ENVIRONMENTAL QUALITY ASSESSMENT USING AGGREGATE INDEX

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1. AN OVERVIEW

❖ Air quality:

There are **four main methods** to assess the environmental quality:

- In some countries, including Vietnam, taking the highest value of the individual indices according to the approximation of curves by line segments method of US Environmental Protection Agency [1,2,3,6]:

$$EQI = \max\left(I_p\right) \qquad (1)$$

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo} \qquad (2)$$

- Taking the summation of the individual indices q_i (according to the approach of the former Soviet Union and some countries) [4]:

$$EQI = \sum_{i=1}^{n} W_i q_i \qquad (3)$$

$$EQI = \sum_{1}^{n} W_i q_i \times 100 \qquad (4)$$

- Taking the arithmetic means or geometric means of the individual indices (Vietnam Department of pollution control and some countries) [5]:

$$\overline{EQI} = \frac{1}{n}\sum_{i=1}^{n} W_i q_i \qquad (5)$$

$$\overline{EQI} = \frac{1}{n}\sum_{i=1}^{n} W_i \left[q_i \times 100\right] \qquad (6)$$

$$EQI^{*} = \left[\prod_{1}^{n}\left(W_i q_i\right)\right]^{1/n} \qquad (7)$$

- Combination of arithmetic means or geometric means [7].

❖ **Water quality:** [10-24]

❖ **Soil quality:** [25-28]

2. THE LIMITATIONS OF ABOVE MENTIONED METHOD

- The hierarchical scale of the environmental assessment is self-regulated (5-7 levels).
- The weighting factor of a parameter is subjectively defined by the criteria of experts.
- Some methods cause the ambiguity and eclipse (collectively called "Virtual effect").
- American method requires users to set up lookup tables or diagrams, so it is not convenient for application into reality.

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX BY PHAM NGOC HO

To overcome some of these limitations of EQI, Pham Ngoc Ho proposed a new approach to develop index for air, water and soil quality assessment, which is called the relative environmental quality index (REQI) [8-9; 22-26].

There are two approaches to build REQI:

- For air quality (set E=A; Q=P):

$$RAPI = 100 \times \left(1 - \frac{P_m}{P_n}\right) \quad (8)$$

- For water and soil:

Set E=W:

$$RWQI = 100 \times \left(1 - \frac{P_k}{P_n}\right) \quad (9)$$

Set E=S:

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

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

Where:

$$P_m = \sum_{1}^{m_1} W_i q_i + \sum_{1}^{m_2} W_i (1 - q_i) \quad (11)$$

$$P_k = \sum_{1}^{k} W_i (q_i - 1) \quad (12)$$

$$P_n = P_m + P_k \quad (13)$$

m_1 is the number of parameters with q_i=1,

m_2 is the number of parameters with q_i<1,

k is the number of parameters with q_i>1,

n is the number of surveyed parameters.

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

- **Air:**

$$q_i = \frac{C_i}{C_i^*}$$

C_i - is the actual monitoring value of parameter i

C_i^* - is the permitted limit value of parameter i

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

- **Water: There are 3 cases:**

✓ **Group below in environmental regulation** (BOD_5, COD, Coliform, heavy metals as Hg, As...): $q_i = \frac{C_i}{C_i^*}$

✓ **Group above in environmental regulation** (DO): $q_{DO} = \frac{C_{DO}^*}{C_i}$

✓ **Group in the interval [a,b]** (pH):

- If $C_i \leq a$ → $q_{pH} = \frac{a}{C_i} \geq 1$ (water with poor quality), when q =1 → water with moderate quality
- If $a < C_i < b$ → $q_i = \frac{b - C_i}{a - b} < 1$ (water with good quality)
- If $C_i \geq b$ → $q_i = \frac{C_i}{b} \geq 1$ (water with poor quality), when q =1 → water with moderate quality

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

- **Soil: There are 3 cases:**

✓ **Group below in environmental regulation** (the heavy metals group) => $q_i = \frac{C_i}{C_i^*}$

✓ **Group in the interval [a,b]** (the group of total content of bioelements and the group of content of available forms of bioelements)

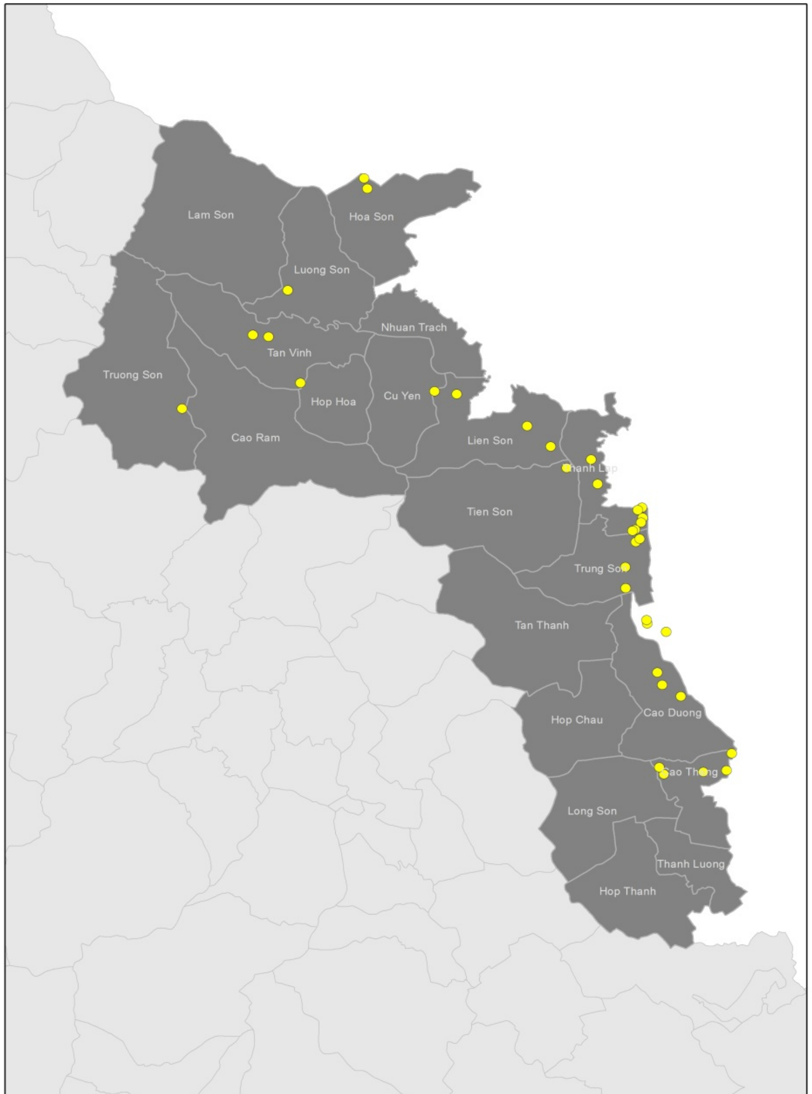
- Nếu $C_i < a$ → $q_i = \frac{a}{C_i} > 1$ (Soil with poor quality)
- Nếu $a \le C_i \le b$ → $q_i = 1$ (Soil with moderate quality)
- Nếu $C_i > b$ → $q_i = \frac{b}{C_i} < 1$ (Soil with good quality)

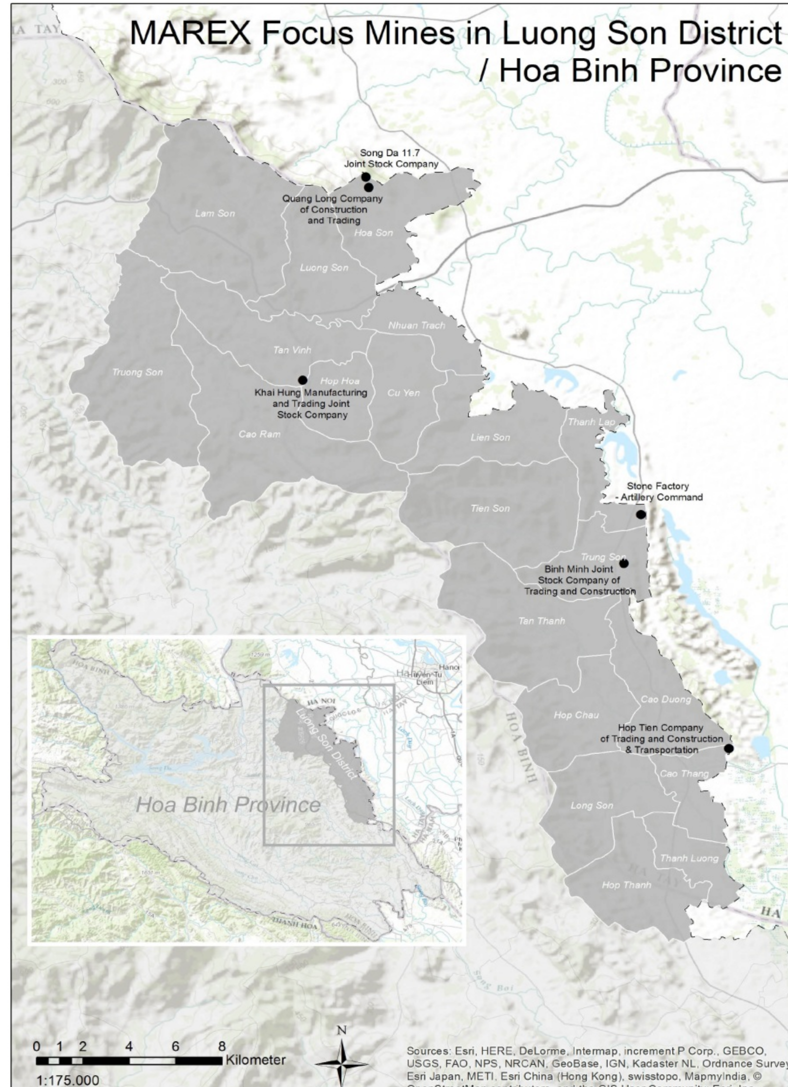
3.1.2. Hierarchical scale for air pollution assessment

Table 2 - Hierarchical scale for air pollution assessment of RAPI/RAPI* (6 levels)

n even	n odd	Level of pollution	Color
$100\frac{n-1}{n} < RAPI_h \leq 100$	$100\frac{n-1}{n} < RAPI_h \leq 100$	Dangerous[6]	Brown
$50 < RAPI_h \leq 100\frac{n-1}{n}$	$50\frac{n-1}{n} < RAPI_h \leq 100\frac{n-1}{n}$	Very heavy pollution[5]	Purple
$\frac{100}{n} < RAPI_h \leq 50$	$\frac{100}{n} < RAPI_h \leq 50\frac{n-1}{n}$	Heavy pollution[4]	Red
$0 < RAPI_h \leq \frac{100}{n}$	$0 < RAPI_h \leq \frac{100}{n}$	Light pollution[3]	Orange
$0,5 < RAPI_h^* \leq 1$	$0,5 < RAPI_h^* \leq 1$	Borderline polution[2]	Yellow
$0 \leq RAPI_h^* \leq 0,5$	$0 \leq RAPI_h^* \leq 0,5$	Non-polluted[1]	Green

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)





3.1. RAPI (air quality of 3 mines)

3.1.1. The final weighting factors Wi of parameters

Table 1 - The final weighting factors Wi of surveyed parameters

No.	Parameters	Unit	TCVN 3733/BYT			QCVN 05:2013/BTNMT		
			the permmited limit value	The temporary weighting factors W'	The final weighting factors W	the permmited limit value	The temporary weighting factors W'	The final weighting factors W
1	TSP	µg/m³	4000	3.210	0.046	300	20.700	0.206
2	SO2	µg/m³	10000	1.284	0.018	350	17.743	0.176
3	NO2	µg/m³	10000	1.284	0.018	200	31.050	0.308
4	O3	µg/m³	200	64.200	0.913	200	31.050	0.308
5	CO	µg/m³	40000	0.321	0.005	30000	0.207	0.002
	$\sum W_i$				1			1

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

Table 3 - Hierarchical scale for air pollution assessment of RAPI/RAPI* with n=5

n odd	Mức độ ô nhiễm	Màu sắc
$80 < RAPI_h \leq 100$	Dangerous	Brown
$40 < RAPI_h \leq 80$	Very heavy pollution	Purple
$20 < RAPI_h \leq 40$	Heavy pollution	Red
$0 < RAPI_h \leq 20$	Light pollution	Orange
$0,5 < RAPI_h^* \leq 1$	Borderline polution	Yellow
$0 \leq RAPI_h^* \leq 0,5$	Non-polluted	Green

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

The resulting bar chart of RAPI are shown in Figure 1 and figure 2.

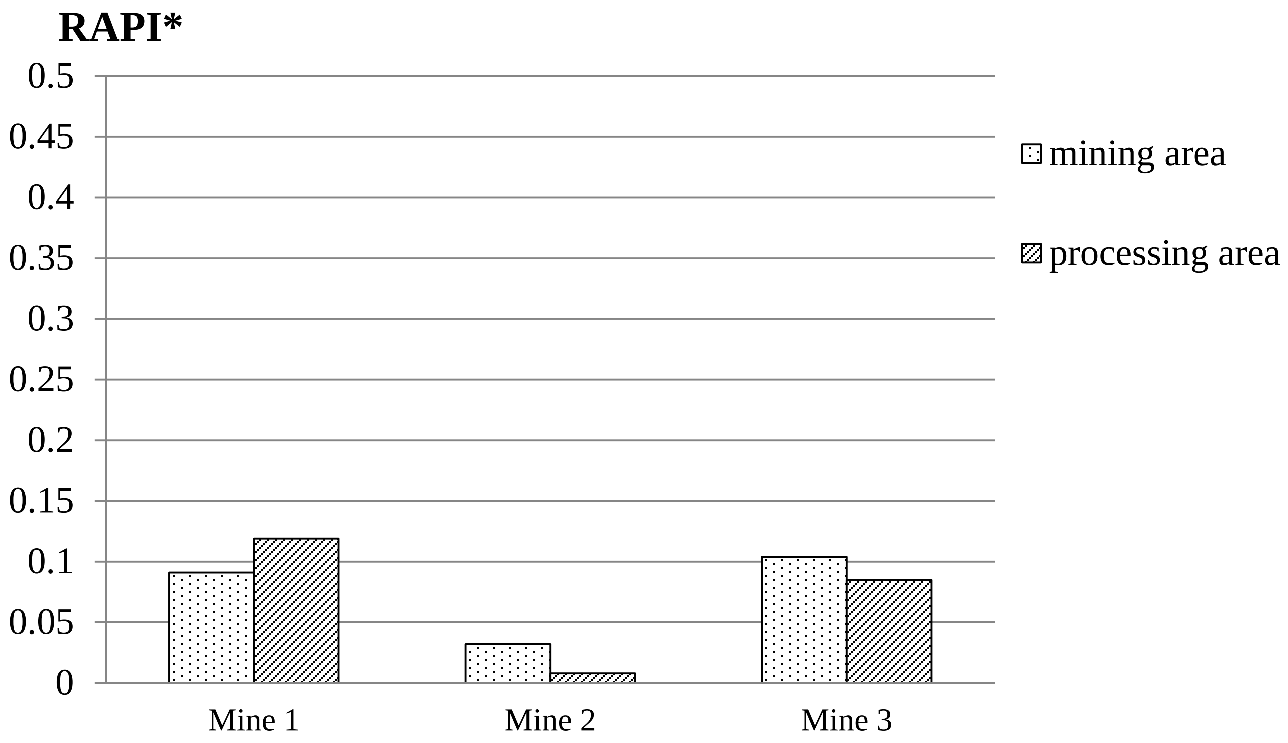


Figure 1 - Bar chart illustrates the relative air pollution index RAPI/RAPI* in mining areas and processing areas of 3 mines

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

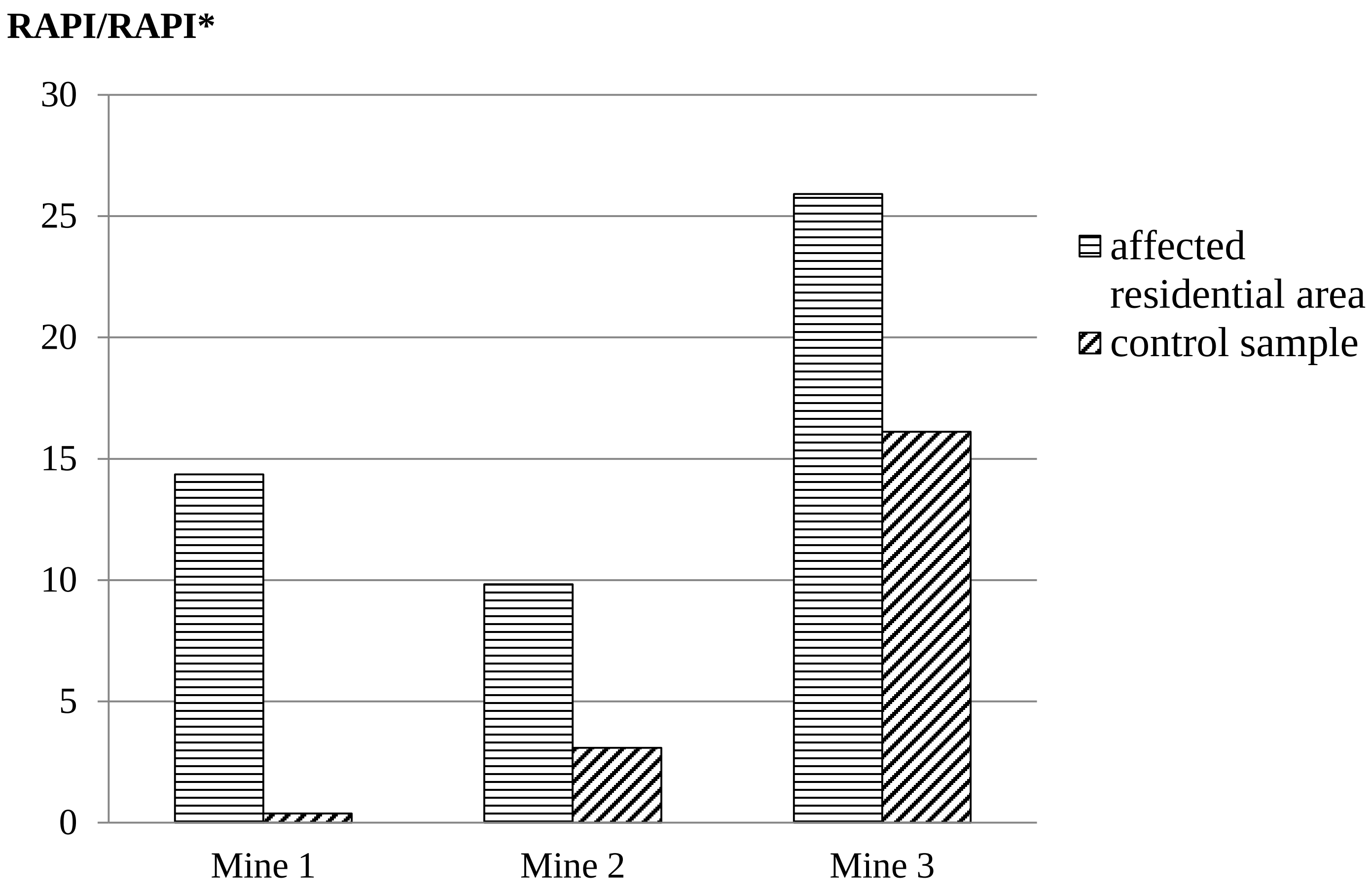


Figure 2 - Bar chart illustrates the relative air pollution index RAPI/RAPI* in the surrounding areas of 3 mines (residential areas)

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

	Air monitoring Coordinates	
	Longitude	Latitude
Mine 1 - Hop Tien Company of Trading and Construction & Transportation		
Mining area	105^{o}40'42,6“ E	20^{o}41'44,0“ N
Processing area	105^{o}40'37,2“ E	20^{o}41'37,1“ N
Affected residential area	105^{o}40'52,4“ E	20^{o}41'14“ N
Control sample	105^{o}41'22,4“ E	20^{o}40'54,1“ N
Mine 2 - Quang Long Company of Construction and Trading		
Mining area	105^{o}32'14,8“ E	20^{o}55'28,3“ N
Processing area	105^{o}32'12,2“ E	20^{o}55'12,3“ N
Affected residential area	105^{o}32'06,3“ E	20^{o}55'19,8“ N
Control sample	105^{o}32'31,0“ E	20^{o}54'55,1“ N
Mine 3 - Khai Hung Manufacturing and Trading Joint Stock Company		
Mining area	105^{o}30'51,7 "E	20^{o}50'32" N
Processing area	105^{o}30'54,1" E	20^{o}50'25,8" N
Affected residential area	105^{o}30'54,4" E	20^{o}50'13,2" N
Control sample	105^{o}31'0,89" E	20^{o}50'16,6" N

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

3.2. ReWQI (surface water: lake, stream)

3.2.1. The final weighting factors Wi of surveyed parameters

Table 4 - The temporary weighting factors and the final weighting factors

TT	Parameters	Unit	the permmited limit value		The temporary weighting factors W'		The final weighting factors W	
			A		A		A	
			A1	A2	A1	A2	A1	A2
1	pH		6 - 8.5	6 - 8.5	1	1	0.063	0.088
2	Dissolved Oxygen (DO)	mg/l	≥ 6	≥ 5	1.1	0.9	0.069	0.080
3	TSS	mg/l	20	30	1.25	0.83	0.078	0.073
4	COD	mg/l	10	15	1.25	0.83	0.078	0.073
5	Ammonium (NH_4^+)	mg/l	0.3	0.3	1	1	0.063	0.088
6	Oils & grease	mg/l	0.3	0.5	1.33	0.8	0.084	0.070
7	Coliform	MPN or CFU/100ml	2500	5000	1.5	0.75	0.094	0.066
8	Fe	mg/l	0.5	1	1.5	0.75	0.094	0.066
9	As	mg/l	0.01	0.02	1.5	0.75	0.094	0.066
10	Pb	mg/l	0.02	0.02	1	1	0.063	0.088
11	Zn	mg/l	0.5	1	1.5	0.75	0.094	0.066
12	Cd	mg/l	0.005	0.005	1	1	0.063	0.088
13	Hg	mg/l	0.001	0.001	1	1	0.063	0.088
	$\sum W_i$						1	1

3.2.2. Hierarchical scale for water quality assessment

Table 5 - Hierarchical scale for water quality assessment of ReWQI=I (5 levels)

n even	n odd	Water quality	Colour
$50\frac{2n-1}{n} < I \leq 100$	$50\frac{2n-1}{n} < I \leq 100$	Very good/Good (Very good when I = 100)	Green
$100\frac{n-1}{n} < I \leq 50\frac{2n-1}{n}$	$100\frac{n-1}{n} < I \leq 50\frac{2n-1}{n}$	Moderate	Yellow
$50 < I \leq 100\frac{n-1}{n}$	$50\frac{n-1}{n} < I \leq 100\frac{n-1}{n}$	Fair	Orange
$\frac{100}{n} < I \leq 50$	$\frac{100}{n} < I \leq 50\frac{n-1}{n}$	Poor	Red
$0 \leq I \leq \frac{100}{n}$	$0 \leq I \leq \frac{100}{n}$	Very Poor	Brown

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

Table 6 - Hierarchical scale for water quality assessment of ReWQI with n=13 parameters (set n=13 in Table 5)

n=13	Water quality	Colour
$96.15 < RSQI \leq 100$	Good/Very good[1] (Very good when I = 100)	Green
$92.31 < RSQI \leq 96.15$	Moderate[2]	Yellow
$46.15 < RSQI \leq 92.31$	Fair[3]	Orange
$7.69 < RSQI \leq 46.15$	Poor[4]	Red
$0 < RSQI \leq 7.69$	Very Poor[5]	Brown

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

The resulting bar chart of ReWQI is shown in Figure 3.

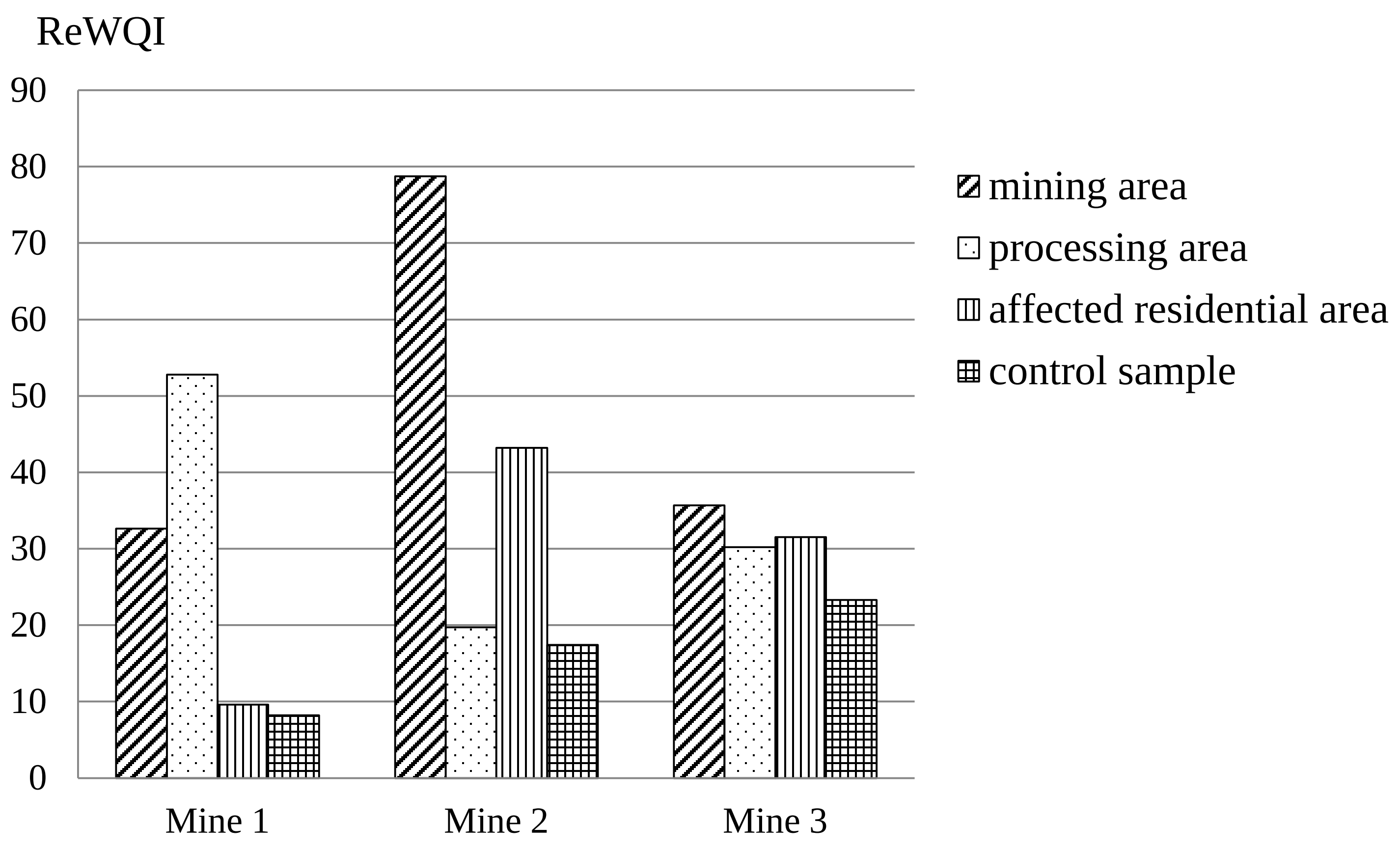


Figure 3 - Bar chart illustrates the surface water quality (lake, stream) of 3 mines by ReWQI

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

	Water monitoring Coordinates	
	Longitude	**Latitude**
Mine 1 - Hop Tien Company of Trading and Construction & Transportation		
Mining area	105º40'42.6"	20º41'44.0"
Processing area	105º40''37.2"	20º41'37.1"
Affected residential area	105º40'52.4"	20º41'14"
Control sample	105º41'22.4"	20º40'54.1"
Mine 2 - Quang Long Company of Construction and Trading		
Mining area	105º32'14.8"	20º55'28.3"
Processing area	105º32'12.2"	20º55'12.3"
Affected residential area	105º32'06.3"	20º55'19.8"
Control sample	105º32'31.0"	20º54'55.1"
Mine 3 - Khai Hung Manufacturing and Trading Joint Stock Company		
Mining area	105^{0}30'51.7"	20^{0}50'32"
Processing area	105^{0}30'54.1"	20^{0}50'25.8"
Affected residential area	105^{0}30'54.4"	20^{0}50'13.2"
Control sample	105^{0}31'0.89"	20^{0}50'16.6"

3.3. RSQI (soil quality)

3.3.1. The final weighting factors W_i of surveyed parameters

Table 7 - The final weighting factors W_i of surveyed parameters

No.	Parameters	Unit	The permmited limit value	The temporary weighting factors W'	The final weighting factors W
	The group of total content of bioelements				
1	OM	%	1.26 - 2.51	0.48	0.02
2	Total N	%	0.1 - 0.2	5.98	0.27
3	Total P_2O_5	%	0.06 - 0.1	14.94	0.68
4	Total K_2O	%	1 - 2	0.6	0.03
	$\sum W_i$				1
	The group of content of available forms of bioelements				
5	P_2O_5 bioavailable	mg/ kg soil	36 - 46	3	0.83
6	K_2O bioavailable	mg/ kg soil	100 - 150	0.6	0.17
	$\sum W_i$				1
	Heavy metals group				
7	Cd	mg/ kg soil	2	40.25	0.93
8	Cu	mg/ kg soil	50	1.61	0.04
9	Pb	mg/ kg soil	70	1.15	0.03
10	Zn	mg/ kg soil	200	0.4	0.01
	$\sum W_i$				1

3.3.2. Hierarchical scale for soil quality assessment

Table 8 - Hierarchical scale for soil quality assessment of RSQI=I

n even	n odd	Soil quality	Colour
$50\frac{2n-1}{n} < I \leq 100$	$50\frac{2n-1}{n} < I \leq 100$	Good/Excellent[1] Excellent when I =100 (no degration)	Xanh
$100\frac{n-1}{n} < I \leq 50\frac{2n-1}{n}$	$100\frac{n-1}{n} < I \leq 50\frac{2n-1}{n}$	Moderate[2] (Start degradation)	Vàng
$50 < I \leq 100\frac{n-1}{n}$	$50\frac{n-1}{n} < I \leq 100\frac{n-1}{n}$	Poor[3] (Degradation)	Da cam
$\frac{100}{n} < I \leq 50$	$\frac{100}{n} < I \leq 50\frac{n-1}{n}$	Very poor[4] (Strong degradation)	Đỏ
$0 \leq I \leq \frac{100}{n}$	$0 \leq I \leq \frac{100}{n}$	Hazardous[5] (Very strong degradation)	Nâu

Table 8 - Hierarchical scale for soil quality assessment of RSQI=I with n=10 surveyed parameters (set n=10 in Table 7)

n=10	Soil quality	Colour
95 < RSQI ≤ 100	**Good/Excellent[1]** **Excellent when RSQI =100 (no degration)**	Green
90 < RSQI ≤ 95	**Moderate[2]** **(Start degradation)**	Yellow
50 < RSQI ≤ 90	**Poor[3]** **(Degradation)**	Orange
10 < RSQI ≤ 50	**Very poor[4]** **(Strong degradation)**	Red
0 < RSQI ≤ 10	**Hazardous[5]** **(Very strong degradation)**	Brown

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

The resulting bar chart of RSQI is shown in Figure 4.

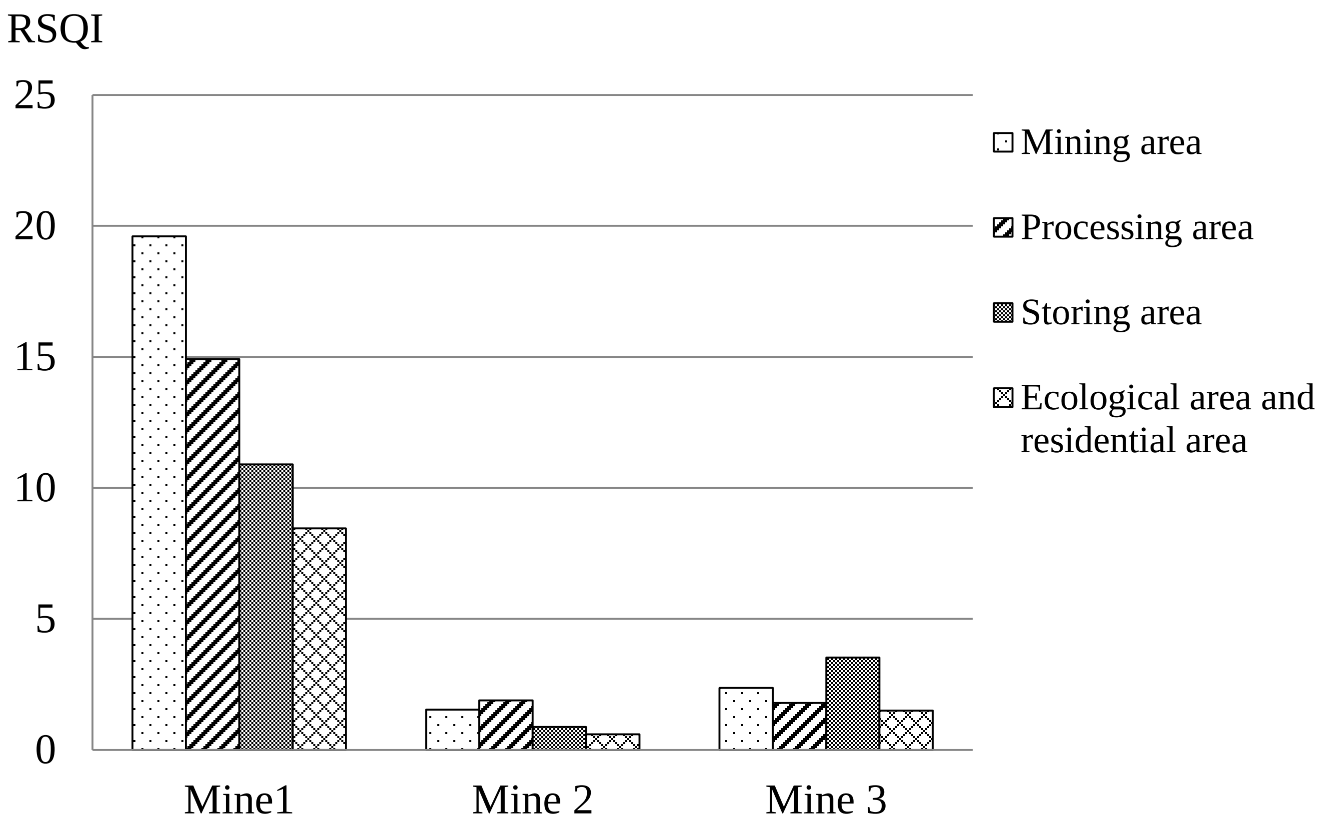


Figure 4 - Bar chart illustrates the soil quality of 3 mines by RSQI

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

	Soil mornitoring Coordinates	
	Longitude	Latitude
Mine 1 - Hop Tien Company of Trading and Construction & Transportation		
Mining area	105º40'48'' E	20º41' 36,7'' N
Processing area	105º40'38.8'' E	20º41' 45.2'' N
Storing area	105º40' 36.4'' E	20º41' 45.8'' N
Ecological and residential area	105º40' 57'' E	20º41' 11.8'' N
Mine 2 - Quang Long Company of Construction and Trading		
Mining area	105º32' 21.3'' E	20º55' 31'' N
Storing area	105º32' 9.8'' E	20º55' 13.7'' N
Ecological and residential area	105º32' 16.6'' E	20º55' 12'' N
Control sample	105º32' 30.5'' E	20º54.5' 6.8'' N
Mine 3 - Khai Hung Manufacturing and Trading Joint Stock Company		
Mining area	105º30'53.44'' E	20º50'34.25'' N
Processing area	105º30'50.04'' E	20°50'31.71'' N
Storing area	105º30'50.27'' E	20°50'34.07'' N
Ecological and residential area	105º30'55.49'' E	20°50'18.78'' N

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

Discussion: From these above bar charts:

- **Air:** The air quality in three surveyed mines is within the permitted limits of the regulation of Vietnam Ministry of Health for the working environment, but according to the technical regulation on ambient air quality (for surrounding areas where are affected), air quality is from light pollution to heavy pollution. According to individual indices, Total Suspended Particles (TSP) is main cause of air pollution.

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

- **Surface water:**

✓ The water quality in mining areas and processing areas (according to A1 and A2 standard of Vietnam technical regulation on surface water quality) is from poor to very poor, it can not be used for water supply purposes, just used for other purposes such as irrigating road and water traffic.

✓ For affected areas (residential areas), water is contaminated, water quality is from fair to poor. The result shows the signs of mercury (Hg) pollution (q_{Hg}=1,05-1,09).

3. METHOD FOR DEVELOPING THE AGGREGATE INDEX (CONTINUING)

- **Soil:**

✓ Mining area/ Processing area/ store area/ ecological and residential area is polluted, the soil quality is from poor to very poor (Strong degradation - very strong degradation respectively)

✓ These results are useful references for land reclamation in the process of environmental restoration after mine closure.

4. RECOMMENDATIONS TO REDUCE POLLUTION

- Spraying water after drilling and blasting in order to reduce environmental dust load.
- Setting up the suitable size of bulkheads in the raw materials processing area.
- Using cleaner production technology.
- Suppress dust by using water sprays on road transportation at least 3 times/day.
- The trucks going from the mine to the outside must be covered by canvas to avoid spillage and dust emissions.
- Covering product conveyors.

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Thank you for attention!