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Topsoil physicochemical properties: A case study in the buffer zone of Tram Chim National Park, Tam Nong district, Dong Thap province, due to the impact of climate change

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Abstract: *Climate change has a significant impact on soil physicochemical properties due to elevated temperatures and changes in precipitation patterns. The physical and chemical analysis of six topsoil types in the buffer zone of Tram Chim National Park indicated that the soil texture is primarily clay, with percentages greater than 40%, bulk density ranges from 0.62 to 1.18 (g/cm^3), followed by silt (28.50 - 37.90%) and sand (19.40 - 28.93%). There is no significant difference in the pH of all topsoil types, which ranges from acidic to slightly acidic (pH_{KCl}: 3.81 – 4.78). The cation-exchange capacity (CEC) of the soil is medium to high (17.88 - 27.83 meq/100g of soil) and nutrients including organic matters (OM) and total nitrogen (N), are rich to very rich (OM: 4.24 - 19.05%; N: 0.21 - 0.37%). These topsoil types are good at adsorbing plant nutrient cations. However, total potassium (K_20) and total phosphorus (P_20_5) are low, and total sulfur (SO_4^{2-}) is at low - medium levels (approximately 0.042-0.08%), which is toxic and harmful to plants. Total soluble salts (TSS) of all samples are at a very low level (< 0.16%). In contrast, for Gleyic Acrisols (Xf), the percentage of sand is the highest, and clay is the lowest. Its cation-exchange capacity and nutrients are almost lower than those of the analyzed topsoil samples in the study. With increasing temperature, drought, and decreasing rainfall in both amount and frequency, the topsoil layer is more frequently exposed to high surface temperatures, leading to heavy acidification, nutrient reduction, and soil degradation.*

Keywords: *Soil properties; Soil texture; Soil nutrients; Degradation; Climate change*

1. Introduction

Soil is a natural resource that is spatially limited. It constantly affected by natural processes and human activity. Soil physical and chemical properties play a fundamental role in evaluating the quality of cultivated land, making it crucial to assess changes in these properties over time due to climate change, a phenomenon often referred to as global warming. Elevated temperatures and changes in both the amount and frequency of precipitation have significantly impacted soil properties, leading to gradual degradation in quality through reduced fertility, increased drought, acidification, etc. These changes can result in decreased agricultural production and productivity, threatening food security and farmers' livelihoods (SINGH, COWIE, & & CHAN, 2011) .

Soil physical properties include key components such as soil texture, porosity, bulk density and pore-size distribution (HILLEL, 1973). The properties play an important role in management of water, air, and heat in soil, all of which significantly influence chemical and biological processes like adsorption, cation exchange capacity (CEC), biological activity, etc. Different soil mechanical compositions react differently climate change. Silt soils, which have the highest water retention capacity, are the most sensitive to climate change, whereas clay soils are the least sensitive (BORMANN, 2012). The evaporation and capillary moisture transport from the surface to the root zone or groundwater and vice versa are more strongly influenced by porosity in silt soils than in clay soils. In recent years, increased drought has caused soils to crack and shrink. Besides, seasonal and regional changes in the amount and distribution of precipitation and elevated temperature affect the soil structure through mechanical disturbance and compaction (BOCKHEIM, 1980; REUBENS, POESEN, DANJON, GEUDENS, & MUYS, 2007). Soil texture, porosity and pore size distribution, which strongly determine ecosystem functioning and chemical processes, primarily control infiltration, water storage capacity, and moisture content.

Some important soil chemical properties, such as pH, soluble salt content, cation exchange capacity, and organic matter content, are sensitive to the impact of climate change. Soil pH is determined by parent materials, weathering rates, vegetation, and climate. Changes in climatic conditions, including increased temperature, prolonged drought, and reduced precipitation, affect capillary water movement and the groundwater regime, coupled with increased soil evaporation (VÁRALLYAY, 2007). This is the main factor causing soil aridity, salinization, and acidification. Soil pH is relevant to the amount of exchangeable cations; neutral and moderately alkaline soils are dominated by Ca^{2+} and Mg^{2+}, while acidic soils may have high H^+ and Al^{3+} concentrations (ROBERTSON, SOLLINS, ELLIS, & & LAJTHA, 1999). Organic matter content (OM) is correlated with the soil texture and cation- exchange capacity (CEC) (LAVEE, IMESO, & & SARAH, 1998). Soils with low organic matter content have limited surfaces available for adsorption and CEC. Annually decreasing precipitation and increasing drought reduce the downward filtration and leaching in soils, leading to increase aridity. The decrease in soil moisture adversely effects vegetation growth and biological activity (PORPORATO, DALY, & & RODRIGUEZ-ITURBE, 2004).

Vietnam is considered one of the countries significantly impacted by long-term annual drought and salinization due to climate change. In the Mekong River delta region, particularly Dong Thap province, the low topography and far distance from the East Sea result in soils that are often arid but not saline during the dry season (Environment, 2017, 2020; Univeristy, 2015). These soils, however, have experienced reduced fertility, aluminization, and other alterations to their original properties, leading to degradation in quality ((UNCCD), 2018). The buffer zone of Tram Chim National Park is located in Tam Nong District, Dong Thap Province, and serves to prevent and protect the impacts on the park as well as support conservation, management, and prevention of illegal migration into the park. With social- economic development and stabilization of the farmers' lives, soils in the buffer zone have been exploited for agriculture, forestry, and fishery purposes. As a result, these soils have gradually lost fertility and become severely dry and aluminized. The results in the findings are compared to those analysed in 2016 (Environment, 2017) to assessment on the physical and chemical changes. Additionally, climate change impacts, such as drought and flooding, have posed risks to farmers' livelihoods in recent years. Therefore, it is essential to study the soil physicochemical properties in the buffer zone of Tram Chim National Park. The research will be conducted in the following years to obtain statistics and determine the change of the physical and chemical properties of the topsoils in spatial distribution. In further study, there are assessments of the impact of climate change on topsoil layer and propose suitable measures to mitigate soil degradation in this area.

2. Study area

The study area is the buffer zone of Tram Chim National Park, Tam Nong District, Dong Thap Province, covering a total area of 16,858 hectares, approved by Dong Thap Provincial People's Committee under Decision No. 1037/QD-UBND.HC dated October 5, 2015. It includes 5 communes: Phu Duc, Phu Thanh B, Phu Hiep, Phu Tho, Tan Cong Sinh, and 2 hamlets in Tram Chim Town (Figure 1). The annual average temperature is 27^0C, with a temperature range from a minimum of 20 - 27^0C to a maximum of 36 - 38°C. The yearly average precipitation reaches 1,138 mm, with more than 90% of rainfall concentrated in the rainy season from May to November, and rare to no rainfall in the dry season from December to April in following year (Office, 2023). The buffer zone has low topography with insignificant elevation differences, ranging from about 2m in height on average to a maximum of 4m and a minimum of under 1m. This area is suitable for growing rice, aquaculture farming, forest planting to benefit local farmers.

3. Methodology

The research methods included:

- Field surveys and drilling 10 boreholes in the topsoil layer at a depth of 0-25cm, with a borehole diameter of 30mm.

- Collecting data related to land-use changes, vegetation cover, and soil properties in the dry and rainy seasons.

- Laboratory analysis of collected samples:

+ Soil texture was categorized based on grain size: clay, silt, sand ((FAO), 2006) and bulk density was determined using the cylinder method (de Souza et al., 2016);

+ Soil pH was measured using an electrode pH meter (E-331); the soil solution was extracted from distilled water and potassium chloride with a ratio of soil: water/KCl = 1:5.

+ Soil chemical properties were determined using the Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES) and titration methods.

- Integrating collected data, analytical results, and assessment of variations in soil physicochemical properties in the buffer zone in accordance with the specified standards in Circular No. 14/2012/BTNMT

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and Circular No. 14/2024/BTNMT of the Ministry of Natural Resources and Environment (Vietnam) (14/2012//BTNMT, 2012; 14/2024//BTNMT, 2024).

4. Results and Discussion

The boreholes were drilled in 06 topsoil types: (1) Umbric Fluvisols (Endo-orthithionic, Sj2p) (BZ1 and BZ7); (2) Umbric Fluvisols (Endo-protothionic, Sp2) (BZ2); (3) Umbric Fluvisols (Epi-orthithionic, Sj1p) (BZ3); (4) Umbric Fluvisols (Epi-prothothionic, Sp1) (BZ4, BZ9 and BZ10); (5) Gleyic Acrisols (Xf) (BZ5 and BZ8); and (6) Histic Fluvisols (Epi-prothothionic, TSp) (BZ6) (Figure 1). The features of these topsoil types are described in the field, as presented in Table 1.

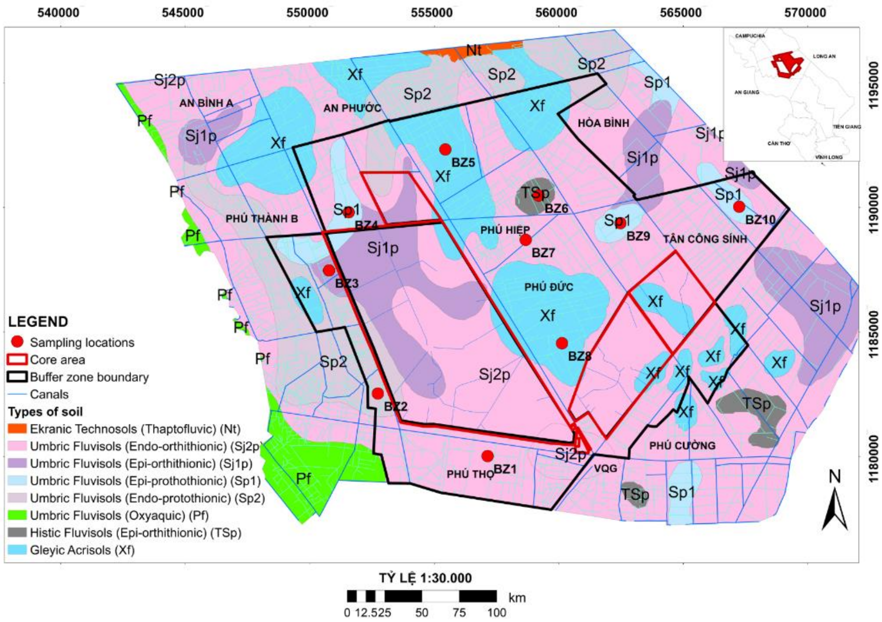

Fig. 1. Study area and sampling locations (Environment, 2017)

Tab. 1. Borehole positions and sample descriptions

Name	Soil type (FAO)	Borehole position		Depth (cm)	Sample description
		Latitude (N)	Longitude (E)		
BZ1	Umbric Fluvisols (Endo-orthithionic) (Sj2p)	10°40'23.9232"	105°31'27.3576"	0 - 25	Greyish brown silty clay with scattered brown spots.
BZ2	Umbric Fluvisols (Endo-protothionic) (Sp2)	10°41'45.996"	105°29'2.4756"	0 - 25	Greyish brown silty clay with plant roots and organic matter spots.
BZ3	Umbric Fluvisols (Epi-orthithionic) (Sj1p)	10°44'26.9772"	105°27'58.302"	0 - 25	Dark-grey silty clay with scattered organic matter spots and plant roots.
BZ4	Umbric Fluvisols (Epi-prothothionic) (Sp1)	10°45'42.93"	105°28'24.4092"	0 - 25	Dark-greyish brown silty clay with organic matter and plant roots.
BZ5	Gleyic Acrisols (Xf)	10°47'4.9956"	105°30'32.4864"	0 - 25	Light-brown silty sand and scattered brown spots and organic matter spots.
BZ6	Histic Fluvisols	10°46'4.5012"	105°32'35.7432"	0 - 10	Dark brown silty clay interbedded dark grey

	(Epi-prothothionic) (TSp)				clay with plant roots and organic matter.
BZ7	Umbric Fluvisols (Endo-orthithionic) (Sj2p)	10°44'1.1472"	105°33'4.9788"	0 - 25	Greyish brown silty clay with scattered brown organic matter spots.
BZ8	Gleyic Acrisols (Xf)	10°41'14.1396"	105°34'42.0744"	0 - 25	Light-brown and grey silty sand and scattered brown spots and organic matter spots.
BZ9	Umbric Fluvisols (Epi-prothothionic) (Sp1)	10°45'28.2132"	105°34'23.8764"	0 - 25	Greyish silty clay with organic matter and plat roots.
BZ10	Umbric Fluvisols (Epi-prothothionic) (Sp1)	10°44'57.1812"	105°36'27.1728"	0 - 25	Light-greyish brown silty clay and plant roots.

The analytical results of the physicochemical properties of 6 topsoil types collected from 10 boreholes indicated that the topsoil texture is primarily composed of sand, silt, and clay, with sand ranging from 19.40% to 46.4%, silt from 28.50% to 38.23%, clay from 16.03% to 49.65%, and bulk density (BD) ranging from 0.62 to 1.42 g/cm^3. The percentage ratio of soil particles varies among the different topsoil types; Gleyic Acrisols (Xf) has the highest sand percentage, greater than 45%, followed by silt (32.76 - 38.23%) and clay (16.03 - 20.80%). Umbric Fluvisols (Epi-orthithionic, Sj1p) and Umbric Fluvisols (Endo-orthithionic, Sj2p) have the lowest sand percentage, approximately 19.40 - 20.16%, while their silt and clay contents are 31.44 - 37.35% and 43.25 - 48.51%, respectively. Umbric Fluvisols (Endo-protothionic, Sp2), Umbric Fluvisols (Epi-prothothionic, Sp1), and Histic Fluvisols (Epi-prothothionic, TSp) have clay content ranging from 41.03% to 49.65%, silt from 28.50% to 37.90%, and sand from 21.07% to 28.93% (Table 2, Figure 2).

The chemical properties showed that the pH of the topsoil types ranges from acidic to slightly acidic, with pH_{KCl} lower than 5, ranging from 3.95 to 4.78, and pH_{H20} approximately 4.42 - 5.62. Histic Fluvisols (Epi-prothothionic) (TSp) has the lowest pH (pH: 3.81). The cation-exchange capacity (CEC), which refers to the number of exchangeable cations including Mg^{2+}, Na^+, Ca^{2+}, and K^+ in the soil, reaches a medium to high level, ranging from 17.88 - 27.83 (meq/100g of soil), while Gleyic Acrisols (Xf) is lower, ranging from 9.75 - 10.56 (meq/100g of soil). Nutrient elements essential for plant growth, such as organic matter (OM), total nitrogen (N), phosphorus (P_20_5) and potassium (K_20), ranges from medium to high levels. Organic matter and total nitrogen range from rich to very rich (OM: 4.24 - 19.05% and N: 0.21 - 0.37%), respectively; total phosphorus (P_20_5) and potassium (K_20) range poor to low medium (K_20: 1.01 – 1.45% and P_20_5: 0.040 – 0.080%), and total sulfur (SO_4^{2-}) ranges from low to medium (SO_4^{2-}: 0.042 - 0.080%). Meanwhile, the nutrient content in Gleyic Acrisols (Xf) is very poor (OM: < 2.4%, N: < 0.2%, P_20_5: 0.047 – 0.053%, K_20: < 0.04%) and total sulfur is very low (SO_4^{2-}: < 0.02%). Total soluble salts (TSS) of the soil types are very low, approximately 0.07 – 0.15% as determined in Table 2.

Tab. 2. Physical and chemical topsoil properties

Name	pH		OM (%)	N (%)	P_2O_5 (%)	K_2O (%)	CEC (meq/100g)	SO_4^{2-} (%)	TSS (%)	Sand (%)	Silt (%)	Clay (%)	BD (g/cm^3)
	H_20	KCl											
BZ1	5.62	4.78	4.24	0.21	0.040	1.21	17.88	0.049	0.068	19.40	37.35	43.25	1.12
BZ2	4.92	4.42	4.83	0.28	0.058	1.12	21.08	0.064	0.151	21.85	28.5	49.65	1.18
BZ3	4.97	3.95	6.15	0.29	0.056	1.45	22.15	0.070	0.125	20.05	31.44	48.51	1.01

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BZ4	5.05	4.20	4.50	0.26	0.050	1.09	21.25	0.076	0.103	26.09	30.02	43.89	0.94
BZ5	5.12	4.40	1.55	0.15	0.047	0.35	9.75	0.012	0.067	45.74	38.23	16.03	1.42
BZ6	4.42	3.81	19.05	0.34	0.078	1.02	27.83	0.042	0.074	28.93	28.83	42.24	0.62
BZ7	5.21	4.36	4.45	0.24	0.080	1.38	19.25	0.065	0.115	20.16	35.68	44.16	1.09
BZ8	5.39	4.60	2.35	0.19	0.053	0.37	10.56	0.019	0.084	46.44	32.76	20.80	1.19
BZ9	4.61	4.09	4.28	0.242	0.052	1.01	20.13	0.065	0.128	21.07	37.9	41.03	1.07
BZ10	4.83	4.12	7.40	0.37	0.040	1.20	19.85	0.080	0.119	22.40	35.10	42.50	0.97

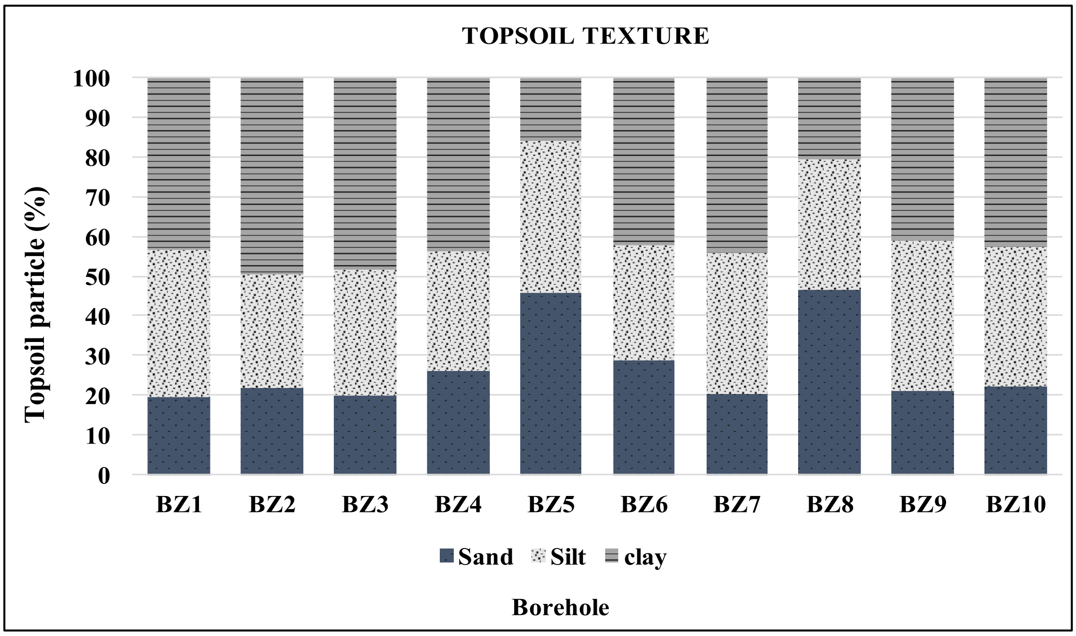

Fig. 2. The topsoil textures of the samples

The constituents of 6 topsoil samples are sand, silt and clay, with the percentage of sand ranging from 19.40% to 46.4%, silt from 28.50% to 38.23%, and clay from 16.03% to 49.65%. BZ5 and BZ8 (Gleyic Acrisols Xf) are mainly composed of sand (45.74 – 46.44%), with lesser amounts of silt (32.76 - 38.23%) and clay (16.03 - 20.80%). BZ3 (Umbric Fluvisols (Epi-orthithionic, Sj1p)) and BZ1, BZ7 (Umbric Fluvisols (Endo-orthithionic, Sj2p)) contain sand (19.40 - 20.16%), silt (31.44 - 37.35%), and clay (43.25 - 48.51%). BZ2 (Umbric Fluvisols (Endo-protothionic, Sp2)), BZ4, BZ9 and BZ10 (Umbric Fluvisols Epi-prothothionic, Sp1)), and BZ6 (Histic Fluvisols (Epi-prothothionic, TSp)) consist of sand (21.07 - 28.93%), silt (28.50 - 37.90%), and clay (41.03 - 49.65%).

The physicochemical properties of the topsoil types were compared with those analysed in 2016 from other sites in Dong Thap province (Table 3) (Environment, 2017).

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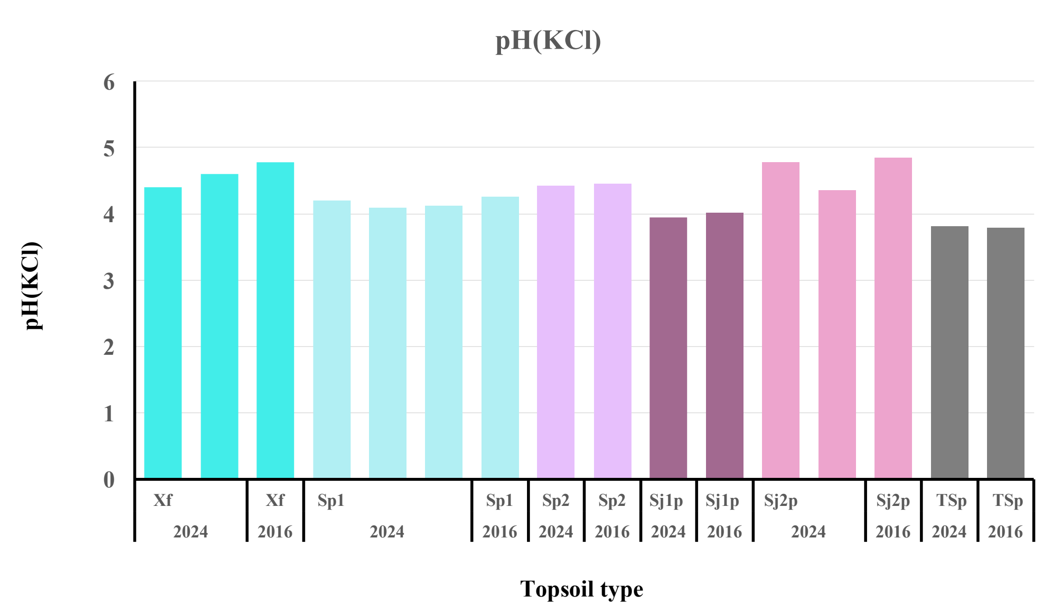
Tab. 3. Physical and chemical topsoil properties resulted in 2016

No.	Location (Commue)	Soil type (FAO)	Depth (cm)	pH		OM (%)	N (%)	P_2O_5 (%)	K_2O (%)	CEC (meq/100g)	SO_4^{2-} (%)	TSS (%)	Sand (%)	Silt (%)	Clay (%)	BD (g/cm^3)
				H_20	KCl											
1	An Phuoc	Gleyic Acrisols (Xf)	0 – 25	5.62	4.78	2.54	0.18	0.054	0.93	11.17	0.01	0.085	43.83	26.99	29.18	1.33
2	Phu uong	Umbric Fluvisols (Epi-prothothionic) (Sp1)	0 – 25	5.18	4.25	4.11	0.27	0.076	1.02	21.30	0.061	0.131	18.73	35.52	45.75	0.90
3	An Phuoc	Umbric Fluvisols (Endo-protothionic) (Sp2)	0 – 25	5.25	4.46	4.71	0.289	0.071	1.04	21.12	0.052	0.085	24.88	33.44	41.68	1.01
4	Phu Hiep	Umbric Fluvisols (Epi-orthithionic) (Sj1p)	0 – 25	4.93	4.01	6.75	0.328	0.042	1.50	28.45	0.021	0.18	25.57	32.6	41.7	0.86
5	An Phuoc	Umbric Fluvisols (Endo-orthithionic) (Sj2p)	0 – 25	5.63	4.84	6.44	0.306	0.06	1.04	20.53	0.053	0.13	18.42	34.15	47.43	0.87
6	Phu Duc	Histic Fluvisols (Epi-prothothionic) (TSp)	0 – 10	4.37	3.79	33.82	0.557	0.037	0.53	29.34	0.02	0.12	27.8	28.5	43.7	0.57

For soil texture, bulk density, and chemical properties such as OM, N, P_2O_5, K_2O, SO_4^2, and TSS, there are no significant differences. However, pH_{KCl} and CEC have changed, gradually decreasing (Figure 3a & b).

(a)



(b)

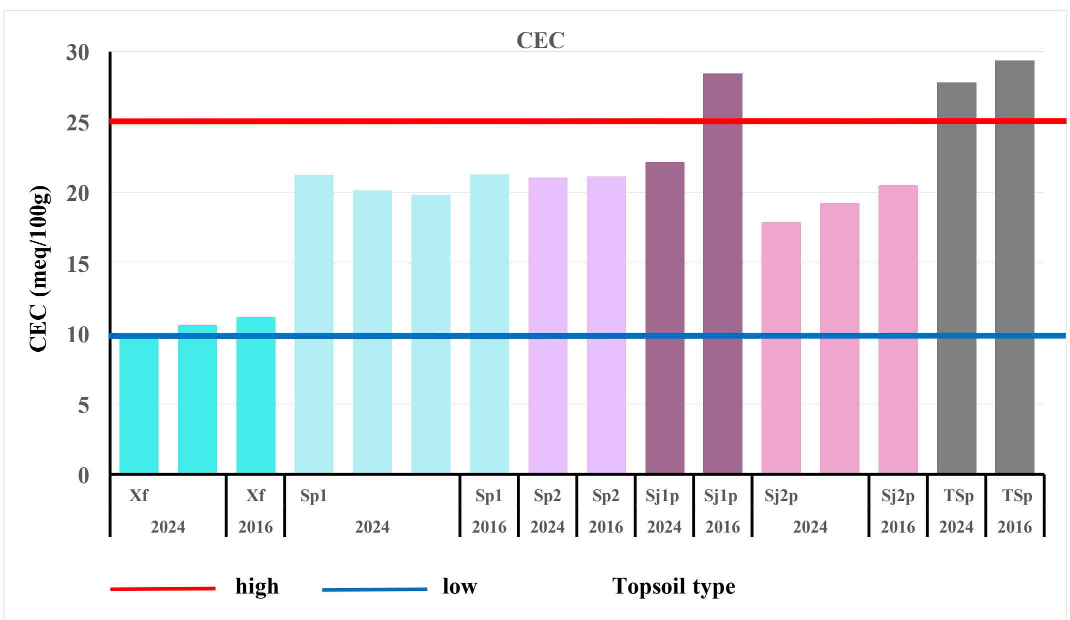


Fig. 3. pH_{KCl} chart (a) and CEC chart (b) of topsoil types analyzed in 2024 and 2016.

(a) The pH_{KCl} of topsoil types ranges from 4 to 5, but Histic Fluvisols (Epi-prothothionic, TSp) is lower than 4. Compared to the topsoil pH analyzed in 2016, pH has decreased by 0.04 to 0.38, with Gleyic Acrisols (Xf) declining by 0.18 to 0.38, Umbric Fluvisols (Endo-orthithionic, Sj2p) by 0.06 – 0.48, and the other types showing slight decrease.

(b) CEC is within the range of 10 – 29 (meq/100g), which is considered medium to high. Compared to the results from 2016, CEC decreased by about 0.04 – 2.65%, with Umbric Fluvisols (Epi-orthithionic, Sj1p) showing a significant decline of up to 6.3%.

The physical and chemical properties of soil play a fundamental role in the quality of cultivated land, particularly in the topsoil layer, which is frequently impacted by environmental factors and human activities. The alteration in the physicochemical properties of the topsoil, particularly the decreasing pH and cation exchange capacity, is attributed to increased human induced activities and natural impacts. The reduction in vegetation cover, rising temperatures, drought, and decreased rainfall have left the topsoil more frequently exposed to high surface temperatures, leading to increased aridity and acidity. As the results, essential nutrients such as Mg^{2+}, Na^{+}, Ca^{2+}, and K^{+} are gradually lost from the soil, contributing to soil degradation.

5. Conclusion

The physicochemical properties of the topsoil in the buffer zone of Tram Chim National Park are characterized by predominantly clay with lesser amounts of silt and sand. The chemical properties of the topsoil types range from acidic to slightly acidic and have the ability to absorb plant nutrient cations, with organic matter and total nitrogen levels ranging from rich to very rich. The cation exchange capacity of the topsoil ranges from medium to high, while levels of toxic and harmful substances to plants are low to medium. The topsoil layer shows no signs of salinization, with very low total soluble salts. However, the physicochemical properties of Gleyic Acrisols differ from the others, as its cation exchange capacity and nutrient levels are slightly lower.

Due to increased temperatures and reduced rainfall in both amount and frequency in 2024, the topsoil layer has become more arid and is more frequently exposed to high surface temperatures. This has led to greater acidification and a reduction in nutrients available to plants compared to topsoil properties observed in 2016. These are signs of impact of climate change and soil degradation in the buffer zone.

Conflicts of Interest: The authors declare no conflict of interest.

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