Hindawi Publishing Corporation
Applied and Environmental Soil Science
Volume 2015, Article ID 253729, 8 pages
http://dx.doi.org/10.1155/2015/253729

Research Article

Aggregate Indices Method in Soil Quality Evaluation Using the Relative Soil Quality Index

Ho Ngoc Pham,[1] Hai Xuan Nguyen,[1] Anh Ngoc Nguyen,[2] and Diep Ngoc Tran[1]

[1] *Research Centre for Environmental Monitoring and Modeling (CEMM), VNU University of Science, 334 Nguyen Trai Street, Thanh Xuan District, Hanoi 120000, Vietnam*
[2] *Faculty of Geography, Hanoi National University of Education, 136 Xuan Thuy Street, Cau Giay District, Hanoi 122000, Vietnam*

Correspondence should be addressed to Ho Ngoc Pham; hopn2008@yahoo.com.vn

Received 21 September 2015; Revised 25 October 2015; Accepted 2 November 2015

Academic Editor: Victor Kavvadias

This paper presents a new approach to assess the soil quality by aggregate indices using the Relative Soil Quality Index (RSQI) proposed by Ho Ngoc Pham. RSQI is integrated from the individual indices into a simple formula for overall assessment of the soil quality. RSQI is different from other approaches. Particularly, the individual indices and the weighting factors of Pham are calculated from the analytical laboratory data and the environmental standards, respectively, and not self-regulated as in methods of some other authors. In this paper, the authors applied the RSQI to assess the Soil Environmental Quality of rice intensive cultivation areas through a case study in Haiduong province in 2013. The RSQI is calculated for sampling points in 12 districts and simulated the Soil Environmental Quality on GIS map. The results show that the Soil Environmental Quality of rice intensive cultivation areas in Haiduong is predominantly divided into three levels: good, moderate, and poor. According to the report of General Statistics Office for Haiduong province, rice intensive cultivation areas in 2013 achieved a relatively high average rice yield of 5.90 tonnes per hectare; it means actual soil properties are in line with results of the research.

1. Introduction

The assessment of soil degradation in the world is primarily based on single criteria to build the assessment thresholds for each group of total content of bioelements, content of available forms of bioelements, heavy metals, and so forth, in which each parameter in the group of total content of bioelements and the group of content of available forms of bioelements is categorized into three levels: high, medium, and low or rich, moderate, and poor, respectively, to serve for the degradation assessment of agricultural land and forestry. The environmental quality index (EQI) approach to assess air, water, and soil was first mentioned in the work of Ott [1], and afterwards, the application of EQI to assess the soil quality (SQ) is continuously developed and widely used [2–7].

The soil degradation assessment in Vietnam has interested many scientists. Vietnamese scientists have made in-depth studies on the thresholds and the assessing scale for the group of total content of bioelements, content of available forms of bioelements and heavy metals, and so forth. In which, typical studies are of Nguyen [8], Le [9], Tran [10], Nguyen [11], Le and Tran [12], and the National Technical Standards on the soil environment for the heavy metals group [13]. However, the approach to assess soil degradation by aggregate indices in Vietnam is still new. Such approach was first mentioned in the dissertation of Nguyen in order to create an environmental land map at the provincial scale [14]. The author applied the Total Soil Quality Index (TSQI) proposed by Pham [15] to determine the Soil Environmental Quality for agricultural land (rice cultivated areas). Nevertheless, calculating the weighting factors of each group is complicated. Therefore, Pham developed the TSQI into the Relative Soil Quality Index (RSQI) which simplifies the calculation of the weighting factors of total content of bioelements, content of available forms of bioelements, pH_{KCl}, and heavy metals group in reality [16]. Because of the paper's scope, the authors only apply RSQI into aggregate assessment of the SQ of rice intensive areas in Haiduong province.

2. Materials and Method

2.1. Materials. (i) The research used the soil sample analysis data for 12 districts with rice intensive cultivation areas in Haiduong province [17].

(ii) Research materials of Vietnamese authors [8–12] and Vietnam's environmental regulations [13] were used to convert the categorized scale of individual index into the individual assessing scale of SQ which served for the calculation of the SQ assessment by aggregate indices, using RSQI.

2.2. Method

2.2.1. Formula of Relative Soil Quality Index (RSQI). RSQI is a new approach to assess the SQ by aggregate indices. It is based on the synthesis or integration of individual index q_i of n surveyed parameters in order to form a formula which simplifies the SQ assessment at each monitoring point. RSQI proposed by Pham is determined by the following formula [16]:

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

where

$$P_k = \sum_{i=1}^{k} W_i\left(q_i - 1\right), \quad (2)$$

$$P_m = \sum_{i=1}^{m_1} W_i q_i + \sum_{i=1}^{m_2} W_i\left(1 - q_i\right), \quad (3)$$

$$P_n = P_m + P_k, \quad (4)$$

$$n = m + k = m_1 + m_2 + k, \quad (5)$$

where P_n is the common sum (sum of separate sums P_k and P_m); P_m includes m of numbers of q_i with values ≤1; P_k includes k of numbers of q_i with values >1; n is the number of monitored parameters.

Noting. Formula (1) clearly shows that RSQI depends on the relative ratio P_k/P_n. The higher the value of the ratio is, the smaller the value of RSQI will be. Thus, the SQ is poorer.

(i) Calculating Individual Index q_i (Subindex) of Each Parameter i. To calculate RSQI in formula (1), we first need to calculate individual index as the following:

(a) The groups below in Vietnam's environmental regulation (to the heavy metals group) are

$$q_i = \frac{C_i}{C_i^*}. \quad (6)$$

There are three cases:

$$\begin{aligned} &\text{Case 1: If } C_i < C_i^* \text{ so } q_i < 1 \\ &(\text{Soil with good quality—nondegraded soil}), \\ &\text{Case 2: If } C_i = C_i^* \text{ so } q_i = 1 \\ &(\text{Soil with moderate quality—soil starting to degrade}), \\ &\text{Case 3: If } C_i > C_i^* \text{ so } q_i > 1 \\ &(\text{Soil with poor quality—degraded soil}). \end{aligned} \quad (7)$$

(b) The groups in the interval $[a, b]$ in Vietnam's environmental regulation (group of total content of bioelements, group of content of available forms of bioelements):

$$\begin{aligned} &\text{Case 1: If } C_i < a \text{ so } q_i = \frac{a}{C_i} > 1 \\ &(\text{Soil with poor quality—degraded soil}), \end{aligned} \quad (8)$$

$$\begin{aligned} &\text{Case 2: If } a \le C_i \le b \text{ so } q_i = \frac{C_i}{C_i^*} = 1 \\ &(\text{Soil with moderate quality—soil starting to degrade}), \end{aligned} \quad (9)$$

$$\begin{aligned} &\text{Case 3: If } C_i > b \text{ so } q_i = \frac{b}{C_i} < 1 \\ &(\text{Soil with good quality—nondegraded soil}). \end{aligned} \quad (10)$$

(ii) Calculating the Separate Sums P_k, P_m, and the Common Sum P_n Using Formulas (2) to (4). From (1) to (10),

C_i is the actual monitoring value of parameter i,

C_i^*, a, and b are the permitted limit values of parameter i,

m_1 is the number of parameters with $q_i = 1$ (as $C_i = C_i^*$),

m_2 is the number of parameters with $q_i < 1$,

k is the number of parameters with $q_i > 1$.

2.2.2. Calculating the Temporary Weighting Factors W_i' and the Final Weighting Factors W_i. W_i is the final weighting factors of the parameter i; W_i accounts for the importance which presents the relation between each parameter i; and j is the number of parameters of each examination group. The final weighting factor W_i is determined through the temporary weighting factor W_i' as follows.

(a) Groups Below in Environmental Regulation (Heavy Metals Group). W_i' is calculated by formula:

$$W_i' = \frac{(1/j)\sum_1^j C_i^*}{C_i^*} = \frac{\sum_1^j C_i^*}{j \times C_i^*}, \quad (11)$$

where C_i^* is allowance limited value of parameter i and j is the number of parameters selected by the group for examination.

(b) Groups in the Interval $[a,b]$ in Environmental Regulations (Group of the Total Content of Bioelements, Group of the Content of Available Forms of Bioelements). Consider parameter groups in the intervals: $[a_1,b_1],[a_2,b_2],[a_3,b_3],\ldots,[a_j,b_j]$.

The formula to calculate W_i' of parameter i for each group is as below:

$$W_i' = \frac{\sum_{i=1}^{j}(b_i - a_i)}{j \times (b_i - a_i)}, \quad (12)$$

where the environmental regulation value of parameter i in the interval $[a_i,b_i]$ is $(b_i - a_i)$ and j is the number of parameters of each group.

Example. There are 2 parameters ($j = 2$) given in $[a_1,b_1]$, $[a_2,b_2]$. The environmental regulation values of $[a_1,b_1]$ and $[a_2,b_2]$ are $(b_1 - a_1)$ and $(b_2 - a_2)$, respectively. According to (12), we calculate

$$W_1' = \frac{(b_1 - a_1) + (b_2 - a_2)}{2 \times (b_1 - a_1)}; \quad W_2' = \frac{(b_1 - a_1) + (b_2 - a_2)}{2 \times (b_2 - a_2)}. \quad (13)$$

(c) Calculate the Final Weighting Factor of Parameter i (W_i). The final weighting factor of each parameter i of each group is identified by the following formula:

$$W_i = \frac{W_i'}{\sum_1^j W_i'} \quad (14)$$

$$\text{Obviously, } \sum_1^j W_i = 1, \quad (15)$$

where j is the number of parameters selected by the group for examination.

2.2.3. Hierarchy for Assessing SQ of RSQI Index [16]. See Table 1.

2.2.4. Converting Hierarchy for Assessing Criterion to Hierarchy for Assessing SQ. To apply (7)–(10) formulas, first, levels and hierarchy for assessing criterion need to be converted to levels and hierarchy for assessing soil quality (SQ) for each individual criterion.

The conversion Tables 2, 3, and 4 are based on the application of Vietnam research materials about criterion for assessing soil groups.

3. Results and Discussion

3.1. Results

3.1.1. Hierarchy for Assessing SQ of RSQI. The hierarchical scale for aggregate assessing soil quality of RSQI corresponding to $n = 10$ parameters in Table 1 is shown in Table 5.

3.1.2. Calculating the Temporary Weighting Factors W_i' and the Final Weighting Factors W_i. (i) Calculating the Temporary Weighting Factors W_i' is as follows:

The group of heavy metals (formula (11)):

$$W_{\mathrm{Cd}}' = \frac{2 + 50 + 70}{3 \times 2} = 20.33; \quad W_{\mathrm{Cu}}' = \frac{2 + 50 + 70}{3 \times 50} = 0.81; \quad W_{\mathrm{Pb}}' = \frac{2 + 50 + 70}{3 \times 70} = 0.58. \quad (16)$$

The group of the total content of bioelements (formula (12)):

$$W_{\mathrm{OM}}' = \frac{(2.5 - 1.25) + (0.2 - 0.1) + (0.1 - 0.06) + (2 - 1)}{4 \times (2.5 - 1.25)} = \frac{2.39}{5} = 0.48;$$
$$W_{\mathrm{N_t}}' = \frac{2.39}{4 \times (0.2 - 0.1)} = 5.98; \quad W_{\mathrm{P_2O_{5t}}}' = \frac{2.39}{4 \times (0.1 - 0.06)} = 14.94; \quad W_{\mathrm{K_2O_t}}' = \frac{2.39}{4 \times (2 - 1)} = 0.60. \quad (17)$$

The group of the content of available forms of bioelements (formula (12)):

$$W_{\mathrm{N_{av}}}' = \frac{(8 - 2) + (4.6 - 3.6) + (15 - 10)}{3 \times (8 - 2)} = \frac{12}{18} = 0.67;$$
$$W_{\mathrm{P_2O_{5av}}}' = \frac{12}{3 \times (4.6 - 3.6)} = 4; \quad W_{\mathrm{K_2O_{av}}}' = \frac{12}{3 \times (15 - 10)} = 0.8. \quad (18)$$

(ii) Calculating the Final Weighting Factors W_i (formula (14)) is as follows:

$$W_{\mathrm{Cd}} = \frac{20.33}{20.33 + 0.81 + 0.58} = \frac{20.33}{21.72} = 0.93; \quad W_{\mathrm{Cu}} = \frac{0.81}{21.72} = 0.04; \quad W_{\mathrm{Pb}} = \frac{0.58}{21.72} = 0.03. \quad (19)$$

The final weighting factors of other parameters of total content of bioelements group and content of available forms of bioelements group are calculated, respectively, and results are shown in Table 6.

Table 1: Hierarchy for assessing SQ of RSQI = I index.

$I - n$ is even	$I - n$ is odd	SQ	Colour
$50\frac{2n-1}{n} < I \le 100$	$50\frac{2n-1}{n} < I \le 100$	Good/excellent ($I = 100$) (no degradation)	Green
$100\frac{n-1}{n} < I \le 50\frac{2n-1}{n}$	$100\frac{n-1}{n} < I \le 50\frac{2n-1}{n}$	Moderate (start degradation)	Yellow
$50 < I \le 100\frac{n-1}{n}$	$50\frac{n-1}{n} < I \le 100\frac{n-1}{n}$	Poor (degradation)	Orange
$\frac{100}{n} < I \le 50$	$\frac{100}{n} < I \le 50\frac{n-1}{n}$	Very poor (strong degradation)	Red
$0 \le I \le \frac{100}{n}$	$0 \le I \le \frac{100}{n}$	Hazardous (very strong degradation)	Brown

Note.
(i) When $n = 2$, the levels poor, very poor, and hazardous are overlapped; therefore the hierarchy will consist of only 3 levels; when $n = 3$, the levels very poor and hazardous are overlapped; therefore the hierarchy will consist of 4 levels.
(ii) When $W_i = 1$ in (2) and (3) formulas, RSQI does not have weighting factors.
(iii) Suggestions are the following:
(a) Good/excellent SQ does not need treatment.
(b) Moderate SQ needs to be monitored.
(c) Poor SQ needs to be properly fertilized.
(d) Very poor: hazardous SQ needs appropriate technological treatment for parameters significantly greater than acceptable standard.

Table 2: Converting hierarchy for assessing criterion to hierarchy for assessing SQ for the group of total content of bioelements.

Parameter	Criterion (%)	Hierarchy	Reference	Hierarchy for SQ ∈ [a, b] (%)	SQ
SOM	>2.5	High	Nguyen [8]	>2.5	Good
	1.25–2.5	Medium		1.25–2.5	Moderate
	<1.25	Low		<1.25	Poor
Total N	>0.2	Rich	Nguyen [11]	>0.2	Good
	0.1–0.2	Moderate		0.1–0.2	Moderate
	<0.1	Poor		<0.1	Poor
Total P	>0.1	Rich	Le [9]	>0.1	Good
	0.06–0.1	Moderate		0.06–0.1	Moderate
	<0.06	Poor		<0.06	Poor
Total K	>2	Rich	Tran [10]	>2	Good
	1-2	Moderate		1-2	Moderate
	<1	Poor		<1	Poor

3.1.3. Calculating q_i, P_{m1}, P_{m2}, P_k, P_n, and RSQI. Based on the research materials mentioned in Section 2.1, this research calculated individual parameter q_i using formulas (7)–(10), calculated P_k and P_n using formulas (2)–(4), and calculated the RSQI index using formula (1) for soil samples.

Because of the large sample size of the rice intensive cultivation areas surveyed in Haiduong including relatively high, medium, and low plains, we present how to calculate individual index q_i, the separate sums P_{m1}, P_{m2}, and P_k, and the common sum P_n ($n = 10$ parameters) in order to determine the RSQI of a particular soil sample S1 (Table 7). Thus, only result of other samples is shown in Table 8:

$$\begin{aligned}
P_{m_1} &= \sum_{i=1}^{3} W_i q_i = 0.02 \times 1 + 0.27 \times 1 + 0.12 \times 1 \\
&= 0.41; \\
P_{m_2} &= \sum_{i=1}^{5} W_i \left(1 - q_i\right) \\
&= 0.93 \times (1 - 0.01) + 0.04 \times (1 - 0.19) + 0.03 \\
&\quad \times (1 - 0.26) + 0.68 \times (1 - 0.6) + 0.73 \\
&\quad \times (1 - 0.3) = 1.76; \\
P_m &= P_{m_1} + P_{m_2} = 0.41 + 1.76 = 2.17; \\
P_k &= \sum_{i=1}^{2} W_i \left(q_i - 1\right) \\
&= 0.03 \times (1.64 - 1) + 0.15 \times (2.5 - 1) = 0.24; \\
P_n &= P_m + P_k = 2.17 + 0.24 = 2.41; \\
\text{RSQI} &= 100 \times \left(1 - \frac{P_k}{P_n}\right) = 100 \times \left(1 - \frac{0.24}{2.41}\right) \\
&= 90.04\text{—Moderate } \left(\text{according to Table 5}\right).
\end{aligned} \tag{20}$$

Table 3: Converting hierarchy for assessing criterion to hierarchy for assessing SQ for the group of content of available forms of bioelements.

Parameter	Criterion (mg·kg^{-1})	Hierarchy	Reference	Hierarchy for SQ ∈ $[a, b]$ (mg·kg^{-1})	SQ
N bioavailable	>80	Rich	Le and Tran [12]	>80	Good
	20–80	Moderate		20–80	Moderate
	<20	Poor		<20	Poor
P bioavailable	>46	Rich	Nguyen [11]	>46	Good
	36–46	Moderate		36–46	Moderate
	<36	Poor		<36	Poor
K bioavailable	>150	Rich	Tran [10]	>150	Good
	100–150	Moderate		100–150	Moderate
	<100	Poor		<100	Poor

Table 4: Converting hierarchy for assessing criterion to hierarchy for assessing SQ for heavy metals (mg·kg^{-1}, top soil).

Parameter	Land for agricultural purpose, reference (QCVN 03:2008/BTNMT) [9]	Hierarchy for SQ	SQ
(1) Cadmium (Cd)	2	<2	Good
		=2	Moderate
		>2	Poor
(2) Copper (Cu)	50	<50	Good
		=50	Moderate
		>50	Poor
(3) Lead (Pb)	70	<70	Good
		=70	Moderate
		>70	Poor

Table 5: Hierarchy for assessing SQ of RSQI = I with $n = 10$ parameters (Cd, Cu, Pb, SOM, N_t, P_t, K_t, N_{av}, P_{av}, and K_{av}).

RSQI	SQ	Colour
96–100	Good/excellent (I = 100) (no degradation)	Green
91–95	Moderate (start degradation)	Yellow
51–90	Poor (degradation)	Orange
11–50	Very poor (strong degradation)	Red
0–10	Hazardous (very strong degradation)	Brown

3.1.4. Creating the Soil Environmental Quality Map. From the Table 8, GIS technology with the spatial interpolation is applied to develop a simulated map of the SEQ assessment at the research area (Figure 1).

3.2. Discussion. (i) From Table 8, the SQ of rice intensive cultivation areas in Haiduong is good (nondegraded soil), moderate (soil starting degradation), and poor (degraded).

(ii) From the SQ map (Figure 1), incorporation with digital land use map (Haiduong DoNRE, 2013 [18]) will calculate the area of rice intensive cultivation for 12 districts in hectare that consists of 3 groups: good (nondegraded), moderate (starting degradation), and poor (degradation) Soil Environmental Quality. Particularly, the nondegraded area of the province is 25,106.85 ha (36.29%), the area which starts to degrade is 28,821.69 ha (41.66%), and the degraded area is 15,254.33 ha (22.05%). To districts in the provinces with the moderate and poor soil quality, the soil with moderate and poor quality needs to be monitored and fertilized properly.

(iii) According to the General Statistics Office (2013) [19], rice intensive cultivation areas in Haiduong province 2013 reached a relatively high average yield of 5.90 tonnes/ha. Because the RSQI approach shows results of the soil with good quality (nondegraded), the soil with moderate quality (start degraded), and the soil with poor quality (degraded), in which the degraded soil area accounts for only 22.05%, the soil quality of rice intensive cultivation areas is considered fairly good. Therefore, results of the research are in line with the relatively high yield in reality.

4. Conclusion

The research used the soil sample analysis data for twelve districts in Haiduong province to calculate individual indices for 10 parameters. The selected basic parameters are Cd, Cu, and Pb; P_t, SOM, N_t, and K_t; N_{av}, P_{av}, and K_{av}. The separate sum P_m is integrated from parameters group with $q_i \leq 1$ whereas the separate sum P_k is integrated from parameters group with $q_i > 1$. The common sum P_n equals P_m plus P_k. Using these sums, we calculated the RSQI values for 36 soil samples (16 samples in relatively high plains; 7 samples in medium plains; and 13 samples in low plains).

The results of calculations show that the soil sample with good quality ($q_i < 1$) accounts for 14/36 = 38.88%; the proportions of soil sample with medium quality ($q_i = 1$) and poor quality ($q_i > 1$) are equal; both of them account for 11/36 = 30.56%.

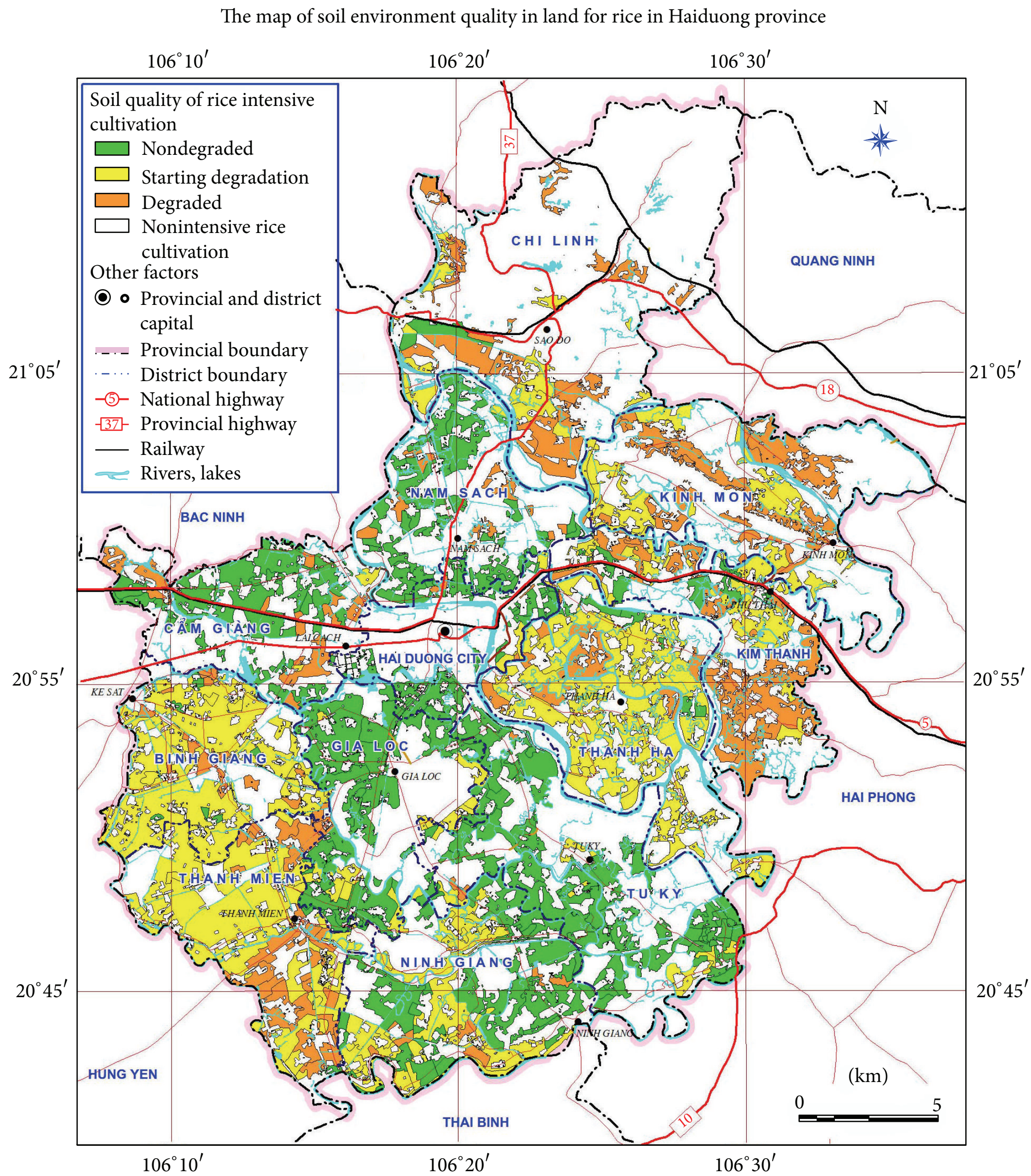

Figure 1: The SEQ map of rice intensive cultivation areas in Haiduong province in 2013 developed from the aggregate SQ assessment approach by using RSQI. (The map is scaled from a map with the scale of 1 : 100,000.)

Table 6: The temporary weighting factors W_i' and the final weighting factors W_i of 10 surveyed parameters.

Parameters	Heavy metals			Total content of bioelements				Content of available forms of bioelements		
	Cd	Cu	Pb	P_t	SOM	N_t	K_t	N_{av}	P_{av}	K_{av}
i	1	2	3	4	5	6	7	8	9	10
W_i'	20.33	0.81	0.58	14.94	0.48	5.98	0.60	0.67	4	0.80
W_i	0.93	0.04	0.03	0.68	0.02	0.27	0.03	0.12	0.73	0.15
$\sum W_i$		1			1				1	

Table 7: Calculating RSQI for a particular soil sample S1 with C_i, monitoring values.

Parameters	Heavy metals			Total content of bioelements				Content of available forms of bioelements		
	Cd	Cu	Pb	P_t	SOM	N_t	K_t	N_{av}	P_{av}	K_{av}
i	1	2	3	4	5	6	7	8	9	10
S1-C_i	0.01	9.55	18.58	0.17	1.64	0.18	0.61	61.60	155.60	40
q_i	0.01	0.19	0.26	0.60	1	1	1.64	1	0.30	2.50
W_i	0.93	0.04	0.03	0.68	0.02	0.27	0.03	0.12	0.73	0.15

Table 8: Results of calculation of RSQI based on monitoring data.

Soil samples	P_m	P_k	P_n	RSQI	SQ
(a) Relatively high plains					
S1	2.17	0.24	2.41	90.04	Moderate (starting degradation)
S3	1.93	0	1.93	100	Excellent (nondegraded)
S5	2.02	0.03	2.05	98.54	Good (nondegraded)
S7	2.03	0.12	2.15	94.42	Moderate (starting degradation)
S9	1.73	0.08	1.81	95.58	Good (nondegraded)
S11	2.30	0.16	2.46	93.50	Moderate (starting degradation)
S13	2.24	0.17	2.41	92.95	Moderate (starting degradation)
S15	2.01	0.23	2.24	89.73	Poor (degradation)
S17	1.94	0.15	2.09	92.82	Moderate (starting degradation)
S19	2.11	0.21	2.32	90.95	Moderate (starting degradation)
S21	1.95	0.22	2.17	89.86	Poor (degradation)
S23	2.05	0.20	2.25	91.11	Moderate (starting degradation)
S25	2.40	0.15	2.55	94.12	Moderate (starting degradation)
S27	2.21	0.09	2.30	96.09	Good (nondegraded)
S29	2.26	0.07	2.33	96.99	Good (nondegraded)
S31	2	0.66	2.66	75.19	Poor (degradation)
(b) Medium plains					
S57	1.82	0.22	2.04	89.22	Poor (degradation)
S59	1.72	0.08	1.80	95.56	Good (nondegraded)
S61	2.09	0.07	2.16	96.76	Good (nondegraded)
S63	2.04	0.45	2.49	81.93	Poor (degradation)
S65	2.03	0.40	2.43	83.54	Poor (degradation)
S67	2.32	0	2.32	100	Excellent (nondegraded)
S69	2.42	0	2.42	100	Excellent (nondegraded)
(c) Low plains					
S73	2.26	0.27	2.53	89.33	Poor (degradation)
S75	2.22	0.37	2.59	85.71	Poor (degradation)
S77	2.25	0.07	2.32	96.98	Good (nondegraded)
S79	1.64	0.03	1.67	98.20	Good (nondegraded)
S81	1.30	0.01	1.31	99.24	Good (nondegraded)
S83	2.04	0.37	2.41	84.65	Poor (degradation)
S85	2.33	0.16	2.49	93.57	Moderate (starting degradation)
S87	2.08	0.35	2.43	85.60	Poor (degradation)
S89	1.70	0.28	1.98	85.86	Poor (degradation)
S91	1.91	0.09	2.00	95.50	Good (nondegraded)
S93	1.93	0.14	2.07	93.24	Moderate (starting degradation)
S95	2.24	0.21	2.45	91.43	Moderate (starting degradation)
S97	2.12	0.11	2.23	95.07	Good (nondegraded)

Based on the hierarchical scale of soil quality of RSQI, the soil quality of rice intensive cultivation areas in Haiduong is predominantly divided into three levels: good (nondegraded soil), moderate (soil starting degradation), and poor (degraded soil), corresponding to 3 levels which were assessed by individual index.

The RSQI values are simulated on digital land use map by GIS technology. Each area has the same level described by the same colour on the map. Based on this map, calculating the area of each level (good, moderate, and poor) in hectare, the nondegraded area of the province is 25,106.85 ha (36.29%), the area which starts to degrade is 28,821.69 ha (41.66%), and the degraded area is 15,254.33 ha (22.05%). The map which is developed from the aggregate SQ assessment approach by using RSQI provides local managers an overview of the level of soil degradation before promptly taking appropriate measures to prevent or reduce pollution.

In summary, our results are consistent with the reality. Therefore, the calculation method using individual indices q_i and the aggregate index RSQI has a scientific basis and high accuracy; the method could be applied in warning service and environmental management at the provincial scale.

Disclosure

The content of this paper is one of the results of theses at level VNU, code QMT.12.01.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

The authors hereby express sincere thanks to the Ministry of Natural Resources and Environment and Vietnam National University for funding the subject.

References

[1] W. R. Ott, *Environmental Indices—Theory and Practice*, Ann Arbor Science Publishers, New York, NY, USA, 1978.

[2] M. C. Amacher, K. P. O'Neil, and C. H. Perry, "Soil vital signs: a new Soil Quality Index (SQI) for assessing forest soil health," Research Paper RMRS-RP-65WWW, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colo, USA, 2007.

[3] J. W. Doran and T. B. Parkin, "Quantitative indicators of soil quality: a minimum data set," in *Methods for Assessing Soil Quality*, J. W. Doran and A. J. Jones, Eds., Soil Science Society of America Special Publication no. 49, pp. 25–37, Soil Science Society of America, Madison, Wis, USA, 1996.

[4] T. Nakajima, R. Lal, and S. Jiang, "Soil quality index of a crosby silt loam in central Ohio," *Soil and Tillage Research B*, vol. 146, pp. 323–328, 2015.

[5] S. Kalu, M. Koirala, U. R. Khadka, and K. C. Anup, "Soil quality assessment for different land use in the Panchase area of Western Nepal," *International Journal of Environmental Protection*, vol. 5, no. 1, pp. 38–43, 2015.

[6] A. Morugán-Coronado, V. Arcenegui, F. García-Orenes, J. Mataix-Solera, and J. Mataix-Beneyto, "Application of soil quality indices to assess the status of agricultural soils irrigated with treated wastewaters," *Solid Earth*, vol. 4, no. 1, pp. 119–127, 2013.

[7] T. Paz-Kagan, M. Shachak, E. Zaady, and A. Karnieli, "A spectral soil quality index (SSQI) for characterizing soil function in areas of changed land use," *Geoderma*, vol. 230-231, pp. 171–184, 2014.

[8] M. Nguyen, *Practice of Soil Science*, Agriculture Publisher, Hanoi, Vietnam, 1979 (Vietnamese).

[9] C. V. Le, *Agrochemistry*, Science and Technology Publishing House, Hanoi, Vietnam, 2005 (Vietnamese).

[10] C. V. Tran, *Soil Science*, Hanoi University of Agriculture I, Hanoi, Vietnam, 2000 (Vietnamese).

[11] H. N. Nguyen, *Soils and Fertilizers*, Hanoi Publishing House, Hanoi, Vietnam, 2005 (Vietnamese).

[12] D. Le and H. K. Tran, *Soil and Soil Protection*, Hanoi Publishing House, Hanoi, Vietnam, 2005 (Vietnamese).

[13] "National technical regulation on the allowable limits of heavy metals in the soils," QCVN 03: 2008/BTNMT, 2008 (Vietnamese).

[14] A. N. Nguyen, *Scientific basis of provincial environmental mapping land serving for land management and environmental protection (sampling of Haiduong province) [Dissertation of Geography]*, 2014 (Vietnamese).

[15] H. N. Pham, "Weighted and standardized total environmental quality index (TEQI) approach in assessing environmental components (air, soil and water)," *VNU Journal of Science, Earth Sciences*, vol. 27, no. 3, pp. 127–134, 2011.

[16] H. N. Pham, "Relative Soil Quality Index (RSQI) of VNU theme: 'Building a set of aggregate index of environmental quality for each element: air, water and soil, service monitoring and environmental management'," code: QMT.12.01, 2012-2014, 2014 (Vietnamese).

[17] H. N. Pham, *Thematic Reports on Investigating and Surveying of the Soil Environmental Parameters of 12 Districts of Haiduong Province in 2013*, Research Centre for Environmental Monitoring and Modeling (CEMM), VNU University of Science, 2013 (Vietnamese).

[18] Department of Natural Resources and Environment of Haiduong province, The land use map, 2013 (Vietnamese).

[19] GSO Vietnam, 2015 (Vietnamese), http://www.gso.gov.vn/.