Weighted and Standardized Total Environmental Quality Index (TEQI) Approach in Assessing Environmental Components (Air, Soil and Water)

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Abstract. The paper investigates an innovative approach in assessing integrated environmental quality using indices that have been applied in many countries, such as Belgium, the former Soviet Union countries, the United States and Canada. The approach (abbreviated as TEQI) is more innovative than other indexed approach. Concretely, in this approach, the important weight of studied parameter taking into account theirs poisonous levels and classification scale for assessment of environmental quality depending on total number of parameters n ($2 \leq n \leq 100$) were established by calculating from theoretical formulas, not be assigned as the others. The results of the application of TEQI to the assessment of soil (n=5), ground water (n=20) and air components (n=5) show that the ranking in TEQI corresponds to the actual monitored data.

Keywords: index, weighted, standardized, scale, environmental components.

1. Some limitations of the indexed approaches that have been applied in some countries worldwide

- The Total Index Approach P in the former Soviet Union [1] as well as the PSI index (the United States of America – USA) which are used to assess air quality did not take into account the weights W_i (which is the level of toxicity) of the assessed parameters. In addition, the P approach has a very strict condition of $P \leq 1$. In reality, it is possible that there is an excess of a parameter (above the standard) but the contamination level is not as serious as to negatively affect the environmental quality and public health; the P approach especially does not rank in detail the level of pollution. Pollution ranking in PSI is very subjective and does not base on a theoretical basic and therefore less convincing.

The water environmental quality index approaches used in other countries include the point-system (as it has been used in Belgium), water quality index approach WQI in USA [2] and CWQI in Canada [3]. Nonetheless, these approaches have following limitations:

- The number of assessed parameters is limited, with n=4 (Belgium), or n=9 (USA).

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- The ranking to assess the environmental quality is subjective, does not base on a theoretical basic and is independent of the number of the assessed parameters n, which could lead to the inaccurate thresholds for environmental quality ranking as compared to the reality, for example when n=2, or when n is a large number.

- The weight W_i which takes into account the importance of each parameter i is assigned from 0 to 1 in the WQI approach (USA), did not derive from a theoretical basic. In addition, to calculate the index I_i, 9 assessment diagrams need to be formed and they are rather complicated.

- The approach used in Canada has the advantage of unlimited n, simple calculation, however there is no weight W_i for each parameter i.

2. Developing a Weighted and Standardized Total Environmental Quality Index (TEQI)

2.1. Developing formula to calculate the total index Pj

To deal with the above-mentioned limitations, Pham Ngoc Ho (11/2010) [4] improved the process of assessing environmental quality for different environmental components (air, soil, water) by using a weighted and standardized integrated environmental quality index in which pollutants are assessed by standardizing to one based parameter (substance) at the starting point to build up a scale (rank) for assessing environmental quality of index TEQI.

In this approach, at a given monitoring time point t, the environmental quality under the impacts of n parameters (substances), is calculated as follow:

$$P_j = \sum_{i=1}^{n} q_{ji} = \sum_{i=1}^{n} \frac{C_{ji}}{C_{ji}^*} \quad (1)$$

in which:

j = 1, 2,…,N – the number of monitoring points;

n – number of assessed parameters;

$q_{ji} = \frac{C_{ji}}{C_{ji}^*}$ - index of the environmental quality of parameter i at the monitoring point j;

C_{ji} – the value of parameter i at the monitoring point j;

C_{ji}^* - the limit value (environmental standard) for parameter i at j based on the national environmental standard for the given country;

P_j – the total index at the monitoring point j.

To standardize P_j to the index q_{11} at point j = 1, i = 1 (the starting point), formula (1) can be modified as follow:

With j = 1, from formula (1):

$$P_1 = q_{11} + q_{12} + q_{13} + \dots + q_{1n}$$

$$= q_{11}\left(1 + \frac{q_{12}}{q_{11}} + \dots + \frac{q_{1n}}{q_{11}}\right)$$

$$= q_{11}\left(\frac{q_{11}}{q_{11}} + \frac{q_{12}}{q_{11}} + \dots + \frac{q_{1n}}{q_{11}}\right) \quad (2)$$

Place $q_{1i} = \frac{C_{1i}}{C_{1i}^*}$ into (2):

$$P_1 = q_{11}\left(\frac{C_{11}}{C_{11}^*} \times \frac{C_{11}^*}{C_{11}} + \frac{C_{12}}{C_{12}^*} \times \frac{C_{11}^*}{C_{11}} + \dots + \frac{C_{1n}}{C_{1n}^*} \times \frac{C_{11}^*}{C_{11}}\right) \quad (3)$$

Assign $W_i = \frac{C^*_{11}}{C^*_{1i}}$, as shown in (3), the division is the weight of the parameter i in comparison to the standardized parameter i = 1, j = 1 or q_{11}, it shows the level of toxicity (or level of pollution) of parameter i. Then (3) becomes:

$$P_1 = q_{11} \times \sum_{i=1}^{n} W_i \frac{C_{1i}}{C_{11}} = \frac{C_{11}}{C^*_{11}} \times \sum_{i=1}^{n} W_i \frac{C_{1i}}{C_{11}} = \frac{C_{11}}{C^*_{11}} \times \alpha_1 \quad (4)$$

here $\alpha_1 = \sum_{i=1}^{n} W_i \frac{C_{1i}}{C_{11}}$ and it is called the total standardized coefficient of the standardized parameter at j=1.

Similar, we have a formula for any point j:

$$P_j = q_{j1} \sum_{i=1}^{n} W_i \frac{C_{ji}}{C_{j1}} \quad (5)$$

Because q_{j1} at point j is different to q_{11} at the standardized point, therefore (5) must be modified to the standardized starting index q_{11}:

$$P_j = \frac{q_{11}}{q_{11}} \times q_{j1} \times \sum_{i=1}^{n} W_i \frac{C_{ji}}{C_{j1}}$$

$$= q_{11} \times \left(\frac{q_{j1}}{q_{11}} \times \sum_{i=1}^{n} W_i \frac{C_{ji}}{C_{j1}}\right)$$

$$= \frac{C_{11}}{C^*_{11}} \times \left(\frac{q_{j1}}{q_{11}} \times \sum_{i=1}^{n} W_i \frac{C_{ji}}{C_{j1}}\right)$$

$$= \frac{C_{11}}{C^*_{11}} \times \alpha_j \quad (6)$$

$$\alpha_j = \frac{C_{j1}}{C_{11}} \times \sum_{i=1}^{n} W_i \frac{C_{ji}}{C_{j1}} \quad (7)$$

in which:

$W_i = \frac{C^*_{j1}}{C^*_{ji}} = \frac{C^*_{11}}{C^*_{ji}}$ - the weight of parameter i as compared to the standardized parameter at any point j;

α_j - the total standardized coefficient at any point j;

C_{ji} – the monitored value of parameter i at j;

C_{j1} – the value of the standardized parameter at j.

When j = 1, formula (5) becomes (4). Therefore, (5) *is the general formula about the total index*, which is the basic to develop the scale to assess the total (or integrated) environmental quality using TEQI.

2.2. Developing the assessment scale

2.2.1. Developing the assessment scale using TEQI

Divide the array n figures q_{ji} from (6) into two groups:

Group 1: Includes m figures q_{ji} which are ≤ 1 (the group of parameters which meet the environmental standards),

$$P_{jm} = \sum_{i=1}^{m} q_{ji} = q_{11} \times \alpha_{jm}, \ \alpha_{jm} = \frac{C_{j1}}{C_{11}} \times \sum_{i=1}^{m} W_i \frac{C_{ji}}{C_{j1}} \quad (8)$$

Group 2: Includes k figures q_{ji} which are > 1 (the group of parameters which do not meet the environmental standards),

$$P_{jk} = \sum_{i=1}^{k} q_{ji} = q_{11} \times \alpha_{jk},$$

$$\alpha_{jk} = \frac{C_{j1}}{C_{11}} \times \sum_{i=1}^{k} W_i \frac{C_{ji}}{C_{j1}} \quad (9)$$

where m + k = n.

Convert P_{jm} and P_{jk} to the scale of 100, because $P_{jm} + P_{jk} = P_j$, therefore: $\frac{P_{jm}}{P_j} \times 100$ and $\frac{P_{jk}}{P_j} \times 100$.

There are two approaches to develop the assessment scale: Based on the pollution level (when the pollution index increases, the pollution level increases, the environment is polluted more) and based on the clean environmental quality (when the index decreases, the environmental quality decreases). In this paper, the second approach is used as it will be easier to compare to WQI and CWQI. In this approach, to create *standardized scale of 100*, the formula for TEQI at any j:

$$TEQI = 100 - \frac{P_{jk}}{P_j} \times 100$$

$$= 100 \times (1 - \frac{P_{jk}}{P_j})$$

$$= 100 \times (1 - \frac{q_{11} \times \alpha_{jk}}{q_{11} \times \alpha_j})$$

$$= 100 \times (1 - \frac{\alpha_{jk}}{\alpha_j})$$

$$= 100 \times (1 - \frac{\frac{C_{j1}}{C_{11}} \sum_{i=1}^{k} W_i \frac{C_{ji}}{C_{j1}}}{\frac{C_{j1}}{C_{11}} \sum_{i=1}^{n} W_i \frac{C_{ji}}{C_{j1}}}) = 100 \times (1 - \frac{\sum_{i=1}^{k} W_i \frac{C_{ji}}{C_{j1}}}{\sum_{i=1}^{n} W_i \frac{C_{ji}}{C_{j1}}}) \quad (10)$$

2.2.2. Criteria to develop TEQI

- Assessment thresholds must be built so that the TEQIs must fall into one of the zones.

- Assessment thresholds must correspond to the 100 scale, which is the scale of TEQI.

Therefore, the thresholds are dependent on the division $\frac{k}{n} \times 100$, in which k is the number of parameters that do not meet the Environmental Standards, n – is the number of assessed parameters:

$$A_k = 100 - \frac{k}{n} \times 100 = 100 \times (1 - \frac{k}{n}) \quad (11)$$

Because n must be a positive integer ($2 \le n \le 100$), and k = 0, 1, 2,… therefore:

1) The upper limit of the assessment scale =100, when k = 0 (the excellent environmental quality); the lower limit of the assessment = 0, when k = n (the worst environmental quality).

2) The good threshold corresponds with min(k) = 1 or $A_k = 100 \times (1 - \frac{1}{n}) = 100 \times \frac{n-1}{n}$.

3) The poor threshold (according to 11):

When n is even then $k = \frac{n}{2}$, or

$$A_k = 100 \times (1 - \frac{n}{2n}) = 50$$

When n is odd then $k = \frac{n+1}{2}$, or

$$A_k = 100 \times (1 - \frac{n+1}{2n}) = 50 \times \frac{n-1}{n}$$

4) The moderate level is the average of the good and the poor thresholds:

When n is even,

$$A_k = (100 \times \frac{n-1}{n} + 50) : 2 = 25 \times (2 \times \frac{n-1}{n} + 1) = 25 \times \frac{3n-2}{n}$$

When n is odd,

$$A_k = (100 \times \frac{n-1}{n} + 50 \times \frac{n-1}{n}) : 2 = 75 \times \frac{n-1}{n}$$

5) The very poor threshold corresponds to max(k) = n – 1 or $A_k = 100 \times (1 - \frac{n-1}{n}) = \frac{100}{n}$

Based on above basic thresholds:

Table 1. The environmental quality scale table with n is an even and odd number

TEQI (n is even)	TEQI (n is odd)	Environmental Quality (EQ)	Color
$100 \times \frac{n-1}{n} < TEQI \leq 100$	$100 \times \frac{n-1}{n} < TEQI \leq 100$	Very Good	Blue
$25 \times \frac{3n-2}{n} < TEQI \leq 100 \times \frac{n-1}{n}$	$75 \times \frac{n-1}{n} < TEQI \leq 100 \times \frac{n-1}{n}$	Good	Green
$50 < TEQI \leq 25 \times \frac{3n-2}{n}$	$50 \times \frac{n-1}{n} < TEQI \leq 75 \times \frac{n-1}{n}$	Moderate	Yellow
$\frac{100}{n} < TEQI \leq 50$	$\frac{100}{n} < TEQI \leq 50 \times \frac{n-1}{n}$	Poor	Orange
$0 \leq TEQI \leq \frac{100}{n}$	$0 \leq TEQI \leq \frac{100}{n}$	Very poor	Red

Notes: In some special cases:

1. With n=2

According to table 1, the thresholds very poor, poor, moderate and good overlaid. In this case, the TEQI scale is as follow:

TEQI	Environmental Quality (EQ)
$50 < TEQI \leq 100$	Good
$0 \leq TEQI \leq 50$	Poor

2. With n=3

According to table 1, the thresholds very poor, and poor overlaid, the TEQI scale is as follow:

TEQI	Environmental Quality (EQ)
$67 < TEQI \leq 100$	Very good
$50 < TEQI \leq 67$	Good
$33 < TEQI \leq 50$	Moderate
$0 \leq TEQI \leq 33$	Poor

2.3. Calculating the product of $W_i \frac{C_{ji}}{C_{j1}}$ *in the formula (10)*

2.3.1. For $\sum_{i=1}^{n} W_i \frac{C_{ji}}{C_{j1}}$ (12)

Case1: The lower limit $C_{ji} \leq C^*_{ji}$ (for example: the air environment), then $q_{ji} = \frac{C_{ji}}{C^*_{ji}} \leq 1$ and $q_{ji} = \frac{C_{ji}}{C^*_{ji}} > 1$, if $C_{ji} > C^*_{ji}$.

As $q_{ji} = \frac{C_{ji}}{C^*_{ji}}, q_{j1} = \frac{C_{j1}}{C^*_{j1}}$, hence

$$\frac{q_{ji}}{q_{j1}} = \frac{C_{ji}}{C^*_{ji}} \times \frac{C^*_{11}}{C_{j1}} = \frac{C^*_{11}}{C^*_{ji}} \times \frac{C_{ji}}{C_{j1}} = W_i \times \frac{C_{ji}}{C_{j1}} = \frac{C^*_{11}}{C^*_{ji}} \times \frac{C_{ji}}{C_{j1}},$$

with $W_i = \frac{C^*_{11}}{C^*_{ji}}$ (13)

Case2: The upper limit $C_{ji} > C^*_{ji}$ (for example: DO in the water environment), if $C_{ji} > C^*_{ji}$, the environmental quality meets standards then $\frac{C^*_{ji}}{C_{ji}} < 1$ and $C_{ji} < C^*_{ji}$ then

$\frac{C^*_{ji}}{C_{ji}} > 1$ (does not meet standards). Then, following the formula to calculate $\frac{q_{ji}}{q_{j1}}$ as in case 1, then $W_i \times \frac{C_{ji}}{C_{j1}} = \frac{C^*_{ji} \times C^*_{11}}{C_{ji} \times C_{j1}}$, with

$W_i = C^*_{ji} \times C^*_{11}$ (14)

Case3: The limits with both lower and upper values [a,b] (for example: pH in soil or water), with a, b are the lower and upper limits of the standards for parameter i.

- If $C_{ji} < a$ then $W_i \times \frac{C_{ji}}{C_{j1}} = \frac{a \times C^*_{11}}{C_{ji} \times C_{j1}}$, with $W_i = a \times C^*_{11}$ (15)

- If $C_{ji} > b$ then $W_i \times \frac{C_{ji}}{C_{j1}} = \frac{C_{ji} \times C^*_{11}}{b \times C_{j1}}$, with $W_i = \frac{C^*_{11}}{b}$ (16)

- If $C_{ji} \in [a,b]$ then $W_i \times \frac{C_{ji}}{C_{j1}} = 1 \times \frac{C^*_{11}}{C_{j1}}$, with $W_i = C^*_{11}$ (17)

2.3.2. For $\sum_{i=1}^{k} W_i \frac{C_{ji}}{C_{j1}}$ (18)

In this case, only the group of $q_{jk} > 1$ (do not meet environmental standards), there are following cases:

Case 1: Lower limit ($C_{ji} \le C^*_{ji}$), only assess when $C_{ji} > C^*_{ji}$

Then $W_i \times \frac{C_{ji}}{C_{j1}} = \frac{C_{ji}}{C^*_{ji}} \times \frac{C^*_{11}}{C_{j1}} = \frac{C^*_{11}}{C^*_{ji}} \times \frac{C_{ji}}{C_{j1}}$,

with $W_i = \frac{C^*_{11}}{C^*_{ji}}$ (19)

Case 2: Upper limit ($C_{ji} > C^*_{ji}$), only assess when $C_{ji} < C^*_{ji}$

$W_i \times \frac{C_{ji}}{C_{j1}} = \frac{C^*_{ji}}{C_{ji}} \times \frac{C^*_{11}}{C_{j1}} = \frac{C^*_{ji} \times C^*_{11}}{C_{ji} \times C_{j1}}$, with

$W_i = C^*_{ji} \times C^*_{11}$ (20)

Case3: The standards has both lower and upper limits [a,b], only assess $C_{ji} < a$ or $C_{ji} > b$, where a, b have the same meaning as in formula (15) – (16)

$W_i \times \frac{C_{ji}}{C_{j1}} = \frac{a \times C^*_{11}}{C_{ji} \times C_{j1}}$, with $W_i = a \times C^*_{11}$ (21)

or $W_i \times \frac{C_{ji}}{C_{j1}} = \frac{C_{ji} \times C^*_{11}}{b \times C_{j1}}$, with $W_i = \frac{C^*_{11}}{b}$ (22)

Notes: In order to calculate for (10), it is very important to select the standardized parameter at the first instance. In principle, the standardized parameter can be chosen randomly in the array of the monitored parameters which includes all n parameters that the values were obtained. However, to illustrate the toxicity level of a parameter in comparison to another parameter, it is best to select *the standardized parameter i that has the lowest environmental standard and assign it as C_{11} corresponding with the starting point i=1, j=1. Then, the environmental standard is assigned* $= C^*_{11}$ *at the point j=1.* Therefore, the weight of the standardized parameter =1, where the weight of other parameters < 1.

2.4. An example, application of the total environmental quality index TEQI to assess air quality around traffic crossroads in Hanoi

2.4.1. Calculation

At 57 crossroads, the hourly monitored parameters were monitored at the same time in rush hours: 7-8 h; 17-18h and at time with low vehicle flow: 11-12h on 19/7/2011. The average results from 3 samples include: noise, CO, SO_2, NO_2, C_6H_6, PM_{10} and Pb. However, we select only 5 parameters for this research: noise, CO, SO_2, NO_2, C_6H_6 because there are no hourly environmental standards for PM_{10} and Pb in the Vietnam standard (QCVN 05-2009/BTNMT).

Applying the calculation method to calculate the weights for the 5 selected parameters, and rank them based on the chronological scale from high to low toxicity: C_6H_6 , noise , NO_2 , SO_2 , CO corresponding to W_i of C_6H_6 (1,00000), noise (0,29300), NO_2 (0,11000), SO_2 (0,063), CO (0,00073).

Applying the assessment scale for n = 5 (n is odd) as in table 1, we have:

Table 2. Rank table of the Air Quality at 57 crossroads with n = 5

TAQI	Air Quality	Color
80 < TAQI ≤ 100	Very Good	Blue
60 < TAQI ≤ 80	Good	Green
40 < TAQI ≤ 60	Moderate	Yellow
20 < TAQI ≤ 40	Poor	Orange
0 ≤ TAQI ≤ 20	Very poor	Red

2.4.2. Results

The calculation results for TEQI at 57 points are presented in table 3.

Table 3. Calculation results at 57 crossroads

j	TAQI	Air quality	j	TAQI	Air quality	j	TAQI	Air quality
1	12,752	Very poor	21	8,338	Very poor	41	11,666	Very poor
2	14,183	Very poor	22	45,661	Moderate	42	9,072	Very poor
3	0,000	Worst	23	11,081	Very poor	43	29,279	Poor
4	0,000	Worst	24	28,876	Poor	44	9,202	Very poor
5	10,166	Very poor	25	31,925	Poor	45	25,323	Poor
6	0,000	Worst	26	0,000	Worst	46	30,291	Poor
7	0,000	Worst	27	41,842	Moderate	47	44,467	Moderate
8	26,549	Poor	28	46,837	Moderate	48	69,568	Good
9	0,000	Worst	29	45,919	Moderate	49	41,908	Moderate
10	47,918	Moderate	30	25,996	Poor	50	67,144	Good
11	0,000	Worst	31	0,000	Worst	51	38,774	Poor
12	31,766	Poor	32	13,143	Very poor	52	0,000	Worst
13	12,660	Very poor	33	100,000	Excellent	53	42,111	Moderate
14	24,120	Poor	34	28,785	Poor	54	70,038	Good
15	12,435	Very poor	35	47,457	Moderate	55	26,062	Poor
16	11,566	Very poor	36	11,578	Very poor	56	46,596	Moderate
17	0,000	Worst	37	45,567	Moderate	57	7,953	Very poor
18	0,000	Worst	38	40,205	Moderate			
19	22,252	Poor	39	49,432	Moderate			
20	0,000	Worst	40	12,209	Very poor			

Remarks

1. For 5 levels of assessment (Very good, good, moderate, poor, very poor), around 29,8% of the crossroads has an Moderate to good quality, the rest 70,2% have poor to very poor and worst quality.

2. The locations that have poor-very poor quality often have high concentration of traffic. In addition, where the streets are narrow, at traffic light or when there is congestion, motor vehicles do not turn the motor off or buses and trucks run on FO or diesel that do not burnt completely creating dangerous substances such as SO_2, CO_2, C_6H_6, NO_2, etc. On the other hands, around many crossroads, there is a high population density as well as many street food stalls that use honeycomb coal for cooking, that contributes to the air pollution in the area.

3. The crossroad that have the excellent air quality (TAQI = 100,00) is at the My Dinh Sport Complex. This is a new developed area with low traffic, mainly motorcycles.

4. The results of the air quality assessment for 57 crossroad in Hanoi as well as the soil quality assessment (based on 5 heavy metals), the ground water quality (with 20 parameters) in Hoa Binh Province [4] show that the assessment scale with 5 levels corresponds with the actual monitoring values.

The environmental component quality (air, soil, water) depends on the physical-chemical property of each parameter, which is regulated by the environmental standards. Therefore, based on the selection of featured parameters n for each component, then using the ranking table of TEQI to assess environmental quality of each component will be convenient and simple.

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