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Unveiling Hydromorphic Soil Formation Dynamics in Andem, Gabon: A Soil Survey Approach

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ABSTRACT

Background: A study was conducted on the processes of formation of hydromorphic soils in the estuary plateau region of Andem, Gabon, Africa through determination of hydromorphic index (HI), particle distribution-ratios and CEC/clay using details soil survey database followed by their appropriate classification in USDA soil taxonomy.

Methods: The experiment carried out at Andem estuary region during 2022-23. The findings indicated that the surface horizons of these soils appeared wet with a reddish-brown coloration, accompanied by the presence of iron (Fe^{2+}) and manganese (Mn^{2+}) nodules in reduction phases at depths ranging from 25 to 60 cm. Additionally, redoximorphic depletions were observed below 60 cm in soils located in lower piedmonts and older alluvial plains.

Result: These indices show a significant relation with the physicochemical properties of the soil. Furthermore, it was observed that these soils tended to accumulate organic matter at a rate surpassing its decomposition. The results also demonstrated a variation in Hydrologic Index (HI), ranging from 11.8 in Humic *Endoaquepts* to 5.2 in *Typic Udifluvents*, these criteria utilized for confirming and establishing hydromorphic soils could provide valuable insights for managing these soils to enhance productivity and optimize land use practices.

Key words: Hydromorphic soils, Land uses, Land reforms.

INTRODUCTION

Hydromorphic soils display a unique characteristic wherein there is a reduction or localized segregation of iron, resulting from temporary or permanent waterlogging of soil pores, leading to a prolonged lack of oxygen. Despite several investigations in these lines of concept were rare in the eastern states of Africa though the hydromorphic soils were reported for the north-eastern states (Gangopadhyay *et al.,* 2015). The occurrence of these soils worldwide in *Histosols, Inceptisols, Entisols* and rarely in *Alfisols* orders) were reported (Bouma *et al.,* 2016) but hydromorphic soils are mostly occurred in Inceptisols order under *Aquic* moisture regimes (*Aquepts*) (Bhattacharyya *et al.,* 2013). According to the Soil Resource Mapping of Gabon on a smaller scale (1:250K), the soils are relatively recent formations, with numerous areas experiencing prolonged waterlogging that adversely affects crop growth. These conditions may lead to variations in pedogenic processes due to differences in parent material composition and microclimate. Basic pedogenic attributes were used to quantitatively express the changes which occurred in soils during their development (Arnaud, 1988). However, the information's are very limited and scattered due to limitation of scale of mapping and attribute consideration. Proper identification and characterization of them would be beneficial for their better management and productivity. Therefore, the study aimed to characterize hydromorphic soils in the estuary plateau of the Andem region, Gabon, to gain a detailed understanding of their pedogenesis processes on a larger scale.

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MATERIALS AND METHODS

Study area

The study was conducted in Andem area of estuary plateau, Gabon in between the geographic extent from 0.195°N to 0.180°N, 9.520° to 9.549°E longitude) having a total geographic area of 5,000 hectare (Fig 1) during March 2022 to August 2023. The major physiographic division is *estuary i.e.* the geology of the study area is constituted of Gabon's basement geology presents a stark contrast between its Eastern region, characterized by predominantly meta sedimentary and meta igneous rocksand its Western region, where a mosaic of carbonate and non-carbonate rock minerals dominates (Thiéblemont *et al.,* 2014). The representative landforms in the study area have altitudinal range from 06 m from MSL in active alluvial plains to 110 m above MSL in lower piedmont. The climate is humid tropical with mean annual rainfall of 3000 mm- The mean annual soil temperature is 24.5°C, mean soil temperature is 29.3°C.

The soil temperature regime is *Hyperthermic* and soil moisture regimes are *Aquic* and *Udic* (Soil Survey Staff, 2003).

Methodology of soil survey

Soil-landform analysis was made in the study area by visual interpretation, ground truth verification and intensive soil survey using Resourcesat2 IRS LISS-IV along with open source digital elevation data like Shuttle Radar Topographic Mission (SRTM) (30 m resolution). Morphological (Soil Survey Staff, 2003), physical (Hillel, 1982) and chemical characteristics (Jackson,1973) were determined in representative landform of the study area. The soil-landform relationships were established following standard methods. Pedogenic considerations. The pedogenic attributes were applied to understand the pedogenesis of hydromorphic soils of the study area. The indices include particle size ratios *viz.,* sand/silt, silt/clay, very fine plus fine sand/ total sand following the method of Schatzael and Thompson (2015) and CEC/Clay as outlined by Smith (1986).

Details of Hydromorphic and land form considerations

Hydromorphic index was calculated following the method outlined by Chaplot *et al.* (2000) using the equation:

$$HI = \frac{P}{Ch \times V}$$

Where,

P= Proportion of the total depth of soil profile constituted by horizons with some degree of hydromorphic feature development (%),

Ch= Moist Munsell colour chroma of the surface horizon.

V= Moist Munsell value of the surface horizon.

(Annual report, 2017-18) five major landform units as, humic endoaquepts, typic humaquepts, typic endoaquepts, Typic Fluvaquents and typic udifluvents were used for details hydromophic characterization. Three hydromorphic pedons were identified from each of the land form and land use units for examination of their morphological, physical and chemical characteristics (Picture 1).

Results and Discussion

Morphological characteristics in different land form situations

Data on Table 1.1, 1.2 and 1.3 revealed that all the soil profiles were very deep, though having varying internal drainage properties across the micro-topographic sequence. Soils on active alluvial plains were moderately well drained, sandy loam textured in surface and sandy loam to loamy sand in sub surface horizons with a regular decrease in clay fraction and subsequent increase in sand fraction with depth. The structure is fine weak sub angular blocky at surface and fine weak sub angular blocky to single grained at sub surface horizons. They have matrix colour of light yellow brown at surface with hue of 10 YR, value 6 and chroma 4 and olive brown to light gray with hue of 2.5 Y, value 4 to 6 and chroma 4. Stratified deposition of fine and coarse sand fractions exhibits fluvial nature of soils due to frequent flood hazards of Komo river. The soils have Ap-AB-2ACg horizon. They were classified as *hyperthermic Typic Udifluvents*. Soils on younger alluvial plains were somewhat poorly drained, silt loam in texture throughout with yellowish brown coloured surface with hue of 10 YR, value 5 and chroma 2 and light yellowish brown to yellowish gray colour at sub surface horizons with hue of 10 YR, value 5 to 6 and chroma 2. Fluvial influence of both Abonga and Komo river has been observed in them with stratified and irregular distribution of sand and clay fractions with depth. They have also Ap-AB-2ACg horizon and were classified as *coarse loamy mixed hyperthermic Typic Fluvaquents*. In older meander plains, soils were some what poorly drained, silt loam in texture throughout with yellowish brown coloured surface with hue of 10 YR, value 4 and chroma 3 and light yellowish brown to light gray colour at sub surface horizons with hue of 10 YR to 2.5 y, value 4 to 6 and chroma 2. Endo-saturation was evident at a depth below 40 cm from surface with redox depletions. They have Ap-Bw-2Bwg horizon and were classified as coarse loamy mixed hyperthermic *Typic Endoaquepts*. In older alluvial plains, soils were poorly

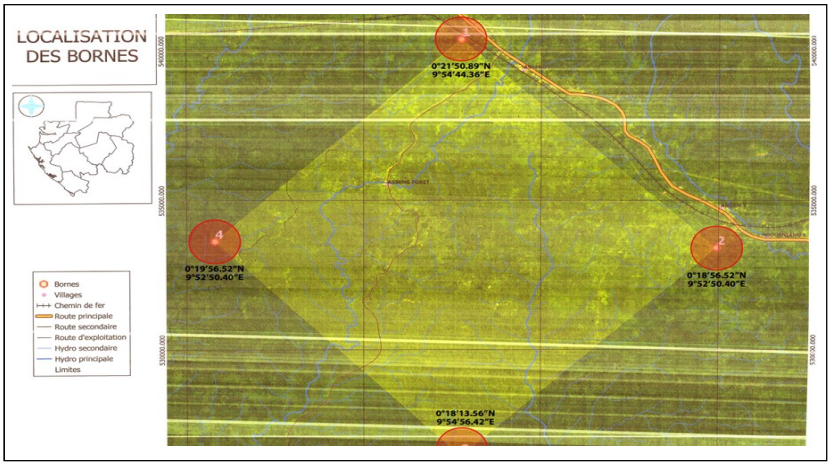


Fig 1: Location map of the study area.

drained, loamy at surface and loamy to sandy loam at sub surface horizons, very dark gray coloured surface with hue of 2.5 Y, value 4 and chroma 1 and dark to light gray coloured sub surface with hue of 2.5 Y, value 4 to 6 and chroma 2. Dark coloured surface may represent high organic carbon content of soils. They have Ap-Bwg horizon and classified as *coarse loamy, mixed hyperthermic Humic Endoaquepts.* Soils on lower piedmonts were poorly drained, silt loam textured throughout, dark gray in colour at surface with hue of 2.5Y, value 5 and chroma 2 and gray tolight gray at subsurface horizons with hue of 2.5Y, value 5 to 6 and chroma 6. Dark coloured surface is gain due to high organic carbon content which gradually decreases with depth of soils. They have Ap-Bwg horizon and classified as *coarse loamy mixed hyperthermic Typic Humaquepts* (Soil Survey Staff, 2014).



Pic 1: Pedons in different landforms and land use systems of the study area.

Table 1.1: Morphological properties of soil mapping unit 1.

Horizon		Colour (moist)	Structure**	Consistence***	InclusionsX
Designation	Depth (cm)				
Mapping Unit ANDEM I Pedon 1. 0°21.23¹N; 09°55.24¹E 45 m above sea level					
Apc	0 - 15	Light yellow brown (10YR 6/4)	w, me, g	f, mp	mfr, mfp
Bt1c	15 - 40	olive brown (2.5 Y 4/4)	w, me, g	vf, slt, p	ffr, mfp
Bt2cg	40 - 70	Reddish yellow (7.5 Y 6/8)	w, me, g	vf, slt, p	ffr, mfp
BCcg	70 - 84	Reddish yellow (7.5 Y 6/8)	w, me, sbk	vf, slt, p	ffr, mfp

Where: ** (structure): c = Coarse; f = Fine; g = Granular; me = Medium; mo = Moderate;s = Strong; sbk = Sub-angular blocky; w = Weak; v = Gravelly; vg = Very gravelly; eg =Extremely gravelly.

***(consistency):f = Firm; mp = Moderately plastic; slt = Moderately sticky; vf = Very firm; vp = Very plastic; vs = Very sticky, v = Gravely, vg= Very gravelly, eg = Extremely gravely.

X (inclusions): mfr = many fine roots; mp = Many pores; mfp = Many fine pores; fmr = Few medium roots; mfp = Many fine pores; mfr = Many fine roots; ffr = Few fine roots.

Physico-chemical characteristics of soils

The described physic-chemical characteristics of soils in Table 2 were - shows that the soils bulk density in the range of 1.35 Mg m^{-3} in active alluvial plains to 1.40 Mg m^{-3} in younger alluvial plains. Occurrence of silt fraction of soils has a significantly positive influence on bulk density and *vice versa*. In the study area, due to frequent fluvial influence of both Komo and Abonga rivers, soils have high silt deposits over sands forming alluvial fans, which may be the reason for higher bulk density of soils with higher silt and lower sand fractions, leading to internally imperfect (some what poor) drainage situations of soils in-spite of having coarse loamy texture. The effect of clay fraction has no significant impact on bulk density. Sand, silt and clay fractions of soils varied from 9.4% (older meander plains) to 87.8% (active alluvial plains), 6.5% (active alluvial plains) to 79.9% (younger alluvial plains) and 4.0% (younger alluvial plains) to 16.8% (lower piedmont), respectively. Sand and silt fractions have a very close indicating the fluvial influence of Komo and Abonga rivers. It is assumed from the study that the occurrence of silt fractions is geogenic influenced by river fluvial actions. But, origin of sand and clay involves soil forming processes from parent materials by *in situ* weathering. Higher sand fractions in active alluvial plains represents slower rate of pedogenic development, whereas, higher clay fractions in lower piedmonts represent relatively rapid pedogenic developments. Different soil depth was one of the major constraints for all the soil series (Sabareeshwari *et al.,* 2023).

The soil pH ranged from very strongly acidic (pH 5.1) in the lower piedmont to neutral (pH 7.1) in the active alluvial plains. In terms of soil organic carbon content at the surface horizon, it varied from low (0.40%) in the active alluvial plains to high (1.92%) in the lower piedmonts. The cation exchange capacity of the soils ranged from low (5 cmol (p+) kg^{-1}) in the active alluvial plains to medium [8.0 cmol (p+) kg^{-1}] in the lower piedmonts. Furthermore, the base saturation fluctuated from 57 to 79% in the active alluvial plains. Bandyopadhyay *et al.* (2017) suggests the highly acidic nature of soils in the lower piedmont, attributed to an abundance of pH-dependent charges at the surface resulting from elevated organic carbon levels and similar research findings were reported in soils of Nagaland. Adhikary *et al.* (2021) found clear support for the soil chemical properties like pH and EC shows to vary significant with the application of blending of saline and sweet water in pitcher pot for pitcher irrigation with different

Table 1.2: Morphological Properties of Soil Mapping Unit II.

Horizon Designation	Depth(cm)	Colour (moist)	Structure**	Consistence	Inclusions X
***Mapping Unit ANDEM II Pedon 2. 0°21.41¹N; 09°45. 47¹E 45 m above sea level					
Ap	0 - 27	Grayish brown (10 YR 5/2)	w, me, g w,	fr, ms, mp	mfr, mmr mp
Bt1c	27 - 60	Yellowish brown(10 YR 5/8)	me, g	fr, ms, mp	mfr, mmr mp
Bt2c	60 - 95	Brownish yellow (10YR 6/8)	w, me, g	fr, ms, mp	mfr,mmr,mp
BCc	95 - 120	Light Red (2.5 YR 5/6)	w, me, g	fr, ms, mp	mfr,mmr,mp

Where: **(structure): c= Coarse; f= Fine; g= Granular; me= Medium; mo= Moderate; s= Strong; sbk= Sub-angular blocky; w= Weak; v= Gravelly; vg= Very gravelly; eg= Extremely gravelly.

*** (consistency):f= Firm; mp= Moderately plastic; slt= Moderately sticky; vf= Very firm; vp= Very plastic; vs= Very sticky, v= Gravely, vg= Very gravelly, eg= Extremely gravely.

X (inclusions): mfr= Many fine roots; mp= Many pores; mfp= Many fine pores, fmr= Few medium roots; mfp= Many fine pores; mfr= Many fine roots; ffr= Few fine roots.

Table 1.3: Morphological Properties of Soil Mapping Unit III.

Horizon Designation	Depth (cm)	Colour (moist)	Structure**	Consistence***	Inclusions X
Mapping Unit ANDEM III Pedon 3. 0°20.42¹N; 09°47. 37¹E 45 m above sea level					
Ap	0 - 7	Weak red (10 R 5/3)	g, w, me, g	fr, ms, mp	mfr, mp
Bt1c	7 - 30	Weak red (10 R 5/4)	eg, mo, c, g	vf, s, p	ffr, mfp
Bt2c	30 - 43	Pale red (10 R 6/4)	eg, mo, c, g	vf, s, p	mfr,fmr,mfp
BCc	43 - 60	Reddish yellow (7.5 YR 7/8)	eg, mo, c, sbk	fr, ms, mp	ffr,,mfp

Where: ** (structure): c = Coarse; f = Fine; g = Granular; me = Medium; mo = Moderate; s =Strong; sbk =Sub-angular blocky; w =Weak; v=Gravelly; vg=Very gravelly; eg =Extremely gravelly.

***(consistency):f = Firm; mp = Moderately plastic; slt = Moderately sticky; vf = Very firm; vp = Very plastic; vs = Very sticky, v = Gravely, vg= Very gravelly, eg = Extremely gravely.

X (inclusions): mfr =many fine roots; mp =Many pores; mfp =Many fine pores, fmr =Few medium roots; mfp =Many fine pores; mfr = Many fine roots; ffr =Few fine roots.

Table 2: Physico-chemical characteristics of soils.

Pedons	Depth (cm)	BD	Sand	Silt	Clay	pH	SOC	CEC	CEC/Clay
P1	0-27	1.35	29.0	37.4	33.6	5.1	1.42	8	0.59
	28-60	1.36	31.4	39.8	28.8	5.4	1.18	7.5	0.45
	60-95	1.38	22.5	51.1	26.4	5.5	0.55	6.9	0.42
	95-120	1.40	36.1	48.1	16.8	5.7	0.32	5	0.74
P2	0-27	1.34	29.0	37.4	33.6	5.2	1.25	6.8	0.48
	28-60	1.35	31.4	39.8	28.8	5.4	0.98	6.5	0.43
	60-95	1.34	22.1	51.5	26.4	5.9	0.75	5.9	0.59
	95-120	1.35	34.9	47.2	17.9	5.8	0.52	4	0.47
P3	0-27	1.34	29.4	59.8	10.8	5.9	1.30	6.5	0.60
	28-60	1.36	33.1	47.7	19.2	6.1	0.87	5.7	0.62
	60-95	1.38	32.2	58.5	9.3	6.4	0.51	5.3	0.57
	95-120	1.39	11.1	79.5	9.4	6.4	0.30	4.3	0.46

Table 3: Hydromorphic characteristics of soils.

Taxonomy	HI	P(%)
Typic humaquepts	9.1	87.1
Humic endoaquepts	11.8	82.4
Typic endoaquepts	6.4	69.2
Typic fluvaquents	6.1	65.9
Typic udifluvents	5.2	54.2

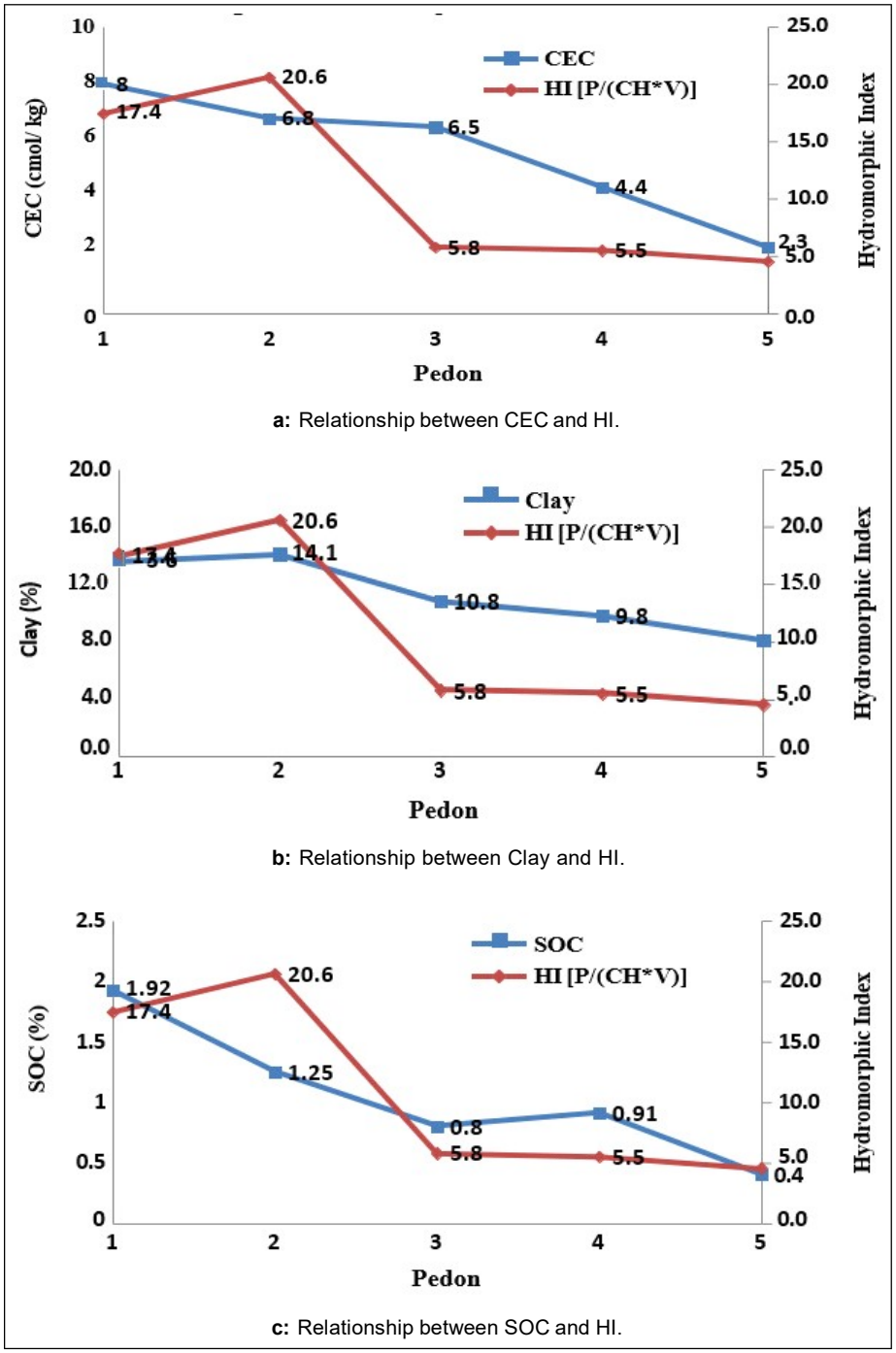
type of tillage. On the other hand, active alluvial plains comprise soils with higher pH due to higher base saturation percentage carried in high silt fractions (Birk land, 1984) deposited by rivers. low clay content (4.6-8.1%) in soils may be attributed to low CEC and low sum of cations in these soils (Gerrad *et al.,* 1992, Queiroz *et al.,* 2022, Akpan *et al.,* 2023). Tamiru *et al.* (2022) share similar result for soil chemical and physical properties like soil organic matter, soil pH, cation exchange capacity, bulk density and soil moisture shows significant difference between conserved and non-conserved lands.

Hydromorphic consideration

Hydromorphic characterization and index (HI) of soils were presented in Table 3. The Hydrologic Index (HI) ranged from 20.6 in soils of older alluvial plains to 4.5 in soils of active alluvial plains, following the order: Humic Endoaquepts (11.8) > Typic Humaquepts (9.1) > Typic Endoaquepts (6.4) > Typic Fluvaquents (6.1) > Typic Udifluvents (5.2). Higher HI values in lower piedmont and older alluvial plains may be attributed to higher degree of hydromorphosis occurring at major proportions of soil depth (P1 82.4 and P2 87.1). It is justified with the fact that hydromorphic soils if better understood by evaluation these parameters as supported by (Chaplot *et al.,* 2000) This has been indicated by dark gray colour of the surface horizons as well as occurrence of iron (Fe^{2+}) and manganese (Mn^{2+}) in reduction phases at a depth below 15 to 40 cm along with redoximorphic depletions at a depth below 40 to 70c min soils of lower piedmonts and older alluvial plains. Sub surface matrix colour of 2.5 Y hue with chroma of 2 is indicative of reduction phases of iron and manganese with depletions, which supports the formation of soils of *Aquepts* sub orders in these two afore said land forms. On the other hands, soils of younger alluvial plains and active alluvial plains were much less hydromorphic compared to that in lower piedmonts and older alluvial plains. The proximity of the river banks of Komo and Abonga rivers can be attributed to the stratification of sand and silt deposition, leading to soil conditions ranging from imperfect to moderately well-drained. Some sparse and faint redoximorphic features were observed at depths ranging from 33 to 46 cm, although depletions of iron and manganese are scarce. Frequent flooding hazards may have a causative effect disturbed hydromorphosis in these soils. These soils were there for have all most no profile development and were placed under *Fluvents* and *Aquents* sub orders. Following these characterization parameters, similar results also reported by Gangopadhyay *et al.* (2015) in soils of Assam.

Pedological considerations

The assessed pedogenic indices *viz.,* sand/silt and have inverse relationship with pedogenesis, whereas, CEC/clay and silt/clay have positive influence on the same (Schatzael and Anderson, 2015). It was apparent from this study that soils on lower piedmonts, older alluvial plain sand older plains have higher value of CEC/clay and silt/ clay compared to that on younger and active alluvial plains. Hence, pedogenic processes are more rapid in these landforms. On the contrary, higher sand/silt ratio in active in active alluvial plains leads to formation of lithologically discontinued gleyed layers below 60 cm from surface. Lithological discontinuity (LD) appears to decline the rate of pedogenesis in soils on active alluvial plains (Bandyopadhyay *et al.,* 2017). Clay, CEC and SOC were found to have synergistic relationship with HI (Fig 2a, 2b, 2c.) *vis-à-vis* pedonesis. Thus, the process of



a: Relationship between CEC and HI.

b: Relationship between Clay and HI.

c: Relationship between SOC and HI.

Fig 2: Relationship between soil properties and hydromorphic index.

hydromorphosis and humification were simultaneous in P1 and P2, which was responsible for the formations of Typic Humaquepts and Humic Endoaquepts in lower piedmonts and older alluvial plains, respectively. Occurrence of humic hydromorphic soils is an indicative of relative elderliness of land forms (Breemen and Buurman, 1998). On the contrary, non humic hydromorphic soils in active alluvial plains and younger alluvial plains exhibits their juvenile nature. The older meander plain represents an intermediate stage of weathering, which stands in between older alluvial and younger alluvial plains. Their formation may be attributed to shifting of river courses in the geological past in the estuary region at Andem region Gabon. Same results found from (Adewumi *et al.,* 2020).

CONCLUSION

It is summarized from observed soil characteristics, including soil horizons and properties, serve as evidence of past processes and indicators of present processes. These areas are characterized by poor drainage and tend to develop hydromorphic soils, a process known as gleyization in pedogenic terms. Humification and gleyization occur simultaneously and exhibit a synergistic relationship, particularly in regions with warm to hot and humid climates. The development of the hydromorphic index confirms pedogenic processes, as these soils show signs of chemical reduction rather than oxidation, such as mottling with spots of reduced iron compounds, resulting in a grayish coloration rather than red. Spatial information on soils with hydromorphic properties can be utilized to comprehend and evaluate soil water retention, flooding potential, erosion hazardsand the depth to the seasonal high water table. These properties significantly influence interpretations for soil use and management, including considerations for construction, waste disposal, plant productionand water management strategies.

Conflict of interest

We have no conflicts of interest to disclose. All authors declare that they have no conflicts of interest regarding the publication of this paper.

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