 million won; 2 if above 2 million below 3 million; 3 if above 3 million below 4 million; 4 if above 4 million below 5 million; 5 if above 5 million below 6 million; 6 if above 6 million below 7 million; if above 7 million below 8 million; 8 if above 8 million; 9 otherwise	2.97	0.643

The empirical results of double-bounded dichotomous choice probit model are presented in Table 2.

TABLE II: Results of the Model

Variable	Model 1 SBDC without Covariate	Model 2 SBDC with Covariate	Model 3 DBDC without Covariate	Model 4 DBDC with Covariate
Constant	-0.0002614***	-0.3024717	0.5169719*** -0.9044644***	-0.3291493 -0.0380235
Bid1	0.517539**	-0.000288**	-0.000261**	-0.0002892**
Bid2			-0.0003035***	-0.0002861**
Gender		0.2776347*		0.2767717* -0.3799584
Age		0.0201111		0.0243973 0.0071727
Use		0.083137		0.0764835 0.1516251
Quality		0.0211623*		0.0216786 -0.2033246
Job		-0.022663		-0.0211152 0.0301291
Edu		0.0615716		0.0706207 0.1069089
House		0.0382084		0.0457109 -0.543614**

Fsize		-0.0294789		-0.0322478 0.0453434
Income		0.0332908		0.03335658 -0.0629923
LR Chi^2/Wald	3.74	9.29	8.26	145.46
Prob> Chi^2	0.0533*	0.5046	0.0161**	0.0000***
Pseudo R^2	0.0113	0.0282		

Note: ***, **, * represent 1%, 5%, and 10% significant level, respectively.

We analysed four different types of probit model. Compared with their results, model with no covariate gave us more significant result than those with covariate. In this sense, we selected model 3's mean WTP, 1,981 won per household per month. Aforementioned WTP was multiplied by the total number of households (about 5.8 million) in the Seoul metropolitan area and annual WP was estimated at 137.9 billion won which would significantly lower than the public investment that MOE announced (i.e. 350 billion won).

TABLE III: WTP

WTP	Coefficient	Standard error	P-value	95% Confidence Interval	
Model 1	1979.915	522.8528	0.000***	955.1427	30004.688
Model 2	1911.228	458.5623	0.000***	1012.462	2809.993
Model 3	1981.006	525.8381	0.000***	950.3826	3011.63
Model 4	1907.860	96.3896	0.000***	1253.90	4882.16

5. Conclusions

This study analysed downstream water users' preference to ameliorate water quality due to algae bloom during summer. Double bounded dichotomous choice survey method used to estimate willingness to pay to improve water quality of Paldang reservoir in Korea as a case study. The mean WTP based on predicted value from the probit model in this study was 1,981 won per household per month. The annual WTP was estimated at 137.9 billion won for Seoul metropolitan area, which is about 40% of 350 billion won that the MOE of Korea planned to invest. Suffice to say that, current algae control policy, 3rd phase of implementing total maximum daily load (TMDL) would inappropriate to downstream water users. However, this study only investigates downstream water users and there might be a deviation between upstream and downstream water users. Further analysis and investigation will be needed to conclude final answer for MOE to implement and scale up total maximum daily load policy to public.

6. Acknowledgements

This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2014S1A5A2A03064796).

7. References

[1] Wang, M., & Shi, W. (2008). "Satellite-observed algae blooms in China's Lake Taihu." *Eos, Transactions American Geophysical Union, 89*(22), 201-202.
http://dx.doi.org/10.1029/2008EO220001

[2] Kim, D. W., Min, J. H., Yoo, M., Kang, M., & Kim, K. (2014). "Long-term effects of hydrometeorological and water quality conditions on algal dynamics in the Paldang dam watershed," Korea. *Water Science & Technology: Water Supply*, *14*(4), 601-608.
http://dx.doi.org/10.2166/ws.2014.014

[3] van Beukering, P., & Cesar, H. S. (2004). "Ecological economic modeling of coral reefs: Evaluating tourist overuse at Hanauma Bay and algae blooms at the Kihei Coast, Hawai'i." *Pacific Science*, *58*(2), 243-260.
http://dx.doi.org/10.1353/psc.2004.0012

[4] Jung, Y. J., Stenstrom, M. K., Jung, D. I., Kim, L. H., & Min, K. S. (2008). "National pilot projects for management of diffuse pollution in Korea." *Desalination*, *226*(1), 97-105.

http://dx.doi.org/10.1016/j.desal.2007.02.101

[5] Whittington, D., Briscoe, J., Mu, X., & Barron, W. (1990). "Estimating the willingness to pay for water services in developing countries: A case study of the use of contingent valuation surveys in Southern Haiti." *Economic Development and Cultural Change*, 293-311.

http://dx.doi.org/10.1086/451794

[6] North, J. H., & Griffin, C. C. (1993). "Water source as a housing characteristic: Hedonic property valuation and willingness to pay for water." *Water Resources Research*, *29*(7), 1923-1929.

http://dx.doi.org/10.1029/92WR02995

[7] Jordan, J. L., & Elnagheeb, A. H. (1993). "Willingness to pay for improvements in drinking water quality." *Water Resources Research*, *29*(2), 237-245.

http://dx.doi.org/10.1029/92WR02420

[8] Whittington, D., Pattanayak, S. K., Yang, J. C., & Kumar, K. B. (2002). "Household demand for improved piped water services: evidence from Kathmandu, Nepal." *Water Policy*, *4*(6), 531-556.

http://dx.doi.org/10.1016/S1366-7017(02)00040-5

[9] Hanemann, M., Loomis, J., & Kanninen, B. (1991). "Statistical efficiency of double-bounded dichotomous choice contingent valuation." *American journal of agricultural economics*, *73*(4), 1255-1263.

http://dx.doi.org/10.2307/1242453

[10] Riddel, M. (2001). "Simulated maximum likelihood for double-bounded referendum models." *Journal of Agricultural and Resource Economics*, 491-507.

[11] Lee, Y., Chang, H., & Hong, Y. (2014). "Is a costly river restoration project beneficial to the public? Empirical evidence from the Republic of Korea." *Desalination and Water Treatment*, (ahead-of-print), 1-8.

http://dx.doi.org/10.1080/19443994.2014.930698

[12] K.G. Mäler and J.R. Vincent, *Handbook of Environmental Economics: Valuing environmental changes*. Vol. 2. North Holland, 2005.

[13] D.S. Brookshire, A. Randall and J.R. Stoll, "Valuing increments and decrements in natural resource service flows," Am. J. Agric. Econ., 62(3) (1980) 478-488.

http://dx.doi.org/10.2307/1240202

[14] K. Arrow, R. Solow, *Report of the NOAA panel on contingent valuation*. Vol. 58. National Oceanic and Atmospheric Administration, 1993.

[15] M. Hanemann, J. Loomis and B. Kanninen, "Statistical efficiency of double-bounded dichotomous choice contingent valuation," Am. J. Agric. Econ., 73(4) (1991) 1255-1263.

http://dx.doi.org/10.2307/1242453

[16] W.M. Hanemann, "Welfare evaluations in contingent valuation experiments with discrete responses," Am. J. Agric. Econ., 66(3) (1984) 332-341.

http://dx.doi.org/10.2307/1240800

[17] W.M. Hanemann, "Welfare evaluations in contingent valuation experiments with discrete response data: reply," Am. J. Agric. Econ., 71(4) (1989) 1057-1061.

http://dx.doi.org/10.2307/1242685

[18] T. Park, J.B. Loomis and M. Creel, "Confidence intervals for evaluating benefits estimates from dichotomous choice contingent valuation studies," Land econ., 67(1) (1991) 64-73.

http://dx.doi.org/10.2307/3146486

[19] I. Krinsky and A.L. Robb, "On approximating the statistical properties of elasticities," Rev. Econ. Stat., 68 (1986) 715-719.

http://dx.doi.org/10.2307/1924536

[20] Kim, S. B. (2005). "AN OPTIMAL GOVERNANCE MODEL OF LAND USE IN WATERSHED." *International Review of Public Administration*, *9*(2), 67-79.

[21] Cho, Y., & Kim, H. J. (2004). "The cost-benefit analysis of the improvement of water quality of the Paldang reservoir in Korea." In *2004 Annual meeting, August 1-4, Denver, CO* (No. 19911). American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association).

[22] Ministry of Environment. Algae Warning System database (www.moe.kr).