APPLICATION OF RELATIVE WATER QUALITY INDEX (ReWQI) A NEW METHOD FOR AGGREGATE WATER QUALITY ASSESSMENT CASE STUDY IN HANOI, VIETNAM

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TÓM TẮT

ÁP DỤNG CHỈ SỐ CHẤT LƯỢNG NƯỚC TƯƠNG ĐỐI (ReWQI) MỘT PHƯƠNG PHÁP MỚI ĐỂ ĐÁNH GIÁ CHẤT LƯỢNG NƯỚC TƯƠNG ĐỐI: TRƯỜNG HỢP TẠI HÀ NỘI, VIỆT NAM

Trong bài báo này, nhóm tác giả áp dụng Chỉ số chất lượng nước tương đối (ReWQI) của tác giả Phạm Ngọc Hồ đề xuất để đánh giá chất lượng nước tương đối bằng chỉ số đơn lẻ và chỉ số tổng hợp cho nước mặt và nước thải. Số liệu quan trắc định kỳ đã được lấy mẫu và phân tích trong phòng thí nghiệm từ tháng 10 – 11/2020 tại 28 điểm nước hồ và nước sông đối với nước mặt và 48 điểm nước thải từ một số khu công nghiệp và làng nghề ở Hà Nội. Sử dụng các số liệu này để tính toán các chỉ số đơn lẻ q_i của các thông số khảo sát và tích hợp các chỉ số đơn lẻ thành chỉ số tổng hợp ReWQI. Chất lượng nước mặt ở Hà Nội chỉ đạt mức kém và xấu và chất lượng nước thải tại các khu/cụm công nghiệp chủ yếu đạt mức kém đến rất xấu. Kết quả tính toán chỉ số tổng hợp đối với nước mặt và nước thải cho thấy sự phù hợp với số liệu quan trắc thực tế tại các khu vực khảo sát.

Keywords: *Water quality index (WQI); Relative Water Quality Index (ReWQI); Individual index; Weighing factors; Hierarchical rating scale; Vietnam.*

1. INTRODUCTION

Currently, a number of countries around the world including Vietnam are adopting the method of aggregate assessment of water quality under the three following main methods:

(1) Water Quality Index (WQI) is established without a weighing factor of each surveyed parameter: Oregon (USA) (Cude 2001 [1]); Canada (CCME 2001 [2]); New Zealand (Nagels *et al.* 2001 [3]); Vietnam (Pham Thi Minh Hanh *et al.* 2011 [4]; VEA, 2011 [5]); India (Pati *et al.* 2012 [6]).

The WQI Indices are calculated easily, however they cannot be used to compare water quality at different observation points because the weighing factor of each surveyed parameter is not taken into account.

(2) Water Quality Index (WQI) is established with the weighing factor of each surveyed parameter: the United States (Ott 1978a,b [7, 8]; US EPA NOAA 2012 [9]); South Africa (Cooper 2000 [10]); Taiwan (Liou *et al.* 2004 [11]); Turkey (Boyacioglu 2007 [12]); Malaysia (Abdullah *et al*. 2008 [13]); India (Misha *et al.* 2008 [14]); Thailand (Prakirake *et al.* 2009 [15]); Ghana (F. Darko *et al*. 2013 [16]).

These indices have different formulations, but all are based on calculating sums, or taking the arithmetic mean, geometric mean of individual indices (sub-indices) according to the method proposed by Ott 1978b [8] that standardizes by segmental linear function to build the schema for each individual index. These indices still have some limitations: the number n of surveyed parameters is limited ($n \leq 9$); hierarchical rating scale is self-regulated; the weighing factor of each parameter is calculated based on the experience of experts and as such continues to be subjective. Thus, calculating the AQI index may result in eclipse and ambiguity (collectively called "virtual effect"); in the other hand, the construction of the diagram of individual indices is not convenient for its application into reality. When the number n of parameters is larger than 9 (e.g. n = 20), a large number of rather complex schemata for individual indices I_i needs to be built.

(3) Pham Ngoc Ho has proposed a new index - ReWQI and its recommendations for aggregately assessment of water quality for each type of water (surface water, ground water, coastal water, etc.) corresponding to the environmental standards of each type of water defined by each country. ReWQI is generally established based on the relative ratio (standardized into scale 100) of pollution subgroups and the total amount of general pollution which are constituted of individual indices of parameters with different standards for different categories of water as regulated in national standard of each country.

The objective of this paper is to apply Pham Ngoc Ho's method for aggregate water quality assessment of surface water and wastewater at different monitoring points around Hanoi, Vietnam. We measured concentration of 10 parameters in Hoan Kiem lake, West lake, Giang Vo lake and 25 different monitoring points at rivers in Hanoi for surface water quality evaluation, and 7 parameters at 45 monitoring points in industrial zones/clusters in Hanoi for wastewater quality evaluation.

2. METERIAL AND METHODM

2.1. Materials

The data was periodically monitored (1hr-average) in October and November in 2020 at 28 monitoring points in lakes and rivers (3 lakes and 25 rivers) for surface water and 48 monitoring points in industrial zones and clusters in Hanoi.

The data was synthesized by Institute of Environment Science and Public Health (IESH), Vietnam Union of Science and Technology Associations (VUSTA). Detail list of monitoring locations, sampling and analysis, QA and QC according to current regulations and standards [17, 18] were provided and conducted by IESH.

2.2. Method of calcualting Relative Water Quality Index ReWQI (Pham Ngoc Ho 2020 [19])

Formula of ReWQI

$$\text{ReWQI} = 100\left(1 - \frac{P_k}{P_n}\right) \quad (1)$$

Where

$$P_m = \sum_{i=1}^{m_1} W_i q_i + \sum_{i=1}^{m_2} W_i \left(1 - q_i\right) \quad (2)$$

$$P_k = \sum_{i=1}^{k} W_i \left(q_i - 1\right) \quad (3)$$

$P_n = P_m + P_k$ is the total amount of pollution of n surveyed parameters (4)

$n = m_1 + m_2 + k$

Where q_i – individual index of parameter i; W_i – final weighing factor of parameter i.

Individual index q_i for water is calculated for the following three groups:

Group 1: Group of lower environmental standards (except DO and pH)

If $C_i \le C_i^*$, $q_i = \frac{C_i}{C_i^*} \le 1$ (Good water quality) (5)

If $C_i \ge C_i^*$, $q_i = \frac{C_i}{C_i^*} \ge 1$ (From fair to very poor quality) (6)

The "=" sign occurs when $q_i = 1$ (Moderate water quality) (7)

Group 2: Group of upper environmental standards:

for parameter DO: $q_{DO} = \frac{C_{DO}^*}{C_{DO}}$

If $C_{DO} \ge C_{DO}^*$, $q_{DO} \le 1$ (Good water quality) (8)

If $C_{DO} \le C_{DO}^*$, $q_{DO} \ge 1$ (From fair to very poor quality) (9)

The "=" sign occurs when $q_{DO} = 1$ (Moderate water quality) (10)

Group 3: Standard group in section [a,b]:

If $C_i \le a$, $q_i = \frac{a}{C_i} \ge 1$ (From fair to very poor quality) (11)

If $C_i \ge b$, $q_i = \frac{C_i}{b} \ge 1$ (From fair to very poor quality) (12)

If $a < C_i < b$: $q_i = \frac{C_i - a}{b - a} < 1$ (Good water quality) (13)

The "=" sign occurs when $q_i = 1$ (Moderate water quality).

Formulas (5) – (13) have:

C_i – monitoring concentration of parameter i;

C^*_i – permissible standard of parameter i according to standard;

a, b are lower and upper bound of section [a, b] according to standard.

Method of calculating weighing factor of parameter i

Calculation of temporary weighing factor W_i'

a) Group of lower environmental standards (except DO and pH)

The temporary weighing factor W_i' of parameter i belonging to the lower environmental standard groups corresponding to categories A_1 or A_2 is determined by the following formulas:

$$W_i'(A_1) = \frac{C_i^*(A_1)+C_i^*(A_2)}{2} : C_i^*(A_1) = \frac{C_i^*(A_1)+C_i^*(A_2)}{2C_i^*(A_1)} \quad (14)$$

$$W_i'(A_2) = \frac{C_i^*(A_1)+C_i^*(A_2)}{2} : C_i^*(A_2) = \frac{C_i^*(A_1)+C_i^*(A_2)}{2C_i^*(A_2)} \quad (15)$$

b) Group of upper environmental standards (DO)

The temporary weighing factor W_i' of parameter i belonging to the upper environmental standard groups corresponding to categories A1 or A2 (for example, DO parameter) is determined by the following formulas:

$$W_{DO}'(A_1) = \frac{C_{DO}^*(A_1)}{\frac{C_{DO}^*(A_1)+C_{DO}^*(A_2)}{2}} = \frac{2C_{DO}^*(A_1)}{C_{DO}^*(A_1)+C_{DO}^*(A_2)} \quad (16)$$

$$W_{DO}'(A_2) = \frac{2C_{DO}^*(A_2)}{C_{DO}^*(A_1)+C_{DO}^*(A_2)} \quad (17)$$

c) Standard group in section [a,b]

The weighing factor W_i' of the group of parameters having environmental standards given in section $[a,b]$ corresponding to the environmental standard category A_1 or A_2, for example pH, the environmental standard of pH is in section (b-a), so:

$$W_{pH}'(A_1) = \frac{(b_1 - a_1) + (b_2 - a_2)}{2(b_1 - a_1)} \quad (18)$$

and $$W_{pH}'(A_2) = \frac{(b_1 - a_1) + (b_2 - a_2)}{2(b_2 - a_2)} \quad (19)$$

From equations (14) - (19), $C_i^*(A_1)$, $C_i^*(A_2)$ and C^*_{DO} are the limit values of parameter i and DO corresponding to water of categories A_1 and A_2; and a_1, a_2, b_1 and b_2 are also the limit values of parameter pH corresponding to water of categories A_1 and A_2. Similar calculations were applied to calculate the weighing factor of parameter i for water of each category B_1 and B_2; or for water of all 4 categories A_1, A_2, B_1 and B_2.

Calculation of final weighing factor W_i

The final weighing factor W_i of parameter i represents the correlation (influence) of parameter i with n surveyed parameters.

Calculate final weighing factor using the following formula:

$$W_i = \frac{W_i^{'}}{\sum_{1}^{n} W_i^{'}} \qquad (20)$$

It can be easily seen that $\sum_{1}^{n} W_i = 1$ (21), where n is the number of the surveyed parameters.

Hierarchical rating scale of ReWQI

The hierarchical rating scale of ReWQI with 5 levels and value of n (n is odd or even) is presented in Table 1.

Table 1. Hierarchical rating scale for assessing water quality of ReWQI=I

n even	n odd	Water quality	Color
$50\frac{2n-1}{n} < I \le 100$	$50\frac{2n-1}{n} < I \le 100$	Good/Excellent (Excellent when I = 100)	Blue
$100\frac{n-1}{n} < I \le 50\frac{2n-1}{n}$	$100\frac{n-1}{n} < I \le 50\frac{2n-1}{n}$	Moderate	Green
$50 < I \le 100\frac{n-1}{n}$	$50\frac{n-1}{n} < I \le 100\frac{n-1}{n}$	Fair	Yellow
$\frac{100}{n} < I \le 50$	$\frac{100}{n} < I \le 50\frac{n-1}{n}$	Poor	Orange
$0 \le I \le \frac{100}{n}$	$0 \le I \le \frac{100}{n}$	Very poor	Red

Note: when n=2, the thresholds “Poor” and “Fair” will not happen, so there remains 3 levels in Table 1; when n=3, the threshold “Poor” will not exist, hence there remains 4 levels in Table 1.

- Put W_i = 1 in formulas (2) and (3), then the index ReWQI has no weighing factor.

3. RESULTS AND DISCUSSION

3.1. Surface water

Weighing factors and hierarchical rating scale

Applying the formula 14 – 19 to calculate temporary weighing factor W'_i and final weighing factor W_i corresponding to 4 categories A_1, A_2, B_1 and B_2, using formula as follows:

$$W_i^{'}(A_1) = \frac{C_i^{*}(A_1) + C_i^{*}(A_2) + C_i^{*}(B_1) + C_i^{*}(B_2)}{4C_i^{*}(A_1)} = \frac{\text{numerator}}{4C_i^{*}(A_1)}$$

$$W_i^{'}(B_2) = \frac{\text{numerator}}{4C_i^{*}(B_2)}$$

And

$$W_i(A_1) = \frac{W_i^{'}(A_1)}{\sum_{1}^{n} W_i^{'}(A_1)};$$

$$\sum_{1}^{12} W_i(A_1) = 1$$

$$W_i(B_2) = \frac{W_i^{'}(B_2)}{\sum_{1}^{n} W_i^{'}(B_2)}; \quad \sum_{1}^{12} W_i(B_2) = 1$$

The results of W'_i and W_i for 10 monitoring parameters are presented in Table 2.

Place n = 10 in Table 1, result of the hierarchical rating scale is presented in Table 3.

Table 2. Environmental standards of 4 categories A1, A2, B1, B2 of surface water and weighing factor of each observed parameter

Parameter		pH	DO	TSS	COD	BOD_5	NH_4^+	NO_3^-	PO_4^{3-}	Fe	Coliform
QCVN 08:2015/MONRE	A_1	6-8.5	≥6	20 mg/l	10 mg/l	4 mg/l	0.3 mg/l	2 mg/l	0.1 mg/l	0.5 mg/l	2500 MNP/100ml
	A_2	6-8.5	≥5	30 mg/l	15 mg/l	6 mg/l	0.3 mg/l	5 mg/l	0.2 mg/l	1 mg/l	5000 MNP/100ml
	B_1	5.5-9	≥4	50 mg/l	30 mg/l	15 mg/l	0.9 mg/l	10 mg/l	0.3 mg/l	1.5 mg/l	7500 MNP/100ml
	B_2	5.5-9	≥2	100mg/l	50 mg/l	25 mg/l	0.9 mg/l	15 mg/l	0.5 mg/l	2 mg/l	10000 MNP/100ml
$W_i^{'}$	A_1	1.2	1.41	2.50	2.63	3.13	2	4	2.75	2.50	2.50
	A_2	1.20	1.18	1.67	1.75	2.08	2	1.60	1.37	1.25	1.25
	B_1	0.86	0.94	1	0.88	0.83	0.67	0.80	0.92	0.83	0.83
	B_2	0.86	0.47	0.50	0.53	0.50	0.67	0.53	0.55	0.63	0.63
W_i	A_1	0,049	0,057	0,102	0,107	0,127	0,081	0,163	0,112	0,102	0,102
	A_2	0,078	0,077	0,109	0,114	0,136	0,130	0,104	0,090	0,081	0,081
	B_1	0,100	0,110	0,117	0,102	0,097	0,078	0,093	0,107	0,097	0,097
	B_2	0,146	0,080	0,085	0,090	0,085	0,114	0,091	0,094	0,107	0,107

Table 3. Hierarchical rating scale for assessing surface water quality with n=10 (put n=10 in Table 1, n even)

ReWQI =I	Water quality	Color	Recommendation
$95 < I \le 100$	Good/Excellent (Excellent when I = 100)	Blue	No treatments needed
$90 < I \le 95$	Moderate	Green	No treatments needed
$50 < I \le 90$	Fair	Yellow	Need to control
$10 < I \le 50$	Poor	Orange	Need treatment
$0 \le I \le 10$	Very poor	Red	Need treatment

Results of ReWQI values at 28 points are illustrated as column chart in Figure 1.

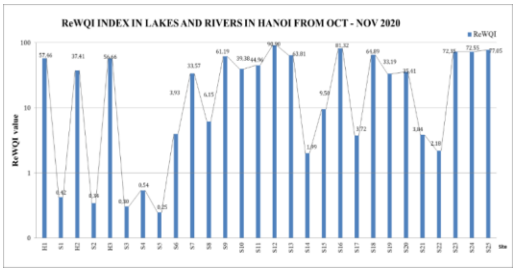

Figure 1. Chart of aggregate ReWQI of surface water in Hanoi (Oct – Nov 2020)

In which: H_i – lake monitoring points;

S_i – points at which river water flowing through locality.

3.2. Wastewater

Weighing factors and hierarchical rating scale

Applying the formula 14 – 19 to calculate temporary weighing factor W'_i and final weighing factor W_i for 7 parameters corresponding to 2 categories A and B using formula as follows:

$$W'_i(A) = \frac{C^*_i(A) + C^*_i(B)}{2C^*_i(A)} = \frac{\text{numerator}}{2C^*_i(A)};$$

$$W'_i(B) = \frac{\text{numerator}}{2C^*_i(B)}$$

And

$$W_i(A) = \frac{W'_i(A)}{\sum_1^n W'_i(A)}; \sum_1^7 W_i(A) = 1$$

$$W_i(B) = \frac{W'_i(B)}{\sum_1^n W'_i(B)}; \sum_1^7 W_i(B) = 1$$

The results of W'_i and W_i for 7 monitoring parameters are presented in Table 4.

Place n = 7 in Table 1, result of the hierarchical rating scale is presented in Table 5.

Table 4. Environmental standards of 2 categories A, B of wastewater and weighing factor of each observed parameter

Parameter		TSS	COD	BOD_5	NH_4^+	As	Fe	Coliform
QCTĐHN 02:2014/MONRE	A	50 mg/l	75 mg/l	30 mg/l	5 mg/l	0.05 mg/l	1 mg/l	3000 MNP/100ml
	B	100 mg/l	150 mg/l	50 mg/l	10 mg/l	0.1 mg/l	5 mg/l	5000 MNP/100ml
W'_i	A	1.500	1.500	1.333	1.500	1.500	3.000	1.333
	B	0.750	0.750	0.800	0.750	0.750	0.600	0.800
W_i	A	0.129	0.129	0.114	0.129	0.129	0.257	0.114
	B	0.144	0.144	0.154	0.144	0.144	0.115	0.154

Table 5. Hierarchical rating scale for assessing wastewater quality with n=7 (put n=7 in Table 1, n odd)

ReWQI=I	**Water quality**	**Color**	**Recommendation**
92.86 < I ≤ 100	Good/Excellent (Excellent when I = 100)	Blue	No treatments needed
85.71 < I ≤92.86	Moderate	Green	No treatment needed
42.86 < I ≤ 85.71	Fair	Yellow	Need to control
14.29 < I ≤ 42.86	Poor	Orange	Need treatment
0 ≤ I ≤ 14.29	Very poor	Red	Need treatment

Results of ReWQI for wastewater and wastewater quality assessment are described in Figure 2.

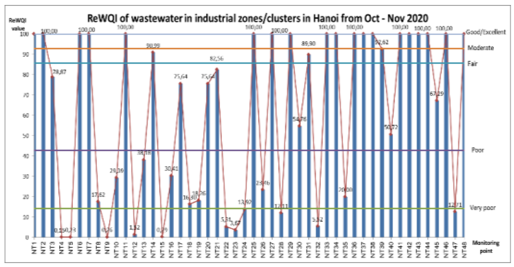

Figure 2. Chart of aggregate ReWQI of wastewater in Hanoi (Oct – Nov 2020)

3.3. Discussion

As illustrated in Figure 1, ReWQI values corresponding to hierarchical scale ***(Table 3)*** have shown the overall surface water quality in Hanoi, fluctuating from fair to poor and very poor. Among 28 monitoring points, 9 points were detected to have fair water quality accounting for 32.14%, 6 points had poor water quality accounting for 21.43%, while the water quality at 12 points, which was 42.86% of all monitoring points was very poor. Only 1 point which was S12 (the Red River in Tien Thinh commune, Me Linh) had a moderate surface water quality.

In addition to the evaluation of individual index, it is shown that the individual indices at some monitoring points were not in accordance with the standard values with q_i was significantly greater than 1 calculated for parameters including COD (q_i changed from 1.08 to 10.11), BOD_5 (q_i changed from 1.2 to 16.88), NH_4^+ (q_i changed from 1.16 to 127.12), NO_3^- (q_i changed from 1.17 to 19.45), PO_4^{3-} (q_i changed from 1.09 to 15.18), Coliform (q_i changed from 1.1 to 420). Almost all surveyed points were polluted by NH_4^+ parameter. At 12 points that had a very poor water quality, NH_4^+ was the highest polluting parameter, followed by Coliform, PO_4^{3-}, BOD_5 and NO_3^-, respectively.

Wastewater quality in industrial zones/clusters in Hanoi in Oct – Nov 2020 mostly ranged from fair to very poor (as in Figure 2). Among 48 survey points, 11 points had very poor quality of wastewater, 8 points had poor wastewater quality and 7 points had fair quality, total accounting for 54.17%. It is noticeable that a large proportion of 39.58% (19/48 sites) had excellent wastewater quality with value of ReWQI equal to 100.

The results have shown that ReWQI is highly accurate and consistent with actual monitoring data.

4. RECOMMENDATION

In order to protect water resources towards sustainable development, the authors propose a number of major solutions as follows:

Technology solutions:

- Impose strict control on facilities whose operations cause water pollution. Especially, for organic parameters that exceed the permissible standards many times, investors of enterprises are required to commit to treat these parameters with appropriate advanced technologies (applying advanced technologies from abroad or calling for investment projects) before being granted permission to operate.
- Require enterprise investors to equip automatic monitoring equipment for their facilities to acquire continuous data with high accuracy. It is the basis for adjusting the periodic monitoring data.

Management solutions:

- Awareness of environmental protection among community should be improved through mass media (television, newspapers) and organizing annual training courses and seminars on laws, sanctions and policies of government on the issue.
- Authority should strictly punish individuals and business owners who violate the provisions of law on environmental protection.
- Research and application of methods of assessing water quality by aggregate index as well as water quality zoning by GIS map in projects on impact assessment, environmental planning, network planning of monitoring points and developing annual reports on environmental status in the area should be actively encouraged.

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