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Analysis of Topsoil Quality Changes Across Soil Groups in Vietnam

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study systematically investigates the changes in topsoil quality across various soil groups in Vietnam over a 13-year period, spanning from 2004 to 2017. The primary objective is to evaluate key soil quality indicators, including pH, organic matter (OM), nitrogen (N), phosphorus (P2O5), potassium (K2O), and cation exchange capacity (CEC), to assess the health, fertility, and sustainability of these soils in response to agricultural practices and environmental factors.
The findings reveal significant alterations in soil parameters across the diverse soil groups studied, which include alluvial, red-yellow, acid sulfate, grey and degraded, and yellow-red humus soils. Notably, the average pH levels exhibited a decline in most soil groups, indicating a trend toward increased acidity. This decline in soil pH was accompanied by a marked reduction in nitrogen and potassium concentrations, which are critical for crop growth and productivity. For instance, alluvial and degraded soils demonstrated particularly pronounced nutrient depletion, with nitrogen levels decreasing from 0.23% to 0.19% and potassium levels from 1.23% to 1.03%.

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In contrast, while phosphorus levels exhibited a slight increase in some soil groups, the overall variability in nutrient content suggests that certain areas may be experiencing more severe deficiencies. Interestingly, the Yellow-Red Humus soils displayed enhanced organic matter retention, with mean OM levels increasing from 4.95% to 5.10%, highlighting their potential for improved nutrient availability and soil health. Cation exchange capacity also showed variability, with a notable decline in the grey and degraded soil group.

Keywords: Topsoil quality; soil groups; Vietnam; land use change; soil management.

1. INTRODUCTION

Soil quality plays a crucial role in determining the sustainability and productivity of agricultural systems [1]. In Vietnam, the diverse range of soil groups [2], each shaped by varying climatic, geographical, and human factors, has resulted in distinct trends in soil fertility and degradation [3]. The growing demand for agricultural production [4], combined with inconsistent land management practices, has led to significant changes in topsoil quality, impacting crop yields and long-term soil health [5].

Recent studies have highlighted the deterioration of soil conditions across different regions of Vietnam [6], with key indicators such as soil acidity, organic matter content, nitrogen levels, and potassium concentrations undergoing negative shifts [7,8,9]. This is particularly evident in intensively farmed areas, where over-reliance on chemical fertilizers and unsustainable agricultural practices have exacerbated soil degradation [10,11,12].

This paper aims to analyze the topsoil quality changes across five major soil groups in Vietnam: Acid Sulfate soils, Alluvial soils, Grey and Degraded soils, Red-Yellow soils, and Yellow-Red Humus soils on mountains. By examining key parameters such as pH, organic matter, nitrogen, phosphorus, potassium, and cation exchange capacity (CEC), this study seeks to provide a comprehensive overview of how these soil types have evolved over time, offering insights into the factors driving soil degradation and highlighting areas where improvements have been made.

2. RESEARCH METHODOLOGY

2.1 Secondary Investigation Method

Information, documents, data, and maps related to natural conditions, socio-economic factors, current land use, and other relevant materials concerning soil quality and land potential were collected from central government departments and local specialized agencies.

2.2 Primary Investigation Method

Land boundary delineations were reviewed and adjusted on field survey maps. Information related to land plots was recorded based on field survey results. Additionally, land use status maps from the 2010-2017 period were compared and cross-referenced to document the current state and changes in land use.

2.3 Interpolation Method (Kriging; IDW)

This method was applied to create maps of climate information layers, including precipitation, temperature, humidity, and the number of dry months. It involved determining continuous values for the distribution of precipitation, sunshine, temperature, and humidity across the surveyed socio-economic regions.

2.4 Soil Sampling and Preservation Method

Soil sampling for analysis was conducted in accordance with TCVN 7538 - 2:2005 (ISO 10381 - 2:2002).

2.5 Soil Sample Analysis Method

The analysis of physical and chemical properties was carried out following Vietnamese Standards as outlined in Section 3, Appendix 1 of Circular No. 60/2015/TT-BTNMT.

3. RESULTS AND DISCUSSION

Topsoil is directly impacted by both natural factors and human activities and has a direct influence on crops [13].

To assess the changes in topsoil quality of different soil groups, the study compares the analysis results of various soil acidity indicators (pHKCl), total organic matter (OM%), total nitrogen (N%), total phosphorus (P2O5%), total potassium (K2O%), and cation exchange capacity (CEC) between past and present samples [14,15]. Specifically:

Past sample analysis results: Using analysis results from 2004 (inherited from the revised provincial soil maps created or revised by the Institute of Planning and Agricultural Design in 2004).

Present sample analysis results: Using the analysis results from this project conducted during the 2016-2018 period (collectively referred to as the 2017 project analysis results), which include 1,494 topsoil samples from primary profiles and 5,976 topsoil samples from secondary profiles. A total of 6,152 topsoil samples (including both primary and secondary profile samples) were selected from alluvial soils, acid sulfate soils, grey and degraded soils, red and yellow soils, and yellow-red humus soils on mountains.

The study employs statistical processing methods to calculate the average values for topsoil samples of the same soil group.

Table 1. Statistical analysis results of topsoil samples for the acid sulfate soil group from 2004 to 2017

Indicator	Parameter	Symbol	Value	
			Data from 2004	Data from 2017
pH_{KCl}	Mean	$\bar{X}$	4.29	4.39
	Range	R	4.43	5.31
	Minimum Value	Min	2.97	2.54
	Maximum Value	Max	7.40	7.85
	Standard Deviation	S	0.85	0.97
	Variance	CV	19.91	21.97
OM%	Mean	$\bar{X}$	3.64	2.97
	Range	R	4.94	5.40
	Minimum Value	Min	0.37	0.30
	Maximum Value	Max	5.31	5.70
	Standard Deviation	S	1.28	1.45
	Variance	CV	35.23	48.74
N%	Mean	$\bar{X}$	0.23	0.19
	Range	R	0.42	0.33
	Minimum Value	Min	0.04	0.04
	Maximum Value	Max	0.46	0.37
	Standard Deviation	S	0.10	0.09
	Variance	CV	45.34	48.38
P_2O_5%	Mean	$\bar{X}$	0.10	0.12
	Range	R	0.22	0.38
	Minimum Value	Min	0.03	0.02
	Maximum Value	Max	0.25	0.40
	Standard Deviation	S	0.05	0.06
	Variance	CV	51.77	51.26
K_2O%	Mean	$\bar{X}$	1.23	1.03
	Range	R	1.22	2.18
	Minimum Value	Min	0.62	0.50
	Maximum Value	Max	1.84	2.68
	Standard Deviation	S	0.29	0.46
	Variance	CV	23.34	44.91
CEC (meq/100g soil)	Mean	$\bar{X}$	19.19	13.26
	Range	R	20.21	20.14
	Minimum Value	Min	6.29	5.76
	Maximum Value	Max	26.50	25.90
	Standard Deviation	S	5.40	3.92
	Variance	CV	28.14	29.60

Between 2004 and 2017, the Acid Sulfate Soil Group experienced significant alterations in several key soil parameters. The mean pHKCl values exhibited a slight decrease from 4.91 to 4.65, suggesting an increase in soil acidity, and this change was accompanied by greater variability in pH levels across samples. Organic matter (OM%) showed a minimal decline, from 2.31% to 2.27%, with a slight reduction in variability, indicating a stable yet decreasing organic content in the soil.

Nitrogen (N%) levels also experienced a small reduction, decreasing from 0.14% to 0.13%. The increase in relative variability suggests that nitrogen depletion may be occurring unevenly among the soil samples. Conversely, phosphorus (P_2O_5%) content increased marginally, with the mean rising from 0.11% to 0.13%. This improvement was accompanied by reduced variability, indicating more consistent availability of phosphorus across the samples.

Table 2. Statistical analysis results of topsoil samples for the alluvial soil group from 2004 to 2017

Indicator	Parameter	Symbol	Value	
			Data from 2004	Data from 2017
pH_{KCl}	Mean	$\bar{X}$	4.91	4.65
	Range	R	4.30	4.90
	Minimum Value	Min	3.40	2.55
	Maximum Value	Max	7.70	7.45
	Standard Deviation	S	0.89	0.94
	Variance	CV	18.14	20.27
OM%	Mean	$\bar{X}$	2.31	2.27
	Range	R	7.94	6.45
	Minimum Value	Min	0.55	0.53
	Maximum Value	Max	8.49	6.98
	Standard Deviation	S	1.19	1.13
	Variance	CV	51.32	49.56
N%	Mean	$\bar{X}$	0.14	0.13
	Range	R	0.49	0.43
	Minimum Value	Min	0.02	0.01
	Maximum Value	Max	0.51	0.44
	Standard Deviation	S	0.07	0.07
	Variance	CV	48.03	49.14
P_2O_5%	Mean	$\bar{X}$	0.11	0.13
	Range	R	0.38	0.48
	Minimum Value	Min	0.02	0.02
	Maximum Value	Max	0.40	0.50
	Standard Deviation	S	0.07	0.07
	Variance	CV	60.80	53.61
K_2O%	Mean	$\bar{X}$	1.11	0.97
	Range	R	2.30	2.71
	Minimum Value	Min	0.05	0.06
	Maximum Value	Max	2.35	2.77
	Standard Deviation	S	0.59	0.60
	Variance	CV	52.57	61.97
CEC (meq/100g soil)	Mean	$\bar{X}$	13.39	10.11
	Range	R	32.65	33.45
	Minimum Value	Min	3.28	3.04
	Maximum Value	Max	35.93	36.49
	Standard Deviation	S	6.09	4.44
	Variance	CV	45.49	43.87

In contrast, potassium (K_2O%) levels demonstrated a substantial decline, with the mean falling from 1.11% to 0.97%, alongside a rise in variability, reflecting inconsistent potassium distribution. The Cation Exchange Capacity (CEC) showed a marked decrease from 13.39 meq/100g soil to 10.11 meq/100g soil, highlighting a diminished capacity for nutrient retention and exchange, although variability in CEC values remained relatively stable.

The key soil parameters, including organic matter, nitrogen, and potassium, all declined from 2004 to 2017, indicating soil degradation that may negatively impact agricultural productivity. Although there was some improvement in phosphorus content, the increased variability in these factors suggests the need for more effective soil management practices to maintain soil quality and agricultural yields.

Between 2004 and 2017, the alluvial soil group exhibited notable changes across various parameters. The mean pHKCl decreased from 4.91 to 4.65, indicating a slight increase in soil acidity, while the range of values remained relatively stable. The variability in pH, reflected by the coefficient of variation (CV), increased slightly from 18.14% to 20.27%, suggesting greater inconsistency in soil pH levels. Organic matter (OM%) showed a minor decline from 2.31% to 2.27%, with a slight reduction in variability as the CV decreased from 51.32% to 49.56%. Nitrogen content also experienced a slight reduction from 0.14% to 0.13%, with minimal changes in variability, as indicated by a marginal increase in CV from 48.03% to 49.14%.

Phosphorus (P_2O_5%) levels increased from 0.11% to 0.13%, with a reduction in variability, as the CV dropped from 60.80% to 53.61%, signaling a more consistent distribution of phosphorus content. However, potassium (K_2O%) content declined from 1.11% to 0.97%, and its variability increased, as evidenced by the rise in CV from 52.57% to 61.97%. This suggests that potassium distribution became more uneven over time. The cation exchange capacity (CEC) also dropped significantly, from 13.39 meq/100g soil to 10.11 meq/100g soil, indicating a decreased ability of the soil to retain and exchange nutrients. Despite this, the variability in CEC values slightly decreased, with the CV falling from 45.49% to 43.87%.

Overall, the data suggest a decline in soil fertility, with increasing acidity, reduced potassium and nitrogen levels, and a significant decrease in CEC, all of which may affect the long-term productivity of alluvial soils.

The analysis of the Grey and Degraded Soil Group from 2004 to 2017 reveals significant changes in key soil parameters. The mean pHKCl values decreased from 4.49 to 4.24, indicating increased acidity, while the range expanded, reflecting greater variability in pH levels.

Organic matter (OM%) slightly declined from 1.65% to 1.60%, with reduced variability. Nitrogen (N%) content also decreased from 0.11% to 0.10%, exhibiting increased variability. Phosphorus (P_2O_5%) levels rose slightly, with an increase in both the mean and variability.

Potassium (K_2O%) content decreased marginally from 0.28% to 0.26%, accompanied by a wider range and high variability. Cation Exchange Capacity (CEC) notably declined from 7.52 to 6.56 meq/100g soil, indicating reduced nutrient retention capability.

Overall, these changes point to declining soil quality and highlight the need for effective soil management practices to improve soil health and agricultural productivity.

The evaluation of the Red-Yellow Soil Group between 2004 and 2017 reveals significant alterations in several key soil parameters. The mean pHKCl value decreased from 4.79 to 4.19, indicating a rise in soil acidity, while the range increased from 3.31 to 3.98, reflecting heightened variability in pH levels. Organic matter (OM%) exhibited a slight reduction from 2.75% to 2.73%, maintaining a consistent range and experiencing a minor decline in variability.

Nitrogen (N%) content also showed a decrease, falling from 0.18% to 0.17%. The range for nitrogen values expanded, indicating increased variability in nitrogen availability. Phosphorus (P_2O_5%) levels declined from 0.16% to 0.14%, with variability remaining relatively constant despite a slight increase in the range. Similarly, potassium (K_2O%) content decreased from 0.79% to 0.76%, accompanied by an increased range and variability, highlighting inconsistencies in potassium levels.

Table 3. Statistical analysis results of topsoil samples for the grey and degraded soil group from 2004 to 2017

Indicator	Parameter	Symbol	Value	
			Data from 2004	Data from 2017
pH_{KCl}	Mean	$\bar{X}$	4.49	4.24
	Range	R	2.15	3.61
	Minimum Value	Min	3.70	3.24
	Maximum Value	Max	5.85	6.85
	Standard Deviation	S	0.50	0.64
	Variance	CV	11.12	15.09
OM%	Mean	$\bar{X}$	1.65	1.60
	Range	R	4.27	3.88
	Minimum Value	Min	0.09	0.14
	Maximum Value	Max	4.36	4.02
	Standard Deviation	S	0.99	0.77
	Variance	CV	60.25	48.06
N%	Mean	$\bar{X}$	0.11	0.10
	Range	R	0.20	0.41
	Minimum Value	Min	0.02	0.02
	Maximum Value	Max	0.22	0.43
	Standard Deviation	S	0.05	0.05
	Variance	CV	51.82	56.13
P_2O_5%	Mean	$\bar{X}$	0.05	0.06
	Range	R	0.16	0.31
	Minimum Value	Min	0.01	0.01
	Maximum Value	Max	0.17	0.32
	Standard Deviation	S	0.04	0.05
	Variance	CV	76.57	86.10
K_2O%	Mean	$\bar{X}$	0.28	0.26
	Range	R	1.67	2.26
	Minimum Value	Min	0.02	0.01
	Maximum Value	Max	1.69	2.27
	Standard Deviation	S	0.35	0.29
	Variance	CV	125.32	109.19
CEC (meq/100g soil)	Mean	$\bar{X}$	7.52	6.56
	Range	R	15.41	19.00
	Minimum Value	Min	2.59	2.00
	Maximum Value	Max	18.00	21.00
	Standard Deviation	S	3.36	3.80
	Variance	CV	44.64	57.99

Cation Exchange Capacity (CEC) experienced a slight decrease from 10.49 to 10.06 meq/100g soil, suggesting a diminished capacity for nutrient retention, although variability remained relatively stable. Collectively, these results indicate a decline in soil quality within the Red-Yellow Soil Group, characterized by increased acidity and reduced nutrient availability, underscoring the necessity for enhanced soil management strategies to improve soil health and agricultural productivity.

The examination of the Yellow-Red Humus Soil Group between 2004 and 2017 reveals notable changes in key soil characteristics. The mean pHKCl value decreased from 4.55 to 4.14, indicating a rise in soil acidity, while the range increased from 2.99 to 4.21, suggesting enhanced variability in pH levels. In contrast, organic matter (OM%) demonstrated a slight rise from 4.95% to 5.10%, with the range expanding significantly from 7.10 to 9.22, reflecting greater variability in organic matter distribution.

Table 4. Statistical analysis results of topsoil samples for the red-yellow soil group from 2004 to 2017

Indicator	Parameter	Symbol	Value	
			Data from 2004	Data from 2017
pH_{KCl}	Mean	$\bar{X}$	4.79	4.19
	Range	R	3.31	3.98
	Minimum Value	Min	3.49	3.01
	Maximum Value	Max	6.80	6.99
	Standard Deviation	S	0.64	0.69
	Variance	CV	13.46	16.55
OM%	Mean	$\bar{X}$	2.75	2.73
	Range	R	7.62	7.64
	Minimum Value	Min	0.22	0.23
	Maximum Value	Max	7.84	7.86
	Standard Deviation	S	1.20	1.12
	Variance	CV	43.52	40.92
N%	Mean	$\bar{X}$	0.18	0.17
	Range	R	0.17	0.25
	Minimum Value	Min	0.11	0.09
	Maximum Value	Max	0.28	0.33
	Standard Deviation	S	0.05	0.06
	Variance	CV	26.56	31.55
P_2O_5%	Mean	$\bar{X}$	0.16	0.14
	Range	R	0.76	0.85
	Minimum Value	Min	0.06	0.06
	Maximum Value	Max	0.82	0.91
	Standard Deviation	S	0.12	0.10
	Variance	CV	77.30	71.62
K_2O%	Mean	$\bar{X}$	0.79	0.76
	Range	R	2.37	2.91
	Minimum Value	Min	0.12	0.08
	Maximum Value	Max	2.49	2.99
	Standard Deviation	S	0.51	0.57
	Variance	CV	64.09	74.64
CEC (meq/100g soil)	Mean	$\bar{X}$	10.49	10.06
	Range	R	16.16	16.94
	Minimum Value	Min	3.17	3.00
	Maximum Value	Max	19.33	19.94
	Standard Deviation	S	3.70	3.80
	Variance	CV	35.30	37.79

Nitrogen (N%) content saw a modest increase, moving from 0.23% to 0.24%, accompanied by an increase in the range from 0.27 to 0.39, highlighting growing variability in nitrogen availability. Phosphorus (P_2O_5%) levels remained consistent, holding steady at a mean of 0.16%, although the range slightly increased from 0.56 to 0.60, indicating stable variability in phosphorus content.

On the other hand, potassium (K_2O%) showed a decline from 0.90% to 0.79%, with both the range (from 1.92 to 2.96) and standard deviation increasing, pointing to inconsistencies in potassium levels among samples. The Cation Exchange Capacity (CEC) revealed a slight increase from 13.47 to 14.04 meq/100g soil, which suggests enhanced nutrient retention capacity, with reduced variability indicated by a decrease in standard deviation.

In summary, the Yellow-Red Humus Soil Group exhibited decreasing acidity levels and stable nutrient concentrations, along with improved organic matter and CEC, highlighting the need for ongoing management practices to sustain soil health and fertility in this category.

Table 5. Statistical analysis results of topsoil samples for the yellow-red humus soil group on mountains from 2004 to 2017

Indicator	Parameter	Symbol	Value	
			Data from 2004	Data from 2017
pH_{KCl}	Mean	$\bar{X}$	4.55	4.14
	Range	R	2.99	4.21
	Minimum Value	Min	3.79	2.77
	Maximum Value	Max	6.78	6.98
	Standard Deviation	S	0.80	0.77
	Variance	CV	17.49	18.57
OM%	Mean	$\bar{X}$	4.95	5.10
	Range	R	7.10	9.22
	Minimum Value	Min	1.94	2.51
	Maximum Value	Max	9.04	11.73
	Standard Deviation	S	1.67	2.01
	Variance	CV	33.66	39.33
N%	Mean	$\bar{X}$	0.23	0.24
	Range	R	0.27	0.39
	Minimum Value	Min	0.13	0.10
	Maximum Value	Max	0.40	0.49
	Standard Deviation	S	0.07	0.07
	Variance	CV	30.27	28.90
P_2O_5%	Mean	$\bar{X}$	0.16	0.16
	Range	R	0.56	0.60
	Minimum Value	Min	0.09	0.08
	Maximum Value	Max	0.65	0.68
	Standard Deviation	S	0.15	0.09
	Variance	CV	94.24	52.14
K_2O%	Mean	$\bar{X}$	0.90	0.79
	Range	R	1.92	2.96
	Minimum Value	Min	0.16	0.10
	Maximum Value	Max	2.08	3.06
	Standard Deviation	S	0.58	0.61
	Variance	CV	64.95	76.93
CEC (meq/100g soil)	Mean	$\bar{X}$	13.47	14.04
	Range	R	15.84	14.40
	Minimum Value	Min	9.86	12.00
	Maximum Value	Max	25.70	26.40
	Standard Deviation	S	3.47	2.85
	Variance	CV	25.79	20.29

4. CONCLUSION

The examination of changes in topsoil quality across different soil groups in Vietnam from 2004 to 2017 provides significant insights into the health and fertility of these vital resources. The results indicate a troubling trend of nutrient depletion, particularly in nitrogen and potassium levels, prevalent across most soil groups. This suggests an increased risk of soil degradation that may negatively impact agricultural productivity. While improvements in organic matter content and cation exchange capacity were observed in Yellow-Red Humus soils, indicating enhanced nutrient retention, other groups, particularly alluvial and degraded soils, showed increased acidity and a decrease in the availability of essential nutrients.

These results highlight the urgent need for comprehensive soil management strategies designed to reverse degradation trends and improve soil quality. Implementing sustainable agricultural practices, such as the incorporation of organic matter, cover cropping, and balanced fertilization, is crucial for maintaining soil health and productivity. As Vietnam confronts challenges related to climate change, urban expansion, and agricultural intensification, a unified effort to monitor and enhance soil quality will be essential for ensuring food security and environmental sustainability in the region.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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