Article

Characterization of physico-chemical properties of soils in the Caraga Region: An assessment of land use systems

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Received 11 April 2025; Accepted 20 May 2025; Published online 25 July 2025; Published 1 December 2025

Abstract

Soil is a natural resource that is essential for both the environment and agriculture, which promotes plant growth and makes up the bulk of the biosphere. Physical characteristics such as MC, BD, and Texture, and chemical characteristics such as SOC, TN, AP, pH, and EC affect the soil's ability to maintain ecosystem health. 31 soil samples (0-30 cm soil depth) were collected from three land use systems (LUSs) (forest, agricultural, and mining lands) across the Caraga Region in the Philippines. The parameters were measured using standard methods and procedures. The results of the study support a consensus that the physico-chemical properties of Mining Lands (MLs) are the poorest in quality, but are counterintuitive to another consensus that the physico-chemical properties of the soils of Forest Lands (FLs) are significantly higher than Agricultural Lands (ALs). This was based on the overall higher chemical quality of ALs than FLs and their contradictory results in terms of BD. Given these results, this research suggests the potential of incorporating soil quality testing as a complementary or alternative approach to GIS and remote sensing in identifying and proposing suitable land use strategies (LUSs).

Keywords agricultural lands; available phosphorus; forest lands; SOC; soil quality.

Proceedings of the International Academy of Ecology and Environmental Sciences
ISSN 2220-8860
URL: http://www.iaees.org/publications/journals/piaees/online-version.asp
RSS: http://www.iaees.org/publications/journals/piaees/rss.xml
E-mail: piaees@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

According to Moraetis et al. (2016), the soil is the dynamic link between the lithosphere and the biosphere and is a natural resource that is practically non-renewable yet essential for both the environment and agriculture. The hydrological, ecological, biological, and geochemical processes are all under its control, making it a crucial part of the Earth System. Soil, which promotes plant growth and nutrient cycling, regulates the water and carbon cycles, and makes up the bulk of the biosphere, is what gives the Earth its unique characteristics.

Soil characteristics include the physical and chemical features of soil, namely its Moisture Content (MC), Bulk Density (BD), Texture, Soil Organic Carbon (SOC), Total Nitrogen (TN), Available Phosphorus (AP), pH, and Electrical Conductivity (EC). These traits affect the soil's ability to support plant growth, maintain ecosystem health, affect the availability of plant nutrients, and affect the solubility of minerals in the soil (Delgado and Gómez, 2016).

In addition to other functions like waste remediation, plant production, and carbon sequestration, soil quality can also be described more specifically. For instance, a manager of a forest plantation would describe soil quality as a region's capacity to generate biomass. The report traces the evolution of the idea of "land quality," investigates the use of "soil chemical and physical attributes as determinants of soil quality," and presents opportunities and challenges for forest soil scientists to play a significant role in the assessment and advancement of sustainable forest management by creating the idea of "soil quality as an indicator of sustainability" (Kekane et al., 2015).

The Caraga Region, consisting of 5 provinces, Agusan del Norte, Agusan del Sur, Surigao del Norte, Surigao del Sur, and Dinagat Islands, is located in the northeast portion of Mindanao of the Philippines, contributed to 9.2% of the agricultural output of the Philippines and 12.6% of its GDP was contributed by agriculture (Philippine Statistics Authority, 2022). With a sizable amount of revenue in this sector, lawmakers must strategize on which type of LUS must be implemented and fostered in that particular terrain by its corresponding soil quality.

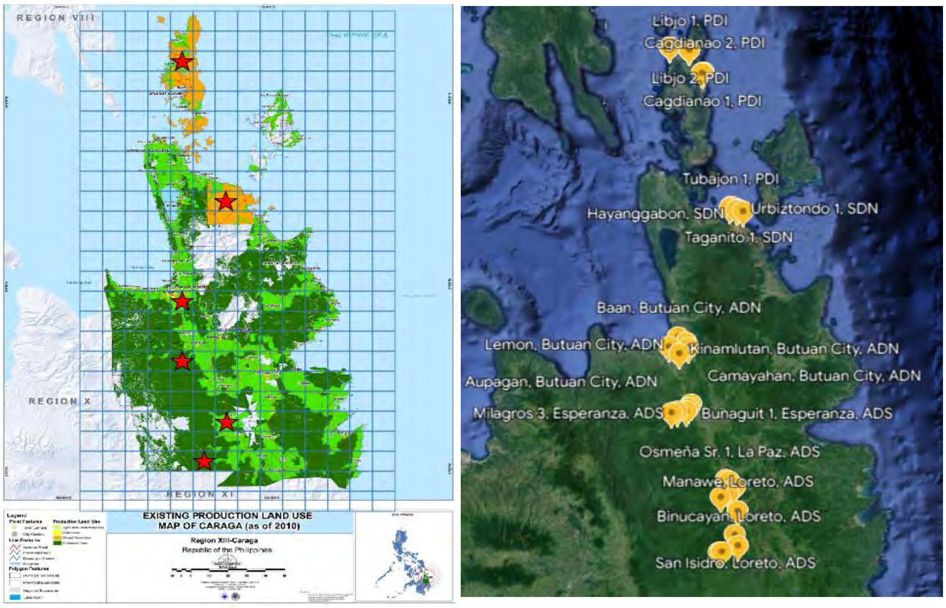
The most common method for determining which LUS is suitable is through the use of a Geospatial Information System (GIS) and remote sensing. Using satellite imagery, LUSs can be drawn and mapped through their apparent land cover and observation (Rwanga and Ndambuki, 2017). However, it failed to assess the soil quality in the area, which is paramount for the development of the specified LUS. Therefore, this study will focus on the soil quality across different LUSs in the Caraga Region and compare its data with that of other research papers regarding LUS in terms of soil quality.

2 Study Area and Methodology

This is applied research that uses a wide variety of tests and methods on different parameters of the soil to assess its soil quality, and if there is a gap between the LUS assigned by the National Economic and Development Authority (NEDA) to the collection site and its corresponding soil quality.

2.1 Study site

Sampling areas were according to the corresponding LUS mapped by the NEDA. Specific sites were determined via the transect and quadrat method. The Caraga Region is divided into 12 km by 12 km grids, as shown in Fig. 1, which also shows the approximate locations of each site labeled with a red star. As shown in the Fig. 2 ALs and FLs, all of which are located in the Caraga Region, were chosen. The sites were further divided into 5 x 5 grids, and 5 of these cells were randomly selected for soil collection.



(a) (b)

Fig. 1 Map of the Land Use Systems of Caraga Region retrieved from NEDA (2019) (a) the selection of soil collecting sites in the Caraga Region (b) Stations (yellow) where the soil collection took place.

2.2 Data collection

Standard soil testing procedures were implemented, namely: MC using the Loss on Drying Method, BD using the simple density formula, Texture using the Feel Method, SOC using the Walkley-Black Wet Oxidation Method, TN using the Kjeldahl Method, AP using Bray-I Method, pH using pH Meter, and EC using EC Meter.

2.3 Analysis of data

The software, Jamovi Version 2.3.24.0, was used for descriptives, Welch's One-way Analysis of Variance (ANOVA; Zhang and Qi, 2024), and Principal Component Analysis (PCA) Biplot. Games-Howell Post Hoc Test was used to pinpoint large influences on the ANOVA's p-value results.

3 Results and Discussion

3.1 Physical properties of soil in the different land use systems

The results of the physical properties of the sites are seen in Table 1. The highest MC is located in ALs, while BD is highest in FLs. In terms of MC, the findings are an affirmation of the data presented by Bizuhoraho et al. (2018) on their soil analysis in the Rulindo District in Rwanda. In their preliminary tests, the results show that farmlands have a higher MC than forest lands; however, they are significantly different from each other, with a 45.35% increase from forest lands to farmlands.

Table 1 Mean Physical Properties of each site as grouped according to LUS.

LUS	Sites	Physical Properties	
		MC (%)	BD (g/cm^3)
Agricultural Lands	Butuan	38.137	1.100
	La Paz	38.892	1.034
Forest Lands	Loreto	36.695	1.142
	Esperanza	36.633	1.127
Mining Lands	Claver	29.899	0.999
	Dinagat Islands	32.303	0.993

Meanwhile, MLs are shown to have the lowest levels of MC and BD. This is on par with the findings of Bai et al. (2018) in their research on soil properties of mines in Northwestern China, where they concluded that moisture content in mines will degrade over time, albeit rather slowly due to the decreasing amount of minerals present in the soil and a decrease in overall porosity. In total, the three LUSs have a p-value of 0.103, which indicates that there are no significant differences according to MC.

In terms of BD, however, a contradiction is seen with Bizuhoraho et al. findings, as forests are said to have lower BD in their data. Moreover, Wang et al. (2012) initial calculation of BD in the Loess Plateau in China suggests that forest lands indeed have lower BD than croplands. It is worth mentioning that all but one out of the 31 sites collected have a heavy soil texture, signifying clay soil in each site (except one, which is medium). The clay nature of the soils, which usually have the largest BD, contributes to the compactness of the soil, as suggested by Materechera and Mkhabela (2001).

MLs have a lower overall bulk density than the other two LUSs, which is another contradiction according to Mukhopadhyay et al. (2019), whose reasoning states that MLs soils must have greater BD due to the soil's compactness. It also mentioned that high amounts of coarse fragments are another factor contributing to an increase of BD, which is not present in the ML soil due to the soil being clayey and heavy as stated previously.

3.2 Chemical properties of soil in the different land use systems

The results of the chemical properties seen in Table 2 show that the ALs generally have the highest chemical properties of the three LUSs, while MLs generally have the lowest values of chemical properties. The latter statement is supported by different research papers as MLs tend to lose the nutrients and the capabilities to grow crops due to soil erosion dispersing such nutrients (Abad et al., 2014; Iqbal and Tiwari, 2017; Muhaimeed and Gomaa, 2018; Selassie and Ayanna, 2013).

Dhaliwal et al. (2023) findings on SOC variation in the Majha Region in India are lower than the findings in Table 2, with their mean values for SOC ranging between 0.21% and 0.69% for inceptisols, which is a common soil order in the Agusan provinces, and 0.14% and 0.99% for entisols, a common soil order in the Surigao provinces, as shown by the data; however, their hypothesis is consistent with several other studies that forests have the largest amount of SOC in all types of land use (Martín-Rodríguez et al., 2016; Abad et al., 2014; Selassie and Ayanna, 2013), a stark contradiction with the data given in Table 2.

From the study of Selassie and Ayanna (2013), there is a significant difference between TN and LUS, with agricultural lands believed to have the lowest TN. However, the tabulated data says the opposite, with

ALs actually having more TN than FLs. Moreover, the same 2013 study concludes that AP also has a higher amount in FLs, which is another contradiction to the data in Table 2.

Lastly, the conclusions of Bezabih et al. (2016) suggest that FLs also have higher EC and pH than other LUSs; another contradiction with the data given in Table 2. Despite this, the pH of the collected sites and the sites collected by Bezabih et al. are both acidic within the range of 5 to 7.

Table 2 Mean Chemical Properties of each site as grouped according to LUS.

LUS	Sites	Chemical Properties				
		SOC (%)	TN (%)	AP (ppm)	pH	EC (μS/cm)
Agricultural Lands	Butuan	1.334	0.138	16.6	6.962	730.2
	La Paz	0.963	0.094	5.6	6.302	957.6
Forest Lands	Loreto	1.137	0.116	4.8	6.256	886.3
	Esperanza	0.580	0.076	1	5.414	344
Mining Lands	Claver	0.29	0.01	1	6.5	122.7
	Dinagat Islands	0.41	0.02	1	7.6	279.4

Despite the aforementioned observations from above, MLs are relatively consistent with their results in each parameter, as they tend to be of poor quality. According to a study by Chileshe et al. (2020) where they tested the chemical properties of a forest and a mining site in Zambia, it was found that selected properties such as SOC, TN, and AP have been seen greater in amounts in the forests than in the mining site, however, it was shown that the mining site has an unsurprisingly higher amount of heavy metals than the forest.

The pH levels of MLs have no particular pattern in comparison to the other two LUSs, although it can be hypothesized that the reason for the more alkaline nature of MLs than the two LUSs is due to the abundance of such heavy metals.

Finally, the EC of MLs shows a stark decrease from the other two, which can be explained by the lack of moisture in MLs, as shown in Table 1. This lack of moisture prevents the abundant metals in the soil to not being freed up as ions and are therefore not responsive when measured in its conductivity (Hawkins et al., 2017).

Table 3 Correlational analysis between parameters and LUS.

Parameter	F	df1	df2	p	Decision
MC	0.388	2	12.0	0.103	Accept H_0
BD	1.440	2	14.3	0.118	Accept H_0
SOC	1.315	2	16.5	0.001	Reject H_0
TN	0.511	2	18.0	<0.001	Reject H_0
AP	6.214	2	12.1	<0.001	Reject H_0
pH	2.991	2	15.5	0.063	Accept H_0
EC	0.452	2	18.0	0.031	Reject H_0

Note: Marked difference is significant at p<0.05, H_0 is stated that there is no significant difference between the parameter and LUS.

Implementing One-Way ANOVA, all physical properties have no significant differences in terms of LUSs. However, almost all of the chemical properties except pH have significant differences. This is shown in the table below.

Table 4 Games-Howell Post Hoc Tests of One-Way ANOVA.

Parameter	AL-FL		AL-ML		FL-ML	
	Mean Difference	p-value	Mean Difference	p-value	Mean Difference	p-value
MC	1.90	0.811	7.35	0.136	5.45	0.122
BD	-0.067	0.472	0.0713	0.326	0.1384	0.097
SOC	0.29	0.5	0.806**	0.008	0.516*	0.019
TN	0.02	0.758	0.1006**	0.002	0.0806**	0.006
AP	8.20	0.067	10.1*	0.021	1.9	0.346
pH	0.797	0.226	-0.368	0.541	-1.165	0.051
EC	229	0.782	650	0.065	421	0.228

Note: * p<0.05, ** p<0.01, *** p<0.001

Despite the significant differences shown in the table, a post-hoc test revealed that, when comparing FLs and ALs, all parameters show signs of homogeneity as the p-values of such differences are extremely greater than 0.05, apart from AP. Moreover, due to the stark differences and extremely low p-values between MLs and the other LUSs in all chemical properties aside from pH, its effects may have influenced the overall results of the One-Way ANOVA. This means that although there was an overall significant difference between SOC, TN, AP, and EC of the LUSs, there is no significant difference when only comparing MLs and ALs, which suggests homogeneity between the values and therefore, can both be grouped in the same group. However, there is more than sufficient evidence that suggests that there is indeed a difference between ALs and FLs (Selassie and Ayanna, 2013; Bizuhoraho et al., 2018; Dhaliwal et al., 2023). From this, it can be said that there is a discrepancy between the assigned LUSs of the region and its assumed soil quality.

3.3 Importance of soil testing for classifying LUS

From the PCA Biplot, some conclusions can be made. For instance, BD and MC are positively correlated with each other, given their almost similar direction, while pH and SOC have no correlation due to the almost 90-degree angle.

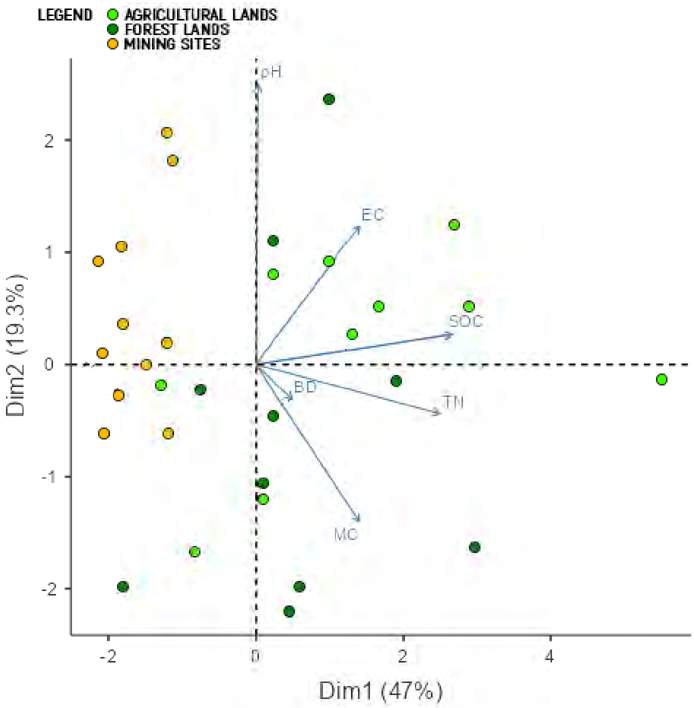


Fig. 2 Principal Component Analysis Biplot of the collected sites.

It can be seen that MLs are clustered in the western and northwestern portions and therefore share similar qualities. However, FLs and ALs are both more spread out and do not cluster. They also overlap each other in the Biplot, which signifies that there is homogeneity between the two and no significant trend between the two LUSs.

According to these studies (Selassie and Ayanna, 2013; Bizuhoraho et al., 2018; Dhaliwal et al., 2023; Muhaimeed and Gomaa, 2018; Abad et al., 2014), there is enough evidence to suggest that there is a significant difference between the soil quality between FLs and ALs, with FLs having a significantly higher amount of MC, SOC, TN, pH, EC than ALs; and ALs having a significantly higher amount of BD and AP (Bizuhoraho et al., 2018; Munishi and Ndakidemi, 2021). However, the Principal Component Analysis in Figure 5 shows that there are no clustered groups between ALs and FLs; instead, they are spread out.

Therefore, it is said that the soil quality between ALs and FLs is homogeneous with one another, a contradiction with the aforementioned literature. By this, it can be said that the assigned FLs collected in the study may be more suitable for ALs; inversely, it can also be said that some assigned ALs collected may be more suitable for FLs, as well.

By this, the way of LUS assignment suggested and performed by Rwanga and Ndambuki (2017) as a standard procedure, which utilizes remote sensing, GIS, historical records, and vegetation, must be updated to also include soil quality testing.

4 Conclusions

The findings of this study highlight a valuable opportunity to enhance current land use classification practices. While Mining Lands (MLs) exhibited relatively lower physico-chemical values compared to Agricultural Lands (ALs) and Forest Lands (FLs), the notably higher soil quality in presumed ALs suggests that certain lands may be underutilized or misclassified. This observation opens up promising possibilities for land optimization. Moreover, the identified gap between the current land use status (LUS) assigned by NEDA and the actual soil conditions reinforces the importance of incorporating soil quality assessments into land surveying methods. By integrating scientific soil testing into the LUS designation process, stakeholders and policymakers can make more informed, sustainable, and productive land use decisions, benefiting both the environment and local communities.

Acknowledgment

We would like to thank DOST - Philippine Science High School - Caraga Region Campus for the reimbursement of the financial expenses under the student research program. We extend our heartfelt gratitude to Mr. Julie S. Berame of Caraga State University for his valuable advice during the ideation of our research; to the Region XIII Regional Soils Laboratory for their assistance in analyzing the chemical properties of the soil; to Mr. and Mrs. Jongko, the parents of Geric, for funding the expenses related to soil sample collection; to Sir Joey Amihan for serving as our chauffeur to various sampling sites in the Caraga Region; and to Mr. JioKlyde T. Paular and Mr. Japeth F. Basil for collecting soil samples near the proposed mining sites.

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