Techno-Science Research Journal V 13 (3) (2025) P 69-79

Content list available at ITC

Techno-Science Research Journal

Journal Homepage: http://techno-srj.itc.edu.kh/

Techno-Science Research Journal

Environmental Variables Determining Soil Physical Properties and Carbon Content at the Catchment Scale, Stung Chrey Bak Observatory, Cambodia

Sithea Sath[1*], Ratha Muon[1], Rainer Zaiss[2], Jeroen Meersmans[3], Vannak Ann[1], Pascal Jouquet[1,2]

[1] *Research and Innovation Center, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, Phnom Penh, Cambodia*

[2] *IRD, Sorbonne Universite, University Paris Est Creteil, CNRS, INRAe, Institute of Ecology and Environmental Sciences (UMR iEES-Paris), Paris, France*

[3] *Terra Teaching and Research Centre Water-Soil-Plant Exchange Unit, University of Liege Gembloux Agro-bio-Tech, EESP,5030 Gembloux, Belgium*

Received: 17 September 2024; Revised: 04 December 2024; Accepted: 24 December 2024; Available online: December 2024

Abstract: *Land cover changes are a prominent driver of environmental changes, impacting various ecosystem components, including soil properties and the dynamics of natural resources, such as the soil particle sizes and the organic carbon stock. The aim of this research study was to define the influence of environmental factors on a set of soil physical and chemical properties (pH, electrical conductivity, bulk density, soil texture, and nitrogen and soil carbon contents) in Stung Chrey Bak catchment. A total of 135 soil samples at 0-10 cm depths were collected all over the catchment from four dominant land cover types (i.e., dense forest, clear forest, brushwood, and rice field) in 1952 and 1981. All these data were mapped by combining spatial data on land cover types and for a visualization of soil properties at the catchment scale. For the mapping of soil properties, we used an interpolation map (IDW) with Quantum Geographic Information System (QGIS 3.22). The distribution of the particle sizes was mostly impacted by the topography rather than the land uses. On average, the soil pH values were higher in rice fields than in forested soil, while low salinity could be measured in the four land use types. The carbon content was higher in the dense forest soil than in the other land use types. The bulk density of the dense forests was 1.28g cm-3, while it reached 1.68g cm-3 on average in the other land use type. This shows that deforestation in the upland leads to soil compaction and a significant loss of soil C.*

Keywords: Sandy soil , Land use/ Land cover, Rice Field, Particle Size

1. INTRODUCTION

The soil system plays a crucial role in providing key ecosystem services such as food production, production of fiber and fuel, and shelter for humans [1].The ecosystem process, including biodiversity preservation, hydrology, nutrient cycles, and plant growth are also intricately linked to the physical and chemical properties of the soils [2].These soil properties are in turn influenced by various factors such as the geology, biology, and climate. These factors interact to shape the physical and chemical characteristics of the soil, including its texture, structure, nutrient content, pH levels, and water-holding capacity. Additionally, human activities and land management practices can also impact the properties of soil in a specific location [2]. The response of soil parameters to variations in land use change and cover (LUCC) has been studied at various temporal and geographical scales. Deforestation is usually associated to a decrease in the soil structural stability, a loss of organic matter, and a reduction in nutrient stock.

Exposing the soil to erosion in sloping lands is considered as a key process of soil, while the deposition of eroded soil from the mountainous areas to the plain might constitute a source of enrichment in carbon and nutrients [3] In addition to erosion, deforestation, intensive agriculture, and livestock grazing decrease soil fertility and constitute major sources of soil degradation worldwide [4]. For example, the loss of a vegetable protective cover through deforestation leads to a degradation of soil fertility and productivity due to reduced rooting depths and losses of soil organic matter and nutrients [5]. Cultivated land after

* Corresponding author: Sithea Sath
E-mail: sathsithea2002@gmail.com; Tel: +855-16-672-948

deforestation can lead to increased soil compaction, rapid decline in hydraulic conductivity, and infiltration capacity as well as reduction in carbon and nitrogen contents [6]. Compacted soil is also more likely to erode, and some studies have linked the mineralization of recently exposed organic matter and the subsequent mineralization of microbial carbon to an increase in CO_2 after rewetting [7].

Cambodia is a developing country projected to double its population, with agriculture playing a crucial role in the nation's economy [8]. Over 20.8% of Cambodia's GDP comes from the agricultural sector [9]. and crop production is a major contributor to that figure. However, soil degradation is a major issue in Cambodia, especially because of the conversion of natural forests to cultivated areas. The recent population increase has led to the expansion of cultivated areas at the expense of forests, in order to meet the growing demand for food. A previous study [10] estimated that 43% of the territory was degraded, primarily due to forest clearance for agricultural intensification since 2008. This degradation has impacted nearly 25% of the population living in these affected areas. The issue of soil degradation is particularly pronounced in the agricultural lands surrounding the Tonle Sap Lake. Given this context, there is a pressing need to understand the processes related to soil quality conservation in Cambodia.

Soil organic carbon (SOC), total nitrogen (TN), and soil acidity (pH) are the primary indicators used to assess the quality of the soil [11] . In addition to increasing soil nutrient accessibility, soil organic carbon influences soil fertility through many of additional ways and is crucial to the global C-cycle, which has the potential to significantly impact atmospheric CO_2-concentrations [11]. The studies have examined the effects of various land use types (i.e., dense forest, clear forest, brushwood and rice field) on pH, TN, and SOC; nevertheless, the findings are still unclear, because studies have been carried out at the local scale, without considering the influence of the geology, topography and old LUCC discovered that compared to other land use types, wooded land had a greater SOC content [12]. Croplands had far less TN than wooded areas, according to Jonczak, 2013. Total organic carbon (TOC) is the general term for the quantity of carbon in soil that is either derived from or related to living things. TOC, which normally ranges from 1.0% to 1.5% of the total soil weight in Vietnamese soils, varies significantly depending on the soil type and terrain. In general, it is 1% in rainfed agricultural systems [11].

Therefore, this study aims to define the influence of environmental factors (i.e., land use types, lithology) and their evolution (comparison of the situation between 1952 and 1981).

1. METHODOLOGY

2.1 Site description

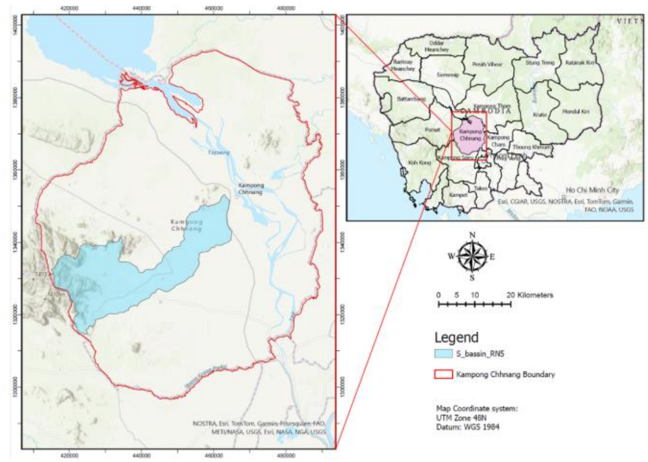

Figure 1. Study Area

The study was realized within the Stung Chrey Bak Observatory (henceforth referred to as the catchment), which is located in the watershed of the Tonle Sap Lake, and flows into the Tonle Sap River. The catchment, which covers a region of around 700 km^2 , is where the experiment sites were situated. It is located in the Kampong Chhnang province [13]. The province is well-known for its pottery in addition to agriculture. A range of stakeholders have invested in land and water resource "development" in the catchment, including local farmers, donors, national and local government agencies and business communities. Agricultural production, in particular the rice production, has had significant expansion and intensification. As a consequence, the catchment has experienced intensive LUCC change, particularly in the last 20 years. An investigation of the changing patterns of LUCC is needed given the increase in forest exploitation and other unsustainable land use practices. The study sites identified for this work incorporates the catchment's middle and upper parts. The study sites' boundary, created from topographic features within the catchment, was used to examine the geography of the catchment.

2.2 Soil Sampling and laboratory Analysis

On November 20, 2023, 135 soil samples were collected in the four dominant land use types (dense forest, clear forest, brushwood, and rice field). Soil samples were collected from the topsoil for the first layer (0–10 cm depth) and stored in plastic bags. All samples were taken to determine their physical and chemical properties.

2.3 Soil Chemical Analysis

2.3.1 Soil pH and Electrical Conductivity

A Hanna Instrument Measurement pH Portable Meter measured the soil pH, and a Mettler Toledo measured the electric conductivity. We determined the pH and electrical conductivity using the glass electrode method in a 1:2.5 soil-water mixture [14].

2.3.2 Soil Organic Carbon and Total Nitrogen

Carbon and Nitrogen levels in the samples were measured using a ThermoFisher Elementar CHN (carbon, hydrogen, nitrogen) elemental analyzer, type Flash HT. Samples of the order of tens of micrograms to tens of milligrams must be perfectly homogeneous. They must therefore be crushed using a mortar and pestle, then sieved to 200 microns. Samples are weighed in tin capsules using a microbalance. After total combustion of the analytical sample at 1020°C under a stream of oxygen and helium (Dumas method), carbon, hydrogen and nitrogen are converted into carbon dioxide, water and nitrogen oxides, respectively[15] .

2.4 Soil Physical Analysis

2.4.1 Soil Bulk Density

Soil bulk volume of soil, which includes the volume of the solids and the pore's space between the soil particles was determined using 100 cm^3 rings. Soils were oven-dried at 105°C [16], for 24h a day.

2.4.2 Soil Particle Size

Particle size is a crucial property in soil science that influences the soil's structure, drainage, aeration, texture, and water retention. Particle size pre-treatment is an important step in preparing soil samples for analysis. Next, we initiated the process of wet sieving, a method that separates soil particles according to their sizes. We have four different steps of sieving: >2 mm, >200 µm, >100 µm, >50 µm, and the mixed well solution <50µm and put it in the bottle for analysis in the machines. Before using the particle size analyzer SALD-2300, we take the <50 µm solution into the ultrasound again and start the measurement: carefully place the sample cell into the SALD-2300 measurement chamber, ensuring it is properly aligned, and initiate the measurement using the instrument's control panel or software interface.

2. 5 Inverse Distance Weighted interpolation

Spatial interpolation techniques (such as, Inverse Distance Weighted (IDW) or other similar ones) are incredibly helpful tools that allow one to estimate values in unmeasured areas using a set of known data points. IDW is a widely used technique in many fields, including agriculture, geosciences, and environmental sciences, for generating continuous surfaces from point data. In QGIS 3.22 and geographical analysis, IDW is a widely used interpolation technique that estimates values at unmeasured points by using the values of nearby measured points. This assumption contributed to the increase in accuracy for map generation due to enhanced power. According to our findings, there was a small variation in the root mean square error when inverse distance weighting of the standard and smooth types with different powers was applied to the data set [17].

2.7 Data Analysis

The effects of four land uses of soil types physical and chemical properties were analyzed. Statistical analysis was computed with R Software. In this study, the data was examined statistically using analysis of variance (ANOVA). The test provides a P-value that allows to determine if groups are statistically significant. Analysis plotting time series of land uses from 1952-1972-1981 to understand a temporal dynamic of land use effect to soil properties. The QGIS 3.22 was used to create the interpolation map of each soil variable.

Table 1: The mean values of each variable from different four soil types

Parameter	Dense Forest	Clear Forest	Brushwood	Rice Field
BD(g/cm3)	1.28	1.66	1.67	1.68
pH	6.5	6.0	6.0	5.7
EC(ms/cm)	0.10	0.06	0.06	0.04
Carbon(g/kgech)	29.72	3.91	7.93	4.07
Nitrogen(g/kgech)	2.09	0.24	0.56	1.94

Table 2: The result of ANOVA test

Parameter	Mean Squares	F-Values	P-values
BD(g/cm3)	0.6716	33.08	5.5e-16***
pH	1.932	4.125	0.007**
EC(ms/cm)	0.12015	3.852	0.011*
Carbon(g/kgech)	2785	63.78	2e-16***
Nitrogen(g/kgech)	13.504	48.91	2e-16***

Table 3: The mean values of soil particle size

Soil Types	Sand%	Silt%	Clay%
Dense Forest	55.1	36.4	8.5
Clear Forest	78.6	18.4	3.0
Brushwood	62.0	23.3	14.7
Rice Field	58.2	25.5	16.3

2. RESULTS AND DISCUSSION

3.1 Soil Bulk Density

The results shown in Table 1 indicate that the bulk density ranged from 1.28 g/cm^3, 1.66 g/cm^3, 1.67 g/cm^3 and 1.68g/cm3 in dense forest, clear forest, brushwood, rice field . These differences were statistically significant ($P < 0.05$) across all four land use soil types (Table 2). Dense forest exhibited the lowest bulk density, suggesting that its top layer has a more porous and less compact structure, which is beneficial for plant growth and overall soil health. In contrast, clear forest, brushwood and rice field had a higher bulk density of 1.66-1.68 g/cm³, indicating that forest removal, but also from frequent trampling by animals and machinery can lead to soil compaction. These findings align with those of [18], who demonstrated that the conversion of forest to cultivated land increases soil bulk density.

3.2 *Soil pH and Soil Electrical Conductivity*

The soils of the catchment have pH values ranging from strongly acidic to moderately acidic (Table 1). Significant differences in soil pH were measured between the land use types, mostly because soils from rice field were more acidic than in forest. The higher pH in non-cultivated soils generally supports the hypothesis of a higher amount of nutrients in soil. The pH values for clear forest and brushwood typically average around 6, which is often considered optimal for many tree species and understory plants, as pH strikes a balance between acidity and nutrient availability. Forest with a pH of around 6 tend to support a diverse range of plant species, including trees, shrubs, and ground cover. Our study does not support the finding of [19]who found that soils from cultivated areas have a higher pH than those in grassland and forest . In contrast, rice field tends to be more acidic compared to forest soils, with cultivated land exhibiting more acidity in the upper layers than other land use types [20].

The soil's electrical conductivity was the highest in the dense forest (Table 1), with values reaching 0.08 mS/cm, while the other three soil types range from 0.04 to 0.05 mS/cm. The high moisture content and mineral concentration of dense forest soils generally result in greater electrical conductivity compared to other soil types. This higher conductivity is often attributed to the elevated levels of organic matter from decaying leaves and plant material. Numerous studies have shown that the electrical conductivity is higher in riverside soils, such as those found in grasslands, compared to soils from cultivated land and other land use types. Conversely, rice field tends to exhibit low electrical conductivity. The reduced EC values in paddy field is likely linked to the loss of exchangeable bases due to leaching from continuous cultivation.

3.3 Soil Organic Carbon and Total Nitrogen

There was a significant difference ($P< 0.05$) in the total soil organic carbon among the four land use soil types (Table 2). Soil types play an important role in influencing carbon content.

The organic carbon levels varied among land use types, with values of 29.72 g/kg for dense forest, 3.91 g/kg for clear forest, 7.93 g/kg for brushwood, and 4.09 g/kg for rice field (Table 1). Dense forest soil exhibited the highest organic carbon content, indicating that this ecosystem is effective at storing carbon. In forest, significant amounts of carbon are stored in the organic layers of the forest floor [21]. In contrast, the clear forest showed lower carbon content, suggesting that even areas with some tree removal can still contribute to carbon storage. Brushwood had a higher carbon content of 7.93 g/kg, indicating that shrub and grassland vegetation can also play a role in carbon sequestration. The lower carbon content in clear forest compared to brushwood may be attributed to the removal of trees and understory vegetation, which can reduce soil carbon levels. Additionally, brushwood vegetation tends to have more leaf litter, contributing to higher carbon content. Rice field displayed the lowest carbon content at 4.09 g/kg, highlighting that this agricultural practice is less effective for carbon storage compared to forested soils. Alluvial soil primarily covers the catchment area, which leads to the CEC, organic C, total N, exchangeable K, and Olsen P levels being extremely low in the Prey Khmer soil. In field tests conducted in Cambodia, sandy rice soils typically exhibit substantial N reactions [22].

Nitrogen content also showed significant difference ($P< 0.05$) across all four soil types (Table 2), with average total nitrogen values of 2.09 g/kg for dense forest, 0.24 g/kg for clear forest, 0.56 g/kg for brushwood, and 0.32 g/kg for rice field. Dense forest soils had the highest nitrogen content, suggesting that intact forest ecosystems possess the greatest capacity for nitrogen storage and cycling within biomass and soil. The clear forest had a lower nitrogen content of 0.24 g/kg, indicating that deforestation can lead to reduced nitrogen storage. Brushwood demonstrated a nitrogen content of 0.56 g/kg, suggesting it can contribute to nitrogen cycling. In comparison, rice field had a nitrogen content of 0.32 g/kg, indicating that rice cultivation results in lower nitrogen content and cycling compared to vegetated ecosystems.

3.4 Soil Particle size

Clay content values ranged from 8.5% in dense forest to 16.3% in rice field, with clear forest and brushwood having values of 3.0 and 14.7%, respectively (Table 3). This finding aligns with [23], who reported that clay content in cultivated lands was significantly higher. Silt content also varied, with values of 36.4% in dense forest, 18.4% in clear forest, 23.3% in rice field, and 26.7% in brushwood (Table 3). The highest silt content was found in dense forest, where dense vegetation helps reduce soil erosion by stabilizing the soil with its root system. This stability aids in retaining silt that might otherwise be washed away in less vegetated areas. Conversely, sand content values ranged from 55.1% in dense forest to 78.6% in clear forest, with rice field and brushwood soils at 62.0% and 60.7%, respectively. Most of the soils studied exhibited high sand content, reflecting the characteristics of sandy lowland soils, which are significant in Cambodian agriculture, particularly for lowland rainfed rice [24].

3.5 Soil Geology Affects Soil Properties

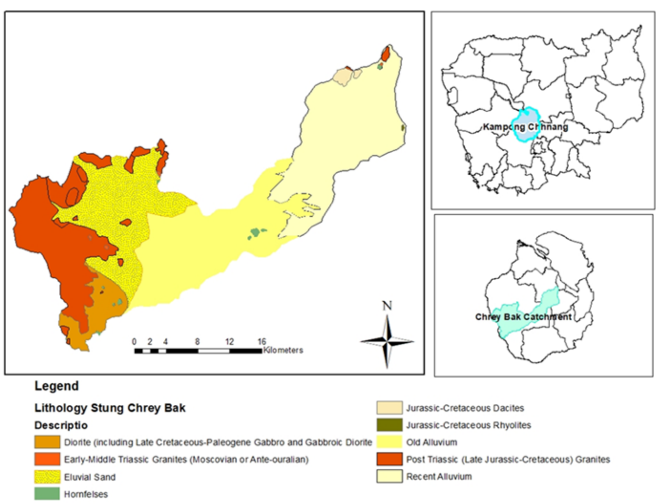

Figure 2. The Lithology of Stung Chrey Bak

The dense forest soil covered by the Post Triassic (Late Jurassic-Cretaceous), typically weathered to form sandy, well-drained soil. This weathering process can lead to the development of nutrient rich layers that support dense vegetation, which lead to dense forest soil having a slightly acidic pH level and low compaction of bulk density. Soil geology plays a fundamental role in determining physical and chemical properties of soil. Soil texture in dense forest soil, has a high level of sand 55.1% and silt 36.4% and a high amount of carbon and nitrogen content. Clear forest soil, mostly covered by alluvial sand formed from sediments deposited by rivers and streams, consists of sand-sized particles of soil texture, which are typically coarse and well-sorted. Alluvial sand is formed through the erosion and transportation of mineral particles by flowing water, and the stream (i.e., the Stung Chrey Bak) is one of the medium tributaries of the Tonle Sap River. Effects of specific land use types and interactions between soil texture on certain physical properties of soil in an alluvial land [25]. Sandy soil achieves maximum compaction at relatively low moisture content, with a significant compaction of 1.67 g/cm3. The soil texture exhibits a high proportion of sand (78.6%), low levels of carbon (3.91 g/kg), and nitrogen (0.24 g/kg). Soil aggregation and texture have an impact on carbon storage, and the silt and clay size fractions can shield SOC from breaking down [26]. As organic matter breaks down, it combines with silt and clay to form aggregates that keep the organic matter from breaking down further [27]. Old and recent alluvium, formed by sediments deposited by rivers and streams over geological periods, cover brushwood soil and rice field soil. Old alluvium frequently contains gravel and larger particles, particularly near riverbanks or floodplain environments, and finer particles, like silt and clay, may dominate as deposition moves away from the river, especially during flooding events. Brushwood has a slightly acidic pH and a low EC level. Its bulk density ranges from 1.66 g/cm3, which is completely compacted due to the high sand content of 58.2% and the carbon content of 7.93 g/kgech and 0.56g/kgech, Sandy soils often have a lower organic matter content than finer-textured soils; soil organic matter serves as a slowly released source of nitrogen [28].

3.6 The land use/ land cover change affects soil properties

The results shown in Figure 3 indicate significant changes ($P<0.05$) in land use within the study catchment, particularly in clear forest, rice field, and brushwood areas. A substantial reduction in clear forest wasobserved, as it degraded to brushwood in the upper part of the catchment due to expanding agricultural activities and increasing settlement demands. In contrast, rice field steadily increased in area as development progressed within the catchment. The built-up area showed no notable change in the time series due to its minor increase. Other land uses, such as plantations, lake or pond tree cutting, home gardens, and grasslands, experienced slight increases, but these changes were statistically insignificant from 1952 to 1981.Dense forest decreased slightly from 20.1% to 12.7%, while clear forest declined from 45% to 32.3% over the past three decades, affecting soil characteristics significantly. Most of the clear forest was converted to brushwood, which increased from 15% to 23.8%. The deforestation of dense forest leading to a significant compaction of soil from

1.28g/cm^3 to 1.67g/cm^3, the reduction in organic matter due to deforestation has led to decreased soil fertility and increased erosion [29] which highlight the critical role of organic matter in maintaining soil structure and nutrition.

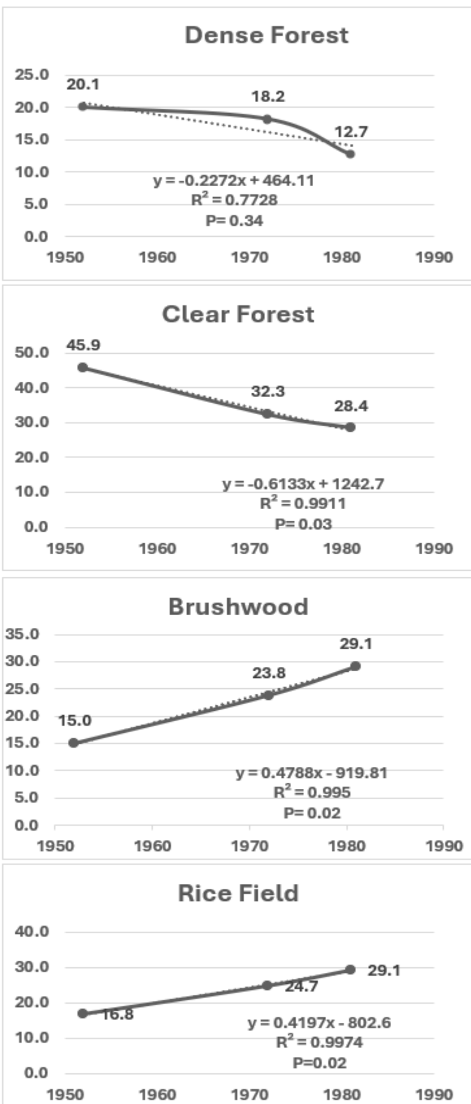

Figure 3. Time Series of Land Use/Cover 1952-1981

3.7 Interpolation of Map Bulk Density

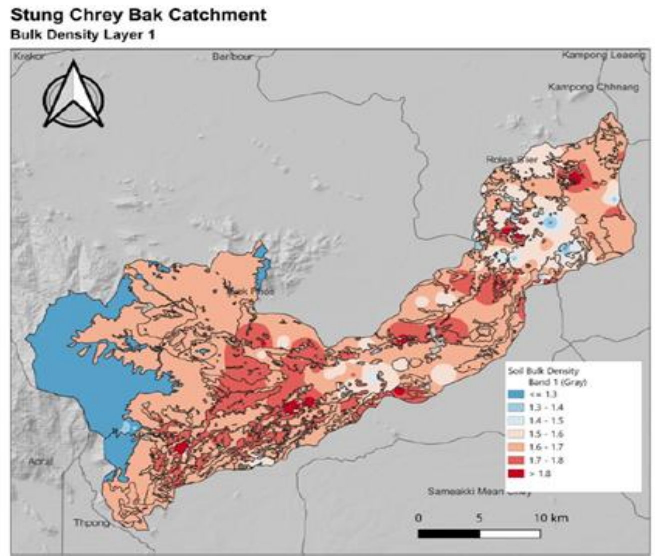

Figure 4. The Interpolation of Bulk Density

Interpolation maps of soil properties play a crucial role in various fields, including agriculture, environmental science, and land management. These maps are especially valuable for farmers looking to enhance crop production and optimize resource use across large agricultural landscapes. Figure 4 llustrates bulk density values across different land cover types. In the dense forest areas, represented by blue colors, bulk density was the lowest (< 1.3 g/cm³). This relatively low bulk density reflects the significant amount of organic material (such as leaf litter and decomposing plant matter) present in these soils, which reduces compaction. The root systems of trees and plants, as well as soil macrofauna activity further create spaces in the soil, enhancing porosity and water retention. In contrast, the clear forest soils and brushwood, indicated by light red in the map, exhibited higher bulk densities ranging from 1.6 g/cm³ to 1.7 g/cm³. This suggests that the soil in these areas may have become compacted due to the removal of vegetation, which diminishes organic matter and disrupts soil structure. Finally, the rice fields, indicated by light red and red colors, showed bulk densities had similar soil bulk densities than clear forest and brushwood (~1.6 to 1.7 g/cm³). High bulk density in these soils is often the result of compaction from heavy machinery used in rice farming. Additionally, rice field soils, which are typically clay-rich, are more prone to compaction under mechanical stress.

3.8 Interpolation of Map pH

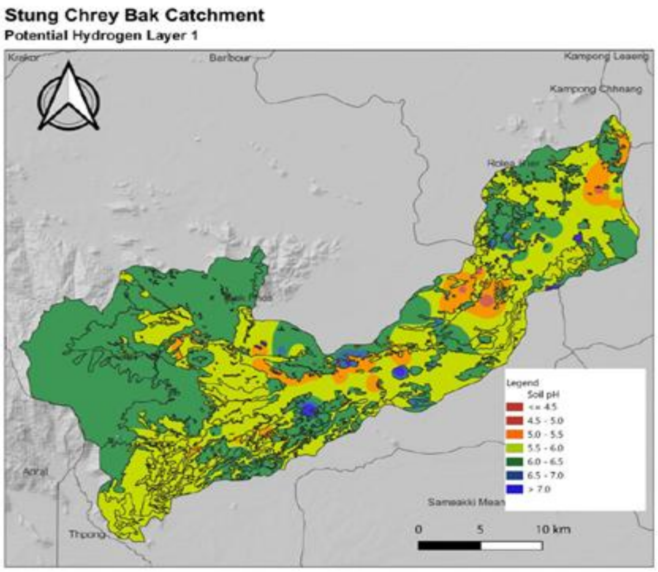

Figure 5. The Interpolation of pH

Soil pH values ranged from 4.5 to 7.0, as illustrated in Figure 4, with significant differences observed among dense forest, clear forest, brushwood, and rice field. The dense forest, represented in dark green, covers the upstream mountainous area to the west. Its pH values typically range from 6.0 to 6.5, which is generally considered neutral to slightly acidic, ideal for the availability of essential nutrients such as nitrogen, phosphorus, and potassium. The acidity of the dense forest soil helps break down organic matter to enrich the soil and indicates a healthy ecosystem that supports biodiversity and nutrient cycling.

In the lower part of the mountainous area, a transition zone exists between steep slopes and clear forest, where pH values are slightly acidic, ranging from 5.5 to 6. Clear forest areas, depicted in both dark and light green, are more susceptible to soil erosion due to vegetation loss and degradation of soil structure, although they still hold potential for healthy plant growth. The pH of the brushwood soils, shown in varying shades of green, is around 6, which is usually considered ideal for nutrient availability. In contrast, rice field , represented in orange and light green, have a pH ranging from 5.0 to 5.5, indicating an acidic soil environment. Grassland soils typically exhibit a higher pH than those found in forested and farmed areas.

3.9 Interpolation Map of electrical conductivity

Soil electrical conductivity has been used as a measure of soil salinity as a basis. Indirectly, EC measures the quantity of nutrients available for plant absorption and salt levels.Soil electrical conductivity in figure 6 ranged from 0.01 mS/cm to 0.25 mS/cm in dense forest, clear forest, brushwood, and rice field soil.

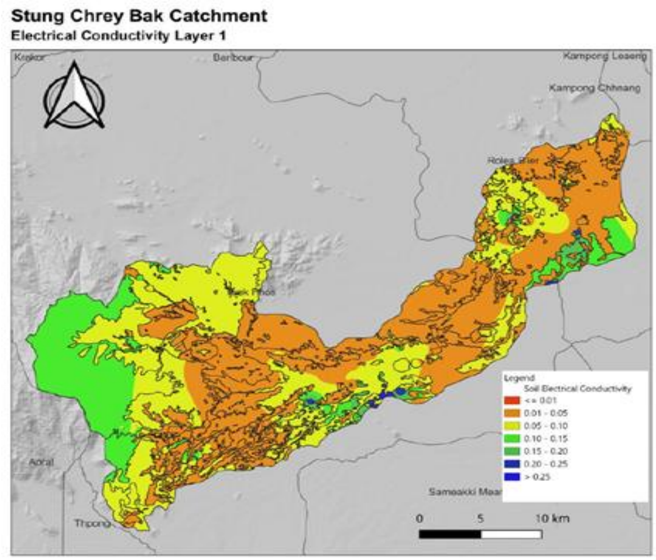

Figure 6. The Interpolation of Eletrical Conductivity

In the interpolation map, dense forest ranged from 0.10 mS/cm to 0.15 mS/cm, which suggests low salinity levels in the soil, a good level for most plants and crops. For clear forest soil areas, the cover yellow colors of the soil ranged from 0.05 mS/cm to 0.10 mS/cm, indicating low levels of soluble salt in the soil and correlated with good nutrient availability, especially supporting healthy growth. Brushwood soil covered by yellow colors; electrical conductivity values also ranged from 0.05 mS/cm to 0.10 mS/cm similar to clear forest. Rice field soil covered by orange colors ranging from 0.01 indicates low salinity, generally favorable for rice.

3.10 Interpolation map of Soil Organic carbon and total nitrogen contents

The C and N contents were the highest in the dense forest soils (Figures 7 and 8). This highlights the critical role of dense forest in carbon sequestration, which also indirectly supports biodiversity conservation and soil health. In contrast, the soil in clear forest areas show significantly lower carbon and nitrogen levels. Several interrelated factors contribute to this decrease, notably the impact of deforestation. The removal of trees and vegetation reduces the amount of biomass that stores soil organic matter, while clearing the forest often results in soil erosion and compaction. Additionally, with the loss of vegetation, there is less organic matter input into the soil, further decreasing carbon content. Obviously, the topography is also likely to play a critical role, since dense forest is located in the mountainous areas, protected from agriculture because of the steep slopes

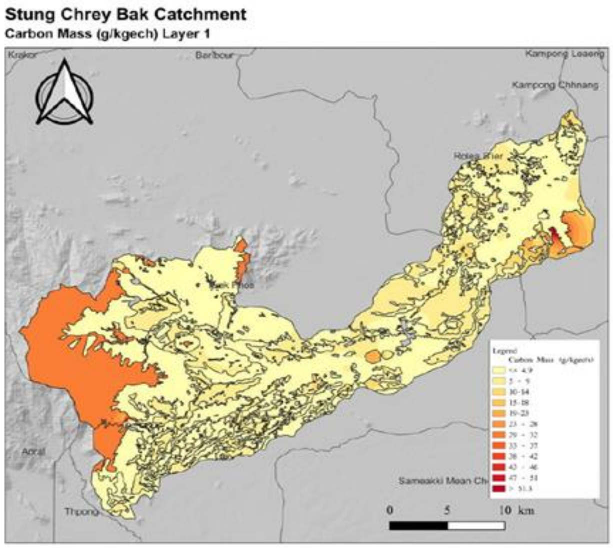

Figure 7. The Interpolation of Carbon Content

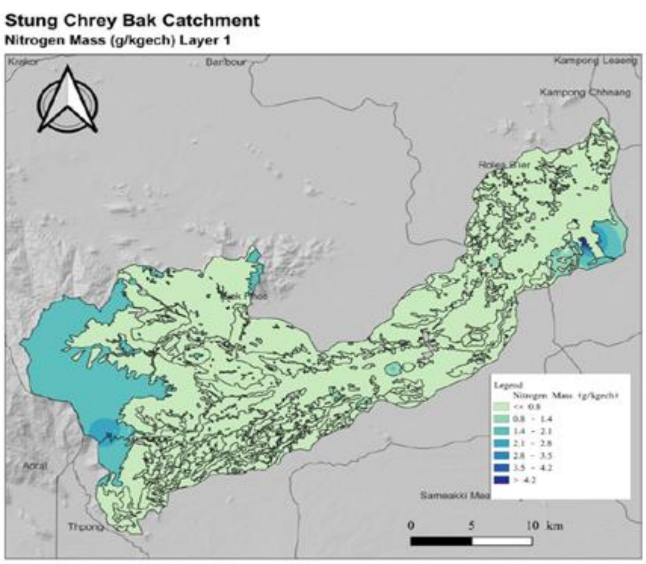

Figure 8. The Interpolation of Total Nitrogen

Although brushwood areas have some biomass density, they typically have lower carbon and nitrogen contents compared to dense forest.Vegetation in these areas is usually smaller and shorter-lived, leading to lower long-term carbon accumulation. However, in some cases, brushwood areas may exhibit slightly higher carbon and nitrogen levels than clear forest , as the dense growth of shrubs can increase biomass and these areas often experience fewer disturbances than clear forests.

Finally, rice field soils typically have the lowest amount of carbon and nitrogen contents. These soils often consist of silt and sand, which limit their ability to retain organic matter. Additionally, the physical properties of these soils may not support high carbon storage. Soil compaction from machinery can reduce pore space, limiting root growth and organic matter distribution. Furthermore, the decrease in soil aggregation, reduced physical protection of organic matter, and increased soil erosion contribute to lower carbon stocks in rice field. As a result, the soil organic carbon (SOC) stocks in agricultural soils, particularly those that have been degraded, is typically lower than their theoretical potential [21].

3.11 The Interpolation Map of soil texture

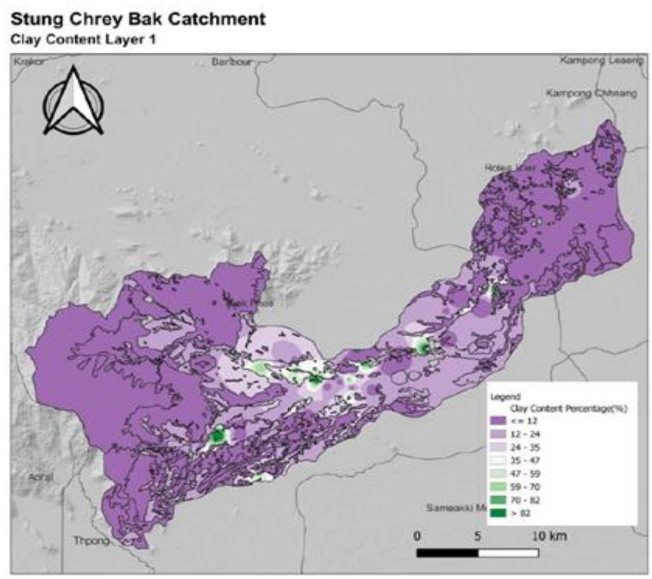

Figure 9. The Interpolation of Clay Content

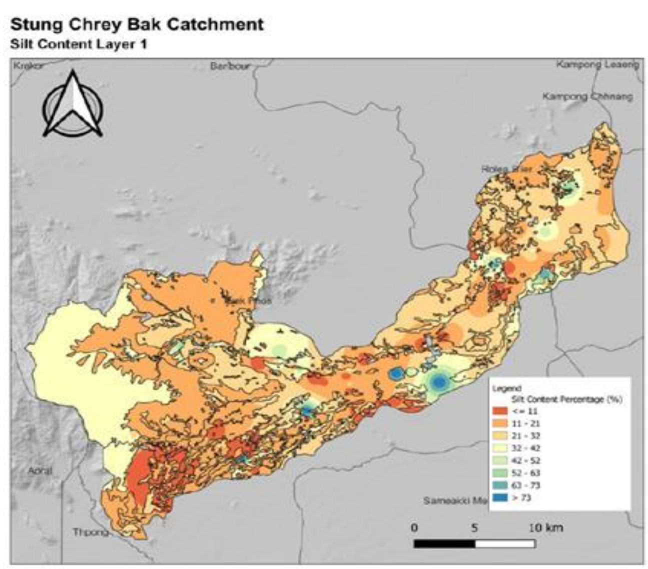

Figure 10. The Interpolation of Silt Content

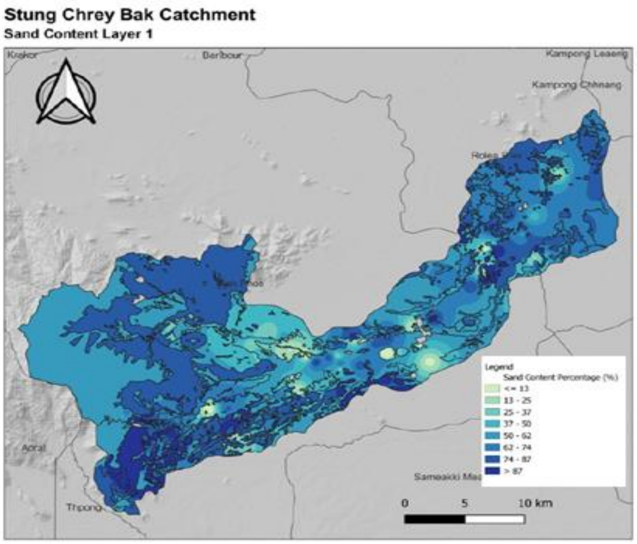

Figure 11. The Interpolation of pH

Figures 9, 10 and 11 show the clay, silt, and sand contents. Clay content in the upper parts (0-10 cm depth) ranged from less than 12% to 80%. The depth and distribution of clay, along with other soil properties, influence the performance and accuracy of the Inverse Distance Weighting (IDW) interpolation method [30]. In the dense forest areas, indicated by dark purple, the clay content was below 12%. The clay content varied by topography. The middle part of the study area contained higher clay content compared to both the upper and lower sections. This variation is partly due to sediment erosion from mountain streams, which transport sand, silt, and clay. The upper part of the catchment has a higher content of sand, while the middle part has a higher clay content. The Tonle Sap river also contributes to sediment deposition in the lower part of the catchment , where the content of sand is typically higher than in the middle part. In addition, compared to the upper and lower parts, the middle part contains a higher amount of clay. The middle part of the study catchment contained higher content of clay compared to both the upper and lower parts. This variation is partly due to sediment erosion from mountain streams, which transport sand, silt, and clay.

3. CONCLUSIONS

In conclusion, this study highlights the significant impact of land use transitions between 1952 and 1981 on soil characteristics in the Stung Chrey Bak catchment. It explores how the conversion of dense forests, cleared forests, brushwood, and rice fields has altered various soil properties. Notably, the transformation of forests into paddy fields predominantly occurred in the lower part of the study area, while dense forests are now limited to the mountainous regions. These changes have led to increased soil compaction, shifts in pH, and declines in soil carbon and nitrogen contents. Further research is needed to quantify the carbon stored in forested areas, with a particular focus on the properties of deeper soil layers. Additionally, investigating biodiversity patches, such as termite mounds relics of the natural forest remains important. These patches, still present in paddy fields, are increasingly threatened by agricultural practices that seek to homogenize and simplify agroecosystem.

ACKNOWLEDGMENTS

To complete this work, first of all, I would like to express my deep gratitude to my supervisors (Dr. Vannak Ann and Dr. Pascal Jouquet), Dr. Ratha Muon, Rainer Zaiss, and Dr. Jeroen Meersmans, who have taken time and effort to guide and support me since the first time we met. Their encouragement and guidance have been acting as my compass to walk on the right track and make me feel that I am the luckiest student. Furthermore, they have always been very close to me in monitoring and evaluating all my progress and results with love and support. This study was supported by the FSPI/FEF REASOL project n° 2023-18, funded by the French Ministry of Europe and Foreign Affair, and by the Académie de recherche et d'enseignement supérieur de Belgique (ARES).

REFERENCES

[1] M. A. N. Anikwe and K. Ife, "The role of soil ecosystem services in the circular bioeconomy," *Front. Soil Sci.*, vol. 3, no. November, pp. 1–18, 2023.

[2] S. Arnhold, D. Otieno, J. Onyango, T. Koellner, B. Huwe, and J. Tenhunen, "Soil properties along a gradient from hillslopes to the savanna plains in the Lambwe Valley, Kenya," *Soil Tillage Res.*, vol. 154, pp. 75–83, 2015.

[3] C. Rumpel *et al.*, "Black carbon contribution to soil organic matter composition in tropical sloping land under slash and burn agriculture," *Geoderma*, vol. 130, no. 1–2, pp. 35–46, 2006.

[4] R. Lal, "teses_ufrj_br_COPPE_M_JoaoFelipeMitreDeAraujo.pdf," *Soil Tillage Res.*, vol. 27, no. 1–4, pp. 1–8, 1993.

[5] R. Lal, "Soil degradation by erosion," *L. Degrad. Dev.*, vol. 12, no. 6, pp. 519–539, 2001.

[6] J. M. Edeso, A. Merino, M. J. González, and P. Marauri, "Soil erosion under different harvesting

managements in steep forestlands from northern Spain," *L. Degrad. Dev.*, vol. 10, no. 1, pp. 79–88, 1999.

[7] M. M. Mikha, C. W. Rice, and G. A. Milliken, "Carbon and nitrogen mineralization as affected by drying and wetting cycles," *Soil Biol. Biochem.*, vol. 37, no. 2, pp. 339–347, 2005.

[8] K. Ngoc *et al.*, "Agriculture , Ecosystems and Environment Evaluating carbon sequestration for conservation agriculture and tillage systems in Cambodia using the EPIC model," *Agric. Ecosyst. Environ.*, vol. 251, no. January 2017, pp. 37–47, 2018.

[9] J. Alvar-Beltrán *et al.*, "Modelling climate change impacts on wet and dry season rice in Cambodia," *J. Agron. Crop Sci.*, no. March, pp. 746–761, 2022.

[10] S. Pheap *et al.*, "Multi-functional assessment of soil health under Conservation Agriculture in Cambodia," *Soil Tillage Res.*, vol. 194, no. July, p. 104349, 2019.

[11] T. G. Pham, H. T. Nguyen, and M. Kappas, "Assessment of soil quality indicators under different agricultural land uses and topographic aspects in Central Vietnam," *Int. Soil Water Conserv. Res.*, vol. 6, no. 4, pp. 280–288, 2018, [Online]. Available: https://doi.org/10.1016/j.iswcr.2018.08.001

[12] S. Kalu, M. Koirala, U. R. Khadka, and A. K. C, "Soil Quality Assessment for Different Land Use in the Panchase Area of Western Nepal," *Int. J. Environ. Prot.*, vol. 5, no. 1, pp. 38–43, 2015.

[13] S. Chann, N. Wales, and T. Frewer, "An Investigation of Land Cover and Land Use Change in Stung Chrey Bak Catchment , Cambodia," *CDRI Work. Pap. Ser. No. 53*, no. 53, p. 70, 2011, [Online]. Available: http://www.cdri.org.kh

[14] A. . Shivanna and G. Nagendrappa, "Chemical Analysis of Soil Samples to Evaluate the Soil Fertility Status of Selected Command Areas of Three Tanks in Tiptur Taluk of Karnataka, India," *IOSR J. Appl. Chem.*, vol. 7, no. 11, pp. 01–05, 2014.

[15] N. V. Grassineau, "High-precision EA-IRMS analysis of S and C isotopes in geological materials," *Appl. Geochemistry*, vol. 21, no. 5, pp. 756–765, 2006.

[16] F. Sun and S. Lu, "Biochars improve aggregate stability, water retention, and pore-space properties of clayey soil," *J. Plant Nutr. Soil Sci.*, vol. 177, no. 1, pp. 26–33, 2014.

[17] H. Ahmed, M. T. Siddique, M. Iqbal, and F. Hussain, "Comparative study of interpolation methods for mapping soil pH in the apple orchards of Murree, Pakistan," *Soil Environ.*, vol. 36, no. 1, pp. 70–76, 2017.

[18] S. F. Fentie, K. Jembere, E. Fekadu, and D. Wasie, "Land Use and Land Cover Dynamics and Properties of Soils under Different Land Uses in the Tejibara Watershed, Ethiopia," *Sci. World J.*, vol. 2020, no. 1, p. 1479460, 2020, [Online]. Available: https://doi.org/10.1155/2020/1479460

[19] F. Yimer, *Soil Properties in Relation to Topographic Aspects, Vegetation Communities and Land Use in the South-eastern Highlands of Ethiopia*. 2007.

[20] D. J. Negasa, "Effects of Land Use Types on Selected Soil Properties in Central Highlands of Ethiopia," *Appl. Environ. Soil Sci.*, vol. 2020, 2020.

[21] R. Lal, "Forest soils and carbon sequestration," *For. Ecol. Manage.*, vol. 220, no. 1–3, pp. 242–258, 2005.

[22] Y. Seng, C. Ros, R. W. Beil, P. F. White, and H. Sarith, "Fukai , S . and Basnayake , J ., (eds .) Increased Lowland Rice Production in the Mekong Region ; proceedings of an international workshop held in Vientiane , Laos , 30 Oct - 1 Nov . Nutrient Requirements of Rainfed Lowland Rice in Cambodia," pp. 169–178, 2001.

[23] G. L. Wu, Y. Liu, N. F. Fang, L. Deng, and Z. H. Shi, "Soil physical properties response to grassland conversion from cropland on the semi-arid area," *Ecohydrology*, vol. 9, no. 8, pp. 1471–1479, 2016.

[24] K. Kaen, "Bell , R . W . and Seng , V . (2007) The management of agro- ecosystems associated with sandy soils . In : Management of Tropical Sandy Soils for Sustainable Agriculture : Symposium on the Management of Tropical Sandy Soils , 27th November – 2nd The man," no. December 2005, pp. 298–304, 2007.

[25] M. Sağlam and O. Dengİz, "Influence of selected land use types and soil texture interactions on some soil physical characteristics in an alluvial land," *Int. J. Agron. Plant Prod.*, vol. 3, no. 11, pp. 508–513, 2012.

[26] L. Ashton, H. P. Lieberman, C. Morrison, and M. É. Samson, "Carbon sequestration in Canada's croplands: a review of multiple disciplines

influencing the science-policy interface," *Environ. Rev.*, vol. 31, no. 4, pp. 652–668, 2023.

[27] A. Schapel, P. Marschner, and J. Churchman, "Clay amount and distribution influence organic carbon content in sand with subsoil clay addition," *Soil Tillage Res.*, vol. 184, no. May, pp. 253–260, 2018, [Online]. Available: https://doi.org/10.1016/j.still.2018.08.001

[28] A. M. Oudesluys-Murphy and W. J. Van Yperen, "Imposed upper airway obstruction and covert video surveillance," *Arch. Dis. Child.*, vol. 67, no. 11, p. 1411, 1992.

[29] R. Lal, C. Monger, L. Nave, and P. Smith, "The role of soil in regulation of climate," *Philos. Trans. R. Soc. B Biol. Sci.*, vol. 376, no. 1834, 2021.

[30] A. M. Raheem, I. J. Naser, M. O. Ibrahim, and N. Q. Omar, "Inverse distance weighted (IDW) and kriging approaches integrated with linear single and multi-regression models to assess particular physico-consolidation soil properties for Kirkuk city," *Model. Earth Syst. Environ.*, vol. 9, no. 4, pp. 3999–4021,2023