Water quality indexing for predicting variation of water quality over time

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Abstract

While expressing water quantity involves a straightforward answer, such as the capacity of a reservoir or the flow rate of a river, expressing the quality of a water body is much more complex. A number of parameters characterise the quality of water, and expressing them to non-technical people may not always be easy. Water quality indexing is an attempt to communicate water quality data to technical and non-technical people. It is basically a numeric expression used to evaluate the quality of a given water body in such a way that it is easily understood by managers. It is a dimensionless scale, which aggregates several water quality parameters into a single value to make it understandable to the public in terms of its suitability to use. The water quality index used for this project is the minimum operator also called the Smith Index (Minimum Operator). This index gives information for the water quality according to its specific use, and it also caters for the problem of 'eclipsing' which arises during aggregation process. Data analysed for three sites, showed that the Smith Index method is well adapted to the characteristics of the quality of our rivers.

Keywords: water quality, surface water, water quality index, minimum operator, NSF method.

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INTRODUCTION

Assessment of water quality involves the measurement of a large number of parameters, and expressing the quality with respect to particular uses may be a complex issue. During the past decades, water quality experts have tried their best to improve the Water Quality index, mainly to stress on the importance of the quality of a water body to technical and non-technical people. The water quality indexing method is therefore an attempt to communicate water quality data. It consists of aggregating several water quality parameters into a single numerical value, to make it simpler for the public in general to appreciate the suitability of a given water body to particular uses.

The concept of water quality index (WQI) was first introduced more than 150 years ago in 1848 in Germany. At that time, the concept in the method was to make use of the presence of microrganisms as indicator to comment on the quality of water and its potential use. The classification system was then divided into two parts; the amount of pollution and the living communities of microscopic and macroscopic organisms. However, these classifications were qualitative, there was no numerical value associated with them. To cater for this deficiency, Horton (1965) develop an index method based upon a numerical scale, commonly known as, Horton's Index. Horton's method (1965), was based upon the following criteria; the number of variables to be considered in the index should be restricted in numbers, the chosen variables should be those having most importance and the variable chosen should be measured with utmost accuracy. Horton selected six parameters for a case study; dissolved oxygen, pH, total coliforms, conductivity level, alkalinity and chloride level. Following his work, several index based methods have been developed. One of the most commonly accepted is the National Sanitation Foundation water quality index (NSF WQI), developed by Brown *et al.* in 1970.

Several national agencies responsible for water supply and water pollution, have strongly advocated and adopted the WQI method. The main reason being that, when water quality data is collected through sampling and analysis, it becomes hectic to comment on the suitability of the water tested with respect to different uses. The WQI method however provides a relatively simpler approach to not only expressing the quality of a water body , but also it helps to express this data as it varies along the reach of a river and over time.

The advantages provided by the WQI method are as follows:

a. Resource allocation: Scientifically sound method which conveys complex water quality data in a simplified form to decision makers.

b. Ranking of allocation: Indices may be applied to assist in comparing water quality at different locations or geographic areas, or even along the reach of a river.

c. Enforcement of Standards: To some locations, indices help to determine the extent to which legislative standards and existing criteria are being satisfied or whether they have exceeded acceptable limits.

d. Trend analysis: The WQI method is widely used in the rehabilitation of river reaches, as this method helps in studying the change in water quality over time.

e. Public Information: Indices are normally easy to make people aware of the water quality and the potential risk if this water is to be used for recreational activities such as bathing, fishing or boating.

Thus, since the water quality indexing method yields a single value, it is immensely valuable in scientific research. Over time, sine this method has been gaining wider and wider acceptance, scientists have come up with even sounder WQI method, the Minimum Operator, also known as the Smith Index, is one such method. For the purpose of the present study, the NSF WQI and the Minimum Operator methods have been used to analyse data and the results have been compared to highlight the advantage of the Minimum Operator over the NSF WQI method.

WATER QUALITY INDEX METHODS

The Water Quality Index method is a physico-chemical index method, since it makes use mainly of physical and chemical parameters. There are four steps involved in the development of a water quality index; the indicator selection, the indicator transformation, the indicator weighting and finally the index-aggregation formulation. Dunette (1979) recommended that the variables of concern to water quality should be selected from those who have major impacts on the water; the oxygen status, the eutrophication potential, health aspects, dissolved substances in the water and the physical appearance of the water. It should be noted that the selection criteria is applicable to freshwater bodies, not marine or estuarine. Once the parameters are selected, the next step is to scale them to a dimensionless value. Rating curves are derived for each parameter based upon historical data. It is also generally acknowledged that some indicators are more important than others. Thus to account for this, appropriate weights are allocated to each indicator. Finally the values generated are combined, and researchers have proposed several ways to aggregate these numbers (House, 1990).

The NSF WQI method

Brown et al., (1970) from the United States National Sanitation Foundation (NSF), developed the NSF WQI for the US. He selected nine parameters from a set of thirty parameters commonly measured in the US. The parameters chosen were dissolved oxygen, faecal coliforms, pH, 5 day Biochemical Oxygen Demand (BOD_5), Temperature Deviation, Nitrate, Phosphate, Turbidity and Total solids. Rating curves and weightage curves were derived for each of the nine parameters, and the values derived for each parameter were finally aggregated (Brown *et al*., 1970). This method is widely used in the US and in many other countries as well.

In this method the first step is to identify key parameters based upon the prevailing environmental conditions of the study area. The next step is then to use the rating curve developed by Brown et al., (1970) for each parameter, and read off the index value from the curve for a given concentration of the parameter. Next, this parameter will be subjected to a weighting factor depending upon its importance. Finally the weighted indices for all the key parameters are aggregated by adding them. More detail about the method can be found in the article by Brown et al., (1970).

The Minimum Operator method

The Minimum Operator (MO) method is a similar method to water quality index method which was developed by Ott (1978) in New Zealand. Later another researcher, Smith (1990) was highly concerned with looking for an index that would be appropriate for various uses of the water, and also one which would keep important information. He noted that the NSF WQI method had the disadvantage of 'losing' some important information during the processing of the data. Smith (1990) developed the MO method, by combing rating curves and weightage curves for each of the key parameter selected. He also derived indexes for different uses, such as; General water quality index, bathing index, water supply index and fish spawning, based upon the understanding that different uses require different quality water and key parameters would also vary accordingly.

Hébert (1996) applied the index in Quebec (Canada) for recreational, agricultural and aquatic life. He noted that the index proposed by Smith (1990) was very appropriate to this type of study. The same method was used in 2005 for the monitoring of rivers and that study also confirmed the validity of this method.

In this method, the approach differs slightly from the NSF WQI method. The first step is to identify key parameters, again depending on site conditions. Next step is to make use of the rating curves for each of the parameter and read off the index value, commonly referred to as ISUB value. The rating curves have already taken into consideration the relative importance of each parameter with regards to water quality. There is therefore no additional weighing factor to be considered. The final step is to note the minimum ISUB value that has been obtained from a given water sample. This minimum value then represents the index value at the sampling station under study. Thus any minimum index value is not 'eclipsed' through the process of aggregation.

APPLICATION OF THE WQI METHOD (International)

Water quality index method is being used in many countries for varying purposes. For example, in India, WQI method is being used to address the issue of drinking water supply. Bhargava (1985) applied this method to the River Yamuna in Delhi and suggested that the water from that river was to be considered accepted, only when the water quality index value was greater than 60. Prakash *et al.* (1990) used the method to evaluate the water quality profile along the entire stretch of River Ganga. Sinha (1995) assessed the potability of the water from two ponds, from where villagers of the Bihar district used water. He considered the following parameters in his study; pH, hardness, dissolved oxygen, sodium, potassium, zinc, iron, turbidity and faecal coliform. Sinha (1995) concluded that the water was not good quality and required proper treatment if it were to be consumed as potable water. In Taiwan, Shyue *et al*. (1996) used this method to map the coastal water quality. He selected the following parameters for his study; pH, dissolved oxygen, BOD, coliform, copper, zinc, lead, cadmium and chromium.

The key parameters to be selected is very much dependent on the importance of that particular parameter in the given environmental conditions, and this is a point that need to be given much attention while making use of the WQI method.

APPLICATION OF THE WQI METHOD (Mauritius)

In Mauritius, the WQI method was applied on a research basis. Sheik Fareed (2001) applied the NSF WQI method to monitor the variation of the quality of water along the reach of a river located in the north of Mauritius. She noted though the surrounding landuse at the selected testing locations varied considerably, the overall rating of the water quality did not vary too much, the same observation was confirmed by a second study carried out at the same site by Gunnessee (2002). In 2002, Dindoyal, used the NSF WQI method to monitor the water quality of a river located near a landfill site, and in 2003 Sunyasi used three WQI methods, the NSF WQI, the potable water supply index and the biotic index method to monitor the quality of a river located in the eastern part of the island. He noted that the three methods yielded positive information about the overall quality of the river.

For the present study, the objective is to compare the validity of the NSF WQI method and the Minimum operator method for three rivers located in different parts of the island.

THE PRESENT STUDY

The present study was carried out a three rivers located in different regions of the island. For each sampling stations were positioned according to their surrounding landuse and also according to the ease of access to the river. The next step was to collect river water samples on a weekly basis and carry out physico-chemical tests on these samples. The data generated were analysed by the two methods, NSF WQI and the Minimum Operator, with a view of testing the validity of these methods in the local conditions.

Ott (1978) noted that though the water quality indexing method was very appropriate for conveying water quality information, most of the WQI methods suffer the problem of ‘eclipsing’. To cater for this particular drawback, in many of the WQI methods, only key water quality parameters are selected, for use of too many parameters increase the problem associated with ‘eclipsing’. Smith (1990), came up with an improved version of the WQI method, and resolved in some way the problem of ‘eclipsing’. So when the minimum operator method is used, the user does not have the problem of selecting only some parameters, he is free to select parameters he considers important.

METHODOLOGY

Samples of water were collected along Rivers Cere (Eastern area) and River Rempart (Northern area), located at different parts of the island, as indicated. Sampling points were selected with respect to surrounding landuse activities and with respect to the ease of access to the sampling sites (Tables 1 & 2). The grab sampling method was used to collect river water samples and both physical and chemical properties were performed.

River Cere is located in the eastern part of the island. The river travels through several types of landuse activities along its path, these including residential zones, commercial zones and forested areas. Ten (10) sampling points were chosen along the reach of River Cere and six (6) along River Rempart. Physico chemical tests were performed on these samples in a laboratory and the following parameters were measured; Temperature, turbidity, pH, nitrates, phosphates, colour, BOD, ammonia and conductivity level.

Station No.	Description	Landuse Activities
C1	St-Anne Bridge	Residential
C2	Near District council	Residential & Commercial
C3	Maurice Rousset Bridge	Commercial
C4	85km Downstream C3	Residential & Commercial
C5	Cite Hibiscus	Residential & Forested
C6	Near Floreal Knitwear	Forested & Sugarcane
C7	After Wastewater Treatment Plant	Sugarcane Plantation
C8	La Porte Bridge	Sugarcane Plantation
C9	125km Downstream to C8	Sugarcane Plantation & Vegetation
C10	La Porte Village	Sugarcane Plantation & Vegetation

Table 1: Landuse activities for sampling points along River Cere

Six sampling stations were selected along River du Rempart, the first one being close to the source of the river and the last one being close to the outlet to the sea. The river being shallow, grab sampling were collected midway along the river and at a depth close to the surface.

Station No.	Description	Landuse Activities
R1	Close to La Nicoliere Reservoir	Forested
R2	Ville Bague	Sugarcane plantation
R3	Belle Vue Maurel	Sugarcane plantation and residential
R4	Amitie	Sugarcane plantation and residential
R5	River Du Rempart	Residential and Industrial
R6	Pointe Lascars	Sugarcane Plantation

Table 2: Sampling points along River Rempart

Samples were collected and tested every two weeks, and the duration of the sampling period lasted over a six months.

RESULTS & DATA ANALYSIS – NSF WQI method and the MINUMUM OPERATOR method

NSF WQI method

The key parameters selected for this particular study are pH, dissolved oxygen, suspended solids, turbidity, temperature, BOD, ammonia and faecal coliform. Then using the rating curves and weightage derived by Brown *et al*., (1970), the NSF WQI index was estimated at each sampling point, on each sampling date. Finally the indices estimates were aggregated as per the formula proposed by Brown *et al.,* (1970) on each sampling date.

Sampling was carried out over six months, and the results were average to represent the water quality index at a given sampling station. The results obtained at each sampling station is indicated in (Table 3) for both rivers, Cere and Du Rempart.

River Cere		**River Du Rempart**	
Sampling station	**NSF WQI**	**Sampling station**	**NSF WQI**
C1	77.71	R1	78.10
C2	77.29	R2	77.00
C3	79.43	R3	78.80
C4	80.57	R4	78.30
C5	79.00	R%	74.50
C6	75.14	R6	76.40
C7	80.43		
C8	80.86		
C9	79.43		
C10	81.00		

Table 3: NSF WQI index values at Rivers Cere and Du Rempart

Similarly the data were analysed by the Minimum Operator method. The results obtained at each sampling point on various sampling dates were first average. The rating curves derived by Smith (1990) were used to work out the ISUB value for each averaged parameter value. Finally the ISUB values for all the key parameters are not aggregated here, as was the case with the NSF WQI method. In this case the minimum ISUB value obtained at the sampling point was recorded as the ISUB value representative of the water quality condition at that sampling point. Table 4 gives the ISUB values at station C1 for a given sample taken at a given point in time.

PARAMETERS	STN C1	ISUB VALUE
Dissolved oxygen	6.61	76
PH	7.49	100
Suspended Solids	2.30	96
Turbidity (NTU)	2.40	90
Temperature	**25.07**	**54**
BOD (mg/l)	1.77	92
Ammonia (mg/l)	0.29	90
Log Feacal Coliform (/100ml)	2.86	60

Table 4: ISUB values for key parameters at station C1, River Cere

In practice, this minimum ISUB value can be compared to a water quality rating table devised by Smith (1990), to identify the suitability of this water body for a particular use, such as water supply, bathing, fish spawning or general uses. For station C1 along river Cere, the quality of the water was found to be marginally suitable for water supply, bathing, fish sprawing or general uses, for station C2, the quality of the water was found to be unsuitable for either of these uses, and same observation was noted at station C9 (Table 5). From table 1, it can be noted that C2 is located within a residential and commercial zone while C9 is located within an agricultural zone (sugarcane and foodcrops). These surrounding landuse explain why the quality of the water in the river at these two points are poor. Such an observation is not obvious from the NSF WQI method.

Similarly, when the Minimum Operator was applied to the data from River du Rempart, sounder observations were made as was the case for River Cere. The quality of the water was found to be poor at station R5. The surrounding landuse activities at this particular station is residential and industrial, which explain the poor quality of the river water at that location.
The ISUB values at each sampling stations were average for both rivers, and results are as shown in Table 5.

River Cere		River Du Rempart	
Sampling station	**Minimum Operator ISUB**	**Sampling station**	**Minimum Operator ISUB**
C1	40	R1	71
C2	36	R2	46
C3	60	R3	64
C4	46	R4	62
C5	50	R5	24
C6	54	R6	58
C7	46		
C8	72		
C9	38		
C10	64		

Table 5: Minimum operator method indices at River Cere & River Du Rempart

DISCUSSION & CONCLUSION

When the results from tables 4 and 5 were plotted (Figures 1 & 2), it can be clearly observed that the NSF WQI method yielded almost similar indices along the reach of the rivers. The variation of the quality of the water along the reach of the river was not obvious, however, the pattern obtained with the Minimum Operator was very much different. With the Minimum Operator method, it could be noted that the quality of the river varied along the reach of the river, as was to be expected given that surrounding landuse activities along the reach of the rivers vary from forested, agricultural to residential zones.

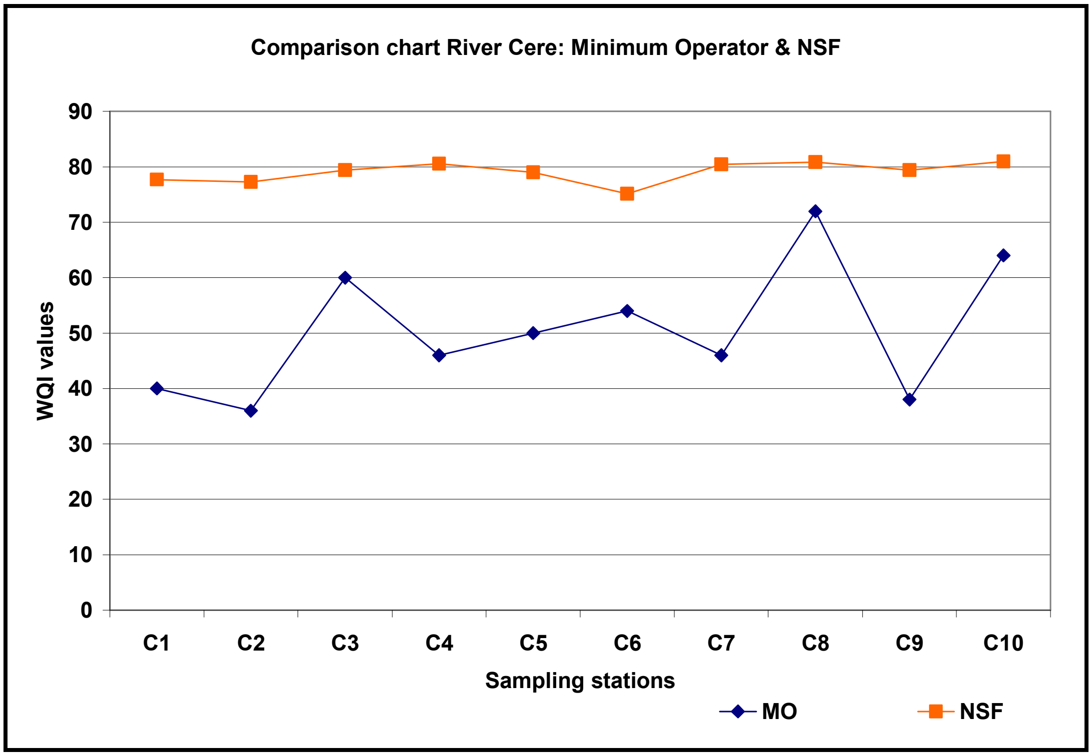

Figure 1: Comparison Chart River Cere – Minimum Operator & NSF

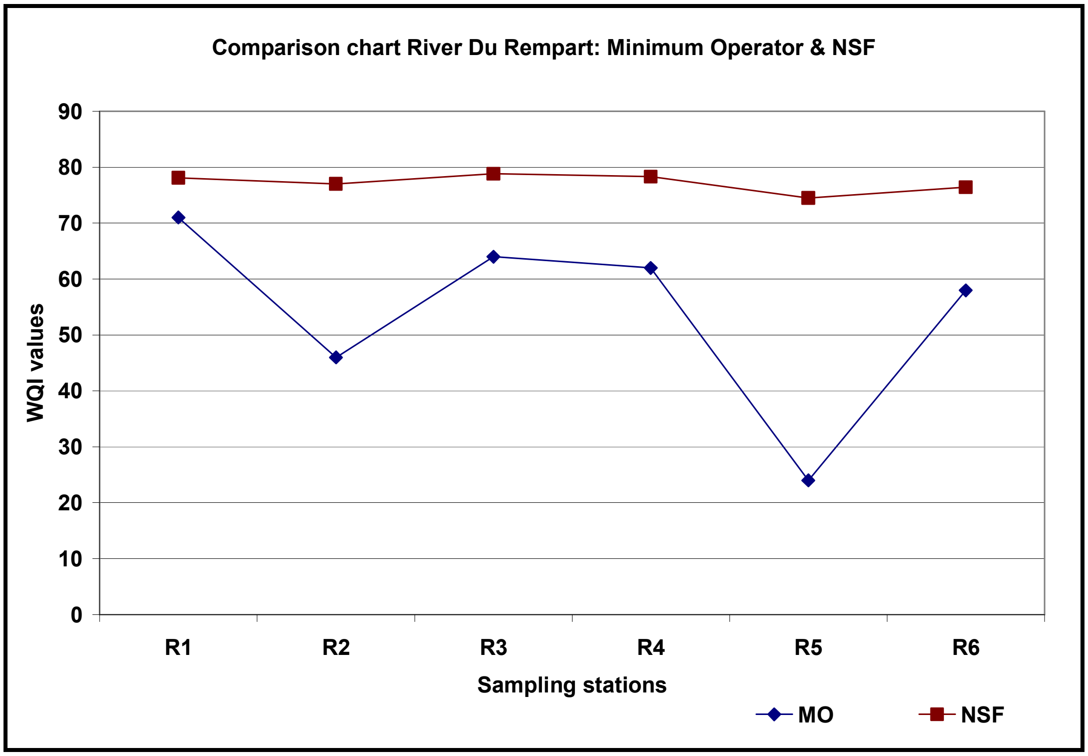

Figure 2: Comparison chart River Du Rempart: Minimum Operator & NSF indices

This study concluded that the Minimum Operator method does provide for the advantage of not 'eclisping' important crucial information, such as the sites were the quality of water along the reach of a river is the poorest. Though both methods are based representing complex water quality data in the form of a single index value, the Minimum Operator or Smith index WQI method can be said to be an improvement over the NSF WQI method. Another main advantage of the Minimum Operator is that the user can modify the number and type of parameters during the course of the study, while estimating the Minimum Operator index.

Water quality indexing method is also a simplified and effective approach to convey complex water quality information to the public. Where river reaches are to be used for recreational purposes, WQI method can be used to convey information to the public on a daily basis. The applicability of the water quality indexing method, either NSF or Minimum Operator depends also to a very large extent on the reliability of the rating curves and their weightage factors. If a country is to adopt this method, then the rating curves and the weightage factor should be derived locally. The limitations of the rating curves would then be known for more effective interpretation of the index values obtained.

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