Evaluation of the suitability of Citarum river water for different uses

Mohamad Ali Fulazzaky[1, 2, *]; Mochammad Basuki Hadimuljono[2]
[1]Department of Water Resources and Environmental Engineering, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia
86400 Parit Raja, Batu Pahat, Johor, Malaysia

[2]Ministry of Public Works
Jalan Pattimura No. 20, Kebayoran Baru, Jakarta 12110, Indonesia

Abstract

The Citarum river water is the most important water sources in Indonesia. The river that supports a population of 28 million people, delivers 20% of Indonesia's gross domestic product, and provides 80% of surface water to carry through the West Tarum Canal to the Jakarta's water supply authority, is one of the most polluted rivers in the world. Water quality degradation of this river increases from the year to year due to the increasing pollutant loads when released particularly from Bandung region of the upstream areas into river without treatment. This will be facing the chronic problems of water pollution for supporting the suitability of water for different uses. This study used the Water Quality Evaluation System to asses the suitability of water in term of the Water Quality Aptitude (WQA) for five different uses and its aquatic ecosystem. The assessment of ten selected stations was found that the WQA ranges from the suitable quality for agriculture and livestock watering uses to unsuitable for biological potential function, drinking water production, and leisure activities and sports upstream the Saguling reservoir, generally. The role of Citarum river water in providing the demands of multipurpose uses particularly for Jakarta's water supply will still be present in question for the years to come. The aptitude of water along the river is evaluated to envisage as decision support system for decision-making process and to contribute to the proper information for water users in allocating their water right wisely.

Key words: Citarum river, water quality aptitude, water quality evaluation system, water use

1. Introduction

The problems of water quality degradation in the Citarum river will increase from the year to year due to the increasing of the pollutant loads particularly from Bandung region located in the upper areas of the river basin when released without treatment. Deterioration of water quality causing by the human activities in upper river basin reduces the usability of the resources for stakeholders in the down-stream areas. Over the past 20 years, rapid urbanization and industrial growth have resulted in growing quantities of untreated domestic sewage, solid waste and industrial effluents being dumped in the river. Pollution levels now compromise public health, and the livelihoods of impoverished fishing families have been jeopardized by widespread fish kill (DGWR, 2007). To handle the problems in implementing of integrated water quality management are necessary to consider all the related aspects entire the river basin catchments area to ensure the quality of stream water managed will improve gradually. For example, a refined the waste load allocation process is proposed with a reexamination of water quality violation to improve the allocation decision under uncertainty (Chen and Ma, 2008).

[*]Corresponding author: Email: fulazzaky@hotmail.com**;** fulazzaky@yahoo.com;
Phone: +62818167775; +60177202207; Fax:+6074536070;

Participatory surface water management is emphasized in order to achieve a holistic and sustainable water management decision-making process (Hartmann et al., 2006).

The government of Indonesia has been acquainted with the integrated approach since the Government Regulation No. 82 on water quality management and pollution control (PP No. 82/2001) was enacted in the year 2001. The PP No. 82/2001 serves as the national guideline to refer in managing of water quality especially for the water managers and operators who work at the national, provincial, and river basin level institutions. Although this regulation guides the role sharing amongst the related institutions and provides the technical arrangements including the classification of the national water quality criteria, the operational guidelines in implementing of the regulation to the specific characteristics of a river basin are still not correctly envisaged. However, conducting an adaptive guideline in managing of water quality to the specific local condition is necessary (Fulazzaky, 2005). For example, salinity tolerance of macro-invertebrate communities varies in Eastern Australia; hence, water quality guidelines should be developed at a local or regional scale (Dunlop et al., 2008), and the nutrient pollution effects of moderate eutrophication on Runde river in Zimbabwe need to be addressed by appropriate agricultural and environmental policies that relate to water pollution and land use (Tafangenyasha and Dube, 2008).

Water quality evaluation system (WQES) has been developed to aim two objectives that are (1) to classify the water quality in accordance with the actual condition of water in the stream and (2) to classify the water suitability for different uses and its ecosystem in accordance with the available water quality in the river (Oudin et al., 1999). Thus, the WQES serves to assess the status of water quality in the stream and to identify what the level of water is suitable to provide for the different uses and its ecosystem. This tool is considerable a comprehensive approach in evaluating of water quality. The earlier study showed that a modeling approach can be used to estimate the impacts of water quality management programs in river basins (Holvoet et al., 2007). The models are possible to analyze the best recommendations needed for different levels of treatment derived in order to improve the water quality (Muhammetoglu et al., 2005). The results of water quality analysis using the WQES are offered to consider in formulating of the water quality standards and the priority of measures to each region in the country or anywhere, based on the specific local conditions. A systematical analysis of water quality data scientifically introduces to translate the data to the actual explanations may be envisaged as decision support system (DSS). The accurate information obtained helps the decision makers in preparing the locally adaptive policies and guidelines to water quality assessment and management and warns the water users to wisely allocate their water right.

The objectives of this study are (1) to identify the suitability of Citarum river water in providing the different water uses and its aquatic ecosystem, (2) to warn the water users in allocating their water right wisely based on the actual quality of water, and (3) to recommend the priorities of measures that need to be envisaged by the local authorities, central government, and all related stakeholders for improving water quality.

2. Why the WQES is important to assess the Citarum river water

The Citarum river is the largest river in western Java, the region which contains Jakarta, the capital of Indonesia. The river originates in the mountain range near the southern coast of Java that includes many high volcanic peaks including Mount Wayang (elevation 2,200 m), and travels in a generally north-westerly direction for about 270 km until it empties into the Java sea east of Jakarta. Its drainage area as shown in Figure 1 is about 6,600 km^2. The upstream reaches of the river run in mountainous to gently undulating hilly lands for about 200 km while the lower 70 km stretch drains a vast plat alluvial plain.

Figure 1 Location of Citarum river basin

The total area of the river basin to include certain bordering rivers and its tributaries is about 11,500 km^2 situated at latitude of 6°43′ S to 7°04′ S and longitude of 107°15′ E to 107°55′ E. The climate of the basin area is characterized by two distinct seasons: rainy season and dry season. The rainy season occurs during the months of November to April, while the dry season occurs during the remaining months. January is the wettest month, while August is the driest month. Naturally, runoff follows the same seasonal pattern. The average annual rainfall varies from 1,500 mm in the coastal areas to 4,000 mm in the mountainous areas in the upper part of the basin. This total runoff from the catchments is generally considered to be adequate to supply demands for all uses well into the future. To regulate surface water the Citarum river system as shown in Figure 1 has three cascade reservoirs, i.e., Saguling in the uppermost, Cirata in the middle, and Jatiluhur in the lower location. However, the spatial distribution of surface water resources is not uniform, and shortages do occur from time to time in certain areas.

The population in the river basin area in 2003 was 17.8 million, with 4.1 million households – 30% derived livelihood from agriculture, 25% from industry and 45% from services. The population is projected to rise to 21.3 million by 2010. Industrial locations are generally interwoven with settlement and there is no clear zoning or separation of these land uses in the region. The area is a key rice producer for the country. There are a total of 390,000 ha of irrigated paddy fields, with 240,000 ha served by the Jatiluhur reservoir and canal system in the lower basin. Average annual demand from the Jatiluhur dam has increased from 140 m^{3}s^{-1} in 1996 to 156 m^{3}s^{-1} in 2004. The river that supports a population of 28 million people, delivers 20% of Indonesia's gross domestic product, and provides 80% of surface water to carry through the West Tarum Canal to the Jakarta's water supply authority is one of the most polluted rivers in the world (DGWR, 2007). Urbanization in the last three decades was followed by rise in untreated household sewage, solid waste and industrial effluents. The more waste enters the river the more chances for spreading diseases, and already there are many fishing families that are starving because of tremendous decrease in fish population due to heavy pollution.

2. Methodology

2.1. General of quality evaluation system

The assessment of river quality as shown in Figure 2 is commonly based on three choices, which are: (1) water choice, referred to as the WQES, to assess the physicochemical and biological quality of water in terms of the water quality index (WQI) and the suitability of water for supporting natural functions of the aquatic environment and water uses in terms of the water quality aptitude (WQA); (2) physical structures choice, referred to as the physical quality evaluation system, to assess the level of manmade change on the main channel, channel margins, and river banks; and (3) biological choice, referred to as the biological quality evaluation system, to assess the state of the biosciences of the aquatic environment (Oudin et al., 1999). The qualities of water and physical structures of a river influence the quality of biological aquatic substances component. This economically influences the exertions of water resources management in order to ensure the sustainable environmental development technicality.

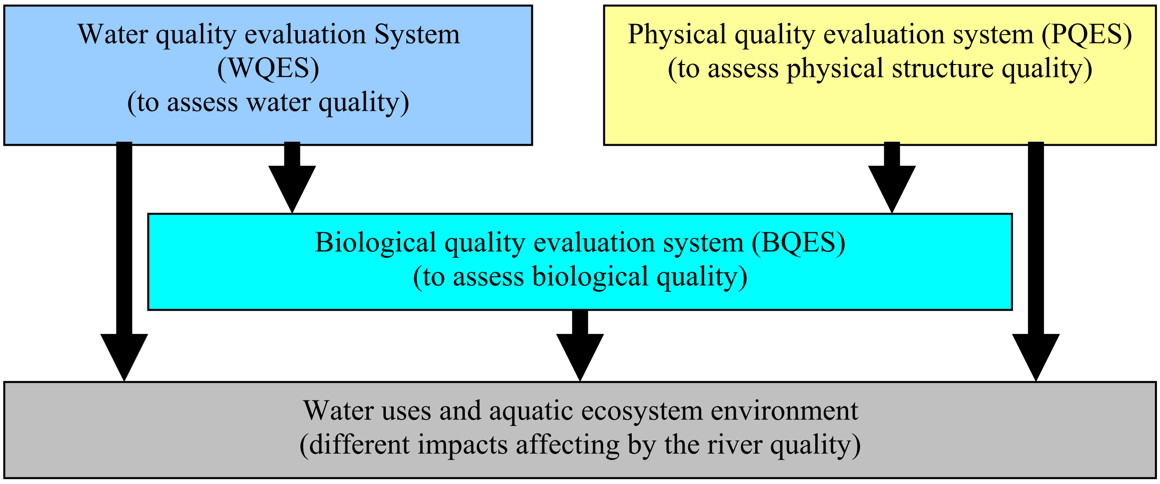

Figure 2 Global quality assessment of a river

The aims of the system are to assess river quality according to the qualities of each component, to identify the alterations in water quality or physical environment which are the cause of biological imbalances, and to assess the effects of an alteration of the river quality for human uses or on the natural functions of rivers. The tools for the assessment of the quality of rivers have been defined in a modular way and are adaptable to scientific and technical development as well as regional peculiarities. For example, water quality is assessed by reference to average alterations of parameter groups; new parameters can be included later in the description of quality by modifying the framework and functions of the evaluation tool. The evaluation tools for river quality consider three quality evaluations system that are: (1) common to all water partners consisting of the technicians, decision makers, and water users, (2) consistent with the international, regional, and local water regulations, and (3) help appreciate the environmental and asset problems. They make a link among partners. In this way, they are a tool for decision-making in the monitoring and the planning of the protection of rivers.

Application of WQES is a part of river quality assessment that aims to convert the data of water quality to information is more suitable. This envisages possess the operational procedure standard generating the data to information based on all the parameters monitored. The information produced from the WQES as shown in Figure 3 provides two categories that are the water quality status and the water suitability for different uses and its aquatic ecosystem (Fulazzaky, 2009; Fulazzaky at al. 2010). Besides, to identify the critical parameter(s) affecting the quality of water and to verify the sources of pollution discharged to the stream water are reasonable (Fulazzaky, 2005). The WQES is based on the notion of indicators of modification from natural conditions. Parameters of similar nature and impact on environment are grouped into 15 alterations of indicators of water quality (see Table 1).

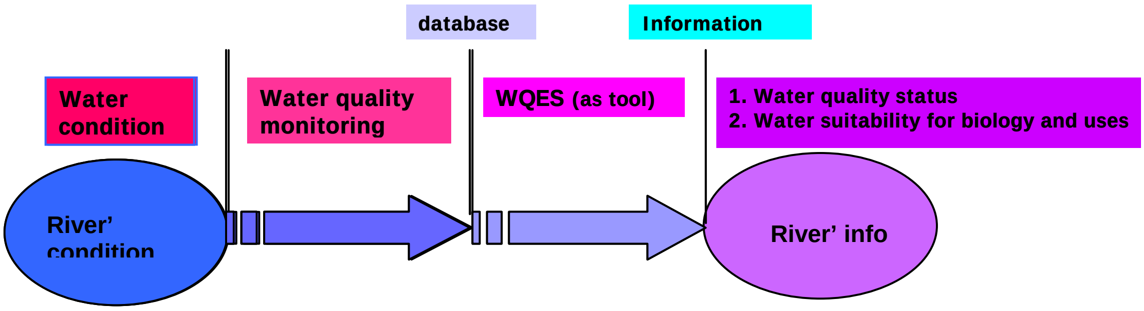

Figure 3 Link of river water quality condition to river water quality information
Sources: Fulazzaky 2009; Fulazzaky et al. 2010

Since the data of water quality may be interpreted individually to explore the impacts of the elements content in water to the environment and human health in accordance with the experiences and knowledge of personal experts, the interpretation of water quality data becomes doubtful and yields uncertain information (Fulazzaky, 2005). An interactive fuzzy multi-objective linear programming model has been introduced to simulate the allocation of waste load efficiencies with satisfactory results which indicate usefulness of the model in managing more complex river basins along with better flexible policies of water management (Singh et al. 2007).

Table 1 Water quality parameters in accordance with their alteration

No	Alteration	Parameters
1	Oxidized organic matter	O_2, $\%O_2$, COD, $KMnO_4$, BOD, DOC, NKJ, NH_4^+
2	Nitrogen matter	NH_4^+, NKJ, NO_2^-
3	Nitrates	NO_3^-
4	Phosphorus matter	PO_4^{3+}, P-total
5	Suspended particles	SS, Turbidity, Transparency
6	Colour	Colour
7	Temperature	Temperature
8	Mineralization	Conductivity, Salinity, Hardness, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, Na^+, TAC, Hardness
9	Acidification	pH, Dissolved Al
10	Microorganisms	Total Coliforms, Feacal Coliforms, Feacal Streptococci
11	Phytoplankton	ΔO_2, ΔpH, $\%O_2$, and pH, Chlorophyl a + pheopigments, Algae
12	Mineral micro-pollutants in raw water	As, Hg, Cd, Cr-total, Pb, Zn, Cu, Ni, Se, Ba, CN
13	Metals in Bryophytes	As, Hg, Cd, Cr-total, Pb, Zn, Cu, Ni
14	Pesticides in raw water	List of pesticides (see Oudin et al., 1999)
15	Organic micropollutants nonpesticides in raw water	List of organic micro-pollutants non-pesticides (see Oudin et al., 1999)

Sources: Oudin et al., 1999

Certain institutions have the different objectives of water quality standardized such as WHO's water quality standards specifically aim to standardize drinking and recreational water qualities, it is not compatible to only use the standard formalized by an institution to assess all the criteria of river water quality for the different uses of aquatic biota, drinking water production, recreation and aquatic sports, irrigation, livestock watering, and aquaculture comprehensively. This study used the thresholds criteria of French Water Agencies Study No. 64 original from the different sources of water quality standards i.e., Directive European, France, EPA USA, WHO and Canada, and completed by the rational advices from the water quality experts (Oudin et al., 1999). The WQES promotes a tool to synchronize the evaluation of all water quality parameters data monitored to convert to the WQI or WQA. Hence, this study only focused on the analysis of WQA for understanding the suitability of Citarum river water for the different uses and its aquatic ecosystem.

The use of WQES for examining the valid data to assess the suitability of water for different uses and aquatic biota is systematized to the aggregation method. Since the aggregation method to study the data of water quality monitored from a river is not necessary to conduct with a statistical analysis, the probability of exceptional situation takes account into evaluation in excluding the inconvenient results of lower than 10% from the list of useable data when the anomalous consequences of samples monitoring were verified. To assess the classes of WQA of stream water in a river using the WQES is to carry out after screening of the data via the Rule of 90% that is

$$F = (i - 0.5)/N \text{ or } i = 0.9\,N + 0.5 \qquad (1)$$

where, i is row of the results, N is total number of results; and F = 0.9 is percentage or 90% of acceptable data to evaluate.

An illustration is given to define the WQA for drinking water production. In keeping the Rule of 90% or F = 0.9, the total number of results (N) as such for COD at a station is 12 to collect from 12 times of monitoring. This gives i = 11.3, rounded to 11, and it should be to keep 11 of 12 COD results. To confirm the WQA class of as such red for oxidized organic matter alteration is due to the worst qualities of eight parameters, i.e., O_2, $\%O_2$, $KMnO_4$, COD, BOD, DOC, NKJ, NH_4^+ of this alteration are for example BOD and COD values which situate within the thresholds of red. Because the worst alterations of as such oxidized organic matters, suspended particles and microorganisms that were monitored at the same station are situating within the thresholds of red, referred to as WQA class is red. This informs that the aptitude of stream water for the location monitored is unusable for drinking water production.

To assess the alteration of suspended particles, the withheld rule is the 50% percentage, to avoid qualifying water after rainfall events which no exceptional characteristics and with a frequency superior to 10%. The formula is then

$$i = 0.5\,N + 0.5 \qquad (2)$$

The rules need to be implemented due to the results monitoring the same parameter(s) of water quality are numerous. For instance, the parameters used to analyze as the valuable data in the preparation of water quality management plan are indispensable to monitor regularly for certain locations along the river.

2.2. WQA assignment for different purposes

The assignment of WQA is fixed to assess the suitability of water for different targets of water uses and the impact of pollution on degradation of biodiversity. The biological potential function shows the suitability of water for aquatic life, when hydrological and morphological conditions of the habitat are good. The pollutants in the stream water such as metals and organic matters affect the biodiversity and sediment quality. For instance, despite high metal concentrations associated with roots, the major part of the metals in the marsh soil is still associated with the sediment as the overall biomass of roots is small compared to the sediment (Teuchies et al., 2008). Five suitability classes of WQA have been defined. They indicate a gradual impoverishment of the biological structure, including the disappearance of the taxa most sensitive to pollution.

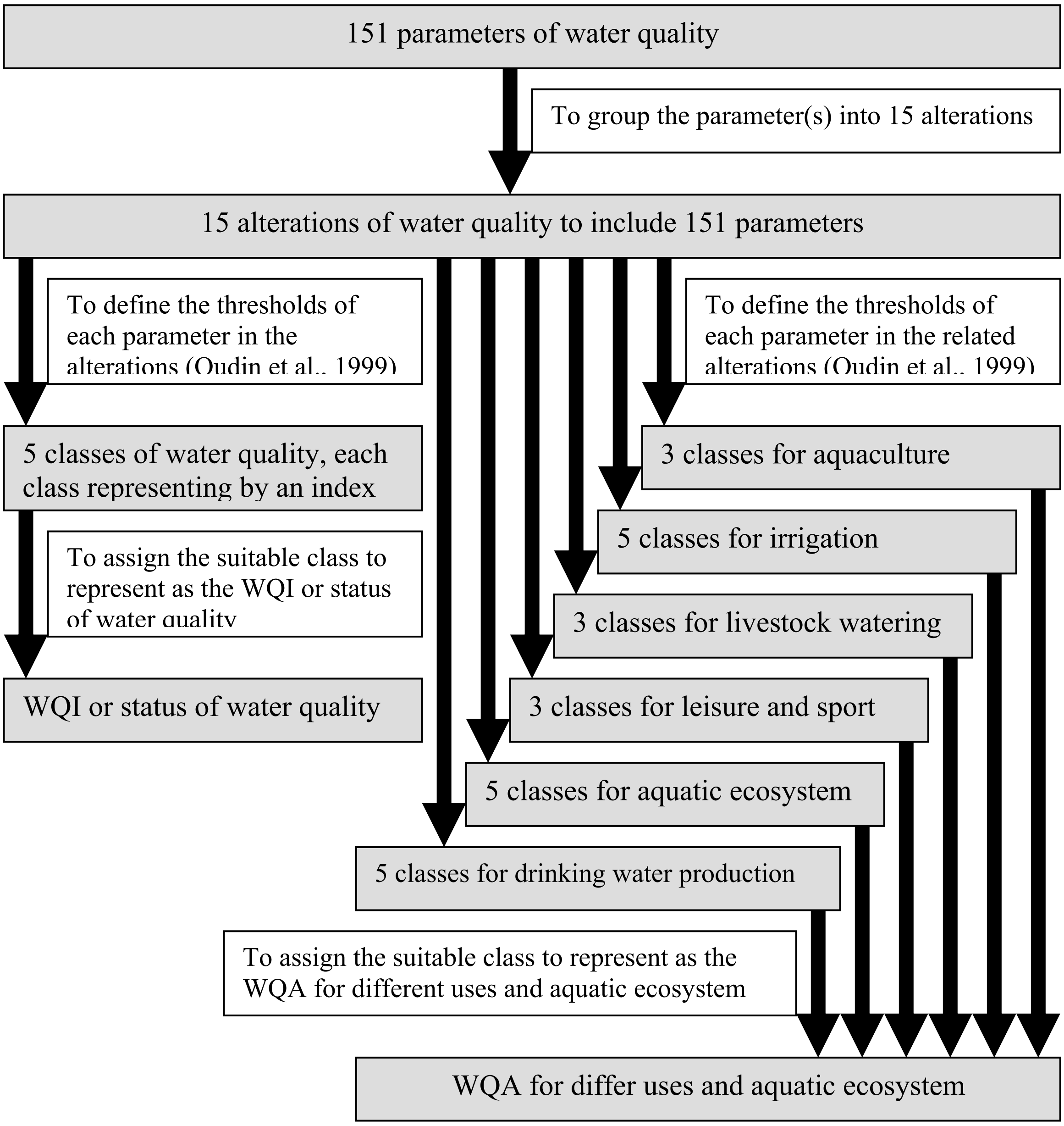

Figure 4 Flow chart of WQI and WQA classes assignment

Defining the suitability classes for the drinking water production depend on (1) the related regulations which are held as priorities for defining the blue/green class thresholds associated with suitability for consumption and orange/red class thresholds associated with unsuitability for the production of drinking water and (2) the opinion of the producers and of the suppliers in defining intermediary thresholds for simple and complex treatments of raw water. The definition of suitability classes is grouped into five classes. The use of leisure and aquatic sports is mainly applied in bathing areas and the legislation thresholds which principally relate to the turbidity of the water and the occurrence of microorganisms. Three suitability classes for recreation and aquatic sports have been defined.

The main factors to classify the suitability of water for irrigation are: ground texture, irrigated crop, frequency, and duration of irrigation. Crops have been divided into four sensitivity groups, ranging from very sensitive plants to very hardy plants. The crops taken into account in these groups are liable to differ from one parameter to another, meaning that the composition of each group is also variable. For instance, the arsenic content in soil and plants is influenced by the degree of arsenic amount in irrigated water (Dahal et al., 2008). It is equally necessary to take into account the type of soils. These have been divided into two groups which overlap, i.e., (1) all soils including the most sensitive and (2) neutral or alkaline soils, which are the most resistant. Combinations of soil/plant groups have been limited to sensitive-very sensitive plants/all soils and to resistant-very resistant plants/alkaline or neutral soils. Five suitability classes for irrigation uses have been defined. Water quality indices provide a simple and understandable tool for managers on the quality and possible uses for irrigation water (Almeida et al., 2008).

Livestock watering use is the suitability of water to allow the watering of breeding animals. These can be classified according to three age classes and sensitivity i.e., (1) young animals as chicken, pigs, calves, which are growing fast and are very sensitive to all pollutants, (2) animals of mature age which have a slow growth and are less vulnerable, and (3) animals for reproduction, they have strict needs during the gestation and milking period. In the case of livestock watering, water has to be useable immediately by the breeder. If the water is not useable, the breeder will then turn to the water supply. Three suitability classes for livestock watering use are adopted (Oudin et al., 1999).

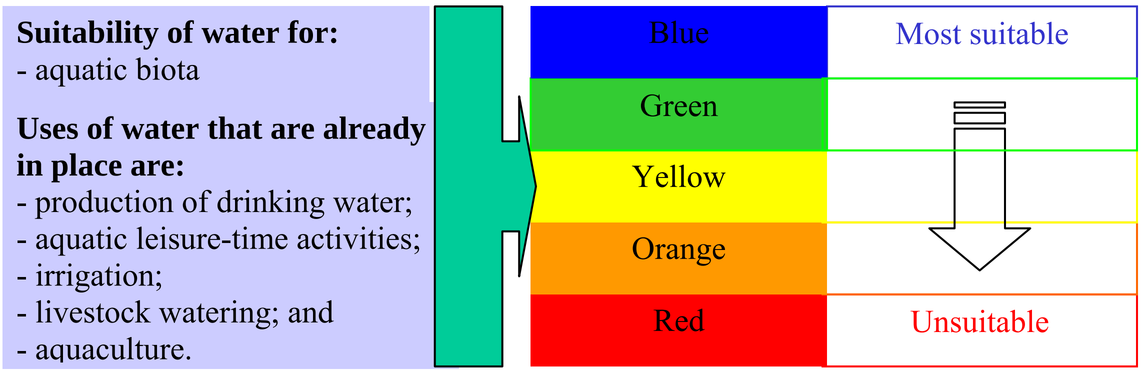

Figure 5 Classification of water suitability for the different uses and aquatic biota

Source: Oudin, et al., 1999 modified by Fulazzaky, 2008

Aquaculture use mainly shows the water suitability to be used in fish breeding. Water is the main factor of production in intensive fish breeding, particularly in salmon breeding. Water carries oxygen, eliminates wastes, and conductions production performances by its physicochemical variability. Three suitability classes for aquaculture have been defined.

2.3. WQES to assess the suitability of water for different uses

Since the aggregation method is only performed to assess the suitability of river water for the different uses and its aquatic ecosystem, the following steps are carried out using the WQES that are: (1) grouping 151 parameters of water quality into 15 alterations that classify in accordance with their similar nature and its impact on environment (see Table 1); (2) defining the thresholds of each parameter into five classes with respective colors of blue, green, yellow, orange, and red to express the most suitable aptitude of unpolluted water, good suitable aptitude, moderate suitable aptitude, bad suitable aptitude, and unusable aptitude of very polluted water, respectively, except thresholds defining by three classes with respective colors of blue, yellow, and red to asses the water uses suitability for leisure and sports, livestock watering, and aquaculture; (3) formulating the classes that are five classes to assess the WQAs of aquatic ecosystem, drinking water production and irrigation uses and three classes to assess the WQAs of leisure and aquatic sports, livestock watering, and aquaculture uses, as shown in Figure 4 and the aptitude of water for the different uses and its ecosystem in accordance with the level of suitability or WQA that ranges from the most suitable to unsuitable water, as shown in Figure 5; (4) assessing the value of each parameter and put it into the respective classes of WQA for water suitability to the different uses and its ecosystem; (5) verifying the worst quality of parameter(s) and choose it to represent the aptitude of related alteration; and (6) identifying the worst quality of alteration(s) and choose it to represent the WQA for water suitability for the different uses and its ecosystem (aquatic biota).

3. Results and Discussions

3.1. Application of WQES for the Citarum' river

The Citarum river segments distinguish into three different parts of water uses destination. The government of West Java province in the local regulation No. 39 Year 2000 (Perda Jabar No. 39/2000) enacted the water quality category in the upper and lower parts of the river as the standards Class C and D for the segments of main river in the upstream of Curug Jompong station and immediate the downstream of Tanjungpura station. The middle parts from immediate the downstream of Curug Jompong to the upstream of Tanjungpura station as shown in Figure 6 is destined as the standards Class B, C and D. Whereas, the stream water in all the tributaries entire the river basin is the standards Class B, C and D. The Class B, C and D means the class of water which is suitable to provide the uses of drinking water production, aquaculture, livestock, agriculture, municipal and industrial affairs, and hydropower energy. The Class B and C means the class of water which is suitable to provide the uses of aquaculture, livestock, agriculture, municipal and industrial affairs, and hydropower energy. The stations of water quality monitoring were chosen at 10 locations that are: 01 Cijeruk, 02 Margahayu, 03 Nanjung, 04 Curug Jompong, 05 Saguling dam, 06 Cirata dam, 07 Jatiluhur dam, 08 Bendung Curug, 09 Tanjungpura and 10 Rengasdengklok along the main river (see Figure 6).

The rules in the Equations (1) and (2) need to implement due to the results of water quality monitoring along the Citarum river are numerous. Since 1990, the Jasa Tirta 2 Public Corporation (PJT2) as the institution in charge to monitor water quality of this river has been traditionally monitored at 10 locations, as shown in Figure 6. This study specifically uses the data that were monitored by the Centre for Water Resources Research and Development of the Indonesian Ministry of Public Works in 2005 to concentrate in the upstream areas of river segment. The data monitoring as shown in Table 2 were tested of 33 parameters. To assess the classes of quality and water suitability in the river were used the data monitored from 10 stations that are: 01a Wangisagara, 01b Majalaya, and 01c Sapan as the additional stations in the upstream of Cijeruk, 01 Cijeruk, 03a Dayeuhkolot and 03b Brujul as the additional stations in the upstream of Nanjung, 03 Nanjung, 08 Bendung Curug, 09a Bendung Walahar as the additional stations in the upstream of Tanjungpura, and 09 Tanjungpura along the main river. This is due to the pollutant loads are more important to discharge the river coming form the Bandung region. The need to insert three additional stations in the upstream of Cijeruk and two stations in the upstream of Nanjung is to investigate the impacts of untreated household sewage, solid waste and industrial effluents on the quality of stream water. One more additional location was also monitored in the upstream of Tanjungpura to understand the impact of industrial pollution loads discharging from the industries located in the downstream areas. Because of the lack of data monitoring, two alterations i.e., pesticides in raw water and organic micropollutants nonpesticides in raw water as shown in Table 2 were no included to evaluate in this study. To assess WQA, this study examines 3 960 testing results that were specially monitored from 10 selected stations above along the main river during the period of 1 year with the frequency of monitoring was one per month.

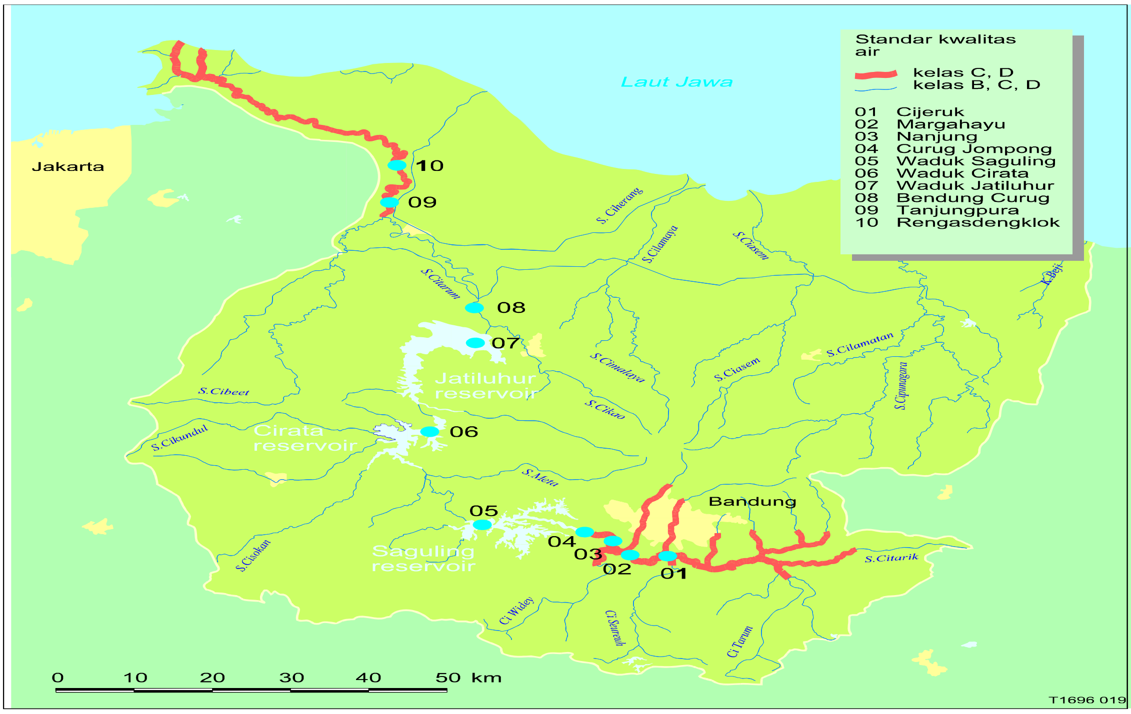

Figure 6 Water quality monitoring stations along the Citarum river

3.2. WQA of the Citarum river

The excessive pollutants in the stream water will face the problems of biodiversity degradation. The earlier study supports the need for incorporating functional measures in evaluations of stream ecological integrity (Castela et al., 2008). The effects on zooplankton were caused by changes in habitat structure due to the strong decline of macrophytes. The slow degradation of metazachlor combined with the absence of recovery in both chlorophytes and macrophytes is likely to cause long-lasting effects on aquatic ecosystems (Mohr et al., 2008). Considering the results of WQA analysis, this study remarks that the stream water in the upper part of Saguling dam as shown in Table 2 is unusable to conduct the sustainability of aquatic ecosystem, judging the WQA class is red. This translates water capability of considerably reducing the number of sensitive taxa or eliminating them with a very low diversity. In the downstream areas of Jatiluhur dam, water quality causing the disappearance of certain sensitive taxa with adequate diversity is evident, see location 09a Bendung Walahar, judging the WQA class is green, or water capabilities of considerably reducing the number of sensitive taxa with adequate diversity are manifested, see locations 08 Bendung Curug and 09 Tanjungpura, judging the WQA classes are yellow. To improve the quality of the stream water particularly in the upper part of the basin is will suitable for aquatic biota this study recommends to the related local authorities including all the stakeholders to envisage as high priority the problems of river pollution. This suggests the need to have a specific legal instrument of integrated water quality management plan in order to guide all the participatory of multiparty entire the river basin to involve in improvement of water quality in accordance with the role and responsibility of each participant.

Table 2 Application of WQES to assess the WQA for the Citarum river water

Type of water uses	**Results of WQA analysis**									
	01a	01b	01c	01	03a	03b	03	08	09a	09
Biological potential function	r	r	r	r	y	r	r	y	g	y
Drinking water production use	y	r	r	r	o	r	r	y	y	o
Leisure and aquatic sports use	r	r	r	r	r	r	r	y	y	r
Irrigation use	b	g	g	g	g	g	g	b	b	g
Livestock watering use	b	b	y	y	y	y	y	b	b	b
Aquaculture use	r	r	r	r	r	r	r	y	y	r
Number of parameters analysis	33	33	33	33	33	33	33	33	33	33

Remarks: 01a Wangisagara, 01b Majalaya, 01c Sapan, 01 Cijeruk, 03a Dayeuhkolot, 03b Brujul, 03 Nanjung, 08 Bendung Curug, 09a Bendung Walahar, 09 Tanjungpura, b = blue, g = green, y = yellow, o = orange, and r = red.

A deeper understanding of the practical and theoretical underpinnings of risk management can be made between organizational capabilities in the essential water business process (MacGillivray and Pollard, 2008). This preventive feature lies at the core of risk management for the provision of safe drinking water (Hrudey et al., 2006). Referring to this study, water in the upper Citarum river as shown in Table 2 is not recommended to produce drinking water generally excluding in the stream water from the upper part of Bandung city see upper part of the station 01a Wangisagara and at the station 03a Dayeuhkolot, judging the WQA classes are red. Because of no more industries located in the upstream areas of Bandung city, water quality upper the station 01a Wangisagara was justified as moderate (yellow). The improvement of water quality at the station 03a Dayeuhkolot was verified as orange due to a good water quality from Ciwidey river penetrates the water quality of Citarum' river. Utilization of Citarum river water from the upstream areas of Bandung city is acceptable to produce drinking water. This study recommends to perform the conventional technologies in producing of drinking water for raw water in the stream from the upper Bandung and the advanced technologies to treat water from the station 03a Dayeuhkolot. Because the intake of raw water from the Jatiluhur dam to supply the Jakarta city in the downstream area is still operated, the study recommends to the Jakarta water supply authority to use conventional technology in treating the water since the piped water canal is used to transport the water from the Jatiluhur dam to Jakarta. This recommendation based on the moderate quality of river water, judging the WQA class as show in Table 2 is yellow. Unfortunately, to date the transport of water is still operated in the open canal. This system will face the risk of pollution discharged from the industrial and domestic wastewaters along the canal when water flows. The contamination of water eventually declines the WQA of such as from the yellow classes at the stations of 08 Bendung Curug and 09a Bendung Walahar to orange class at the station of 09 Tanjungpura so the application of advanced technologies should be considered by the Jakarta water supply authority in treating the river water purposed for public consumers.

Water in the main river as shown in Table 2 is not acceptable to be used for leisure and aquatic sports excluding the stations 08 Bendung Curug and 09a Bendung Walahar, judging the WQA class is red. A moderate water quality at these stations caused by self purification occurs in three cascade reservoirs, i.e., Saguling, Cirata, and Jatiluhur. Due to the pollutant loads from industries discharging the river in the downstream area are evident, degradation of water quality as shown in Table 2 increases gradually in the stream towards the sea. Considering the strategic role of Citarum river regulated effectively by three cascade reservoirs functioning as the potential recreational parks, hydropower generation, sources of water for domestic, municipality and industry, as well as the source of irrigated water for paddy fields and fishponds delivers 20% of Indonesia's gross domestic product, this study recommends to the central government of Indonesia to envisage as first priority the problems of this river pollution. This suggests the need to install correctly the wastewater treatment plants for each industry and for each city of the entire the Citarum river basin catchment area particularly for the upstream areas of the basin to reduce the pollutants of organic matter, microorganisms, and suspended particles. Besides to improve quality of water related to suspended particles, there is a need to consider the occupation of lands to implement the best practice of soil conservation effectively.

To analyze the suitability of water for irrigation purpose is summarized in Table 2. This informs that water quality in the river is suitable to allocate for irrigated lands especially the paddy fields as a major part of water uses in the region, judging the WQA classes for all the station selected are classified as blue or green. It is remarkable that the Jatiluhur dam suitability serves water for 240,000 ha of paddy fields in the downstream areas. Unfortunately, the overflow of irrigated water is usually to drain back into the river. The runoff from paddy field as verified in the Ile de Camargue, France, carries important loads of dissolved pesticides to the wetlands including river (Comoretto et al., 2008). Drinking water pollution in the Evros region Northern Greece can be attributed to excessive fertilizer use from agricultural sources (Nikolaidis et al., 2008).

For more accurate assessment of the effects of water quality, for a given livestock production system the format should be based on ingestion levels, as opposed to a mg/l basis, and should take into account site-specific synergistic and antagonistic interactions within and external to the water to a greater extent (Meyer et al. 1997). The aggregation method of WQES using in this study led to the formulation of a water quality guideline index system based on WQA basis. Referring to the classification in the literature (Oudin et al., 1999), this study concludes that utilization of Citarum water to provide the livestock watering of all animals including the most sensitive such as young animals, animals in gestation or milking is still suitable for the stream waters from the upper Bandung city (see the stations 01a Wangisagara and 01b Majalaya) and the downstream of Jatiluhur dam (see the stations 08 Bendung Curug, 09a Bendung Walahar, 09 Tanjungpura), judging the WQA classes are blue (see Table 2). The stream water along the river segments between Bandung city and Saguling dam is suitable to provide the livestock watering of mature animals that are less vulnerable such bovine and ovine and needs to control strictly the quality of water used, judging the WQA classes as shown in Table 2 are yellow (see the stations 01c Sapan, 01 Cijeruk, 03a Dayeuhkolot, 03b Brujul, 03 Nanjung).

Fish and crayfish perform all bodily functions in water which include eating, breathing, excreting wastes, reproducing and taking in or removing salts. Water quality can affect these functions and therefore will determine the health of the fish and consequently the success or failure of a fish farming operation. For example, carbohydrate addition in water affects to (1) increase the nitrogen retention in harvested shrimp biomass, (2) reduce the demand for feed protein, (3) reduce the concentration of NKJ and NO_2^-, and (4) reduce nitrogen discharge making extensive shrimp farming more ecologically sustainable and economically viable (Hari et al. 2006). Despite the stream water in the river is unsuitable for direct use in aquaculture generally, judging the WQA classes are red (see stations 01a Wangisagara, 01b Majalaya, 01c Sapan, 01 Cijeruk, 03a Dayeuhkolot, 03b Brujul, 03 Nanjung, and 09 Tanjungpura), Table 2 shows that the river water immediate the downstream of Jatiluhur dam is suitable for all adult fishes which are not very sensitive to pollution, judging the WQA classes are yellow.

4. Conclusion

This study used the WQES to assess the suitability of water for different uses and its ecosystem for the Citarum river water. The suitability of the river water was examined through WQA assessment to forbid strongly the uses of water in the upstream the Saguling dam to provide (1) suitability of biodiversity growth and productivity, (2) drinking water production except the stream water upper Bandung city, (3) leisure and sport activities, and (4) aquaculture uses. Although the stream water of the river segment between the Bandung city and Saguling dam needs to control strictly, the quality of water is still suitable to use for irrigated lands and livestock watering. The improvement of water quality was verified immediate the downstream areas of Jatiluhur dam due to the self purification occurs in three cascade reservoirs, i.e., Saguling, Cirata, and Jatiluhur, consecutively. This gives the advantage to supply raw water from the Jatiluhur dam to Jakarta city for drinking water production with adequate quality since the closed canal is used for transporting the water.

The stream water upstream the Suguling dam (see upper the station 03 Nanjung) is totally prohibited for supporting the biological potential function, leisure and aquatic sports, and aquaculture purposes judging the WQAs of these water uses are unsuitable, indicating as red color (see Table 2). This study justifies that the factual water quality of the river no matches the standards regulated in Perda Jabar No. 39/2000. This gives the rational argument to urge the local authorities, central government, and all related stakeholders to concern for improving the river water quality. This study shows that the use of WQES practically remained comprehensive in evaluating water quality systematically. There is the analysis of water quality data to convert into the usable information that serves as DSS in managing of water quality comprehensively.

To improve the quality of the Citarum river water will be facing the following policy implications that (1) the need to prepare and to implement consistently the integrated water quality management plan becomes a commitment together for all the stakeholders; (2) the revision of Perda Jabar No. 39/2000 is required in defining the water quality criteria for the different uses of each river segment; (3) the targets of water quality improvement should be defined clearly in the real actions, there is a need to be implemented with committed timetable by the related stakeholders; (4) the polluters and users pay principles in managing water resources are necessary to be implemented in order to internalize the external impacts of environmental deterioration; (5) the perspective of managing water resources to promote the mechanisms of river basin upstream-downstream interaction is necessary to be regulated by the law to handle the problems of erosion; (6) the synchronization of the programs between the river basin management authority and the political administrative authority is needed to set up together; (7) the related government agencies, private institutions, and other stakeholders entire the basin must be to implement (i) zero ΔQ policy to maintain run offs, (ii) zero ΔS policy to preserve erosion rate, and (iii) zero ΔP policy to safeguard the pollution loads resulting from human activities.

References

Almeida, C., Quintar, S., González. P., & Mallea, M. (2008). Assessment of irrigation water quality: A proposal of a quality profile. Environmental Monitoring and Assessment, 142(1-3), 149-152

Castela, J., Ferreira, V., & Graça, M.A.S. (2008). Evaluation of stream ecological integrity using litter decomposition and benthic invertebrates. Environmental Pollution, 153(2), 440-449

Chen, C.F., & Ma, H.W. (2008). The uncertainty effects of design flow on water quality management. Environmental Monitoring and Assessment, 144(1-3), 81-91

Comoretto, L., Arfib, B., Talva, R., et al (2008). Runoff of pesticides from rice fields in the Ile de Camargue (Rhône river delta, France): Field study and modeling. Environmental Pollution, 151(3), 486-493

Dahal, BM., Fuerhacker, M., Mentler, A., et. al., (2008). Arsenic contamination of soils and agricultural plants through irrigation water in Nepal. Environmental Pollution, 155(1), 157-163

Directorate General of Water Resources (DGWR). (2007). Integrated Ciatrum water resources management project: Report on roadmap and program development. In: Technical assistance consultant's report.
Dunlop J.E., Horrigan N., McGregor, G., et al., (2008). Effect of spatial variation on salinity tolerance of macro-invertebrates in Eastern Australia and implications for ecosystem protection trigger values. Environmental Pollution, 151(3), 621-630
Fulazzaky, M.A. (2005). Assessment of river water quality degradation of the Citarum and Brantas rivers by using a new developed water quality index system. In: Proceeding of The 2nd Southeast Asia Water Forum:, Bali, Indonesia, 31 August to 3 September 2005
Fulazzaky MA (2008). Water quality evaluation system to assess the river water quality. In: Universiti Tun Hussein Onn Malaysia Colloquium.
Fulazzaky MA (2009). Water quality evaluation system to assess the Brantas river water. Water Resources Management, 23(14), 3019-3033
Fulazzaky, M.A; Teng, W.S; & Mohd Masirin, M.I. (2010). Assessment of water quality status for the Selangor river in Malaysia. Water, Air & Soil Pollution, 205(1): 63-77.
Hari, B., Madhusoodana Kurup, B., Varghese, J.T., et al., (2006). The effect of carbohydrate addition on water quality and the nitrogen budget in extensive shrimp culture systems. Aquaculture, 252(2-4), 248-263
Hartmann, J., Lev, J.K., & Okada, N. (2006). Managing surface water contamination in Nagoya, Japan: An integrated water basin management decision framework. Water Resources Management, 20(3), 411-430
Holvoet, K., Gevaert, V., van Griensven, A., et al., (2007). Modelling the effectiveness of agricultural measures to reduce the amount of pesticides entering surface waters. Water Resources Management, 21(12), 2027-2035
Hrudey, S.E., Hrudey, E.J., & Pollard, S.J.T., (2006). Risk management for assuring safe drinking water. Environment International 32 (2006) 948–957
MacGillivray, B.H., & Pollard, S.J.T., (2008). What can water utilities do to improve risk management within their business functions? An improved tool and application of process benchmarking. Environment International 34: 1120–1131
Meyer, J.A., Casey, N.H., & Coetzee, C.B. (1997). Water quality guidelines for livestock watering in Southern Africa. Water S.A. 23(1), 7-12
Mohr, S., Feibicke, M., Berghahn, R., et.al., (2008). Response of plankton communities in freshwater pond and stream mesocosms to the herbicide metazachlor. Environmental Pollution, 152(3), 530-542
Muhammetoglu, A., Muhammetoglu, H., Oktas, S., et. al., (2005). Impact assessment of different management scenarios on water quality of Porsuk river and dam system – Turkey. Water Resources Management, 19(2), 199-210
Nikolaidis, C., Mandalos, P., & Vantarakis, A. (2008). Impact of intensive agricultural practices on drinking water quality in the Evros region (Northern Greece) by GIS analysis. Environmental Monitoring and Assessment, 143(1-3), 43-50
Oudin, L.C., Meybeck, M., & Roussel, P. (1999). Système d'évaluation de la qualité de l'eau des cours d'eau. Rapport de presentation SEQ-Eau (version 1), Agence de l'eau Loire-Bretagne, France.
Singh, A.P., Ghosh, S.K., & Sharma, P. (2007). Water quality management of a stretch of river Yamuna: An interactive fuzzy multi-objective approach. Water Resources Management, 21(2), 515-532
Tafangenyasha, C., & Dube, L.T. (2008). An investigation of the impacts of agricultural runoff on the water quality and aquatic organisms in a Lowveld Sand river system in Southeast Zimbabwe. Water Resources Management, 22(3), 119-130
Teuchies, J., de Deckere, E., Bervoets, L., et. al., (2008) Influence of tidal regime on the distribution of trace metals in a contaminated tidal freshwater marsh soil colonized with common reed. Environmental Pollution, 155(1), 20-30