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A comparative review on Malaysia's water quality index model with international water quality index models for surface water quality classification

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Abstract. Water Quality Index (WQI) is a grading and classification system. It is used to quantify the overall water quality status of a water resource for a given location and time. This paper aims at comparing the advantages and the limitations across several different types of WQI models (CCMEWQI, NSFWQI, IWQI, WQI Malaysia), in order to provide suggestions to improve the accuracy and sensitivity of the WQI models. IWQI and CCMEWQI are fully unbiased due to no weightage, however, statistical technique is recommended to be included in parameter selection step to increase its accuracy. WQI Malaysia is less sensitive in detection of emerging contaminants, as it is confined to six target specific parameters. To acquire more comprehensive result, upgrades should be made to optimise parameter selection and weightage assignment of different WQI models. Combined value and weightage method for each subindex could be considered in the WQI index calculation.

1. Introduction

Availability of high-quality water is one of the most crucial components for a healthy and sustainable development [1]. Yet, land use changes and effluent discharges into surface water have been reported to have degraded the quality of water resources. Therefore, it is vital to maintain and ensure the water quality is within the acceptable level in order to protect water resources from pollution [2, 3, 4]. A proper water quality assessment is recognised as the main step toward better water quality management of rivers [5]. The result of the assessment will help with tracking the efficiency of water resource management and decision making for water quality guidelines, laws and policies [6, 7] The compositions of water resources are significantly influenced by spatial and temporal variation [8, 3, 9]. Therefore, the water quality data and spatial–temporal information of study area are the basic requirements of water quality assessment [8].

The water quality evaluation is dependent on a variety of parameters [10]. There is no individual water quality parameter to indicate and represent the whole water quality of a water resource sufficiently [11]. To determine the water quality status within a system, its best to consider by its physical, chemical and biological components [6, 10, 12]. Wu et al. (2021) stated that selected parameters could also indicate spatial variability. 12 common physiochemical parameters are often selected and measured to represent the water quality status within a system. Which includes pH, electrical conduct (EC), temperature, turbidity, total solids (TS), dissolved oxygen (DO), coliforms, biochemical oxygen demand (BOD), alkalinity, chloride (Cl^-), total phosphate (TP) and nitrate (NO_3^-) [13]. Therefore, higher operative and analysis costs are required on top of being time-consuming due to dealing with a large number of parameters ranging from physicochemical to bacteriological aspects. [7,14].

Traditional water quality evaluation method, on the other hand, compares the detected concentration of the parameters with standard limit or guidelines individually to evaluate and determine the water quality of the water resource [12,14]. This method provides a proper identification of contaminants but this method needs to deal with large number of parameter data [12, 15, 13]. The water quality is analysed, in terms of individual parameter that do not give an overall water quality in a watershed [12, 15]. Traditional method is difficult and complex to interpret and determine the result due to large number of water quality parameter data. Moreover, the method does not provide an overview of water quality [6, 13,16].

The complete picture of water quality needs to be interpreted using an appropriate and efficient method that is low-cost, time-saving and simplifies a large amount of data into understandable results. [16]. Water quality index (WQI) is recognised as a classifying and grading technique to determine the overall water quality status based on the aggregation and composite effect of measured water quality parameters [17, 18, 13, 19, 20]. Many researchers stated that WQI produce a single dimensionless numerical term which is known as a simple and valuable indicator to express and represent the water quality of water resource for a specific location and time [11, 21, 17, 18, 13 ,19, 3, 4, 9]. WQI has been widely used in many countries, especially in developing countries, not just Malaysia. Among these countries are Finland, Slovakia, India, Iran, Spain, the United States, Tunisia, China, and Morocco. [22, 17, 1, 11]. In this paper, the basic of WQI model is explored, as well as comparing the advantages and limitations of different types of WQI model.

2. Background study of WQI

The single numerical term of WQI is transformed from multi-selected water quality indicators data which include physical, chemical and biological parameters [21, 22, 13, 23, 3, 9]. WQI can classify the river's health status into good, medium or bad quality [4, 13, 24, 12, 6]. Over the years, there have been various kinds of researches conducted to introduce different WQI models and improving its uses for different purposes. [25]. The history and development of WQI is shown in Table 1.

Table 1. The history and the development of WQI.

Year	History of WQI	References
1848	WQI was introduced in Germany	[25,19,21]
1965	First formal presentation of a Water Quality Index (WQI) was initially proposed in Germany by Horton. Horton proposed that the water quality level can be represent in a numerical scale	[25,12, 26 ,19, 6, 15]
	National Sanitation Foundation Water quality index (NSF WQI) was introduced	[38]
1970	The uses of WQI initially proposed by Brown et al.	[12]
1974	Application of WQI Malaysia is recommended DOE Malaysia to determine the ranking of the river pollution level	[11]
2001	Canadian Council of Ministers of Environment Water Quality Index (CCME WQI) is introduced and applied	[27]
2019	IWQI is the new developed WQI model	[10]

WQI aimed to transform large number of water quality parameters into a clear and understandable value on quality [1, 13, 23]. This index provides a representative picture for the overall water quality. Moreover, since WQI is rich with information about water resource behaviours, the index will help users with understanding and classifying the different purposes of available water bodies, such as drinking, irrigation, domestic uses, aquatic life or other uses [5, 6, 15, 28, 18, 17]. WQI is also useful in tracking and monitoring the changes of water quality at a particular location and will help with making comparison of the water quality between spatial or temporal variation resources according to water classes [15, 11,29].

Furthermore, WQI can interpret and represent the water quality in numerical terms and reduce redundant information and summarize the data in a short time [11]. Hence, making it is easy for non-technical stakeholders to understand the water quality condition with the help of this index. [6, 15, 1, 21]. Overall, WQI have been widely used because of the advantages it brings. The index is convenient to policy maker and easy to understand for users and stakeholders as well.

In Malaysia, WQI has been proven as a practical method, hence, the use of WQI was recommended by the Department of Environment (DOE) for indication and ranking purposes (good, medium or poor). Along with obtaining the result within a short period of time [19, 24, 18]. At the same time, this method will reflect the pollution status of the water resource. This will enable users/policy makers/stakeholders to take remedial action at the right time in order to control and manage water pollution [18, 9, 11]. The follow-up action can be done by monitoring WQI of rivers over a period of time [11]. Hence, WQI is recognised as a valuable tool and is widely used amongst decision makers to manage water resources for any specific site which have stream water, lake water and groundwater [19, 17, 9]. The policy decision that is based on WQI will be more reliable compared to the traditional methods. Hence, able to provide a better management of rivers [19, 15].

3. The Basics in WQI

The reliability of the WQI is largely dependent on the basic steps of WQI [13]. The method comprose of four steps: (i) selection of parameters, (ii) determination of values of sub-index, (iii) assignment of appropriate parameter weights, (iv) aggregation of the weighted sub-index to compute the final WQI [24, 23, 5, 6, 12, 13]. These steps are focused in order to better interpret the water quality status and obtained high accuracy on water quality result.

3.1 Parameter selection

The spatial and temporal variation such as change of geography, geology and land use of the watershed affect the chemical, physical, and biological compositions of water resources [4, 8, 3, 9]. According to Tian et al. (2019) and Tomas et al. (2017), the criteria that must be focused may differ since temporal and spatial varies. Hence, the water quality parameters should be selected based on the condition of the water resource as different water quality parameter may detect varying effects on water quality. The parameter selection is the main factor to reduce and simply the complex and large number of selected parameters into a comprehensive data.

Most of the previous studies has focused and relied on statistical techniques in order to select and determine the most influential water quality parameters [12, 26, 15, 30]. The statistical technique is recognised as a more reliable parameter reduction technique as it is sensitive and unbiased [31]. The suitability of the selected parameter can be justified and detected by statistical technique [12, 26, 15]. This technique picks out the important and influential parameter, and then eliminate the closely related parameters to the selected parameter based on the correlation and relationship between the water quality parameters [22, 12, 9, 26]. As example, biochemical oxygen demand (BOD) is closely related to Total organic carbon (TOC). Therefore, one of the parameters will be eliminated instead and will be replaced by others [12].

The common statistical techniques used are regression, the Principal Component Analysis (PCA), Cluster Analysis (CA), Factor analysis (FA), Fuzzy Logic, and Multiple Linear Regression (MLR) [31, 12, 26, 15, 30]. According to Jahin et al. (2020), PCA and FA is recognised as the most objective data reduction tools for water quality data [15, 5, 30]. The applications of these techniques are useful with reducing the number of variables [9]. Generally, statistical technique was recognised as a more suitable and reliable parameter reduction techniques, but there has been some researchers suggest that the parameter selection should be considered as references [24,30].

According to the work of (please mention author), availability of data sets, accuracy, key representation of water quality condition, and the specific proposed use of watershed are the main references should be considered for parameter selection [24, 30]. For instance, according to literature reviews found between the year 2000 until 2019, the influential and important parameters included in a WQI research are biological oxygen demand (BOD), dissolve oxygen (DO) and pH [7, 19, 15]. In previous study, BOD and DO are closely related but both parameters are needed. The same goes with Total dissolve solid (TDS) and BOD [15]. Fulazzaky, et al. (2010) stated that the lowest quality of the parameter(s) should take priority over others parameters. Therefore, the final shortlisted parameter needs to be filter by the researcher and not only refer to the statistical result in order to make sure the important and representative water quality parameters are included in WQI calculation. Overall, researcher should employ a reliable parameter selection method to ensure significant parameters have been included and not simply focus on statistical analysis.

3.2 Determination of values of sub-index

The second step of WQI method is determination of sub-index. Different WQI models have various method of calculation of sub index. The sub-index values are established by standard guideline values of water quality. The selected standard guideline may be different from the WQI model and spatial variation [37]. Most of the previous researches often referred to World Health Organization (WHO) guidelines [18, 32]. Ustaogluu et al. (2020) and Njuguna et al., (2020) stated that the sub-index is calculated by multiplying the relative weight and water quality rating (Qi). For instance, Malaysia's WQI, the parameter concentrations are converted into sub-index by rating curve functions. This rating curve was developed according to the water quality parameter standard guideline [37].

3.3 Weighting of the parameter

The weight of the parameter may influence the accuracy and sensitivity of WQI due to the assigned weight might affect the relative important of the parameter to WQI. Few weighing methods are used to determine the weight of each parameter [20]. Some researchers claimed that all the weight value of water quality parameter should be assigned equally in calculation of WQI, but some researchers disagree with this idea [24]. In several researches, the weights of the parameters should be assigned based on their relative importance and alteration effect to the water quality [8, 30, 21]. However, there is no one-size-fit-all method. According to Tripathi & Singal [6], the weighting method can be characterised into two which are subjective methods and objective methods.

In weight values of parameter study, the weight value is determined based on opinions, knowledge and experience of the stakeholder, researcher or expert as the case is recognised as subjective techniques [6]. There are also researchers that will determine the weight of the variables based on the effect of the parameter [20] but the heavily judgement of the weight value might caused the index imbalance in sensitivity. The final result based on this judgement method is unacceptable [24, 13]. The false interpretation of WQI has happened when higher assigned weight on less impacted water quality parameter [13]. The subjective methods are considered as ambiguity and bias, but in some cases the expert may help to provide an appropriate weight based on the local environment conditions [6]. In previous studies, the weightings of the parameters were determine based on 50 sets of questionnaires from 50 water specialists to minimize the bias [29]. Therefore, the subjective methods is precise and unbiased by increasing the number of expert opinions and judgement of weight when determining appropriate weights.

The subjective technique ascertains appropriate weights by judgement while the objective techniques ascertain appropriate weights using statistical analysis [6]. In general, PCA and FA are the common and reliable tool in objective techniques [6, 5]. The weight value of the parameter can be determined effectively by PCA/ FA and was used in research that involves sustainable development index, environmental sustainability index and Langat River quality index [5]. In conclusion, the objective techniques are considered as the most reliable techniques than subjective techniques due to higher probability of bias and ambiguity, which was found during weighting procedure of subjective techniques [6].

There are various methods to determine the parameter and weight values in previous studies. Table 2 shows the method of previous studies of WQI at different region. The statistical and subjective methods are commonly selected in previous study because there is no universally accepted standard method in parameter selection and weight determination.

Table 2. The method of previous studies of WQI at different region.

Region	Selected water quality parameters	Parameter selection method	Weight value determination method	References
Kafr El-Sheikh Governorate, north Nile Delta of Egypt		Correlation analysis and PCA/FA	PCA/FA	[5]
Turnasuyu Stream that located in the Eastern Black Sea Basin of Turkey	14	According to their importance in water quality	Depending on the water quality effects and the importance for human health	[18]
Godavari River, India	5	Delphi method		[33]
Boundary zone between the African and Eurasian	6	Based on their indication to eutrophication of watercourses and to organic pollution	Based on the basis of importance of the parameter	[12]
Luanhe River Basin, lies in North China	12		Based on the perceived effect on primary health	[34]
River Ganga in India	9	PCA and correlation analysis	FA and PCA	[6]
Yellow river, northern China	9	PCA		[22]
Tigris River, eastern Turkey	11	According to their importance	Based on the views of experts in previous studies	[9]

3.4 Aggregation of the weighted sub-index to compute the final WQI

The final WQI value is computed by the weight value of the parameter and quality score [28, 5, 17, 18]. The weight values can be determined by objective and subjective values. The sub-index values are obtained by comparing the standard value and the actual value of parameters. The formula to calculate the WQI: [5, 17, 18, 32, 12]

$$WQI = \sum_{i=1}^{n} Si \times Wi$$

A weight value (Wi) for each parameter was developed based on the results of the PCA/FA or judgement. A common unitless scale or score (Si) ranging from zero to 100 and transformed from original and crucial parameters. The WQI value can be categorised into five classes; excellent quality, good quality, moderate, poor quality and very poor [19, 1, 5, 34].

4. Summary and review of different WQI models

Since there are no single standard method of calculation for WQI is recognize, there are different and unique way to calculate WQI. Different index has its own set of parameters, weights, and aggregation algorithm [35]. In this paper, the Canadian Council of Ministers of Environment Water Quality Index (CCME WQI), National Sanitation Foundation Water Quality Index (NSF WQI) and Integrated Water

Quality Index (IWQI) have been selected along with comparison of their advantages and limitations to WQI Malaysia. These WQI models were selected due to their different method of calculation. The CCME WQI and NSF WQI are the most common WQI index which is often been used worldwide. IWQI is the new developed WQI model in 2019, which is recognized as a comprehensive and unbiased WQI [10]. In Malaysia, Department of Environment (DoE) introduced and applied WQI Malaysia in 1974 to determine the quality of fresh water in Malaysi,a especially river water [11, 19]. Figure 1 shows the several types of WQI model along with their application calculation.

Based on their specific calculation method, there are several reviews about the overall usage, advantages and limitations (Table 3). The parameter selection of IWQI and CCME WQI is very flexible depend on the land use surrounding the water resources and the specific use of the water. No weightage is assigned to each parameter, as such these two WQI models are capable of providing unbiased estimation. For IWQI, statistical technique is recommended for parameter selection in order to pick the more suitable and reliable parameter and obtain unbiased result. The limitation of these two WQI models are main hindering factor on recommendation for water quality comparison between different water resources. This is because there is no specific list of parameters to be used. Therefore, distinctive parameters could be presented between two different water bodies. As such, it wouldn't be the case of an apple-to-apple comparison.

For NSFWQI and WQI Malaysia, specific listing on parameters is provided. Therefore, these models are more suitable to be used in comparison of water quality between different water resources. However, this may cause the WQI models to be less sensitive towards the newly emerging pollutants, and biological indicators are not in the current listing. The parameter selection method of NSFWQI and WQI Malaysia are based on the expertise judgment, it would be suggested to include the statistical technique in parameter selection step to increase the reliability of the WQI result. Pak et al. (2021) stated that fecal coliform, heavy metals and phosphate indicators should be included in WQI Malaysia due to large and industrial sector in Malaysia. In order to enhance the accuracy and sensitivity of WQI Malaysia, there is a need to proposed some other parameters such as biological parameter in order to add on into the WQI Malaysia. The weightage assignation of NSFWQI and WQI Malaysia are based on the subjective methods. It would be suggested to use the statistical technique in weightage assignation to avoid biased of the result. The statistical technique is recommended to be used in parameter selection and weightage assignation in order to increase the accuracy and unbiased result.

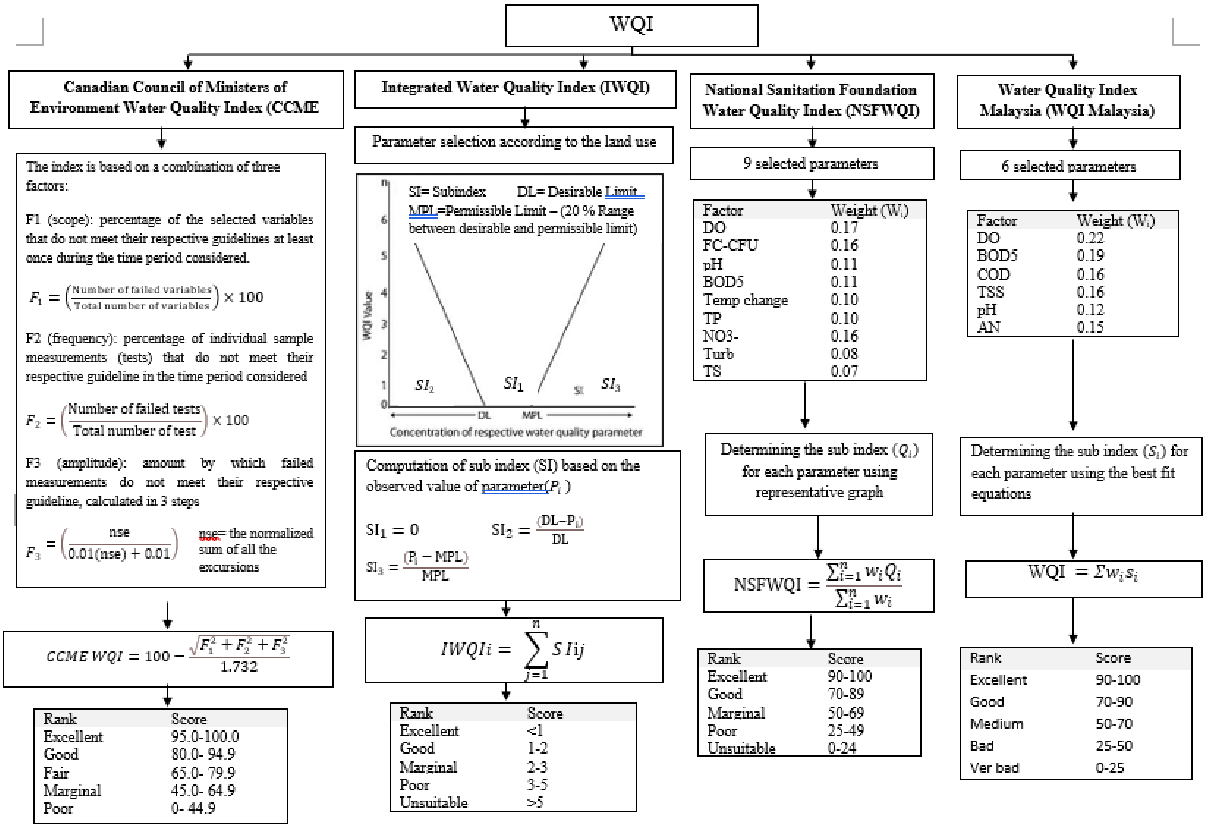

Figure 1. Summary of different WQI model.

Table 3. Summary of review about different water quality index models.

Main finding and review	IWQI	CCMEWQI	NSFWQI	WQI Malaysia
Overall usage	Time-saving calculating approach that is simple to use and can be modified to meet the demands of the user [10]	More flexible, free to use in any geographic location, and any set of criteria can be chosen [16, 36]	A standardized and universal system for classifying the quality of surface water in diverse bodies of water. bodies [36, 5, 35]	Easy and simple to calculate due to the specific selected parameter and weight are provided.
Limitation	Not suitable to do the water quality comparison between different water resources	Not suitable to do the water quality comparison between different water resources	Less sensitive in detection of new introducing pollutants	Less sensitive in detection of new introducing pollutants. Six selected parameters were not comprehensive enough to qualify the status [3]
Advantage	Fully unbias due to no weight provided	Fully unbias due to no weight provided	Suitable for water quality comparison between different water resources	Suitable for water quality comparison between different water resources

5. Conclusion

Water Quality Index (WQI) is known as a simple water quality interpretation technique to classify the overall water quality status of a water resource. WQI result is express in a single and easy understandable numerical term that generates from large quantity of water quality parameters information for a specific location and time. The basic steps of WQI method include: (i) selection of parameters, (ii) determination of values of sub-index, (iii) assignment of appropriate parameter weights, (iv) aggregation of the weighted sub-index to compute the final WQI. Every step has their own factors, rules and techniques for a better interpretation with higher accuracy results.

At present state, there is no single standard accepted for WQI calculation method. Therefore, various kind of WQI models such as CCMEWQI, NSFWQI, IWQI and WQI Malaysia are introduced with different and unique calculation. Through the summary and comparison between the WQI models, several suggestions were stated to improve the accuracy of the WQI result. To improve the WQI Malaysia, other parameter such as biological parameter are suggested to be included into the list of selected parameters. In conclusion, efforts are needed to improve WQI in order to obtain more comprehensive results.

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