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Relative Air Pollution Index (RAPI) - A New Method for Aggregate Air Pollution Assessment

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ABSTRACT

In this article, the author proposes a new method for integrating the relatively individual pollution indexes into an aggregate index called Relative Air Pollution Index (RAPI). This index has overcome some limitations of the air pollution index (API) or air quality index (AQI) which is being used in countries around the world as well as in Vietnam. Using the automated observation data recorded at Nguyen Van Cu station in Hanoi in 2016 to test the RAPI calculations, the results show that RAPI is conformed to the ambient air pollution level at Nguyen Van Cu station.

Keywords: Indices, Aggregates, Weights, Thresholds and scales, Frequency of pollution

INTRODUCTION

The air pollution index (API) and the air quality index (AQI) have been commonly applied in Vietnam and abroad. These indices are aggregated from the individual indices (sub-indices), calculated from daily standards (1 h, 8 h and 24 h) or yearly standards (24 h, year) and they form a simple formula for overall assessment of the level of pollution/air quality. There are three main methods to build the daily index API/AQI:

Using the highest value of the individual indices [1-3]. This method was used by the US Environmental Protection Agency [4]. Similar methods were also used by Hong Kong Environmental Protection Department [5], State Environmental Protection Administration of China [6], Singapore National Environment Agency [7], Hoang et al. [8], Vietnam Environment Administration [9], Nghiem et al. [10]. However, these indices have several limitations as thresholds and hierarchy rating is self-regulation (5-7 levels); Some indices take into account the weight which is subjectively scored by the expert's criteria; indices do not take into account the total amount of pollution from individual indices; When expanding to the number of parameters $n \geq 2$ contained in the country's toxic gas standards, it is necessary to build up the lower and higher breakpoints, or complex search schemes that are not conducive to apply.

Using the summation of the individual indices, according to the method of the former Soviet Union [11]. There are only three levels of the rating hierarchy; no weight.

Using the geometric means of the individual indices [12] or arithmetic means of the individual indicies [13]. Similar to the first method, the rating scale of this approach is also self-regulation; It does not take into account the total amount of pollution from individual indices; The weight of each parameter is in accordance with the expert grading method, so subjective. The index has a "virtual" effect including eclipsing and ambiguity, which means that in some cases the index does not match the actual results.

The article aims at proposing a new method to overcome some limits of API/AQI as mentioned above.

MATERIALS AND METHODS

Data

The automatically monitored data for successive 12 months in 2016 at the monitoring station Nguyen Van Cu [14] were used to calculate the daily RAPI. The monitoring station is from HORIBA-Japan. The station is located at coordinates 21º02'56.3"N, 105º52'58.8"E and 2.5 m from the ground; detector is 3-3.5 m above the ground. The width of pavement is 5 m (adjacent to the highway).

The selected basic parameters (µg/m^3) are O_3, PM_{10}, CO, SO_2, NO_2 and the processing of input data to calculate average concentration value of each parameter (1 h average, 8 h average and 24 h average) is conducted according to the standard/regulation of each country. As for average hourly data, the highest concentration value of each parameter monitored during 24 h of a day was used to calculate individual index q_i (1 h); As for 8 h average data, the average values of 8 observations (there are three 8 h average values per day) were taken, then the highest value from these 8 h average values was used to calculate the individual index q_i (8 h); as for 24 h average data, the average value of 24 observations was taken to calculate individual index q_i (24 h).

METHOD OF BUILDING DAILY RELATIVE AIR POLLUTION INDEX $RAPI_D$

Approach

The level of air pollution at an observation point at one time point is the concomitant effect of n parameters, so the aggregate index P is determined by the formula:

$$P = \sum_{i=1}^{n} W_i q_i \quad (1)$$

$$q_i = \frac{C_i}{C_i^*} \text{ (Relatively individual index)} \quad (2)$$

C_i= monitoring concentration of parameter i; C_i^*=permissible standard of parameter i; n=number of parameters; W_i=Important weight of parameter i (based on standard of 1 h, 8 h and 24 h)

1st case: $C_i < C_i^*$ mean q_i<1 – no pollution (3)

2nd case: $C_i = C_i^*$ mean q_i=1 – borderline pollution (4)

3rd case: $C_i > C_i^*$ mean q_i>1 – pollution (5)

Building the formula of daily relative air pollution indexes ($RAPI_d$)

Divide q_i from (1) into 3 groups: Group 1 consists of m_1 parameter(s) having q_i=1; Group 2 contains m_2 parameter(s) having q_i<1 and group 3 contains k parameter(s) having q_i>1.

Multiply the two sides of the inequalities $q_i = 1$, $q_i <1$, and $q_i> 1$ respectively with W_i:

$W_i q_i>0$ with $q_i=1$; $W_i(1-q_i)>0$ with $q_i<1$ and $W_i(q_i-1)>0$ with $q_i>1$

From (1) we have:

$$P_m = \sum_{i=1}^{m_1} W_i q_i + \sum_{i=1}^{m_2} W_i (1 - q_i) \quad (6)$$

$$P_k = \sum_{i=1}^{k} W_i (q_i - 1) \quad (7)$$

$P_n = P_m + P_k$ is the total amount of pollution of n individual indices (8)

Because $P_m/P_n \leq 1$ and $P_k/P_n \leq 1$, so: $100\times\frac{P_m}{P_n}\leq 100 \Rightarrow 100\times\left(1-\frac{P_m}{P_n}\right)\geq 0$ and $100\times\frac{P_k}{P_n}\leq 100 \Rightarrow 100\times\left(1-\frac{P_k}{P_n}\right)\geq 0$

There are two approaches to building aggregate indexes:

Aggregate Pollution Index: The higher the value of RAPI is, the greater the extent of the air pollution is, so on the 100th scale, we have

$$RAPI_d = 100\left(1-\frac{P_m}{P_n}\right) \quad 9$$

Aggregate quality index: The smaller the value of RAQI is, the worse the air quality is, so on a scale of 100, we have:

$$RAQI_d = 100\left(1-\frac{P_k}{P_n}\right) \quad (10)$$

Here the author uses the formula (9):

$$RAPI_d = 100\left(1-\frac{P_m}{P_m+P_k}\right) \quad (11)$$

Setting the rating threshold of $RAPI_d$

The rating threshold is determined by the following formula:

$$T_m = 100\left(1-\frac{m}{n}\right) \quad (12)$$

Use mathematical conditions: infimum (inf), supremum (sup), minimum value, maximum value, average value and median value.

Consider the following cases:

1st case: The bottom of the threshold is 0

When sup (m)=n, that means all survey parameters are lower than the permitted concentration limit, then by formula (12), we have

$$T_m = 100(1-1) = 0 \quad (13)$$

2nd case: The upper limit of the threshold is 100

When inf (m)=0, that means all n parameters are higher than the permitted concentration limit

$$T_m = 100(1-0) = 100 \quad (14)$$

3rd case: Light pollution threshold

When m=max (n)=n - 1, it means that there is n-1 parameter lower than the permitted concentration limit

$$T_m = 100\left(1-\frac{n-1}{n}\right) = \frac{100}{n} \quad (15)$$

4th case: Heavy pollution threshold:

For n positive integers, m is the median of n, $n \geq 2$ and m=0, 1, 2, ..., so two cases occur:

If n is even, then $m = \frac{n}{2}$, $T_m = 100\left(1 - \frac{n}{2n}\right) = 50$ (16)

If n odd, then $m = \frac{n+1}{2}$, $T_m = 100\left(1 - \frac{n+1}{2n}\right) = 50\frac{n-1}{n}$ (17)

5th case: Very heavy pollution threshold:

When m=min (n)=1, there is only 1 parameter smaller than permitted standard (others are higher than permitted standard), $T_m = 100\left(1 - \frac{1}{n}\right) = 100 \times \frac{n-1}{n}$ (18)

6th case: Non-polluted threshold

It is the mean value of the bottom of the threshold and light pollution threshold:

$$T_m = \frac{1}{2}\left(0 + \frac{100}{n}\right) = \frac{50}{n} \quad (19)$$

The evaluation hierarchy of RAPI$_d$

The set of thresholds (13)-(19) we have the evaluation hierarchy presented in Table 1.

When n=2 (even), there are no heavy and very heavy levels of pollution, Table 1 has three levels, where Serious pollution level is defined: $\frac{100}{n} < I \leq 100$

When n=3 (odd), there is no heavy pollution level, Table 1 has 4 levels, the level of very heavy pollution is defined:

$$\frac{100}{n} < I \leq 100\frac{n-1}{n}$$

Method of calculating the temporary weights $W_i^{'}$ and final weights Wi of parameters

Temporary weights C_i^* are standardized to convert the C_i^* into non-dimensional. It denotes the relationship of parameters i with standards j (1 h, 8 h and 24 h):

Temporary weights $W_i^{'}$ is calculated by formula:

$$W_i^{'}(S_j) = \frac{\sum_{j=1}^{m} C_i^*(S_j)}{m \times C_i^*(S_j)} \quad (20)$$

The final weights W_i is calculated by formula:

$$W_i(S_j) = \frac{W_i^{'}(S_j)}{\sum_{i=1}^{n} W_i^{'}(S_j)} \quad (21)$$

Easy to see: $\sum_{i=1}^{n} W_i = 1$ (22)

Where: S_j=standard of parameter i (1 h/8 h/24 h), m=number of standard, m=2 or m=3; n=number of parameter having same standard.

Frequency of pollution

To assess the air pollution variations by months in each year, the daily means of the $RAPI_d$ indices are not taken to avoid "virtual" effects occurring. It is necessary to calculate the frequency of f (%) of RAPId by month by the following formula:

$$f(\%) = \frac{\text{The total of the } RAPI_d \text{ has the same level of pollution in each month}}{\text{The total of all the } RAPI_d \text{ in each month}} \times 100 \quad (23)$$

RESULTS AND DISCUSSION

Results of calculations

Place n=5 in Table 1, resulting in the rating hierarchy presented in Table 2.

Using the formulas (20)-(22), we have the weights W_i' and Wi presented in Table 3.

It can be seen from Table 4, there is no value q_i=1, so formulae (6), (7), (8), (11) are applied and we have:

$P_m = \sum_{1}^{8} Wi \times (1 - qi) = W_{SO2}(1h) \times (1 - q_{SO2}(1h)) + W_{CO}(1h) \times (1 - q_{CO}(1h)) + W_{NO2}(1h) \times (1 - q_{NO2}(1h)) + W_{O3}(1h) \times (1 - q_{O3}(1h)) + W_{CO}(8h) \times (1 - q_{CO}(8h)) + W_{O3}(8h) \times (1 - q_{O3}(8h)) + W_{SO2}(24h) \times (1 - q_{SO2}(24h)) + W_{NO2}(24h) \times (1 - q_{NO2}(24h))$=0.18 × (1 - 0.137) + 0.17 × (1 - 0.156) + 0.2 × (1 - 0.563) + 0.23 × (1 - 0.103) + 0.6 × (1-0.354) + 0.4 × (1 - 0.102) + 0.41 × (1 - 0.128) + 0.32 × (1 - 0.496)=1.856

$P_k = \sum_{1}^{2} Wi(qi-1) = W_{PM10}(1h) \times (q_{PM10}(1h) - 1) + W_{PM10}(24h) \times (q_{PM10}(24h) - 1)$=0.22 × (1.389 - 1) + 0.27 × (1.586 -1)=0.244

$P_n = P_m + P_k$=2.100

$$RAPI = 100 \times (1 - \frac{Pm}{Pn}) = 100 \times (1 - \frac{1.856}{2.100}) = 11.608$$

From Table 2, it can be indicated that air quality is light level.

Above calculation is applied to other days in a similar way.

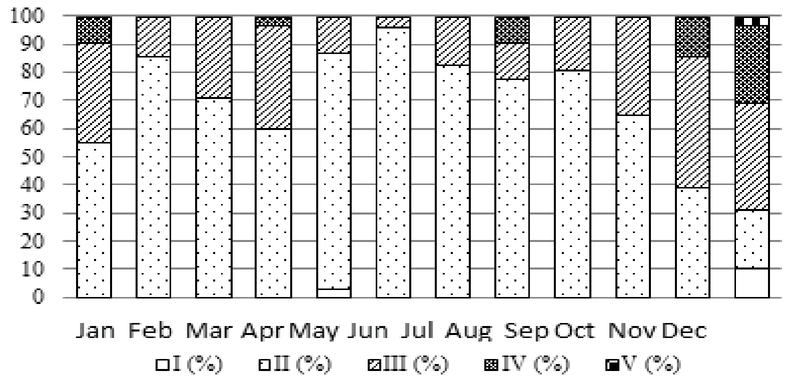

Figure 1: Frequency of air pollution level around the Van Cu station by month by $RAPI_d$ in 2016 [14]

Table 1: Rating scale of RAPId=I

n even	n odd	Level of pollution	Color	Warning level to health
$100\frac{n-1}{n} < I \le 100$	$100\frac{n-1}{n} < I \le 100$	Serious pollution (Dangerous)	Brown	Serious effected on health
$50\frac{n-1}{n} < I \le 100\frac{n-1}{n}$	$50\frac{n-1}{n} < I \le 100\frac{n-1}{n}$	Very heavy pollution (very bad quality)	Red	Very effected on health
$\frac{100}{n} < I \le 50\frac{n-1}{n}$	$\frac{100}{n} < I \le 50\frac{n-1}{n}$	Heavy pollution (bad quality)	Orange	Effected health
$\frac{50}{n} < I \le \frac{100}{n}$	$\frac{50}{n} < I \le \frac{100}{n}$	Light pollution (Fair quality)	Yellow	Effected on the sensitive people
$0 \le I \le \frac{50}{n}$	$0 \le I \le \frac{50}{n}$	No pollution (Good quality)	Green	No effected

Note*:* Special case

n odd	No	Level of pollution	Color	Warning level to health
$80<I \le 100$	V	Serious pollution (Dangerous)	Brown	Serious effected on health
$40<I \le 80$	IV	Very heavy pollution (very bad quality)	Red	Very effected on health
$20<I \le 40$	III	Heavy pollution (bad quality)	Orange	Effected health
$10<I \le 20$	II	Light pollution (Fair quality)	Yellow	Effected on the sensitive people
$0<I \le 10$	I	No pollution(Good quality)	Green	No effected

Table 3: Weights of 5 surveyed parameters according to Vietnamese technical regulation 05:2013/MVNRE for standards 1 h, 8 h and 24 h [15]

No.	Parameter (µg/m³)	Average standard 1 h	Average standard 8 h	Average standard 24 h	W' (1 h)	W' (8 h)	W' (24 h)	W (1 h)	W (8 h)	W (24 h)
1	SO_2	350	-	125	0.67	-	1.90	0.18	-	0.41
2	CO	30000	10000	-	0.66	2.00	-	0.17	0.60	-
3	NO_2	200	-	100	0.75	-	1.50	0.20	-	0.32
4	O_3	200	120	-	0.80	1.33	-	0.23	0.40	-
5	PM_{10}	300	-	200	0.83	-	1.25	0.22	-	0.27
$\sum W_i$								1	1	1

Note*:* " - ": no requirement

Table 4: Database to calculate the RAPI on 1/1/2016, in which, $C_{i\,Max}$(1 h) , $C_{i\,Max}$(8 h) is the highest values of parameter i; $\overline{C}_i$(24 h) is the average value of parameter i; q_i is the individual index of parameter i

No	Parameters (µg/m3)	C_iMax(1h)	q_i(Average standard 1-hr)	C_iMax(8h)	q_i(Average standard 8-hr)	$\overline{C}_i$(24h)	q_i(Average standard 24-hr)
1	SO_2	48.06	0.137			15.941	0.128
2	CO	4686	0.156	3542	0.354		
3	NO_2	112.5	0.563			49.576	0.496
4	O_3	20.6	0.103	12.24	0.102		
5	PM_{10}	416.85	1.389			317.206	1.586

Table 5. Frequency of air pollution around the station Nguyen Van Cu 2016

Month	f % ($RAPI_d$)					
	I (%)	II (%)	III (%)	IV (%)	V (%)	$\sum f(\%)$
1	0	54.8	35.5	9.7	0	100
2	0	85.7	14.3	0	0	100
3	0	71	29	0	0	100
4	0	60	36.7	3.3	0	100
5	3.4	83.3	13.3	0	0	100
6	0	96	4	0	0	100
7	0	82.6	17.4	0	0	100
8	0	77.4	12.9	9.7	0	100
9	0	80.8	19.2	0	0	100
10	0	64.7	35.3	0	0	100
11	0	39.3	46.4	14.3	0	100
12	10.4	20.7	37.9	27.6	3.4	100
Rainy season (%)	25	59	34	20	0	
Dry season (%)	75	41	66	80	100	
$\sum R+D(\%)$	100	100	100	100	100	

Note*:* A rainy season is from April to September, dry season is from October to March

Frequency of pollution f (%)

Use formula (2), (3), (4), (5), (6), (7) and (8) to calculate RAPId according to Equation (11), then apply formula (23). Results of frequency of pollution f (%) presented on Table 5 and frequency chart of months in 2016 is presented in Figure 1.

DISCUSSION

Comparison by month

Calculation result based on index $RAPI_d$ shows the air pollution levels according to rating scale from grade I to grade V, of which the $RAPI_d$ has two levels in February, March, June, July, September, October, the $RAPI_d$ values vary from 4 to 96; the $RAPI_d$ has three levels in January, April, May, August, November, the $RAPI_d$ values vary from 3.4 to 83.3, and the $RAPI_d$ has five levels in December with the $RAPI_d$ values vary from 3.4 to 37.9 (Table 5).

Comparison by season

Result of $RAPI_d$ shows that the pollution level of ambient air at Nguyen Van Cu station in the dry season (from October to March) is almost worse than the rainy season (from April to September). This matches the physical sense: in the rainy season, radiation intensity, air temperature and humidity in Hanoi are usually higher than in the dry season, therefore the intensity of atmospheric turbulence is strong, causing atmospheric conditions to become unstable, and the air to spread and diffuse intensively into the higher atmospheric layers. In the dry season, radiation intensity, air temperature and humidity in Hanoi are usually lower than in the rainy season, intensity of turbulent exchange is weak, making atmospheric condition either stable or very stable, especially, in cases of high temperature inversion, leading to weak intensity of turbulent diffusion of atmosphere. The pollutants are mainly concentrated in the atmospheric layer close to the ground, which increases the level of pollution on the ground surface in comparison with the rainy season.

CONCLUSION

The $RAPI_d$ (Relative Air Pollution Index) has overcome some of the limitations of the API/AQI indices being used in the world and in Vietnam. The $RAPI_d$ rating hierarchy is set based on mathematical conditions: infimum (inf), supremum (sup), minimum value, maximum value), Mean value and median value; The weight of each parameter is calculated according to the standard (1 h, 8 h and 24 h) of each country; The $RAPI_d$ and the frequency of pollution f (%) by month in each year are not affected by virtual effects (Virtual effects includes eclipsing and ambiguity. Eclipsing usually happens with aggregate index which is arimethmetic means of individual indicies. Therefore, individual indicies are much higher than standard value will be eclipsed by other indicies which are much lower than standard values. About ambiguity, it is also aggregate index without considering weight of individual indicies and evaluation hierarchy is self-regulation so the calculated aggregate indicies can be not suitable with the monitoring data). The $RAPI_d$ can be extended to the number of toxic gas parameters (not the basic parameters) with $n \geq 2$, the toxic gas parameters are in the standard of each country.

$RAPI_d$ was calculated experimentally for the Nguyen Van Cu automatic observation station. The results showed that the frequency of pollution f (%) was consistent with the level of air pollution around Nguyen Van Cu area (characterizing for ambient air of the traffic areas in Hanoi, Vietnam) for rainy season and dry season in 2016.

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REFERENCES

[1] Ott WR, Thom GC. Air pollution indices in United States and Canada – The present picture. National Meeting of the American Chemical Society, New York, NY, **1976**.

[2] Ott WR. Environmental indices - Theory and practice. Ann Arbor Science, New York, USA, **1978**, 147-169.

[3] Wallace, Lance A, Wayne Ott R. Rapid techniques for calculating the pollutant standards index (PSI). U S Environmental Protection Agency, Washington, DC, EPA-600/4-78-002, **1978**.

[4] Environmental Protection Agency. Guideline for reporting daily air quality: Air quality index (AQI). United States, **2006**.

[5] http://www.epd.gov.hk/epd/english/environmentinhk/air/air_quality/air_quality.html

[6] http://www.semc.gov.cn/

[7] http://www.nea.gov.sg/anti-pollution-radiation-protection/air-pollution-control/psi/psi

[8] Hoang XC, Hoang TT. Assess the development of air quality by pollution coefficient (API) through data of the automatic measurement station Lang, Hanoi 2004-2008. *Journal of the National University Hanoi, Natural Sciences and Technology*, **2010**, 26: 678.

[9] Vietnam Environment Administration Guidance for calculating AQI (Quality Index of Air Environment), **2011**.

[10] Nghiem TD, Dinh TH, Nguyen TD. Study the application of air quality index (AQI) for management of air quality. *J Hydrometeorol*, **2012**, 613: 13-16.

[11] Berliand ME. Forecast and atmospheric contamination. Hydro meteorological Publishing House, Leningrad, Russia, **1985**.

[12] Kyrkilis G, Chaloulakou A, Kassomenos PA. Development of an aggregate Air Quality Index for an urban Mediterranean agglomeration: Relation to potential health effects. *Environ Int*, **2007**, 33: 670-676.

[13] Vietnam Pollution Control Department. Build a set of indicators encompassing the area of air pollution, **2010**.

[14] Van Cu N. The monitoring station, Hanoi, Vietnam.

[15] Vietnamese technical regulation 05: **2013**/MVNRE (Vietnamese).