

Aquaculture Water Quality Index: a low-cost index to accelerate aquaculture development in Indonesia

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Abstract Due to a lack of the related data, there were no simple water indexes available for indicating water quality. Motivated by the fact that many lakes and reservoirs in Indonesia have been polluted because of aquacultural activity, this paper proposed a Water Quality Index, called the Aquaculture Water Quality Index (AWQI), and presented the development of practical tool to aid the development of aquaculture in Indonesia. Specific purposes included: (a) providing a brief summary of the assessment results of the existing WQI; (b) developing the AWQI method for applying in an aquacultural context; (c) implementing the AWQI method in Depok Area (Indonesia) as study area. An AHP method was also processed to define the weights of selected water quality parameters: DO, ammonia, pH, and fecal coliform. The AWQI had several features: (a) a low-cost water quality monitoring program that could be used by developing countries; (b) a useful tool for water resource agencies, especially for local agencies, to manage waterbodies and to raise public awareness of water pollution for its data, as its data could be easily understood and interpreted.

Keywords AHP method · AWQI · Aquaculture · Depok Area (Indonesia) · Expert panel · Government regulation

Abbreviations

AHP	Analytical hierarchy process
AWQI	Aquaculture Water Quality Index
MDE	Malaysian Department of Environment
NSF	National Sanitation Foundation
RPI	River Pollution Index
WQI	Water Quality Index

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Introduction

Degradation of surface water conditions, as reflected in the water quality status, has become an issue of environmental concern worldwide (Silva Alves et al. 2013; Soldán and Badurová 2013; Santos et al. 2013; Rodgher et al. 2013). Many countries now use a Water Quality Index (WQI) to assess the condition of waterbodies (Pesce and Wunderlin 2000; Jonnalagadda and Mhere 2001; Bordalo et al. 2006; Rahman et al. 2011; Horton 1965; Sanchez et al. 2007). However, most WQIs have been developed for general water purposes, such as Horton's Index, the National Sanitation Foundation (NSF) Index, the British Columbia Water Quality Index, the Oregon Water Quality Index, the Overall Index of Pollution, the River Pollution Index (RPI), and the Universal Water Quality Index (Liou et al. 2004). Only a few WQIs have been developed based on specific water-use purposes, such as the water supply or drinking water (Mohebbi et al. 2013; Wanda et al. 2012; Ramesh et al. 2010), recreation or water sports (Smith and Daviescolley 1992; Anderson et al. 2012; Kamizoulis and Saliba 2004; Marino et al. 1995; Nagels et al. 2001), public bathing (Smith et al. 1991; Kamizoulis and Saliba 2004; Kay 1988), estuaries or coastal water systems (Garcia-Marin et al. 2013; Neto et al. 2013), irrigation or agriculture (Goss and Richards 2008; Herricks and Suen 2006; Al-Bassam and Ai-Rumikhani 2003; Wang et al. 2011), livestock (Gharibi et al. 2012), and marine shrimp culture (Ferreira et al. 2011). Many government agencies have applied WQI to develop their own standards for various water purposes, which differ with regard to the specific terms used for the classification schemes and in the selection of indicator parameters (Bordalo et al. 2006; Sarkar and Abbasi 2006; Suen and Herricks 2009; Bordalo et al. 2001).

The many applications of WQI worldwide thus use different methods based on their specific aims. This study developed a WQI that was intended to provide an easy low-cost approach to assess the water quality in relation to aquaculture. This work is motivated by the fact that many lakes and reservoirs in Indonesia have become polluted due to aquacultural activity (Mungkung et al. 2013; Pawitan and Haryani 2011), with these negative environmental impacts most often being due to poor planning, inappropriate management procedures, and lack of awareness and guidelines with regard to environmental protection.

This study thus has the following three major purposes: (1) to provide a brief summary of applications of existing WQI methods as an assessment result; (2) to develop the Aquaculture Water Quality Index (AWQI) method for use in an aquacultural context; and (3) to identify the water status of aquaculture lakes in Depok Area, Indonesia, by implementing the AWQI.

Materials and methods

Study area

This research was carried out in Depok Area, West Java Province, Indonesia (Fig. 1), located at $6^{\circ}19'00''$ – $6^{\circ}28'00''$ S and $106^{\circ}43'00''$ – $106^{\circ}55'30''$ E. Administratively, the Depok Area is part of the Jakarta–Bogor–Depok–Tangerang–Bekasi (Jabodetabek) metro area, and has a total area of 200.29 km². From north to south, Depok Area is composed of lowlands with gently undulating hills and an elevation of between 50 and 140 m above sea level. The waterbody system in the Depok Area has several first- and second-order rivers,

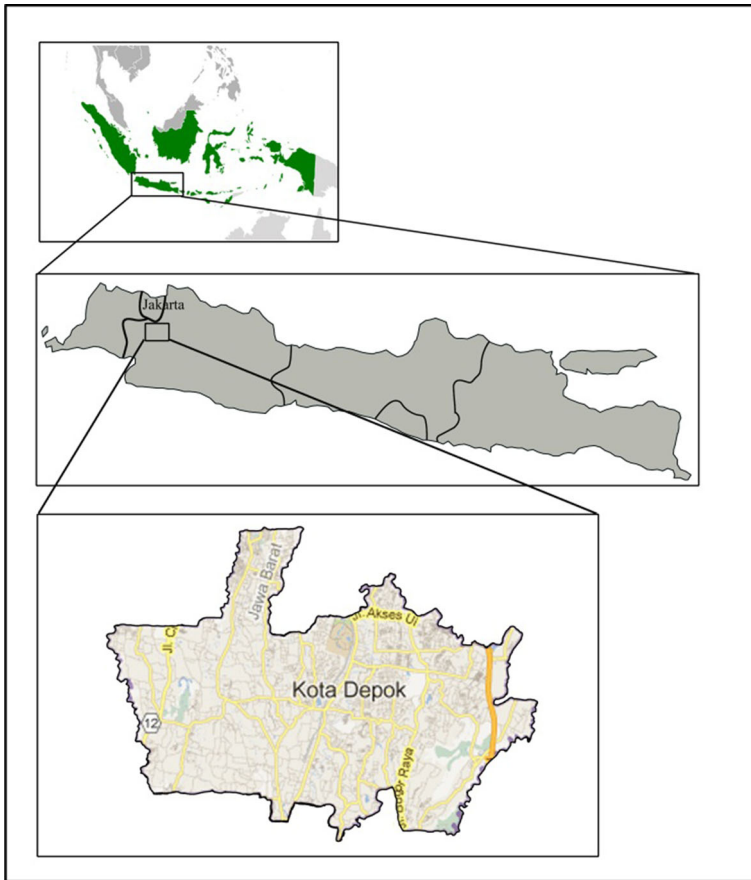


Fig. 1 Location of Depok Area, West Java, Indonesia

such as Ciliwung River and Cisadane River, as well as both natural and artificial lakes within the watershed.

Depok Area is also known as hydrological buffer zone of Jakarta City, the capital city of Indonesia. The government has planned and constructed many retention lakes associated with the master plan of drainage system of Jakarta City. The local government of Depok Area has improved the water purpose by aquaculture to increase the benefits of these lakes. However, the presence of aquaculture activity indicates a new threat of environmental pollution in the lake system. Therefore, the study demonstrates how the influence of aquaculture activity works in different level on the selected lakes by indexing the water quality. This study focuses on four major aquaculture lakes in the Depok Area: Bojong Sari, Rawa Besar, Citayam, and Rawa Kalong, which have the greatest potential for this particular use.

Data processing

The obtained data for this study were secondary data on water quality over 3 years (2009–2011) from Environmental Protection Local Agency of the Depok Area, interviews

and questionnaires, as well as literature reviews from research reports, books, and related scientific papers. Selection of WQI then working on appraisal study is the rapid assessment method to investigate the performance of selected WQI methods in study area. The result is a brief summary as base motivation to develop AWQI. Reports from FAO and local fisheries agency elaborated with literature reviews from recent papers were used to select the fish types and water quality parameters in order to process AHP method. As the benchmark regulation in Indonesia, government regulation No. 82/2001 on management of water quality and control over water pollution was used to standardize selected water quality parameters. Details of the methodology used in this study are shown in Fig. 2. The AWQI itself was developed in four main stages, based on the related appropriate information and data. A summary of these stages, as well as the core resources, is shown in Table 1. The data were analyzed using several analytical tools and software applications, such as SPSS Statistics 17.0 and the Expert Choice 11.0 software.

Selection of WQI

The use of index to condense and process water quality data has increasingly gained acceptance in recent times. The development of index is solely unique and different according to their characteristics at many locations. Therefore, the selection of NSF, RPI,

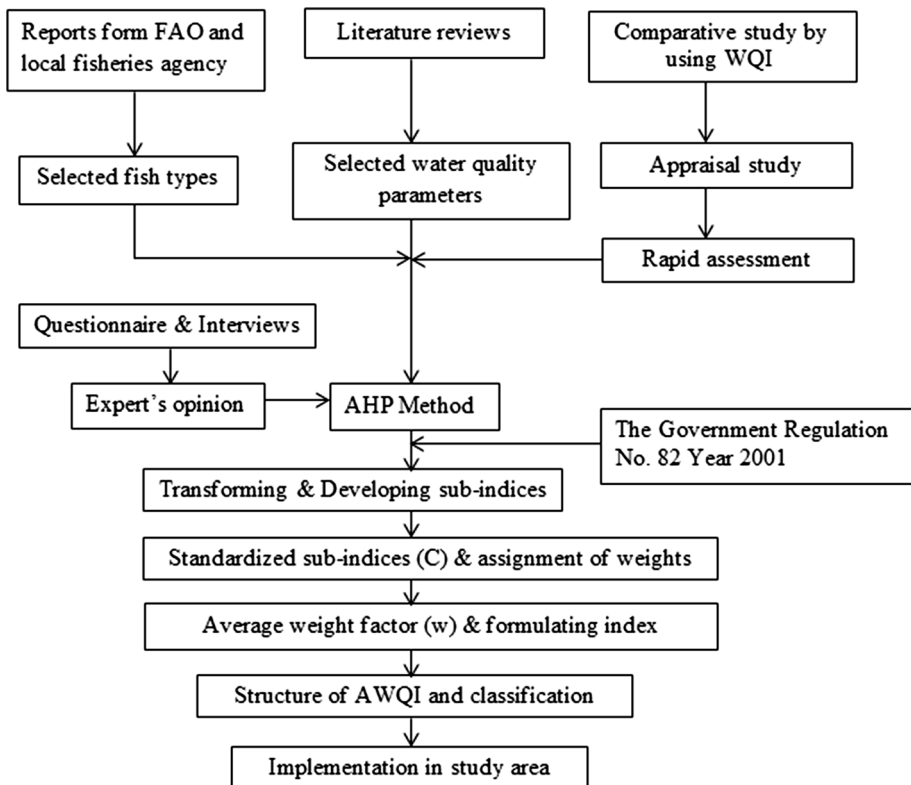


Fig. 2 Schematic diagram of the steps followed to develop the AWQI

Table 1 Main data resources for the four stages

No.	Stages	Water quality data	Interviews and questionnaires	Literature reviews	Regulations
1	Screening and selecting parameter	●	●	●	
2	Transforming and developing subindices		●	●	●
3	Assignment of weights		●		
4	Formulating an index	●			●

Table 2 Summary of descriptive statistic of water quality data over 3 years (2009–2011) in study area

	Unit	Minimum	Maximum	Mean	Standard deviation
pH	–	6.92	9.73	8.01	0.97
TDS	mg/L	60	150	105	29.92
TSS	mg/L	6	126	27.42	34.028
Temp	°C	23.40	34.70	28.62	3.81
Nitrate	mg/L	0.06	1.59	0.78	0.48
Nitrite	mg/L	0	0.35	0.06	0.09
DO	mg/L	3.40	8.40	6.15	1.58
BOD	mg/L	1.25	87.58	24.51	28.09
COD	mg/L	3.73	116.07	47.52	37.74
TP	mg/L	0	0.10	0.0296	0.03
Zinc	mg/L	0	0.11	0.02	0.03
Phenol	mg/L	0	0.04	0.01	0.02
Ammonia	mg/L	0.03	1.69	0.50	0.58
Cl	mg/L	6.80	24.97	16.22	5.18
SO ₄	mg/L	0.13	7.89	3.19	2.83
Detergent	mg/L	0.02	0.34	0.13	0.11
Fecal coliform	Total number/100 ml	8	90,000	14,366.50	3,3062.62
Total coliform	Total number/100 ml	23	3000000	264376.92	863000

Bold text is the selected water quality parameters

and MDE to accomplish the comparative study is following important rationales: NSF has been widely used and applied by the various scientists around the world (Sarkar and Abbasi 2006; Karbassi et al. 2011). NSF is also considered as a simple method to define the status of waterbody in terms of Water Quality Index. RPI is an existing index from Taiwan to monitor trends of water quality in waterbodies (Liou et al. 2004). Meanwhile, MDE is developed their own index to be used in Malaysia based on their characteristics. We used these two methods with considering similarity of geographical location.

Selection of water quality parameters

Water quality data recorded in this study consisted three groups: physical parameters [pH, total dissolved solids (TDS), total suspended solids (TSS), and temperature]; chemical

parameters [nitrate, nitrite, DO, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus (TP), zinc, phenol, ammonia, chloride (Cl), sulfate (SO₄), and detergent]; and microbial parameters (fecal coliform and total coliform). A summary of descriptive statistic of water quality data over 3 years (2009–2011) in study area is shown in Table 2. The initial step was to reduce the number of water quality parameters so that they reflected the local characteristics of the study area, as well as the water requirements of aquaculture. As mentioned in data processing section, one can only try to reduce subjectivity and inaccuracy by involving expert panel in collecting opinion, and doing it by the AHP approach (Karbassi et al. 2011). Therefore, we selected one essential parameter for each group of water quality.

This was carried out based on common theoretical knowledge drawn from the literature. Many previous research papers have investigated water quality parameters connected with certain purposes. For example, DO was selected as an important parameter of water quality, as it is a critical parameter and barometer for aquatic life and water vegetation (Kannel et al. 2007). In an aquacultural context, DO also affects fish growth rate (McDaniel et al. 2005). In addition, ammonia and pH are closely related with the requirements of specific fish types in the way that they can alter water acidity and toxicity (Scott et al. 2005). The fact that low pH reduces ammonia toxicity is fortuitous for fish culturists. Fish produce both carbon dioxide and ammonia as waste products. Carbon dioxide reacts with water to form carbonic acid. In the absence of buffering, this lowers the pH of the water, lowering the toxicity of the ammonia that is also being produced. Ammonia is also one of the most representative parameters of aquaculture impacts than any other water quality parameters (Koçer and Sevgili 2014).

The presence of microbiological quality in the water lakes determined the presence and concentration of microbiological quality in the certain fish such as *Common carp* and *Nile Tilapia* (Buras et al. 1987; El-Shafai et al. 2004; Harnisz and Tucholski 2010). The effect of fecal coliform on fish contamination also has been investigated (El-Shafai et al. 2004). Since the microbiological quality of lakes is often threatened by contamination due to aquacultural activity, it is necessary to consider fecal coliform as key parameter when determining water quality status, as contaminated fish pose a risk to public health (de Donno et al. 2002; Ntengwe and Edema 2008). Based on previous arguments, we selected DO, pH, ammonia, and fecal coliform as the four essential water quality parameters which reflected the local characteristics as well as the water requirements of aquaculture in the study area.

Selection of fish types

Freshwater aquaculture is a key activity in commercial fisheries in Indonesia, with the related products being an important source of protein for many people, especially those who live in urban areas (Effendie et al. 2005). Food and Agriculture Organization (FAO) aquaculture statistics also confirmed that Indonesia produced a great many fish types to meet both domestic demand and export needs with the highest rank of fish types being *Common carp* (67.95 %), *Nile tilapia* (24.56 %), and *Giant gourami* (2.09 %), among others. Some literature reviews also proved that in Asian countries, three of those fish types are the most popular in aquaculture than others (Chapman and Fernando 1994; Frei et al. 2007; Sumantadinata 1995). Because of their popularity in aquaculture activity in Indonesia and interviews results from local farmers and officers from Fisheries and Agriculture Agency of the Depok Area, therefore *Common carp*, *Nile tilapia* and *Giant gourami* are considered the important fish types in this study.

Selection of the expert panel

The expert panel of this study comprised 25 government officials, three academics, and six aquaculturists. The government officials were recruited from several different agencies: (a) the Fisheries and Agriculture Agency of the Depok Area ($n = 10$), including officials from the subdivisions of fish production, fishery community development, training and counseling, etc. and (b) the Environmental Protection Local Agencies of the Depok Area ($n = 8$) and the West Java Region ($n = 7$). Those agencies are located in the Depok Area, except for the Environmental Protection Agency of the West Java Region, located in Bandung City. The expert panel is familiar with the characteristics of these selected parameters, which are different for each situation, time, and location.

The AHP method

The AHP is one of the most popular methods which have been successfully implemented in many fields and areas (Saaty 2001; Sipahi and Timor 2010; Vaidya and Kumar 2006; Vargas 1990; Ho 2008; Huang et al. 2013; Hayati et al. 2013). In general, the AHP method consists of five main steps (Fig. 3). It is a system analysis technique for solving decision problems by comparing several alternatives on the basis of the same set of attributes (Benitez et al. 2011; Saaty et al. 2007; Chakraborty and Dey 2006). The AHP method was used to calculate the weights of the water quality parameters.

The water quality parameters and types of aquaculture fish were first selected, and then interviews and questionnaires were used to obtain opinions of expert panel from many government agencies. The expert panel is considered familiar with the characteristics of these selected parameters which are different for every situation, time, and location. Their members consisted of officers from Fisheries and Agriculture Agency of the Depok Area, Environmental Protection Local Agency of the Depok Area, the Environmental Protection Agency of West Java Region, and also some professionals. The judgments from them have been used to obtain criteria weights when there is a lack of the required data (Reza et al. 2013). They were asked to rank the priority values according to their experiences using a ratio scale and verbal judgments of preference which requires no units in the comparison (Kainulainen et al. 2009; Table 3).

Expert Choice 11.0 was used to analyze the data, as it is widely applied in the literature to analyze multicriterion decision-making problems based on the AHP approach (Ooshaksaraie et al. 2012; Karbassi et al. 2011). This software has many capabilities, such

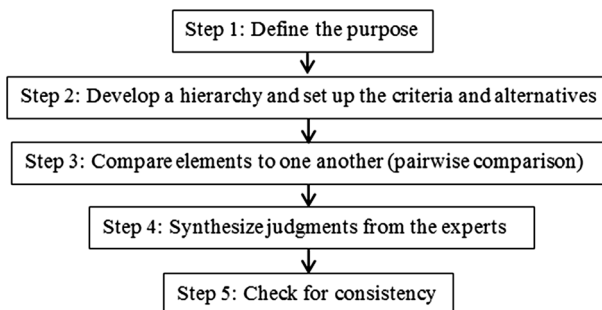


Fig. 3 Main steps of the AHP method

as priority determination, final weight calculation, sensitivity analyses, and question design. Multiple regression analyses were thus conducted to confirm the aptness of the four selected parameters with the AWQI as the final product of this study. Multiple linear regressions are considered and widely used to correlate the observed data and to create models that can be used for prediction and verification in many research fields, including the environment and the health of waterbodies (Cho et al. 2009; Shrestha et al. 2008).

Results

In order to achieve the rapid assessment results, a comparative study combined with appraisal study was completed to perform the existing WQI methods. Several considerations related with the advantages and disadvantages of the existing WQI methods were taken to this rapid assessment as major principle to determine their level.

A comparative study

A comparative study using three different WQI methods (NSF, RPI, and MDE) were used to evaluate the spatial and temporal changes in water quality in the study area. The results (Table 4) indicated that the status of aquaculture lakes in study area was fluctuated.

Appraisal study

Performance of the used WQI methods would be checked regarding adequacy of data, process, and information quality in the study area. A rapid assessment checklist was provided along with field survey method and the available data for assessment of core performance of WQI methods.

Rapid assessment results

Table 5 shows the key finding from this comparison, which is that the parameters used in the NSF and MDE are comprehensive than those in the RPI method. However, the accuracy of the results was not directly related to the number of parameters, as some of these may have been inappropriate to the specific context of aquaculture lakes. With regard to complexity, the RPI method was the simplest. Due to the various inadequacies of the three WQI examined above, it was thus necessary to develop a new method based on the specific characteristics and conditions of the study area. The resulting AWQI can be used to determine the suitability of a waterbody for aquacultural purposes, based on the type of fish that will be raised.

Table 3 Ratio scale used in AHP. 2, 4, 6 and 8 are the mid-values between two adjoining ones

Ratio Scale	Comparison between two factors
1	Equally important
3	Moderately important
5	Strongly important
7	Very strongly important
9	Extremely important

Table 4 Results of a comparative study of applying three WQI to the aquaculture lakes in study area

Method	Year	Aquaculture Lakes							
		Bojong Sari		Rawa Besar		Citayam		Rawa Kalong	
		WQI	Status	WQI	Status	WQI	Status	WQI	Status
NSF	2009	75	G	58	M	57	M	60	M
	2010	75	G	87	G	71	G	69	M
	2011	70	M	66	M	62	M	64	M
RPI	2009	2.5	SP	4.25	MP	7.25	GP	4.25	MP
	2010	2.25	SP	1	G	2	SP	3.25	MP
	2011	4.5	MP	3.25	MP	5	MP	3.5	MP
MDE	2009	68.98	M	−6.51	B	−3.58	B	50.39	M
	2010	72.84	G	80.79	G	77.27	G	63.32	M
	2011	58.43	M	41.63	F	32.62	F	48.17	F

G Good, M Medium, F Fair, B Bad, SP Slightly Polluted, MP Moderately Polluted, GP Grossly Polluted

The development of AQWI

The AHP method was processed using Expert Choice 11.0. The structural hierarchy in the AHP was developed in this work to investigate the weights of various parameters which affect aquaculture fish (Fig. 4). The goal in AHP method was to define the weights of selected water quality parameters with fish types as criteria and water quality parameters as alternatives. In the process of assigning the weights, the initial step was entering the criteria and the alternatives. Second, we developed the assessment software with the opinions from the expert panel. Finally, the data were calculated with the software in order to determine the average weight factors from the selected water quality parameters, which were based on fish types.

The results showed that the weights of the parameters were quite similar, and thus it could be concluded that the three aquaculture fishes (*Common Carp*, *Giant Gourami*, and *Nile Tilapia*) examined in this work had similar requirements for water quality (Table 6). In addition, we analyzed the inconsistency rate of the model. Although an acceptable inconsistency rate within a matrix or a system would be varied according to decision makers, the literature suggested a value below 0.1 (Saaty and Vargas 1984). In this study, the inconsistency rate averaged 0.02, and thus was highly acceptable. The last step of the

Table 5 Performance of selected WQI methods in the study area

No	Consideration	WQI		
		NSF	RPI	MDE
1	Number of parameters	●	○	⊙
2	Complexity of analysis	⊙	●	○
3	Time needed (process time)	○	●	⊙
4	Cost	○	●	⊙
5	Methods and tools used	⊙	●	○
6	Assignment of weighting factor	⊙	⊙	⊙
7	Suitability	⊙	⊙	○

● = good, ⊙ = fair, ○ = bad

AHP process was to analyze the sensitivity of various fish species to the selected parameters (DO, ammonia, pH, and fecal coliform).

In the decision-making process, the sensitivity analysis was the final stage where the input data were slightly modified in order to observe the impact on the results. If the ranking did not change, the results were said to be robust. In short, we needed to see whether the small variations in the weights would change the decision. If not, we would be reassured that our choice was reasonable. In Expert Choice 11.0 software, sensitivity graphs were provided to test the possible changes in the decision. The overall sensitivity ratios of *Common carp*, *Giant gourami*, and *Nile tilapia* are 0.369, 0.333, and 0.298, respectively. These results show that *Common carp* is the least resistant species, compared to *Giant gourami* and *Nile tilapia*.

The AWQI was developed according to the proposed method to assess the water quality status at the aquaculture lakes. After selecting the parameters of water quality, the standardized subindices (C) were then transformed and developed. These standardized subindices should have the same scale and the same upper and lower limits as The Government Regulation No. 82 Year 2001 (Table 7). This regulation is the key source of the standardized subindices which are different for each country.

The AWQI can therefore be represented as:

$$AWQI = \sum_{i=1}^n w_i C_i \quad (1)$$

where w_i is the average weight factor for the i th parameter, and C_i is the standardized subindex for the i th parameter. The results of implementing the AWQI to the aquaculture lakes in the Depok Area are shown in Table 8. Each quality value was then multiplied by an average weight factor, to take into account the relative contribution of each variable to the overall water quality.

Finally, the index value was calculated and classified as the sum of the weighted quality values, ranging from 0 (poorest state) to 100 (best condition). This study based its parameters on the Government Regulation No. 82 Year 2001 especially Chapter 8, which has four categories of water purposes (class 1: drinking water supply, class 2: recreation, class 3: aquaculture and class 4: agriculture). With regard to aquaculture purposes, the criteria were reclassified and a range of acceptable scores was derived based on the upper

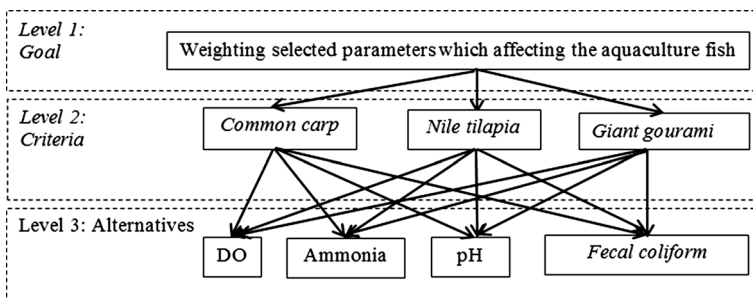


Fig. 4 Structural hierarchy of the AHP. The goal was to define the weights of selected water quality parameters. *Level 1* indicates the goal of applying the AHP method in the study. *Level 2* consists of the criteria (types of fish) that are used to assess the alternatives. *Level 3* is the selected water quality parameters that are used as the alternatives

Table 6 Average weight factor for each water quality parameter considering fish types (*Common carp*, *Giant gourami*, and *Nile tilapia*)

Parameter	Fish types			Average weight factor (w)
	<i>Common carp</i>	<i>Giant gourami</i>	<i>Nile tilapia</i>	
DO	0.531	0.575	0.534	0.546
Ammonia	0.237	0.216	0.227	0.227
pH	0.174	0.142	0.184	0.167
Fecal Coliform	0.058	0.067	0.055	0.060

Table 7 Standardization of selected water quality parameters using the upper and lower limits from The Government Regulation No. 82 Year 2001

Parameter Unit	DO mg/L	Ammonia mg/L	PH –	Fecal Coliform Total/100 ml
<i>Standardization factor (Ci)</i>				
100	≥ 6	< 0.02	7	< 100
90	$5.5 \leq x < 6$	$0.02 \leq x < 0.05$	$6.9 \leq x < 7$ or $7 < x \leq 7.2$	$100 \leq x < 300$
80	$5 \leq x < 5.5$	$0.05 \leq x < 0.1$	$6.8 \leq x < 6.9$ or $7.2 < x \leq 7.4$	$300 \leq x < 500$
70	$4.5 \leq x < 5$	$0.1 \leq x < 0.2$	$6.7 \leq x < 6.8$ or $7.4 < x \leq 7.6$	$500 \leq x < 700$
60	$4 \leq x < 4.5$	$0.2 \leq x < 0.3$	$6.6 \leq x < 6.7$ or $7.6 < x \leq 7.8$	$700 \leq x < 900$
50	$3.5 \leq x < 4$	$0.3 \leq x < 0.4$	$6.5 \leq x < 6.6$ or $7.8 < x \leq 8$	$900 \leq x < 1100$
40	$3 \leq x < 3.5$	$0.4 \leq x < 0.5$	$6.4 \leq x < 6.5$ or $8 < x \leq 8.2$	$1100 \leq x < 1300$
30	$2.5 \leq x < 3$	$0.5 \leq x < 0.6$	$6.3 \leq x < 6.4$ or $8.2 < x \leq 8.4$	$1300 \leq x < 1500$
20	$2 \leq x < 2.5$	$0.6 \leq x < 0.7$	$6.2 \leq x < 6.3$ or $8.4 < x \leq 8.6$	$1500 \leq x < 1700$
10	$1.5 \leq x < 2$	$0.7 \leq x < 0.8$	$6.1 \leq x < 6.2$ or $8.6 < x \leq 8.8$	$1700 \leq x < 1900$
0	< 1.5	≥ 0.8	$x < 6.1$ or $x > 8.8$	≥ 1900

and lower limits from class 3 of the government standards, focusing on the selected parameters (DO, ammonia, pH, and fecal coliform). The three primary classes were determined to be in ranges from 100 to 61 (good quality), 60 to 41 (fair quality), and 40 to 0 (poor quality), with descriptions of each class given in Table 9. The resulting classifications are useful with regard to the acceptable levels of the selected water quality parameters in the context of developing a sustainable aquaculture activity within the study area.

Table 8 Results of implementing the AWQI to aquaculture lakes in Depok Area

Aquaculture lakes	AWQI					
	2009	Status	2010	Status	2011	Status
Bojong Sari	64.71	Good	87.45	Good	49.68	Fair
Rawa Besar	76.19	Good	87.11	Good	71.35	Good
Citayam	56.38	Fair	87.79	Good	47.88	Fair
Rawa Kalong	71.78	Good	86.12	Good	60	Fair

Multiple regression analyses were thus conducted using SPSS 17.0 to examine the relationship between the AWQI and the four selected parameters. Table 10 summarizes the correlations from the regression analyses. It indicates that the AWQI is only positively and significantly correlated with DO and fecal coliform. In addition, higher DO scores tend to be related to a higher overall AQWI. In contrast, ammonia and pH are negatively correlated with the overall AWQI.

The multiple regression model with all four predictors produced $R^2 = 0.935$, $F(4,7) = 25.031$, $p < 0.001$. After executing the input data on SPSS 17.0, the results were tested by F and t tests, which indicated that DO, ammonia, pH, and fecal coliform simultaneously correlated with the AWQI. Multicollinearity, autocorrelation, and heteroskedasticity tests were also completed to examine the input data. Each selected control parameter must be independent from other control parameters to avoid the problem of multicollinearity and ensure that the tolerance of all the control parameters is about 1. The standardized residuals must be independent from each other, and this was the case when the Durbin–Watson value of the model was set between 1.5 and 2.5 (Seeboonruang 2012). In this study, the standardized residuals were independent from one another, due to the Durbin–Watson value of 1.823. In the multicollinearity test, to detect the tolerance value and VIF, the lower the tolerance value and higher the VIF is, the greater the problem of multicollinearity is. In many studies, it is assumed that if the tolerance value >0.1 and $VIF < 10$, then this means that multicollinearity is not an issue. A scatter plot was also produced using the regression standardized residual and regression standardized predicted values, which was used to detect the presence or absence of heteroskedasticity (Fig. 5). The dots were distributed with a fuzzy pattern both above and below zero on the Y axis, indicating that heteroskedasticity is not an issue. Lastly, the coefficient determination (R^2) was 0.935, which means that the influence on the distribution from the independent variables was 93.5 % and that from the external variables was 6.5 %.

Discussion

The results of the AQWI (Table 9) indicate that the waters in the four aquaculture lakes in study area were in fair-to-good status. More specifically, Rawa Besar Lake had a good status, despite some variations in the scores. On the other hand, Citayam Lake had the worst water status, as the water has been very negatively influenced by human activity, especially through the disposal of sewage and wastewater. The results also show that the overall water quality condition of all the lakes has gradually changed, particularly in 2010, when there was significant improvement in water quality. This was due to some revitalization efforts and the implementation of Indonesian Environmental Ministry Regulation No. 28 Year 2009 regarding the loading capacity of pollution for lakes or reservoirs. While

Table 9 Offered classification of the AWQI for aquaculture lakes

Range score	Status	Description
61–100	Good	Very suitable without restrictions
41–60	Fair	Relatively suitable with restrictions
0–40	Poor	Unsuitable water condition for aquaculture activity

Table 10 Results from the regression analysis of the four selected parameters

Variables	Correlation with AWQI	Multiple regression (b)	Weights (β)
AWQI			
DO	0.645*	5.647**	0.599
Ammonia	-0.819***	-16.966***	-0.659
pH	-0.238	-2.766	-0.181
Fecal coliform	0.373	-6.046×10^{-6}	-0.094

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

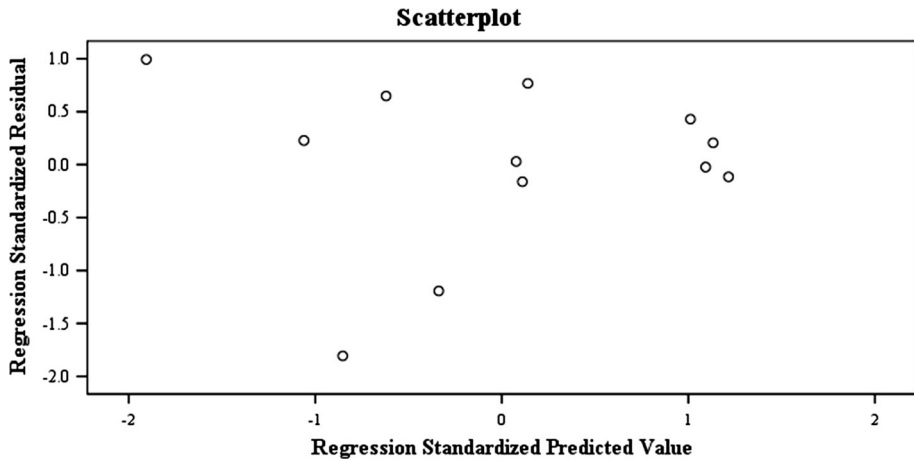


Fig. 5 Scatter plot of the multiple linear regression results

this move was initially rather successful, the water quality then fell significantly due to overloading the capacity of the lakes with regard to aquaculture activity. The higher levels of DO, pH, and ammonia also led to mass fish deaths in all four lakes. Moreover, the presence of both solid and liquid waste products caused a rise in the concentration of fecal coliform, which caused the overall AWQI value in 2011 to become lower. A lack of enforcement of the related regulations, as well as low public awareness, was the main cause of this decline in water quality. However, the overall water condition in the four aquaculture lakes is fair, and thus they are relatively suitable for this purpose. However, some restrictions should still be applied to limit overuse, such as a limitation of the number of nets and the total area devoted to aquaculture.

After validation using multiple regression models, the results confirmed that DO has an important role in the AWQI, as it had the highest weight factor in AHP method. Several studies offered the concept of a minimum indicator to develop WQI for specific purposes. For example, DO and dissolved oxygen deficit (D) were used as minimum indicators to evaluate the water quality in different reservoirs and watersheds (Sanchez et al. 2007). It has also been assumed that DO is a critical parameter based on a combination of the physical, chemical, and biological characteristics of a waterbody (Williams et al. 2000;

Mulholland et al. 2005; Rudolph et al. 2002). Therefore, DO has been seen as the most important parameter with regard to determining WQI for the protection of aquatic life (Silva and Jardim 2006).

AHP approach was also considered suitable and effective for developing WQI method due to lack of experiments or data fields. However, we highlighted one important issue in the AHP, which is confirming the consistency of comparison matrix to verify the judgments from expert panel. In case the acceptable inconsistency rate is not fulfilled (more than 0.1), ANTAHP is offered as an alternative to repair inconsistent matrix. The set weight criteria of ANTAHP are derived from the inconsistent judgment of expert panel, which cannot be used to take a decision. Further explanations can be seen on the certain related paper (Girsang et al. 2014).

An example of the application of AWQI was also presented in the results. Therefore, the proposed AWQI framework (Fig. 2) could be applied in other locations in Indonesia or other areas by following the process steps in the schematic diagram. Remind that the input data of AHP method from the expert panel on fish types and water quality parameters also altered the development as well as the evaluation of the index. The related regulations from government were further considered as constraint or criteria in both developing and applying AWQI.

Conclusion

Water status in aquaculture lakes will continue to degrade and be uncontrolled unless we take proper policy measures for preventive and restorative strategies to achieve the balance condition and integrity of regional aquaculture lake ecosystems (Abeyasinghe et al. 1996; Naigaga et al. 2011). Some contaminants flowing in lakes could accumulate to a point where it threatens human health even in low quantities and causes no obvious adverse effects. Under such circumstances, it is necessary to develop a WQI for use in aquaculture, although this requires the measurement of many physical and chemical parameters. The selection of water quality parameters depends on the designated water-use purposes and local conditions. This study thus developed the AWQI to measure water quality in aquaculture lakes.

In this index, indicators based on four selected water quality parameters, i.e., DO, ammonia, pH, and fecal coliform, were suggested. The selected water quality parameters are representing the integration of physicochemical and microbiological properties of aquaculture lakes. The AWQI developed in this work can be used as an effective, low-cost water quality monitoring program for developing countries. AWQI emphasizes the simplicity and understandability as it must communicate to decision makers and the experts. It is especially a useful tool that can help water resource agencies to manage their water-bodies and raise public awareness of the related issues.

The relationship between the AWQI and specific aspects of aquaculture activity, such as the type of fish food and frequency of feeding, is an issue that deserves further attention (Hlophe and Moyo 2013). The social and environmental conditions surrounding a lake, as well as human activities, can affect water quality. The competition for space, resulting from uncontrolled growth of aquaculture activities, as well as other purposes, such as tourism, can harm the aquatic environment. However, if aquaculture is carried out in lakes operating under good management practices, then it can be both profitable and beneficial to local communities in many areas, as well as can provide benefits with regard to increased

tourism (Bosma and Verdegem 2011). The design of integrated aquaculture lake index is necessary since water users and water problems are diverse and related with many aspects such as water quality, waterscape, and fishery management.

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