

Research Article

Susceptibility Zonation of the Soils of Mayo-Danay in East Part of the Sudano-Sahelian Cameroon, Central Africa

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Publication Date: 20 September 2018

DOI: <https://doi.org/10.23953/cloud.ijaese.384>

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Abstract The study of soil resources of Mayo-Danay, located in the tropical zone of Cameroon, shows a diversity of soils characterized by specific properties. Indeed, this study area is generally a plain landscape whose average relative altitude (300 m). However, it indicates a vegetation of savanna type, very dominant. Hydrologically, Logone River, Maga Lake and tributary streams of the Mandara Mountains regularly flood the study area. The sharing of these parameters leads to soil's genesis, which have a sandy texture for floodplain soils and a very dominant clay texture for lacustrine soils. Otherwise, the geochemistry of these soils shows SiO₂ contents globally 70% in the different soils studied; Al₂O₃ contents are less than 10% in lacustrine soils and less than 5% in floodplain soils; while the major elements data of soils such as Fe₂O₃, CaO and MgO indicate relatively low contents ($\leq 2\%$) on soils studied. In addition, the mineralogy index of alteration expresses a moderate alteration of these soils. Thus, the distribution of these major elements of soil reveals its susceptibility to zonation, which is a consequence of intrinsic and extrinsic parameters to formation and differentiation of soils of the study area.

Keywords *Mayo-Danay division; Major elements Susceptibility zonation; Sudano-sahelian Cameroon*

1. Introduction

Due to its position on the globe, Sudano-Sahelian zone is located in Africa between 9° and 13° Northern latitude. It encloses Far-North Cameroon Region, located between 10° and 13° North Latitude and between 13° and 16° East Longitude. However, identified in eastern part of this region, these flood plains locally named "yaéré", extend over about 10.000 km² and actually start once crossed the Yagoua-Limani dune whose altitude are obviously less than 400 m; they consist essentially of alluviums of various types on which a variety of soils develop (Brabant and Gavaud, 1985; Garba, 2000). The soils of this sector dominated by sandy and clay texture, that are consequence of the direct contribution of the mountain zones located to above 800 m and piedmonts (between 400 and 800 m). Sandy-clayey or sandy-silty alluvial deposits of Logone River and Mayos

give little evolved soils, sometimes deep, with very variable drainage. They are punctuated by zones of hydromorphic spot of "hardé" which most often indicate paleo-stand sites (Brabant and Gavaud, 1985; Garba, 2000). The topography offers only lower slopes, most often at 1%. Soils are compact in the dry state and sticky when wet. The soils are deep on alluvia. The exchange capacity is always very high. On these fragile soils, the risks of gully erosion and flooding are obvious (Mamadou, 2000; Morin, 2000; Raunet, 2003; Sighomnou, 2003; Milleville and Serpantie, 1994; Seignobos and Moukouri, 2000).

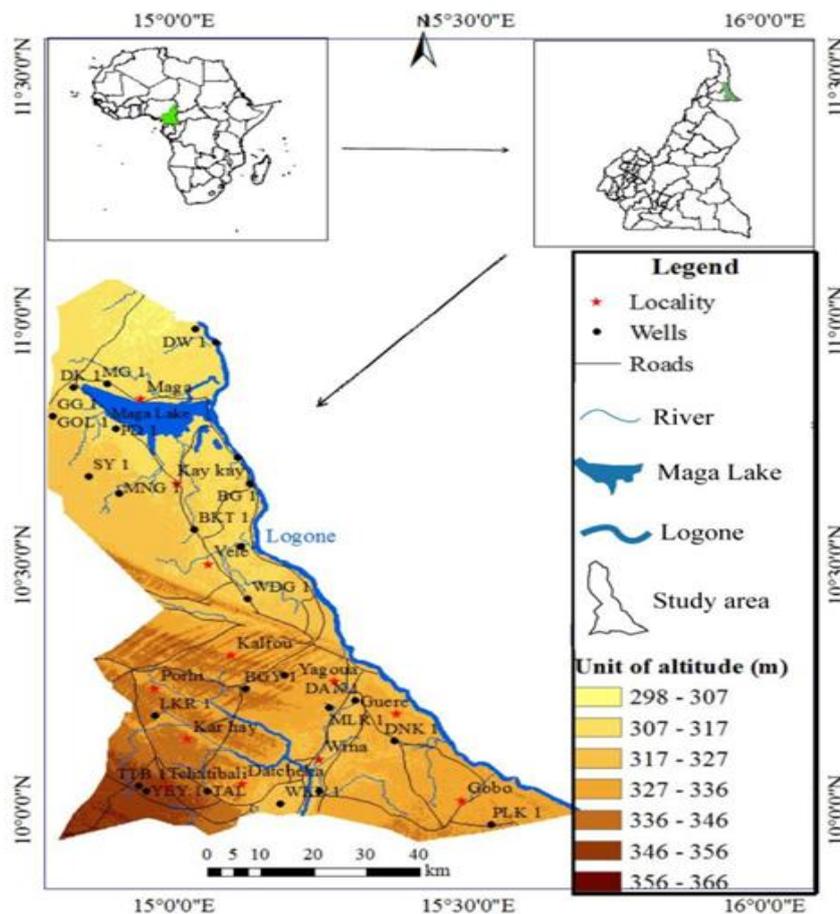


Figure 1: Localization of study area

As a natural element, soils constitute a three-dimensional dynamic complex occupying the superficial part of the earth's crust and thus supporting plants. As a result of interactions of varying duration between climate, living organisms (including human activity), parent materials and relief (including hydrography), have well-defined properties. Although it has been the subject of several studies, none of them has emphasized the susceptibility zonation of these soils. By their mode of formation and distribution in the landscape, the soils of the sector showed a specific zoning and characteristic of the plains zones. The aim of this research is to understand the susceptibility zonation of soil of Mayo-Danay Division, that is, the dynamic of soils in relation with their formation and distribution modes.

2. Study Area

The Mayo-Danay division is located between 10°00' and 11°10' north latitude and between 14°50' and 15°40' east longitude in Far-North Cameroon (Figure 1). It is triangular form and covers an area of about 6.300 km², oriented north-south. Delimiting part of the border with the Republic of Chad

through the Logone River, the head of Mayo-Danay division is Yagoua. It is limited to north by the Logone and Chari division, to south by the Republic of Chad (*Mayo-Kebbi*), to the west by Mayo-kani division and the Diamare division and to the east by the Republic of Chad (Logone/Bongor).

The climate of Sudano-Sahelian, characterized by a long dry season starts in early October and ends in late April to May and a short rainy season, from May to September. Rainfall density varies from 530 to 850 mm/year. The average temperature is 28°C; the hottest months are March, April and May with a maximum value of 35°C. The annual evapotranspiration is 1800 mm. The morphology is dominated by a floodplain and the lacustrine deposits as similar in Nigeria, Niger and Chad (Sighomnou, 2003). The floristic grouping consists of a shrubby savannah (low trees), herbaceous steppes with periodically flooded grasslands very marked in the lacustrine plains and sparse vegetation in degraded areas (Milleville and Serpantie, 1994). Geologically, recent and ancient alluvial deposits of various kinds occupy the study area (Barbery and Gavaud, 1980). Pedologically, we find poor soils, vertisols, and ferruginous tropical soils, hydromorphic soils and halomorphic soils (French soils classification) (Seignobos and Moukouri, 2000; Barbery and Gavaud, 1980; Tiki, 2014; Ibrahim, 2014; Leumbe et al., 2015; Temga, 2008). The human stands are composed of Massa, Toupouri, Musgum, Mousey, Peulhs, Kanuri, Kéra, etc. The main activities are agriculture, livestock farming and fishing (Seignobos and Moukouri, 2000).

3. Methods

3.1. Sampling and Analytical Techniques

3.1.1. Sampling

A field campaign was carried out by using topographic map of Yagoua at 1/20000 scale. It consisted of opening of the soil pits (average depths of 1.5 to 2.5 m with 1.5 x 1 m of opening). The latter made it possible to characterize soil samples morphologically, to collect them and to label them in polyethylene packaging and then to transport them to the laboratory for related analyzes.

3.1.2. Analytical Techniques

In the laboratory of Geological Survey of Pakistan (GSP), geochemical analysis carried out on following elements: SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, K₂O, Na₂O, P₂O₅, TiO₂ and MnO by pearl production and X-ray fluorescence (XRF). The preparation principle is to bring the sample and flux mixture (99.9% anhydrous di-lithium tetraborate tetra platinum) crucible in the muffle furnace at 1150° C for 5 minutes. The contents of the crucible at the outlet of the oven are poured into a cup for cooling, and a pearl is obtained. X-ray fluorescence spectrometry is a fast, non-destructive analytical technique. It consists of an irradiation of the sample to be analyzed by x-rays emitted by the spectrometer tube. The sample thus bombarded then emits x-rays (this is the fluorescence) characteristic of the composition of the sample; the energies of this secondary radiation are detected by the apparatus and the intensities measured are proportional to the concentration of the different elements composing the sample.

4. Results

4.1. Soil Morphology

4.1.1. Lacustrine Soil

The northern part of the study area, more specifically around Maga Lake, lacustrine soils are generally located on an altitude unit less than more or less to 310 m and develop particularly on floodplains with drying slots observed on the surface (1 m depth on average). In addition, the weeds

mainly consist of periodically flooded grasslands associated with savannah shrubs with trees. The lacustrine soils are mainly deposited on clayed to clayed-sandy alluviums. In order to characterize these soils horizon, MG1, BR1 and DW1; three (03) soil profiles were chosen in study area; these includes:

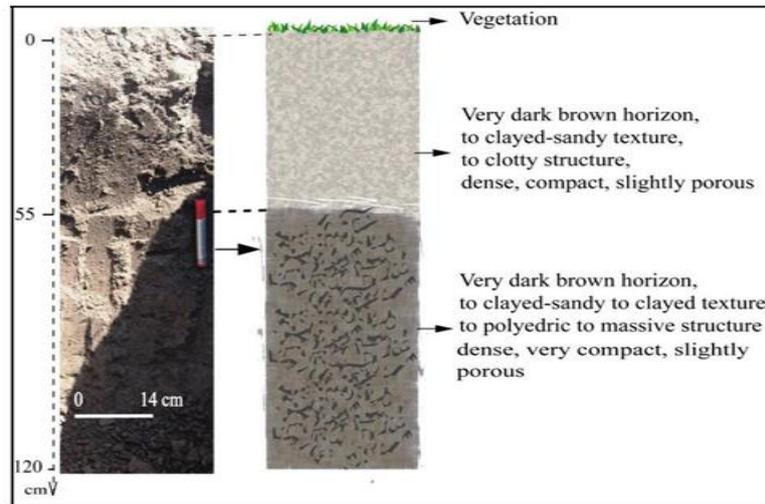


Figure 2: Lacustrine soil of profile MG 1

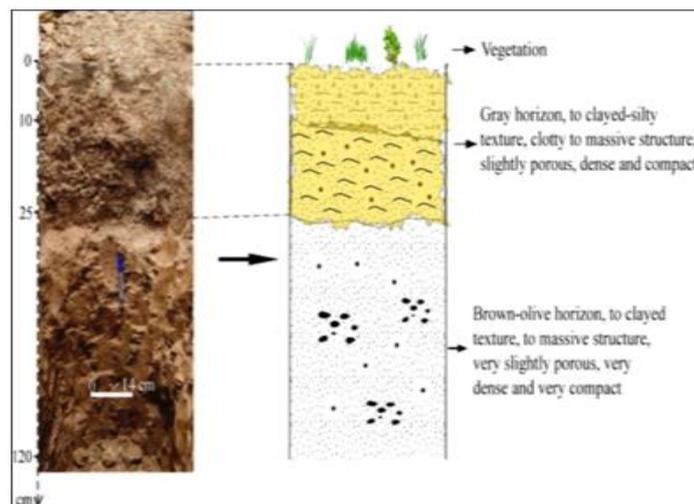


Figure 3: Lacustrine soils of profile BR 1

Profile MG 1

The profile MG 1 is located at 10° 52' 19" North latitude and 14° 53' 17" East longitude, at 310 m altitude and is approximately 120 cm deep. It is a differentiated well profile and presents two main horizons (Figure 2):

0 - 55 cm. Very dark brown horizon (10YR2/2), clay sandy to clay texture, clotty structure, dense, very slightly porous and compact. It is moist in depth and show hydromorphic spots, roots, rootlets with a gradual boundary to the underlying horizon of the same color;

55 - 120 cm. Very dark brown horizon (10YR2/2), clay-sandy to clay texture, polyedric to massive structure, very compact, dense and very slightly porous. It is not very moist, with deeper yellow spots and roots and rootlets.

Profile BR 1

The profile BR 1 is located at 10° 57' 22" North latitude and 15° 04' 19" East longitude and 310 m altitude. It is 120 cm deep and has two (02) specific horizons (Figure 3):

0-25 cm: Thin horizon, gray (2.5Y6/0), clay-silty to clay texture, clotty to massive structure, porous, slightly dense, plastic and very sticky to wet condition, desiccation slits ranging from 0.2 m to 1 m deep, friable and slightly brittle. It has rusty spots, light sub-rounded nodules of diameter between 0.3 and 0.6 cm, roots, rootlets and living organisms, gradual boundary to the underlying horizon;

25 to 120 cm: very thick horizon, brown olive (2.5Y4/4), clay texture, massive structure, very slightly porous, dense, plastic and very sticky, not friable and not fragile. It has rust spots and dark sub-rounded nodules of diameter between 0.3 and 0.6 cm, rock fragments (light gray) of diameter between 0.5 and 1.5 cm, many dark concretions and some roots and rootlets.

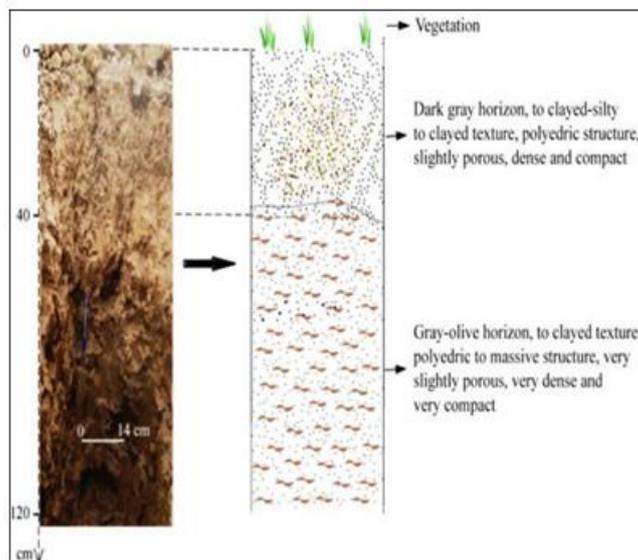


Figure 4: Lacustrine soils of profile DW 1

Profile DW 1

The profile DW 1 is located at 10° 58' 59" North latitude and 15° 02' 13" East longitude, a depth of 120 cm and an altitude of 310 m. It consists of two (02) horizons (Figure 4):

0 - 40 cm. Dark gray horizon (5Y4/1), clay-silty texture, polyedric structure, slightly porous, not very plastic, friable and not very brittle, show hydromorphic spots of 30 to 40%, characteristics of a constant humidity, an abundance of roots and rootlets, presence of living organisms and a sudden boundary to underlying horizon materialized by relatively light color;

40 - 120 cm. Gray olive horizon (5Y4/2), clay-silty texture, polyedric to massive structure, slightly porous, dense, sticky, presence of rust and hydromorphic spots of 20 to 25%, an abundance of roots and rootlets.

4.1.2. Floodplain Soil

They were mainly identified in the southern and central zone of study area on the sandy ergs of Kalfou, the sandy cord Yagoua-Limani and their surroundings. Primarily floodplain soils are formed at altitudes between 315 and 340 m. In contrast to lacustrine soils, floodplain soils are predominantly dominated by savannah shrubs with trees around which are also bare soils with sparse vegetation. The zone lithology essentially consists of very dominant sandy alluvial deposits, associated with sandy-clay alluvial deposits. Three (03) soil profiles were chosen in the study area to characterize morphostructural floodplain soils; these include DAN 1, TTB 1 and NDY 1.

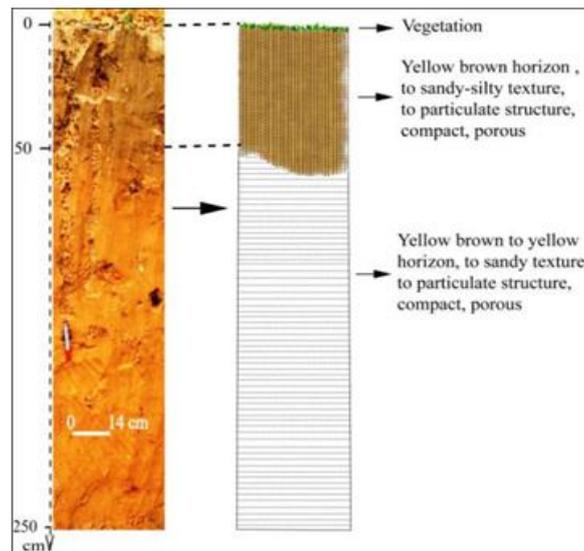


Figure 5: Floodplain soil of profile DAN 1

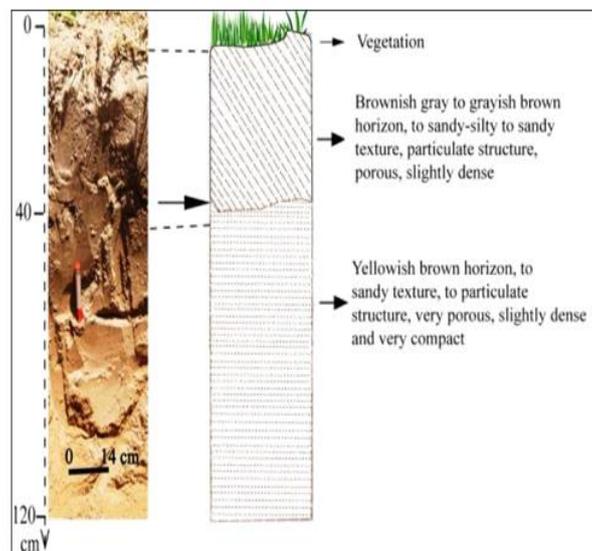


Figure 6: Floodplain soils of profile NDN 1

Profile DAN 1

The profile DAN (DAN 1) is located at 10° 13' 19" North latitude and 15° 18' 29" East longitude at 325 m altitude. It is very well developed, well differentiated and measures about 250 cm deep and has two (02) distinct horizons (Figure 5):

0 - 50 cm. Yellowish brown horizon (10YR5/4), sandy-silty to sandy texture, particulate structure, compact, porous and dense. It has roots, rootlets and a gradual boundary to brownish-yellow underlying horizon;

50 - 250 cm. Brownish yellow horizon (10YR7/8) to yellow (10YR7/8), sandy texture, particulate structure, compact, porous with the presence of roots and rootlets.

Profile NDN 1

The profile NDN 1 is located at 10°03'50" North latitude and 15°32'20" East longitude, at 329 m altitude. It is about 120 cm deep and shows two (02) horizons (Figure 6):

0 - 40 cm. Brownish gray horizon (10YR5/4), sandy-silty to sandy texture, particulate structure with hydromorphic spots. It is moist in depth and a gradual boundary to underlying horizon of yellowish brown color; 40 - 120 cm. Yellowish brown horizon (10YR5/4), sandy texture, particulate structure with few roots and rootlets. It is wetter at depth with hydromorphic spots of 30%.

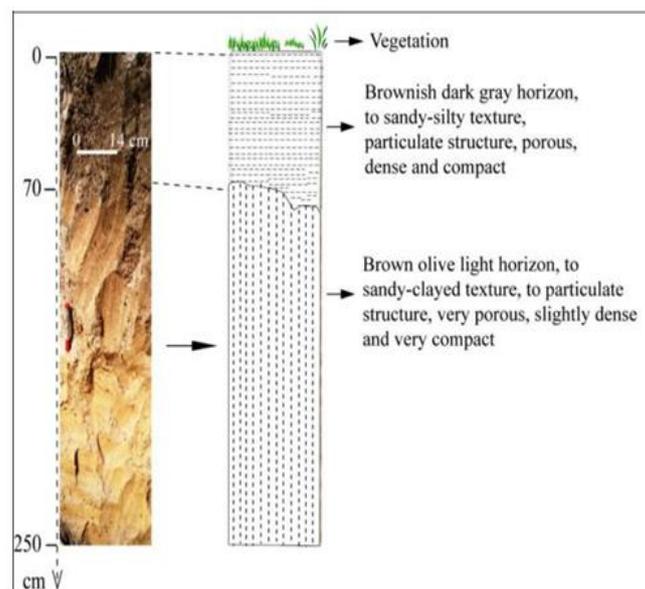


Figure 7: Floodplain soils of profile TTB 1

Profile of TTB 1

The profile TTB 1 is located at 10° 02' 48" North latitude and 14° 56' 30" East longitude at 350 m altitude. It measures approximately 250 cm and presents two (02) main horizons (Figure 7):

0 - 70 cm. Brownish dark gray horizon (2.5Y4/2) sandy-silty to sandy texture, particulate structure, compact, dense and porous. It is slightly moist with surface erosion figures, roots and rootlets and a gradual boundary of light olive-brown underlying horizon;

70 - 250 cm. Brown light olive horizon (2.5Y5/6), sandy texture, particulate structure, slightly compact and dense. It shows hydromorphy spots of 60% in depth, yellowish spots and black nodules. It is very humid in depth with some roots.

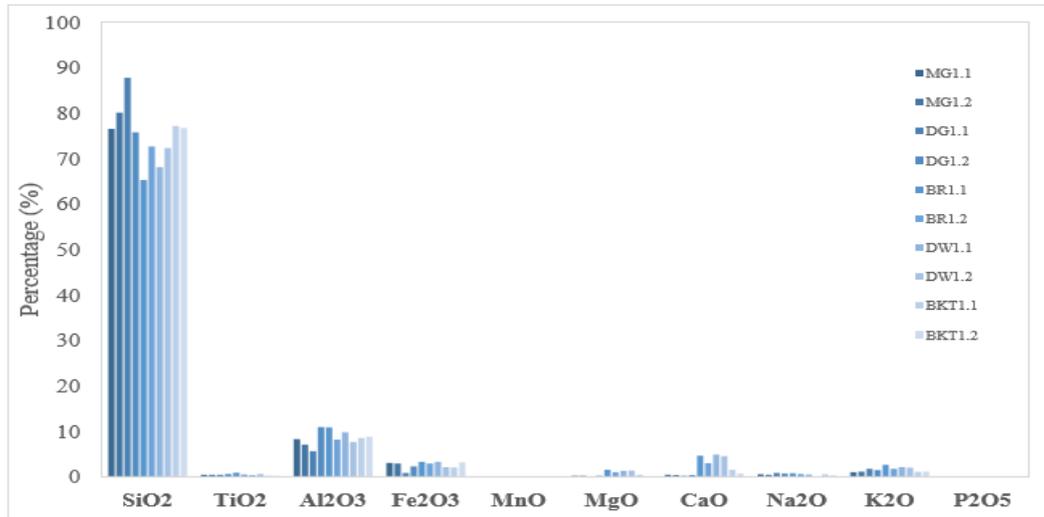


Figure 8: Major elements oxides (in weight %) of lacustrine soils

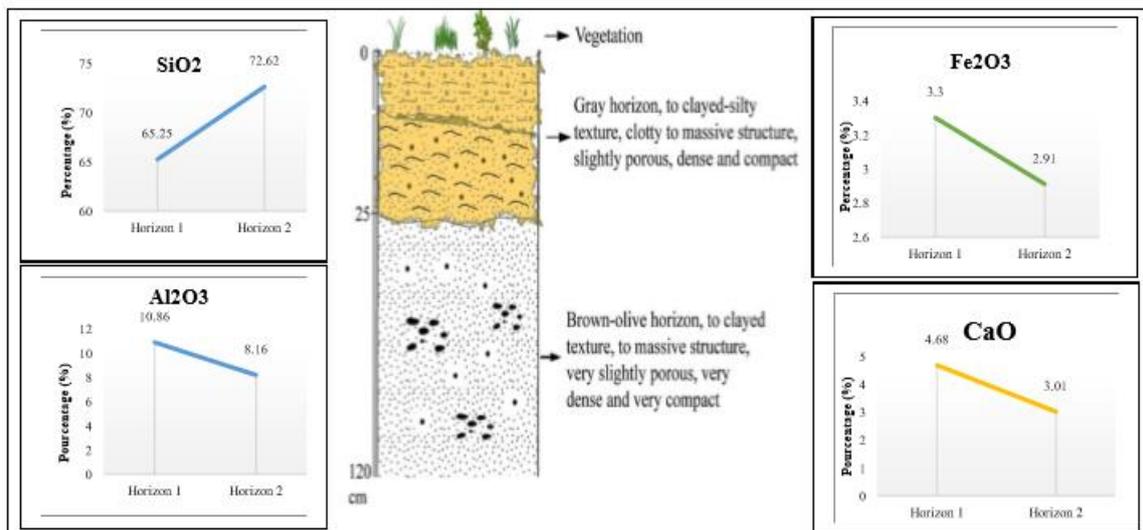


Figure 9: Variation of some oxides (in weight %) of lacustrine soils profile

5. Soils Geochemistry

Soil geochemical analysis focuses on major elements oxides. These elements make to understand origin of different soils associated with their alteration and evolution mode of distinct minerals.

MIA is the mineralogical index of alteration. It is calculated by applying the following formula:

$$MIA = 2 \left[\frac{Al_2O_3}{Al_2O_3 + CaO + Na_2O + K_2O} \right] \times 100 - 50$$

It calculated the degree of transformation of primary minerals into secondary minerals. Voicu and Bardoux (2002) have established that for MIA <20% the alteration is insignificant; MIA between 20-40%, the alteration is weak; between 40-60%, the alteration is moderate and >60% the alteration is intense. When the values reached 100%, they correspond to a total alteration.

The Ruxton index is the SiO₂/Al₂O₃ ratio. It makes to evaluate the nature of secondary minerals along the profile. The secondary minerals are gibbsite when the SiO₂/Al₂O₃ ratio is less than 2,

kaolinites when $\text{SiO}_2/\text{Al}_2\text{O}_3$ is 2 and montmorillonites when $\text{SiO}_2/\text{Al}_2\text{O}_3$ is greater than 2 (Browelow, 1979; Ruxton, 1968; Chittleborough, 1991; Tardy, 1993).

5.1. Lacustrine Soil

Table 1: Major elements oxides (in weight %) of lacustrine soil

Profiles	MG1.1	MG1.2	DG1.1	DG1.2	BR1.1	BR1.2	DW1.1	DW1.2	BKT1.1	BKT1.2	Ave.
SiO₂	76.53	80.06	87.75	75.75	65.25	72.62	68.12	72.28	77.15	76.75	75.23
TiO₂	0.46	0.43	0.43	0.60	0.90	0.52	0.41	0.62	0.23	0.18	0.48
Al₂O₃	8.27	7.09	5.66	10.96	10.86	8.16	9.82	7.68	8.50	8.82	8.58
Fe₂O₃	3.06	2.91	0.85	2.32	3.30	2.91	3.30	2.10	2.09	3.17	2.60
MnO	0.03	0.11	0.02	0.02	0.04	0.02	0.03	0.03	0.03	0.02	0.04
MgO	0.24	0.20	0.02	0.22	1.53	1.02	1.30	1.37	0.45	0.12	0.65
CaO	0.45	0.40	0.22	0.39	4.68	3.01	4.88	4.52	1.55	0.71	2.08
Na₂O	0.56	0.47	0.87	0.76	0.80	0.62	0.53	0.13	0.57	0.32	0.56
K₂O	1.04	1.13	1.76	1.51	2.65	1.78	2.13	2.01	1.07	1.12	1.62
P₂O₅	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.00	0.00	0.01
Total	90.64	92.8	97.58	92.53	90.02	90.68	90.53	90.75	91.64	91.21	91.84
SiO₂/Al₂O₃	9.25	11.29	15.50	9.91	6.00	8.90	6.94	9.41	9.08	8.70	9.50
MIA	60.19	75.27	33.02	61.65	14.37	20.26	13.13	36.96	46.04	60.8	42.17

The geochemical data for lacustrine soils of study area are richer in SiO_2 (75%) in profiles characteristic (Table 1). This high content of SiO_2 is not limited to the surface horizons; rather it increased gradually in-depth horizons. However, it should be noted that, depending on the topographic positions, some samples showed horizons with higher levels of SiO_2 (87.75%) in sample DG1.1 and also relatively low values of 65.25% in BR1.1 sample. However, Al_2O_3 has relative low levels to SiO_2 , which varies overall around 8.50% in all gray soils (sample BKT1.1). Specifically, it should be noted that its content gradually decreases with the depth going to 7.09% in sample MG1.2, while on the surface it increased to 10.96% (sample DG1.2). Similarly, Fe_2O_3 , content is higher in some lower horizons up to 3.17% (sample BKT1.2). But it should be noted that the iron content varies around 2.60% over the entire profile. A little further, the CaO is very remarkable with maximum values of 4.88% in sample DW1.1, but decreasing with depth. It should be noted that the CaO content remains very low in some samples (0.22%), but the average content however around 2.08%. Similarly, K_2O gives an average of 1.62%, with a peak of 2.65% (Table 1). Finally, elements such as TiO_2 , MnO, Na_2O and P_2O_5 have very low levels and even zero (P_2O_5 in some wells). In addition, the Ruxton index, which is the $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio and which makes it possible to evaluate the nature of the secondary minerals along the profile, showed value greater than 2 (between 6.00 and 15.50). Its values grow according to the depth in some wells, while in others the opposite is true. However, it should be noted that the average value of the Ruxton index in lacustrine soils in general varies around 9.50. In the case of the MIA (Mineralogical Index of Alteration) which indicates the degree of primary minerals alteration in secondary minerals; it has values of the order of 60, except in wells where the CaO and K_2O contents are relatively high. It showed a net growth over the whole of the profiles of the surface (going even to 60.19%) towards the depth (going to 75.27%), but its average value varies of order 42.17% (Table 1, Figure 9).

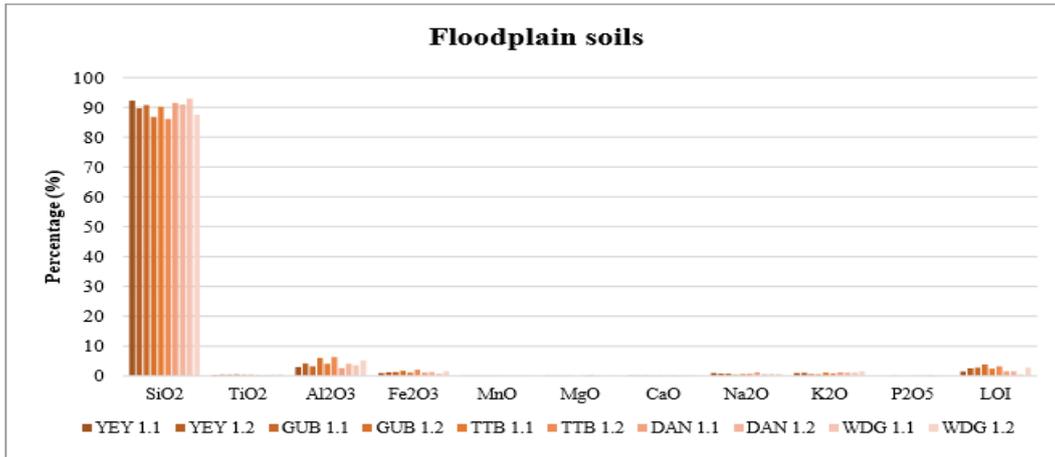


Figure 10: Variation of major elements oxides (in weight %) of floodplain soils

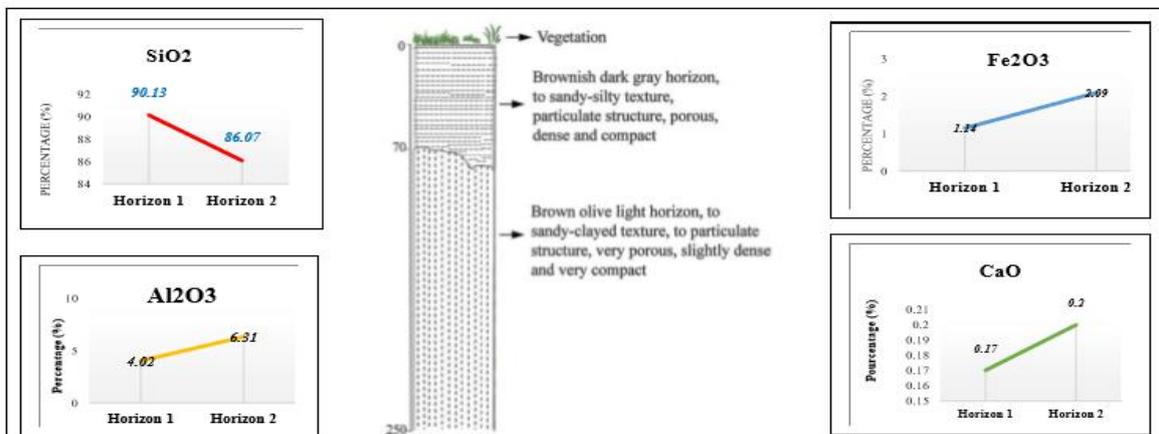


Figure 11: Variation of some oxides (in weight %) of the floodplain soils profile

5.2. Floodplain Soil

In its specificity, floodplains soils showed high level of SiO₂ around 90% with an irregular overall variation on the different horizons and whose lowest content is 86.07% (Table 2). Just below, despite its low representativeness, alumina gradually increased with depth (from 2.21% to 6.31%) with an average content estimated at 4.18%. Similarly, Fe₂O₃ increased with depth but with even lower levels (estimated at 1.29% across all profiles) (Table 2 & Figure 10). Elements such as TiO₂, MnO, CaO, Na₂O, K₂O are very low over profiles (with values less than 1%). The Ruxton index in floodplains soil is greater than 2 across all the different horizons and profiles (23.63). On the other hand, the MIA is of order of 42.25, but it grows with the depth going to more than 60 in certain horizons of soil (Figure 11).

Table 2: Major elements oxides (in weight %) of floodplain soils

Profile	GUB1.1	GUB1.2	TTB1.1	TTB1.2	DAN1.1	DAN1.2	WDG1.1	WDG1.2	DNW11	DNW12	SYL11	SYL12	Aver.
SiO ₂	90.78	86.80	90.13	86.07	91.43	90.91	92.93	87.48	89.29	91.8	90.5	91.2	89.93
TiO ₂	0.38	0.47	0.44	0.45	0.31	0.33	0.42	0.48	0.57	0.48	0.25	0.63	0.43
Al ₂ O ₃	3.21	5.94	4.02	6.31	2.60	4.02	3.58	5.15	4.55	2.21	4.15	4.36	4.18
Fe ₂ O ₃	1.27	1.71	1.14	2.09	1.15	1.32	0.77	1.57	1.25	0.97	1.41	0.80	1.29
MnO	0.02	0.02	0.03	0.01	0.03	0.02	0.02	0.05	0.01	0.02	0.03	0.02	0.02
MgO	0.07	0.07	/	0.10	0.32	0.05	/	0.03	0.23	0.05	/	0.02	0.12
CaO	0.17	0.15	0.17	0.20	0.23	0.13	0.12	0.15	0.15	0.17	0.15	0.12	0.16
Na ₂ O	0.73	0.45	0.62	0.68	1.18	0.56	0.68	0.72	0.89	0.73	0.02	0.55	0.65
K ₂ O	0.61	0.51	1.07	0.88	1.17	1.07	1.13	1.57	0.01	0.03	1.15	1.02	0.85
P ₂ O ₅	0.01	0.00	0.00	0.01	0.03	0.33	0.01	0.00	0.01	0.01	0.00	0.01	0.04
Total	9.25	96.12	97.62	96.80	98.45	98.74	99.66	97.2	96.96	96.5	97.6	98.7	97.67
SiO ₂ /Al ₂ O ₃	28.28	14.61	22.42	13.64	35.16	22.61	25.96	16.99	19.62	41.5	21.8	20.9	23.63
MIA	41.1	68.51	36.73	56.38	0.38	39.10	29.95	35.7	62.5	40.8	51.7	44.1	42.25

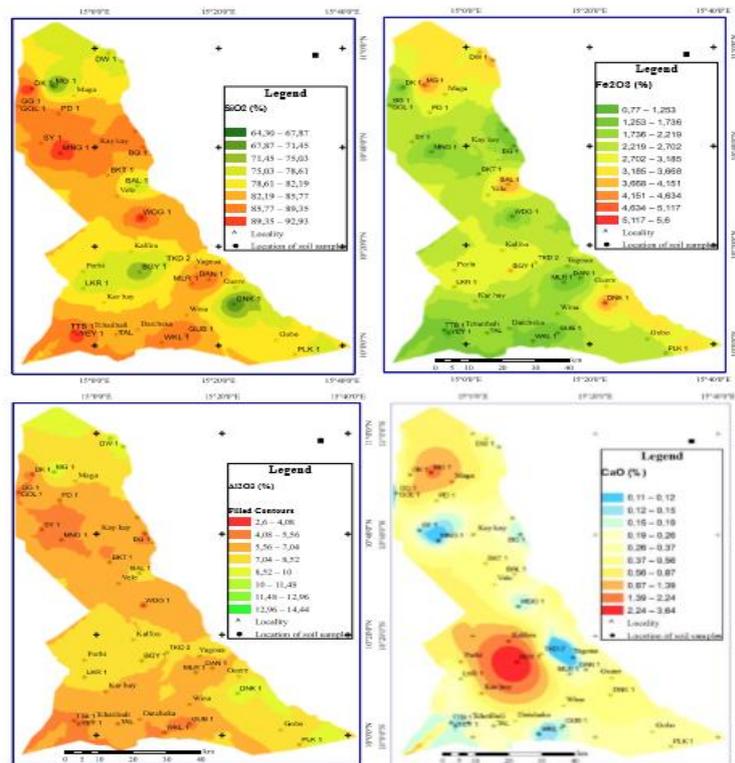


Figure 12: Distribution map of SiO₂, Al₂O₃, Fe₂O₃ and CaO elements (in weight %)

6. Comparative Geochemical Analysis

The comparative synthetic analysis of different types of soil (Figure 12) reveals more and less remarkable and appreciable variation of chemical elements and in particular of Ruxton index and Mineralogical Index of Alteration (MIA). Specifically, SiO₂ content remains above 70% on

characteristic soils of study area; however, it should be noted this element indicated an estimated 90% content in floodplain soils unlike lacustrine soils (75%). Although SiO_2 , alumina indicated a low content in floodplain soils (4.18%); but it is still slightly higher in lacustrine soils at 8%. Similarly, Fe_2O_3 expressed at least very low values overall, but with appreciable levels in lacustrine soils (more than 2.50%); contrasting the floodplain soils where it showed very little of order of 1%. Distinctly from others elements, CaO showed a content of 2% in lacustrine soils; likewise, for K_2O , which remains more or less appreciable in these soils (more than 1.20%). Others elements (Na_2O , TiO_2 , MnO, MgO and P_2O_5) are relatively very low on all soils characteristic of study area. In case of Ruxton index, it should be noted simply that its value is greater than 2 on the soils studied. And finally, the mineralogical alteration index (MIA) shows values greater than 60% in lacustrine soils; while in plain soils, this index is constant in order of 45%.

The comparative synthetic analysis of different types of soil reveals more and less remarkable and appreciable variation of chemical elements and in particular of Ruxton index and Mineralogical Index of Alteration (MIA). Specifically, SiO_2 content remains above 70% on characteristic soils of study area; however, it should be noted this element indicates an estimated 90% content in floodplain soils unlike lacustrine soils (75%). Unlike SiO_2 , alumina indicates a low content in floodplain soils (4.18%); but it is still slightly higher in lacustrine soils at 8%. Similarly, Fe_2O_3 expresses at least very low values overall, but with appreciable levels in lacustrine soils (more than 2.50%); contrasting the floodplain soils where it expresses very little of order of 1%. Distinctly from others elements, CaO showed a content of 2% in lacustrine soils; likewise, for K_2O , which remains more or less appreciable in these soils (more than 1.20%). Others elements (Na_2O , TiO_2 , MnO, MgO and P_2O_5) are relatively very low on all soils characteristic of study area. In case of Ruxton index, it should be noted simply that its value is greater than 2 on the soils studied. And finally, the mineralogical alteration index (MIA) shows values greater than 60% in lacustrine soils; while in plain soils, this index is constant in order of 45%.

7. Discussion

The lacustrine soils studied are generally located on a unit of altitude less than or equal to 310 m and are formed in particular around Maga Lake with drying slots observed on the surface (1 m deep on average). These drying slots indicated gilgai-type micro-reliefs that are regularly encountered in these soil types, as described by authors such as Barbery and Gavaud (1980), Sieffermann and Vallerie (1986), Garba (2000), Temga (2008) and Vizier (2010). This is due to their permanent contact with water and the dominant 2/1 clay minerals (smectites) in these soils. However, these soils are dominated by periodically flooded grasslands, shrub savannah and herbaceous steppes. On other hand, profile is characterized by a gray to dark gray color as described by CPCS (1967), Duchaufour (1977), Garba (2000) and Temga (2008). In agreement with Duchaufour (1977) and Temga (2008), it is accepted that organic matter plays a large role in pedogenetic processes. Their clay texture and clotty to polyedric to massive structure are result of their cultivation and high proportion of deep clay minerals and nature of lithologic materials.

Floodplain soils, unlike lacustrine soils, are located on floodplain zones, on a unit of altitude greater than or equal to 315 m, on plains rich in sandy-clay to sandy alluvial deposits. They develop a shrub savanna with trees, similar to those described by Baize et al. (2008). Their profile has in particular yellowish-brown to light brownish-gray to dark-gray horizons of variable thickness, sandy to sandy-clay-silty texture and particulate to massive structure. According to Barbery and Gavaud's work (1980), this seems to be explained by matter's movements and slow internal drainage (vertical leaching). In contrast to lacustrine soils showed dominant sandy texture and particulate structure; this is due to the nature of the lithology which consists essentially of sandy alluvium (Leumbe Leumbe et al., 2015). Soils geochemistry of study area highlights lateral and vertical variation of major elements that were the subject of this analysis.

Influence of Lithologic Materials

Lithologic nature of entire study area is essentially composed of alluvia. Thus, lithology of floodplain soils is mainly dominated by alluvia deposits of sandy nature associated with sandy-clay alluvium located upstream of the Limani-Yagoua dune. This explained why it has very high silica great quantity (90%) on all floodplain soils profiles. On other hand, lacustrine soils are exclusively formed on clay alluvia with slightly association of sandy-clay to sandy-clay alluvia; this nature contributed to its relative dominance in SiO₂ (75%) compared to floodplain soils. In addition, these lacustrine soils have been contributions of "Mayos" from Mandara Mountains located a little further in the western part (1400 m of altitude) of study area. It should be noted that these inputs have high levels of clays and silts (Tiki, 2014; Ibrahim, 2014; Leumbe Leumbe et al., 2015; CPCS, 1967; Duchaufour, 1977).

Influence of Topography

Study area has two distinct zones; the elevated zone located generally between 315 and 340 m of altitude on which floodplain soils are deposited; and the low zone which is organized around 290 and 315 m of altitude on which lacustrine soils are deposited. This difference in altitude would explain contents of different soil types. Bases indicated somewhat higher levels in lacustrine soils. The cases of CaO and K₂O showed a relative variation in content. The higher levels in lacustrine soils (2.68% for Ca₂O, 1.62% for K₂O and 0.65% for MgO) compared with higher levels in floodplain soils (0.16% for Ca₂O, 0.85% for K₂O and 0.12% for MgO). By their nature, bases are very mobile in soil and occupy low elevation areas by drainage processes. Ferruginous concretions up to 60% recognizable along lacustrine soils profiles confirm the relatively Fe₂O₃ content found in lacustrine compared to floodplain soils; they can be explained by the seasonal contrast characteristic of intertropical regions with a dry season of 4 to 5 months, a rainy season with annual rainfall of 400 to 1000 mm/year and high temperatures (28° C on average) as have shown it CPCS (1967), Baize et al., (2008), Vizier (2010), Tiki (2014), Basga (2015).

Comparison between alluvial plains soils of Mayo Danay (eastern part of Sudano-Sahelian zone of Cameroon) and Peshawar Basin of soils of Pakistan (Southern foothills of lesser Himalayas in the Khyber Pakhtunkhwa (KP).

Table 3: Comparison between alluvial plain soils of Mayo-Danay and soils of Peshawar Basin (KP Pakistan)

Soils	Alluvial plain soils of Mayo-Danay		Peshawar Basin Soils	
	Lacustrine	Floodplain	Lacustrine	Floodplain
Localization	10°00' - 11°10'N, 14°50' - 15°40'E		33°20'- 34°20'N, 71°25' – 72°40'E	
Climate	Subtropical hot		subtropical semi-arid hot	
Rainfall (mm/year)	650	800	400	
Temperature (°C)	27		23	
Lithology	clay and clay sand alluvia	sand and sand clay alluvia	clay and sand lake deposits	sand sediments with intercalation of clay
Topography (m)	290-315		315-340	

Soils of Peshawar Basin present geochemical data that shows significant difference in level of major elements in these soils relative to soils in study area. To better understand susceptibility to zonation of these soils, rigorous analyses of pedogenesis factors are highlighted; these include lithologic nature, climate and topography (Table 3). Thus, SiO₂ content is lower (about 50% in lacustrine and floodplain soils) than those of soils in study area (overall greater than 75%). This variation in SiO₂ content is due to nature of lithologic materials, which in case of soils of study area are mainly formed on dominant sandy alluvial soils (floodplain soils) associated with clay-sand to clay soils (lacustrine soils) resulting from the alteration of granitic and volcanic rocks (Ibrahim, 2014; Leumbe Leumbe et al., 2015; Segalen, 1964; Temga et al., 2015; Mohammad and Shahina, 2006). Silica, which is in

quartz form, represents a high proportion of sandy fractions (Vizier, 2010; Bear, 1975). Thus, sandy-clay texture of soil of study area may explain abundance in SiO_2 compared to Peshawar Basin soils. On the other hand, soils of Peshawar basin are formed in sedimentation zone where the soils show dominant clay-sand to clayey texture. In contrast to first element, alumina and iron indicate higher values in soils of Peshawar basin (5% Fe_2O_3 and 18% Al_2O_3); while in soils of sector, these values are lower (2% Fe_2O_3 and 8.5% Al_2O_3) (Table 3). Fe_2O_3 and Al_2O_3 contents are related to altered primary minerals present in the sandy-clay fraction. With regard to clay, to which iron is often associated, as well as phosphorus, which becomes more strongly bound to iron and alumina; the high soil levels in Peshawar Basin are mainly due to clay nature of these sediments from inputs from floods often very rich in clay and silt (Temga et al., 2015; Mohammad and Shahina, 2006). Similarly, alkaline (Na_2O and K_2O) and alkaline-earth elements contents remain higher in soils of Peshawar basin; this would be related to limestone deposits that are intimately related to sedimentary deposits (Temga et al., 2015; Mohammad and Shahina, 2006). However, it should be emphasized soils of Peshawar basin are mainly formed on sediments rich in limestones. These are flood products very frequently encountered in the area. This latitudinal difference observed on of major element variation content on lacustrine soils of these sectors would be essentially due to lithologic material nature. It should be emphasized that pedogenesis plays a very important role in this distribution, given the differences in the geochemical composition of soil classes studied (Vizier, 2010; Azinwi et al., 2011; Boukar, 2007) in the Peshawar Basin and the alluvial plains of Mayo Danay division (Table 3).

8. Conclusion

As part of Mayo Danay's alluvial plains are well developed morphologically with deep horizons in depth. They have a very dominant clay texture in case of lacustrine soils, while floodplain soils are sandy. Geochemically, they are very rich in SiO_2 and have relatively low levels of Fe_2O_3 , Al_2O_3 and the group of alkaline and alkaline earth elements. This result is a direct consequence of lithologic nature, climate, relief and pedogenetic processes which play a very important role in formation, evolution of soils and their susceptibility zonation.

Acknowledgements

We express our sincere thanks to TWAS (The World Academy of Sciences) and all those who have contributed to success of this work, especially my supervisors.

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