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SOIL-LANDSCAPE RELATIONSHIP IN A WATERSHED LOCATED ON PLEISTOCENIC TERRACES AND FLUVIO-LAGUNARIAN SEDIMENTS IN MUNICIPALITY OF RECIFE, BRAZIL

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KEYWORDS

SiBCS, Ferralsols, Barreiras group, soil map.

ABSTRACT

In the Prata watershed there are units corresponding to the Pleistocene Terraces and the Fluvium-Lagoon Sediments. This watershed is inserted almost entirely in the area of plateaus (Tabuleiros) with altitudes of 10 to 100 meters, and in areas with altitudes of 2 to 10 meters in the area of floodplains and fluvio-lagoon terraces. The present work aimed to characterize and classify soils in the Brazilian Soil Classification System - SiBCS and correlate them with the IUSS Working Group WRB-FAO (in parentheses), besides evidence some soil-landscape relations, that occur in Pleistocene terraces and fluvium-lagoon sediments in the Prata watershed, located in the ecological reserve of Dois Irmãos State Park in Recife – PE, Brazil. Soil samples were used to perform physical, chemical and mineralogical analysis in laboratory. Watershed delimitation, Digital Elevation Model (DEM), slope map, soil map and slope x soil map were obtained and studied. The soils are quite acidic and have a very low natural fertility, with the Latossolos (Ferralsols) predominating in the landscape. The silt and clay fractions of the studied Argissolos (Acrisols) and Latossolos (Ferralsols) presented quartz and kaolinite as the main component. In the profile of Neossolo Quartzarênico (Arenosols) only quartz was identified as a component of the silt and clay fractions. The kaolinitic mineralogy of the clay fraction is consistent with the environment of its formation, that is, hot and humid. There is no relationship between the colors of soils and their exposure to the sun on the slopes where they occur. The occurrence of a sandy and whitish horizon between the litter and the A horizon, is not foreseen in the norms and criteria adopted in the Brazilian Soil Classification System - SiBCS.

INTRODUCTION

The metropolitan region of Recife is geologically characterized by rocks from the Crystalline Basement, represented by lithotypes of the Gneiss-migmatitic Complexes, Belém do São Francisco and Vertentes, in addition to several granitoids. This whole set of lithotypes, can appear or be covered by meso-cenozoic sediments from the Paraíba-Pernambuco states and Cabo municipality coastal sedimentary basins. Cretaceous sedimentary coverings of the Barreiras Group and quaternary corresponding to pleistocene terraces, holocenic marine terraces, detritus fluvium-lagoon sediments, mangrove sediments, beach sediments, sandstone reefs and alluvial sediments also occur (Cruz et al., 2017).

The Gneiss-migmatitic Complex, of paleoproterozoic age, is orthogneiss from granitic to tonalitic in composition, sometimes monzonitic and

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dioritic, migmatized, not individualized (Lima Neto et al., 2009; Nunes et al., 2019).

The Belém de São Francisco Complex, of Mesoproterozoic age, was defined by Cruz et al. (2017), as being made up of orthogneisses and migmatites with supracrustal relics. The Vertentes Complex, of Mesoproterozoic age, comprises quartzites, metapelites and diverse metavolcanics (Fernandes et al., 2017). Granitoid batholiths consist of leukogranites, syenites, monzonites, granodiorites and quartzodiorites (Lima Neto et al., 2009). The gneisses, cataclastics and granites rich in quartz, feldspars and ferromagnesian minerals, which make up the Crystalline Basement, have a strong tendency to form clay during the formation of the soil over the local climate (Giarola et al., 2009; Nunes et al., 2019).

The Paraíba-Pernambuco basin is represented by the Paraíba Group, which comprises the Beberibe formations (coarse to conglomeratic sandstones, with possible intercalations of conglomerates and clay siltstones), Gramame (limestones, marsh limestones, marl and clays, with phosphate horizons in their basal portion) and Maria Farinha, which is composed of detrital limestones interspersed with marsh limestones, clays and dolomitized limestones. The Cabo basin is formed by the sediments and cretaceous vulcanites belonging to the Pernambuco Group, constituted by the following formations: Cabo (conglomerates, conglomeratic sandstones, arcosean sandstones, turbidites and shales), Estiva (limestones and calcilutites, associated with shales, siltstons and clays) and Algodoais (conglomerates and conglomeratic sandstones with rare fragments of volcanic rocks) and the lithotypes of the Ipojuca Volcanic Suite which is composed of rhyolites, trachytes, basalt and intrusive granite from Cabo de Santo Agostinho, in addition to ignibrites and pyroclastic rocks (Biondi et al., 2011; Martins et al., 2011; Ramos et al., 2021).

The Barreiras Group is made up of sandy-clayey sediments, poorly consolidated, with variegated coloring, with lateritized and kaolinic levels. These sediments discordantly cover not only the crystalline basement rocks, but also the sediments of the meso-cenozoic coastal basins (Demattê et al., 2012). The genesis of this formation seems to be anastomous fluvial, passing to the top, to a meandering fluvial system, and according to the variability of sediments and relief, the soils developed on these materials are associations of Latossolos (Ferralsols), Argissolos (Acrisols) and Espodossolos (Podzols) (Assunção et al., 2018; Andrade et al., 2022).

Pleistocene marine terraces occur strikingly on the plain of Recife, consisting of quartz sand of varying size from fine to medium, with a degree of regular selection and associated with the remains of limestone shells. The Holocenic marine terraces have a similar constitution to the Pleistocene marine terraces, standing out for being better selected, with fine granulometry predominating. Shell remains are also frequent. The detritus fluvial-lagoon sediments constitute the quaternary unit with the largest area of occurrence in the metropolitan region of Recife, being composed of fine sands, silts, clays, diatoms and peat sediments. The mangrove sediments are predominantly made up of clays, silts, fine sands, silica carapaces of diatoms, sponges of spongiaries, organic remains and shells (Demattê et al., 2012; Teramoto et al., 2021; Andrade et al., 2022).

The beach sediments are sandy, unconsolidated, essentially quartz, well selected, occupying narrow strips along the entire coast of the metropolitan region of Recife. The sandstone reefs (beach rocks) correspond to strands or banks of sandstones made up of quartz grains and fragments of shells. The alluvial deposits have a sandy to sandy-clay character and are distributed along the main rivers of the metropolitan region of Recife, with emphasis on the Ipojuca, Jaboatão and Capibaribe rivers (Lima et al., 2021).

In a regional geomorphological analysis, it can be said that the coast of Pernambuco in its northern portion is basically constituted by the relief of plateaus, interrupted by small plains. The area of the municipality of Recife comprises two sets of topographically distinct areas, hills and coastal plain. They are distinct morphological units of origin, but interrelated with each other. The dissection of plateaus by fluvial, pluvial and gravitational agents and the destructive / constructive activity of the sea on the coastal plain, result from tectonic and climatic processes (Teramoto et al., 2021).

In the Prata watershed, a compartment in the Dois Irmãos Environmental Reserve that will have its soil covered in this work, there are units corresponding to the Pleistocene Terraces and the Fluvium-Lagoon Sediments. This reserve is inserted almost entirely in the area of plateaus known as Tabuleiros Costeiros (Coastal Tablelands) with altitudes of 10 to 100 meters, and in areas with altitudes of 2 to 10 meters in the area of floodplains and fluvio-lagoon terraces (Caldas et al., 2021). The studies by Moura et al. (2009) show that the area, being in the geological event of the Barreiras Formation, its surface is a consequence of Neotectonism, a fact evidenced by the great unevenness in the area that reaches 20 m in height and that also favored the formation of aquifers confined in the area. According to Caldas et al. (2021), the dominant soils in the slope areas of this watershed, from a pedological point of view, are of the Argissolos (Acrisols) type with subordinate Latossolos (Ferralsols). In the west and south of this watershed, incipient lateration occurs with the formation of concretions involving iron oxide and organic matter. The present work had as objectives to characterize and classify soils in the Brazilian Soil Classification System – SiBCS, and correlate them with the IUSS Working Group WRB-FAO (in parentheses), besides evidence soil-landscape relations, that occur in Pleistocene terraces and fluvium-lagoon sediments in the Prata watershed, located in the ecological reserve of Dois Irmãos State Park in Recife – PE, Brazil.

MATERIAL AND METHODS

Study area

It comprises the Prata watershed, with the Prata River being its main watercourse, which is a tributary of the left bank of the Capibaribe River. It is geographically located between the vertices 07º 59' 58"/ 34º 56' 23" and 08° 01' 02"/ 34° 57' 27", in the Zona da Mata of the State of Pernambuco, Brazil, in the metropolitan region of Recife (Figure 1) within the limits of the Dois Irmãos State Park. It has an area of 196.0 hectares, of which 5.5% is a water mirror, and corresponds to approximately 50% of the 387.4 hectares of the Dois Irmãos State Park (Caldas et al., 2021).

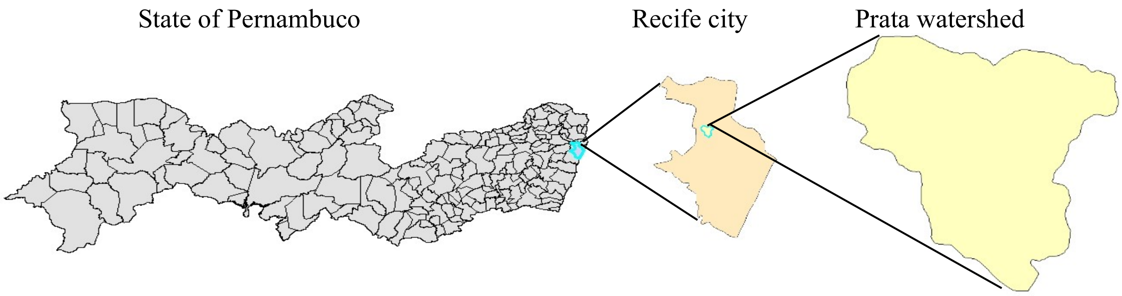


FIGURE 1. Location of the Prata watershed in the Zona da Mata of the State of Pernambuco, Brazil.

The climate, according to the Köppen classification, is of the As' type, hot and humid, with a minimum temperature of 18 ºC, monthly averages above 23 ºC, but with a small thermal amplitude and average annual precipitation around 2,460 mm (Moura et al., 2009).

Field work

Initially a planning was made from orthophotocards, where the paths were traced in the most evident dividers and thalwegs, as well as in the top and lower parts. The entire study area was covered by performing 63 auger drillings. From the results observed in these auger drillings, 6 locations were defined for opening trenches and described the soil profile in each one.

On many occasions the progression was made inside the forest itself, as there were no paths. At each auger drilling point and trench opening for the description of soil profiles, the geographical coordinates were collected through a satellite receiver in the GPS system, recording the outstanding characteristics of the relief, vegetation, anthropization and especially of the soil morphology. The auger drillings were carried out up to 2.0 meters deep, except when there was an impediment, consisting of a layer or line of stones.

During the opening of the trenches to describe the profiles, soil samples were also collected from each horizon of the profile, for later physical, chemical and mineralogical analyzes in laboratories. On occasion the soil samples were packed and labeled in plastic bags.

The description of the soil profiles was in accordance with Santos et al. (2015), with the nomenclature of horizons according to the rules of Embrapa (1988a, 1988b).

Determinations made on soil samples

After being air-dried, soil samples were prepared by destroying clods with the aid of a wooden roller and passed through a 2 mm mesh sieve, thus obtaining the air-dried fine soil. Subsequently, the samples were sent to the Laboratory for physical and chemical analysis.

Physical analysis

For the physical analysis of soils, the methods recommended by (Texeira et al., 2017) were used, determining granulometry, clay dispersed in water, soil density, particle density, hydraulic conductivity and moisture attributes.

Chemical analysis

Chemical analyzes were performed according to the recommendations of Embrapa (Texeira et al., 2017). They consisted of the following determinations: pH in H_2O and KCl 1 mol L^{-1}; Exchangeable aluminum; Potential acidity (H^+ + Al^{3+}); Exchangeable calcium and magnesium; Exchangeable sodium and potassium; and Extractable phosphorus in Mehlich 1.

Mineralogy of soil horizon samples

The mineralogy of the silt and clay fractions was carried out by X-ray diffraction, after preparation of slides with parallel orientation, according to the methodology described by Marcolin & Calegari (2020). The basal or interplanar distance (d value) of each mineral was obtained by converting the values of 2θ (angle of incidence of primary radiation), provided in the diffractograms. The values were calculated using the Bragg equation, $n\lambda = 2d \sin \theta$.

Soil Classification

During and after the soil survey, at the level of semi-detail, inferences were made about the taxonomic classification based on Araújo Filho et al. (2000) and Silva et al. (2001). The final classification, however, was carried out based on Brazilian Soil Classification System - SiBCS published by Santos et al. (2018) and correlated with the IUSS Working Group WRB-FAO (2014), the latter appearing in parentheses.

Watershed delimitation, Digital Elevation Model (DEM), slope map, soil map and slope x soil map

Eight (8) orthophotocharts from the city of Recife - PE were used, resulting from the restoration and rectification of aerial photographs from 1974, from the State Agency for Planning and Research - CONDEPE / FIDEM, all on a scale of 1: 2,000 and with 2 meters of equidistance between the contour lines.

In possession of the orthophoto, were performed georeferencing, mosaic, delimitation of the watershed, digitization of contour lines and rated points, using the ArcGIS program from ESRI GIS and Mapping Software.

The DEM map was created from: the map of the contour lines, the quoted points in the orthophotocharts and the watershed limit. The slope map was created from the DEM and the slope classes were adapted from Embrapa (1988b) and Santos et al. (2018), with relief types based only on the slope classes.

To make the map of the mapping units, initially the auger drillings were plotted on the orthophotocharts in analog format, and after defining the existing soil classes, the units were delimited. After this stage, the limits of the units were digitized, which were marked in the orthophotocharts. The soil feature was transformed from vector to raster using a resolution of 20 meters.

The soil x slope map was built from the overlap of the two themes, and their areas were calculated based on the intercession of their occurrences.

RESULTS AND DISCUSSION

Soils

According to the soil survey carried out in the study area, the main soils found are represented by their profiles below.

Profile 1(P1) - Geographic location: 25L UTM 9115203,62; 284864,49 - Classified according to the Brazilian Soil Classification System - SiBCS (Santos et al., 2018) as ARGISSOLO AMARELO Distrófico típico A moderado textura média/argilosa fase floresta subperenifólia relevo plano; and correlated with the IUSS Working Group (WRB-FAO, 2014) as Humic Clayic Xanthic Acrisol.

Profile 2 (P2) - Geographic location: 25L UTM 9114211,96; 285350,86 - Classified according to the Brazilian Soil Classification System - SiBCS (Santos et al., 2018) as LATOSSOLO AMARELO Distrófico típico "A" moderado textura média fase floresta subperenefólia relevo suave ondulado; and correlated with the IUSS Working Group (WRB-FAO, 2014) as Humic Dystric Loamic Xanthic Ferralsol.

Profile 3 (P3) – Geographic location: 25L UTM 9114284,12; 285581,10 - Classified according to the Brazilian Soil Classification System - SiBCS (Santos et al., 2018) as NEOSSOLO QUARTZARÊNICO Órtico típico A moderado fase floresta subperenefólia relevo plano; and correlated with the IUSS Working Group (WRB-FAO, 2014) as Hydrophobic Ochric Dystric Arenosol.

Profile 4 (P4) - Geographic location: 25L UTM 9114938,14; 284474,79 - Classified according to the Brazilian Soil Classification System - SiBCS (Santos et al., 2018) as ARGISSOLO AMARELO Distrocoeso típico A moderado textura média/argilosa fase floresta subperenifólia relevo ondulado; and correlated with the IUSS Working Group (WRB-FAO, 2014) as Humic Densic Xanthic Acrisol.

Profile 5 (P5) - Geographic location: 25L UTM 9114209,34; 285722,79 - Classified according to the Brazilian Soil Classification System - SiBCS (Santos et al., 2018) as ARGISSOLO VERMELHO-AMARELO Distrófico típico "A" moderado textura média/argilosa fase floresta subperenifólia relevo plano; and correlated with the IUSS Working Group (WRB-FAO, 2014) as Clayic Rhodic Acrisol.

Profile 6 (P6) – Geographic location: 25L UTM 9113757,84; 285276,38 - Classified according to the Brazilian Soil Classification System - SiBCS (Santos et al., 2018) as GLEISSOLO MELÂNICO Tb Distrófico organossólico textura arenosa fase campos de várzea relevo plano; and correlated with the IUSS Working Group (WRB-FAO, 2014) as Arenic Dystric Histic Gleysol.

Physical and morphological characteristics of soils

The soils varied from deep to very deep (Table 1) according to the criteria of Santos et al. (2018) and Embrapa (1988a), with the exception of the Gleissolo (Gleysol) (Profile 6), which was considered to be shallow.

TABLE 1. Some morphological and physical attributes of the studied soils.

Horizon and depth (cm)		Soil color (wet)		Sand	Silt	Clay	CDW	Texture	Silt/Clay	DS	DP
				------------------g/Kg-----------------						g/cm³	
Profile 1 - ARGISSOLO AMARELO Distrófico típico* (Humic Clayic Xanthic Acrisol**)											
A	0-19	Very dark grayish brown	10YR 3/2	561	70	369	9.0	Sandy clay	0.19	1.15	2.41
BA	19-38	Dark yellowish brown	10 YR 3/4	442	40	518	0.0	Sandy clay	0.08	1.12	2.44
Bt1	38-76	Dark yellowish brown	10 YR 4/6	382	20	598	0.0	Clay	0.03	1.15	2.47
Bt2	76-142	Dark yellowish brown	10 YR 4/6	395	17	588	0.0	Clay	0.03	1.23	2.50
Bt3	142-180+	Strong brown	7.5 YR 4/6	402	30	568	3.0	Clay	0.05	1.24	2.50
Profile 2 - LATOSSOLO AMARELO Distrófico típico* (Humic Dystric Loamic Xanthic Ferralsol**)											
A1	0 – 20	Very dark brown	10 YR 2/2	861	40	99	2.0	Loamy sand	0.40	1.36	2.44
A2	20 – 60	Very dark grayish brown	10 YR 3/2	841	10	149	2.0	Loamy sand	0.07	1.38	2.41
AB	60 – 100	Dark yellowish brown	10 YR 4/4	771	45	184	0.0	Loamy sand	0.24	1.42	2.50
Bw1	100 – 160	Yellowish brown	10 YR 5/4	788	34	178	0.0	Sandy loam	0.19	1.34	2.41
Bw2	160 – 200+	Yellowish brown	10 YR 5/4	791	30	179	0.0	Sandy loam	0.17	1.40	2.44
Profile 3 – NEOSSOLO QUARTZARÊNICO Órtico típico* (Hydrophobic Ochric Dystric Arenosol**)											
A	0-26	Dark grayish brown	10 YR 4/2	951	10	39	0.0	Sand	0.26	1.43	2.44
C1	26-80	Dark grayish brown	10 YR 4/2	926	35	39	0.0	Sand	0.90	1.57	2.63
C2	80-140	Light brownish gray	10 YR 6/2	931	40	29	0.0	Sand	1.39	1.60	2.47
C3	140-180+	Gray	10 YR 6/1	941	25	34	4.0	Sand	0.74	1.65	2.47
Profile 4 - ARGISSOLO AMARELO Distrocoeso típico* (Humic Densic Xanthic Acrisol**)											
A	0-15	Very dark grayish brown	10 YR 3/2	811	30	159	3.5	Sandy loam	0.19	1.19	2.38
BA	15-36	Dark yellowish brown	10 YR 3/4	711	70	219	0.0	Sandy clay loam	0.32	1.20	2.44
Bt1	36-77	Dark yellowish brown	10 YR 4/6	651	50	299	0.0	Sandy clay loam	0.17	1.22	2.47
Bt2	77-115	Yellowish brown	10 YR 5/8	657	34	309	0.0	Sandy clay loam	0.11	1.20	2.47
Bt3	115-168+	Yellowish brown	10 YR 5/8	622	60	318	0.0	Sandy clay loam	0.19	1.29	2.41
Profile 5 - ARGISSOLO VERMELHO-AMARELO Distrófico típico* (Clayic Rhodic Acrisol**)											
A	0-15	Dark brown	7.5 YR 3/3	711	50	239	0.0	Sandy clay loam	0.21	1.18	2.41
Bt1	15-38	Brown	7.5 YR 4/4	455	47	498	0.0	Sandy clay	0.09	1.13	2.44
Bt2	38-88	Strong brown	7.5 YR 4/6	382	40	578	0.0	Clay	0.07	1.13	2.47
Bt3	88-155+	Dark red	2.5 YR 3/6	405	55	540	0.0	Clay	0.10	1.22	2.50
Profile 6 – GLEISSOLO MELÂNICO Tb Distrófico* (Arenic Dystric Histic Gleysol**)											
A	0 – 15	Black	10 YR 2/1	-	-	-	-	-	-	-	-
A2	15 – 40	Very dark grayish brown	10 YR 3/2	-	-	-	-	-	-	-	-
Cg1	40 – 60	Grayish brown	10 YR 5/2	-	-	-	-	-	-	-	-
Cg2	60 – 80	Olive brown	2.5 Y 4/2	863	41	96	-	Loamy sand	0.43	1.44	2.60
Cg3	80 – 90 +	Olive brown	2.5 Y 4/2	829	25	146	-	Loamy sand	0.17	1.56	2.53

* Brazilian System of Soil Classification – SiBCS (Santos et al., 2018); ** IUSS Working Group (WRB-FAO, 2014); CDW - Clay dispersed in water; DS - Soil Density; DP - Particle Density; - value not obtained

In general, the predominant colors in the soils are brownish, varying from dark grayish to yellowish, and only in P5 the hues of 7.5 YR and 2.5 YR appear, which resulted in its classification as Argissolo Vermelho-Amarelo (Clayic Rhodic Acrisol). With a little less evidence in P5, there should be a predominance of goethite over hematite, as according to Vasconcelos et al. (2014), the presence of only 1% of this last oxide would be enough to dye the soil material with red color.

Feitosa et al. (2020) and Zanchin et al. (2021a) report that a more humid regime, that is, with more moisture, is favored the formation of goethite, iron oxide that gives yellowish colors to soils.

With regard to granulometry, the sandy texture is found, particularly on the surface (P2 and P3) and in the lower and depressed parts of the relief (P3 and P6). The clay texture is basically restricted to the P1 and P5 profiles of Argissolos (Acrisols), particularly in their subsurface horizons Bt, the same with higher percentages of fine fractions.

As is characteristic of the class of Argissolos (Acrisols), the clay content increases in depth, resulting in a textural relationship ranging from 1.55 to 2.25, which suggests the occurrence of clay eluviation and the presence of the textural (argilic) B horizon, corroborating with the results obtained by Lima et al. (2016), Costa et al. (2021) and Zanchin et al. (2021b).

The low values of clay dispersed in water (CDW), as shown in Table 1, suggest that there is particle aggregation, which is reflected by the degree of flocculation. Some type of substance may be acting as a cementing agent, contributing to the aggregation of the particles. According to Andrade et al., (2020) e Giarola et al. (2009), lower values of natural clay, generally below 5%, should appear in oxic B horizons (Bw), being higher in textural (argilic) B horizons (Bt). In the case of higher values that appear on the surface horizons of profiles P1, P2 and P4, these must be related to the presence of organic acids, capable of destroying the clays.

The silt / clay ratio appears, with the exception of the C1 horizon of P3 Neossolo Quartzarênico (Hydrophobic Ochric Dystric Arenosol), with values below 0.7, which according to the proposition of Santos et al. (2018) is considered the maximum limit and one of the conditions for the characterization of Bw horizons (oxic).

The values of soil density, corroborate those existing in the literature, in which the variations must be from 1.00 to 1.25 g/cm^3 for clay soils and 1.25 to 1.40 g/cm^3 for sandy soils. It appears that the highest values belong to the profiles P2, P3 and P6, respectively the Latossolo Amarelo (Humic Dystric Loamic Xanthic Ferralsol), the Neossolo Quartzarênico (Hydrophobic Ochric Dystric Arenosol) and the Gleissolo (Arenic Dystric Histic Gleysol), specifically those soils with the highest percentage of sand.

According to the observed values of particle density, and compared with the expected values, it appears that they were underestimated, since according to Santos et al. (2021) in regions with tropical climate, soils with values close to 3.0 g/cm^3 are frequent. Under these conditions, there is a predominance of iron oxides, with goethite having a value of 4.37 g/cm^3 and hematite having a value ranging from 4.9 to 5.30 g/cm^3. Add to this, particularly in the horizons with a higher percentage of sand, as is the case of profiles P2 and P3, that quartz also presents values ranging from 2.65 to 2.66 g/cm^3.

Chemical characteristics

The pH values in water (Table 2) show that, with the exception of the C2 and C3 horizons of the P3 profile of the Neossolo Quartzarênico (Hydrophobic Ochric Dystric Arenosol), the soils present an acid reaction and can be classified according to Lima et al. (2017), as having a high acidity. Also according to these authors, the horizons C2 and C3 of the P3 profile, have a medium acidity. Therefore, the soils together have an acidity varying from medium to high, being a normal condition of soils in regions where precipitation is high, which removes by continuous leaching, the exchangeable bases of the colloidal complex of the horizons, particularly the upper ones, leaving hydrogen ions in their places.

TABLE 2. Some chemical attributes of the studied soils.

Horizons	pH		Δ pH	Na^+	Ca^{2+}	Mg^{2+}	K^+	Al^{3+}	H^+	SB	t	CEC	m	V	$S.Na^+$	OC	N	O.M	C/N	CE	P
	H_2O	KCl																			
				------------------(cmol$_c$/dm^3) --------------------									----------%-----------			---g/Kg---				dS/m	mg/dm^3
Profile 1 - ARGISSOLO AMARELO Distrófico típico* (Humic Clayic Xanthic Acrisol)**																					
A	4.00	3.50	0.5	0.0	0.61	0.71	0.05	1.83	6.86	1.37	3.20	10.06	57.19	14.0	0.0	5.50	0.40	9.48	13.7	0.39	3
BA	4.20	3.80	-0.4	0.0	0.41	0.20	0.02	1.45	3.83	0.63	2.08	5.91	69.71	11.0	0.0	3.00	0.40	5.17	7.5	0.21	2
Bt1	4.30	3.90	-0.4	0.06	0.61	0.51	0.02	1.05	2.69	1.20	2.25	4.93	46.88	24.0	1.22	1.20	0.30	2.07	4.0	0.21	2
Bt2	4.30	3.80	-0.5	0.0	0.31	0.20	0.0	1.07	1.90	0.51	1.58	3.48	67.72	15.0	0.0	0.50	0.20	0.86	2.5	0.16	1
Bt3	4.50	4.00	-0.5	0.0	0.51	0.31	0.0	0.62	2.02	0.82	1.44	3.45	43.36	23.0	0.0	0.20	0.10	0.34	2.0	0.17	1
Profile 2 - LATOSSOLO AMARELO Distrófico típico* (Humic Dystric Loamic Xanthic Ferrasol)**																					
A1	4.40	3.60	-0.8	0.0	0.41	0.20	0.03	0.80	3.71	0.64	1.44	5.15	55.56	12.0	0.0	3.60	0.40	6.21	9.0	0.32	4
A2	4.60	4.00	-0.6	0.0	0.31	0.20	0.02	0.75	3.10	0.53	1.28	4.38	58.59	12.0	0.0	1.80	0.30	3.10	6.0	0.25	2
AB	4.70	4.30	-0.4	0.0	0.41	0.20	0.02	0.60	2.15	0.63	1.23	3.38	48.78	19.0	0.0	1.00	0.20	1.72	5.0	0.18	2
Bw1	4.60	4.40	-0.2	0.0	0.41	0.20	0.0	0.40	2.13	0.61	1.01	3.14	39.6	19.0	0.0	0.30	0.10	0.52	3.0	0.21	1
Bw2	4.70	4.50	-0.2	0.0	0.31	0.10	0.0	0.30	2.34	0.41	0.71	3.05	42.25	13.0	0.0	0.10	0.10	0.17	1.0	0.31	2
Profile 3 – NEOSSOLO QUARTZARÊNICO Órtico típico* (Hydrophobic Ochric Dystric Arenosol)**																					
A	4.20	3.90	-0.3	0.0	0.41	0.20	0.0	0.32	2.54	0.61	0.93	3.47	34.41	18.0	0.0	0.70	0.20	1.21	3.5	0.23	4
C1	5.10	4.20	-0.9	0.0	0.20	0.20	0.0	0.21	0.56	0.40	0.61	1.18	33.87	35.0	0.0	0.40	0.10	0.69	4.0	0.23	2
C2	5.80	4.70	-1.1	0.0	0.31	0.20	0.0	0.01	0.43	0.51	0.52	0.95	1.92	54.0	0.0	0.20	0.10	0.34	2.0	0.25	2
C3	6.00	5.10	-0.9	0.0	0.20	0.20	0.0	0.0	0.33	0.40	0.40	0.74	0.0	55.0	0.0	0.10	0.10	0.17	1.0	0.23	1
Profile 4 - ARGISSOLO AMARELO Distrocoeso típico* (Humic Densic Xanthic Acrisol)**																					
A	3.70	3.00	-0.7	0.11	0.51	0.20	0.06	2.28	8.39	0.88	3.16	11.56	71.92	8.0	0.95	6.70	0.40	11.55	16.7	0.35	4
BA	4.00	3.40	-0.6	0.06	0.61	0.31	0.03	1.78	6.36	1.01	2.79	9.14	64.03	11.0	0.66	1.70	0.30	2.93	5.6	0.28	2
Bt1	4.50	4.00	-0.5	0.0	0.41	0.20	0.02	1.14	2.82	0.63	1.77	4.59	64.41	14.0	0.0	1.00	0.20	1.72	5.0	0.21	1
Bt2	4.50	4.20	-0.3	0.0	0.41	0.10	0.0	0.68	1.74	0.51	1.19	2.93	57.14	17.0	0.0	0.60	0.20	1.03	3.0	0.17	1
Bt3	4.60	4.20	-0.4	0.0	0.31	0.20	0.0	0.59	1.28	0.51	1.10	2.38	53.64	21.0	0.0	0.20	0.10	0.34	2.0	0.18	<1
Profile 5 - ARGISSOLO VERMELHO-AMARELO Distrófico típico* (Clayic Rhodic Acrisol)**																					
A	4.40	4.80	0.4	0.06	0.71	0.20	0.05	1.85	6.84	1.02	2.87	9.71	64.46	11.0	0.62	5.10	0.40	8.79	12.7	0.38	2
Bt1	0.11	0.10	-0.01	0.06	0.71	0.20	0.03	1.50	3.67	1.00	2.50	6.17	60.0	16.0	0.97	1.40	0.20	2.41	7.0	0.14	1
Bt2	4.20	4.50	0.3	0.0	0.61	0.31	0.0	1.10	1.87	0.92	2.02	3.89	54.46	24.0	0.0	0.30	0.10	0.52	3.0	0.11	1
Bt3	3.80	4.00	0.2	0.0	0.61	0.10	0.0	0.73	1.36	0.71	1.44	2.80	50.69	25.0	0.0	0.10	0.10	0.17	1.0	0.10	1
Profile 6 – GLEISSOLO MELÂNICO Tb Distrófico* (Arenic Dystric Histic Gleysol)																					
A	5.4	5.0	-0.4	16.17	8.80	5.36	0.31	0.37	11.51	16.17	16.54	28.05	2.24	58	6.06	80.40	7.10	138.61	11.32	1.01	57
A2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cg1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cg 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cg 3	5.3	4.7	-0.6	0.06	0.81	0.30	0.01	0.33	3.41	1.19	1.52	4.93	21.71	24	1.22	14	1.10	24.14	12.73	0.25	5

* Brazilian System of Soil Classification – SiBCS (Santos et al., 2018); ** IUSS Working Group (WRB-FAO, 2014); SB - Sum of bases; t - Effective Cation Exchange Capacity; CEC - Total Cation Exchange Capacity; m - Aluminum saturation; V - Bases saturation; $S.Na^+$ - Sodium saturation; OC - Organic carbon; N – Nitrogen; O.M - Organic matter; C/N - C / N ratio; CE - Electrical conductivity saturation extract; P - Phosphorus.

Regarding the pH variation (ΔpH), which is the difference between the pH in KCl and pH in water, the vast majority of soils can be considered electronegative, which shows a predominance of silicate clays. According to Corrêa et al. (2015), in systems dominated by 1: 1 clay minerals, ΔpH is always negative.

In the horizons of the P5 profile of Argissolo Vermelho-Amarelo (Clayic Rhodic Acrisol), the difference is positive in horizons A, Bt2 and Bt3 and almost null in Bt1, suggesting that there are mineralogical differences in this profile, and perhaps a predominance of iron oxides (goethite and hematite) and aluminum (gibbsite).

The saturation by aluminum (index m) presents values greater than 50% in most of the studied soils, characterizing them with an alic character, except in the Bw horizons of the P2 profile of the Latossolo Amarelo (Humic Dystric Loamic Xanthic Ferrasol) and in the entire P3 profile of the Neossolo Quartzarênico (Hydrophobic Ochric Dystric Arenosol). On the other hand, values of V% (base saturation) below 50%, except in the horizons C2 and C3 of the Neossolo Quartzarênico (Hydrophobic

Ochric Dystric Arenosol) P3 profile, indicate that the soils are dystrophic. Even in the case of the P3 profile, it is considered to be epidistrophic, as its superficial horizons present with V% values less than 50%.

The low values of exchangeable sodium, those of its saturation and those of electrical conductivity, indicate that there are no problems related to sodium and salts, because even though it is an area relatively close to the coast, it appears that there was no influence of spray saline from the sea, as mentioned in a study by Oldoni et al. (2019) carried out in the Lagos region in the state of Rio de Janeiro in Brazil. If this occurred in times when there was a marine transgression, in past times, the amount of rain was already sufficient to leach the salts.

In turn, the phosphorus values, whose importance is fundamental for the development of plants, also according to the classes established by Vinha et al. (2021), reveal low levels of this element. In the conditions of the Prata watershed, this element is below its critical level in the soil, however the local vegetation of the Mata Atlântica is exuberant. It may be happening as reported by Moura et al., (2009), that in natural ecosystems, not disturbed by man, the existence of several biological and chemical processes allows plants, even in conditions of low availability, to use them efficiently, there may be direct absorption of organic forms of phosphorus, without its passage to the mineral phase of the soil.

According to the classes established for organic carbon by Alvarez et al. (1999), except for the values of the P3 profile of Neossolo Quartzarênico (Hydrophobic Ochric Dystric Arenosol) and some subsurface horizons of the other soils, all other superficial horizons present values varying from good to very good. In depth, the values of organic carbon are negligible, indicating that the pedobiological activity does not play a decisive role in the formation of soils in the Prata watershed. This situation is very different from what was evidenced in the work of Pereira & Paisani (2020), in soils in south Brazil. This author reports that termites and termites, could have acted in the transport of organic matter to the deepest layers of the soil, favoring the formation of microaggregates, while transporting material from the subsoil to the surface.

As would be expected for soils under forest, the largest amount of organic matter is concentrated on the surface, having a marked influence of litter and also of roots that are concentrated in the most fertile part, decreasing sharply with depth.

Still observing the percentages of organic matter in Table 2, it appears that the highest values are found in the first two horizons of all profiles, concomitantly with the occurrence of the highest values of Al^{3+} and H^+. This fact is corroborated, in part, with reports in the literature, as it is stated that in acidic soils, humus contains large amounts of such ions.

Also observing the C/N ratio (Table 2), values above 12 are verified, which is the upper limit for the characterization of the humus (Gama-Rodrigues et al, (2008), in the horizons A of the profiles P1, P4 and P5. In these horizons, there is, as identified with the naked eye, non-decomposed plant remains, mixed with more decomposed and unidentifiable material. In the other horizons, the C/N ratio is below 12, which indicates that the organic matter is already humidified.

In a well-defined manner, it appears that the studied soils are excessively acidic and have low natural fertility, with low values of base sum (SB), in the range of 0.4 to 1.51 $cmol_c/dm^3$. The values of effective cation exchange capacity (t) were also low, with a variation from 0.40 to 3.20 $cmol_c/dm^3$, which after adding the ions Al^{3+} and H^+ to obtain a CEC (Cation Exchange Capacity) at pH 7, resulted respectively, in the values 0.74 and 10.06 $cmol_c/dm^3$. It appears that due to the addition of Al^{3+} and H^+, even though the values are still low, there was an increase of 45.94% and 68.19%, respectively. This fact corroborates the importance of such ions in the CEC and, associated with the predominance of almost 100% of the sandy texture in the superficial horizons of the studied soils, denotes that the CEC is almost entirely a function of organic matter.

In general, the cation exchange capacity (CEC) was greater in the superficial horizons (Table 2). For the Bt horizons from the Argissolos (Acrisols), their values were low, always below 5 $cmol_c/dm^3$, except for the Bt1 horizon of profile 5, reflecting the kaolinitic mineralogy of these materials. Similar values were found by Silva et al. (2016) and Nasser et al. (2021) for Brazilian Latossolos (Ferralsols) and Argissolos (Acrisols).

Soil mineralogy

The diffractograms (Figure 2) of the silt and clay fractions produced separately in certain horizons of the six soil profiles studied, were quite uniform throughout each profile. An exception is the diffractogram in Figure 2A, of the Argissolo Amarelo (Humic Clayic Xanthic Acrisol), which presented very varied peaks in width, larger than the other diffractograms, thus characterizing a sample with microparticles of smaller sizes or with a worse degree of crystallinity.

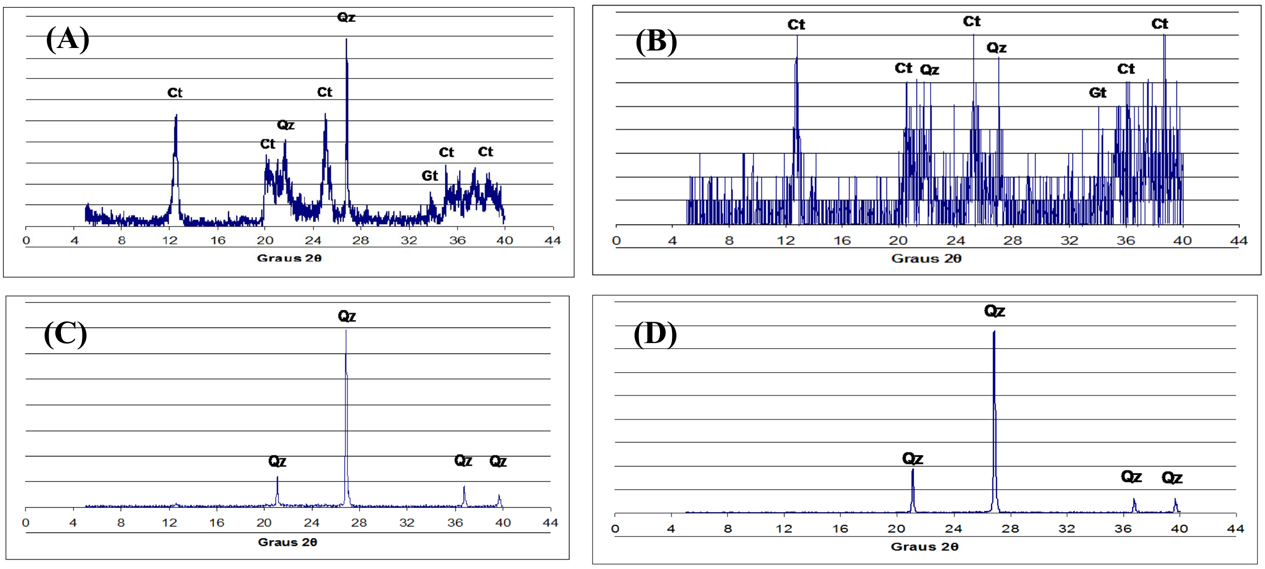


FIGURE 2. X-ray diffractograms - (A) silt and clay fractions of the Bt2 horizon of the Argissolo Amarelo (Humic Clayic Xanthic Acrisol); (B) silt and clay fractions of the Bt2 horizon of the Argissolo Vermelho Amarelo (Clayic Rhodic Acrisol); (C) silt and clay fractions of the A horizon of the Neossolo Quartzarênico (Hydrophobic Ochric Dystric Arenosol); (D) silt and clay fractions of the C2 horizon of the Neossolo Quartzarênico (Hydrophobic Ochric Dystric Arenosol).

On the other hand, the sample of the Argissolo Vermelho Amarelo (Clayic Rhodic Acrisol) showed multivariate peaks, of very narrow widths, characterizing a sample with large and well crystallized particles (Figure 2B).

The silt and clay fractions of the studied Argissolos (Acrisols) and Latossolo (Ferralsol) have quartz and kaolinite, respectively, as their main component. In the profile of Neossolo Quartzarênico (Hydrophobic Ochric Dystric Arenosol), only quartz was identified as a component of the silt and clay fractions, represented in the diffractograms of figures 2C and 2D, which corroborates its classification.

The only iron oxide identified was goethite, in the Argissolo Amarelo (Humic Clayic Xanthic Acrisol) in figure 2A and in the Argissolo Vermelho Amarelo (Clayic Rhodic Acrisol) shown in figure 2B, which is consistent with the coloring of the Argissolo (Acrisol) and Latossolo (Ferralsol). However, the kaolinitic mineralogy of the clay fraction is consistent with the environment of its formation, that is, hot and humid. Similar answers were found by Giarola et al. (2009), Marcolin & Calegari (2020) and Silva et al. (2021).

Soil-landscape relations

According to the classification of the soils and based on the auger drillings and modeling of the terrain, 11 Mapping Units were defined, described below and which appear in the legend of the Prata watershed map (Figure 3).

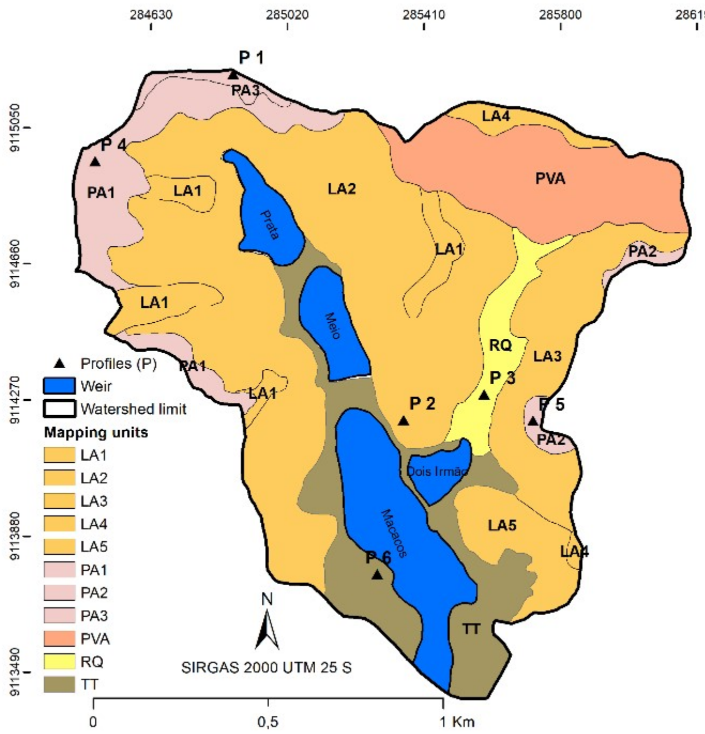


FIGURE 3. Soil map with the mapping units of the Prata watershed.

LA1 – LATOSSOLO AMARELO Distrófico típico (Ochric Loamic Xanthic Ferralsol) A moderado textura média fase floresta subperenifólia relevo plano e suave ondulado.

LA2 – LATOSSOLO AMARELO Distrófico típico (Ochric Loamic Xanthic Ferralsol) textura média relevo suave ondulado a forte ondulado + ARGISSOLO AMARELO Distrófico latossólico (Profondic Ochric Xanthic Acrisol) textura média/argilosa fase relevo ondulado e forte ondulado, both A moderado frase floresta subperenifólia (70% + 30%).

LA3 - Associação de: LATOSSOLO AMARELO Distrófico textura média (Ochric Loamic Xanthic Ferralsol) + ARGISSOLO AMARELO Distrófico latossólico textura média/argilosa (Profondic Clavic Ochric Xanthic Acrisol), both A moderado fase floresta subperenifólia relevo ondulado e forte ondulado (70% + 30%). Inclusão: ARGISSOLO AMARELO Distrófico típico (Ochric Xanthic Acrisol) A moderado fase floresta subperenifólia relevo ondulado e forte ondulado.

LA4 – Associação de: LATOSSOLO AMARELO Distrófico típico textura argilosa (Ochric Clayic Xanthic Ferralsol) fase relevo suave ondulado e plano + ARGISSOLO AMARELO Distrófico latossólico textura média/argilosa (Profondic Clavic Ochric Xanthic Acrisol) fase relevo ondulado e forte ondulado, both A moderado fase floresta subperenifólia (60% + 40%). Inclusão: ARGISSOLO VERMELHO-AMARELO Distrófico típico textura média/argilosa (Ochric Clayic Rhodic Acrisol) A moderado fase floresta subperenifólia relevo suave ondulado.

LA5 – Associação de: LATOSSOLO AMARELO Distrófico típico textura argilosa (Ochric Clayic Xanthic Ferralsol) relevo plano e suave ondulado + ARGISSOLO AMARELO Distrófico típico textura média/argilosa (Ochric Clayic Xanthic Acrisol) fase relevo ondulado e forte ondulado + ARGISSOLO VERMELHO-AMARELO Distrófico típico textura média/argilosa (Ochric Clayic Rhodic Acrisol) fase relevo plano e suave ondulado, all A moderado fase floresta subperenifólia (45% + 35% + 20%). Inclusão: ARGISSOLO AMARELO Distrófico latossólico textura média/argilosa (Profondic Clavic Ochric Xanthic Acrisol) fase relevo ondulado e forte ondulado, ambos A moderado fase floresta subperenifólia.

PA1 – Associação de: ARGISSOLO AMARELO Distrocoeso típico (Ochric Clayic Densic Xanthic Acrisol) e ARGISSOLO AMARELO Distrófico latossólico (Profondic Clavic Ochric Xanthic Acrisol) fase relevo ondulado e forte ondulado + ARGISSOLO VERMELHO-AMARELO Distrófico típico (Ochric Clayic Rhodic Acrisol) fase relevo plano e suave ondulado, todos A moderado textura média/argilosa fase floresta subperenifólia (80% + 20%).

PA2 – Associação de: ARGISSOLO AMARELO Distrófico latossólico (Profondic Ochric Clayic Xanthic Acrisol) e ARGISSOLO AMARELO Distrófico típico (Ochric Clayic Xanthic Acrisol) + ARGISSOLO VERMELHO-AMARELO Distrófico (Ochric Clayic Rhodic,Acrisol), all A moderado textura média/argilosa fase floresta subperenifólia relevo plano e suave ondulado (70% + 30%).

PA3 – Associação de: ARGISSOLO AMARELO Distrófico típico (Ochric Clayic Xanthic Acrisol) + ARGISSOLO VERMELHO-AMARELO Distrófico típico (Ochric Clayic Rhodic Acrisol), both A moderado textura média/argilosa fase floresta subperenifólia relevo plano e suave ondulado (60% + 40%). Inclusão: ARGISSOLO AMARELO Distrófico latossólico (Profondic Ochric Clayic Xanthic Acrisol) A moderado textura média/argilosa, fase floresta subperenifólia relevo suave ondulado.

PVA – Associação de: ARGISSOLO VERMELHO-AMARELO Distrófico típico (Ochric Clayic Rhodic Acrisol) + ARGISSOLO AMARELO Distrófico típico (Ochric Clayic Xanthic Acrisol), both A moderado textura média/argilosa fase floresta subperenifólia relevo ondulado e forte ondulado (55% + 45%). Inclusão: LATOSSOLO AMARELO Distrófico típico (Ochric Loamic Xanthic Ferralsol) A moderado textura média fase floresta subperenifólia relevo ondulado e forte ondulado.

RQ – Associação de: NEOSSOLO QUARTZARÊNICO Órtico típico (Ochric Distryc Arenosol) + LATOSSOLO AMARELO Distrófico típico (Ochric Loamic Xanthic Ferralsol), textura média, both A moderado, fase floresta subperenifólia, relevo suave ondulado e plano (70% + 30%).

TT – Tipo de terreno (constituído de construções) + GLEISSOLO MELÂNICO Tb Distrófico organossólico textura arenosa (Arenic Humic Dytric Molic Gleysol) fase campos de várzea relevo plano (85% + 15%).

Among the soils that occur in the basin (Figure 3), in general the Latossolos Amarelos (Xanthic Acrisols) are located at altitudes between 10 and 50 meters, mainly in the lower third of the slopes; the Argissolos (Acrisols) are distributed in the middle and upper thirds of the slopes and the Neossolos Quartzarêncios (Arenosols) in the lowest and widest portion of the main thalwegs of the local drainage. The occurrence of Gleissolos (Gleysols) is restricted to localized inclusions, as expected, on the banks of water bodies.

Among the mapping units are bodies of water with 12.16% and types of terrain with 11.08% (Table 3), which represent a considerable portion of the area, that is, 23.24% of the total. The percentage of water bodies is distributed in 4 (four) dams, with Dois Irmãos participating with 1.04%, Prata with 1.98%, Meio with 2.07% and Macacos with 7.07% of the total area. With regard to the Type of Land unit, its percentage basically consists of the existing infrastructure at the Dois Irmãos zoo within the State Park and areas surrounding the weirs, particularly the Macacos and Meio (Figure 3).

TABLE 3. Mapping units and their respective areas in the Prata watershed.

Mapping units	Areas			
	Occurrence	*m^2	**ha	%
Water bodies	4	225,686.97	22.56	12.16
LA1	4	73,955.74	7.40	3.99
LA2	1	670,500.95	67.05	36.13
LA3	1	153,886.24	15.39	8.29
LA4	2	26,044.80	2.60	1.40
LA5	1	69,464.16	6.95	3.74
PA1	2	136,636.70	13.66	7.36
PA2	2	21,054.90	2.11	1.13
PA3	1	15,698.37	1.57	0.85
PVA	1	195,018.84	19.50	10.51
RQ	1	58,670.68	5.87	3.16
TT	1	209,217.46	20.92	11.28
Total	21	1,855,835.86	185.58	100

m^2 – square meter; **ha – hectare (1 ha = 10,000 square meters)

According to the areas of the mapping units (Table 3) and respective percentages of the types of soil existing in the legend, the areas of each type of soil were obtained (Table 4). In decreasing order of the percentage of occurrence of the soils, there are the Latossolos Amarelos (Xanthic Ferralsols) with 38.56%, the Argissolos Amarelos (Xanthic Acrisols) with 27.12%, the Argissolos Vermelho-Amarelos (Rhodic Acrisols) with 8.68%, the Neossolos Quartzarênicos (Arenosols) with 2.21% and for order Gleissolos (Gleysols) with only 1.69%.

TABLE 4. Soil classes and respective areas, calculated from their percentages in the associations that occur in the Prata watershed.

Soil Types	Areas	
	*ha	% do total da área
Latossolo Amarelo (Xanthic Ferralsols)	71.56	38.56
Argissolo Amarelo (Xanthic Acrisols)	50.33	27.12
Argissolo Vermelho-Amarelo (Rhodic Acrisols)	16.11	8.68
Neossolo Quartzarênico (Arenosols)	4.11	2.21
Gleissolo Melânico (Gleysols)	3.14	1.69

*ha – hectare (1 ha = 10,000 square meters)

The slope map (Figure 4) and table with areas of slope classes (table 5), show that the watershed totals 183.04 hectares, and that there is a predominance of strong undulating relief, which represents approximately 47% of the total area of the watershed. Similar values were observed in morphometric studies performed by Caldas et al. (2021).

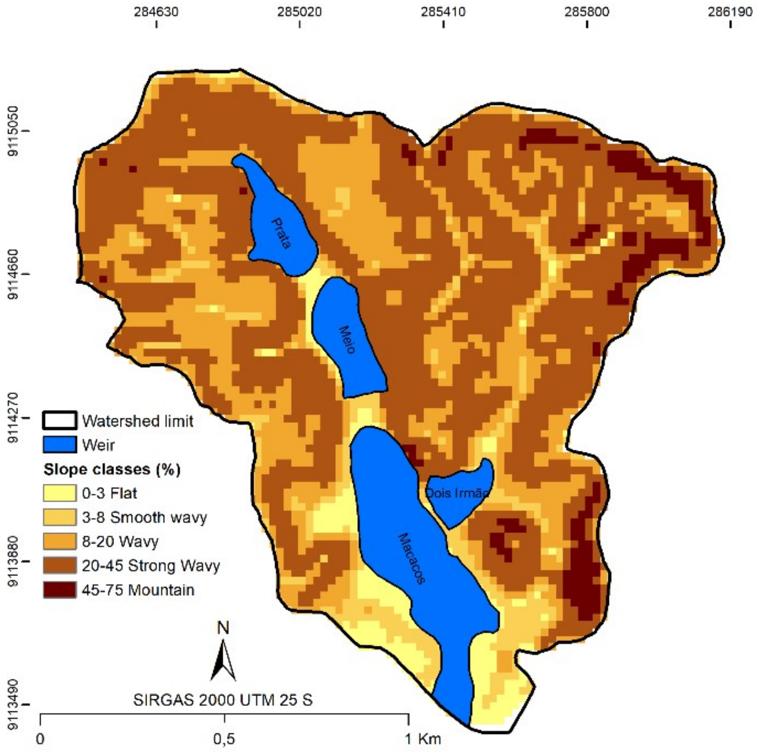


FIGURE 4. Slope map of the Prata watershed.

TABLE 5. Types of relief and slope classes with their respective areas in the Prata watershed.

Types of relief	Slope classes	Areas		
		*m^2	**ha	%
Flat	0 – 3	257,200	25.72	14.05
Smooth wavy	3 – 8	162,000	16.20	8.85
Wavy	8 – 20	474,800	47.48	25.94
Strong Wavy	20 – 45	856,800	85.68	46.81
Mountain	45 – 75	79,600	7.96	4.35
Total	–	1,830,400	183.04	100

m^2 – square meter; **ha – hectare (1 ha = 10,000 square meters)

This value of 183.04 hectares differs from the 185.58 hectares calculated in Table 3. This difference was caused by the difference between the areas calculated on the same map, but with different data types, that is, raster and vector. When the type of format of the generated map of the basin was transformed, there was an increase in the areas from the raster format (Figure 4 and Table 5) to the vector (Table 3 and Figure 3).

Corroborating this fact, it can be seen from the tables mentioned above, that there was an increase in the areas of the mapping units from 98.44 ha to 99.39 ha in Latossolos (Ferralsols), from 35.68 ha to 36.84 ha in Argissolos (Acrisols), from 5.84 ha to 5.87 ha in Neossolos (Arenosols) and from 20.20 ha to 20.56 ha in Land Types. The total difference is 2.5 hectares, which added to 183.04 ha (Table 5) will have a total of approximately 185.58 hectares.

The lowest percentage corresponds to the flat relief, because despite appearing with values of 25.72 ha (14.05% of the total) in Table 5, which includes the 22.56 hectares of the surfaces of the water bodies (Table 3), if these are subtracted there will be a value of 3.15 ha, which will correspond to approximately 1.72%. This panorama reveals that in the Prata watershed there is a predominance of steep slopes, with the flat areas being restricted to the lower parts of the thalwegs. This fact shows that despite being an area within the Barreiras Group's sediment domain, there was a strong dissection of the relief, not characterizing typical shapes of the so-called Tabuleiros Costeiros (Coastal Tablelands) as mentioned in Santos & Castro (2016) e Fernandes et al. (2017).

Despite the influence of recent sediments in the lower parts of the thalwegs, the watershed is in the context of the Barreiras Group sediments, with altitudes ranging from 10 to 104 meters.

The map with the mapping units in Figure 3, superimposed on the slope map in Figure 4, giving rise to Figure 5 and, consequently, Table 6, allows the distributions of the mapping units to be analyzed according to the relief.

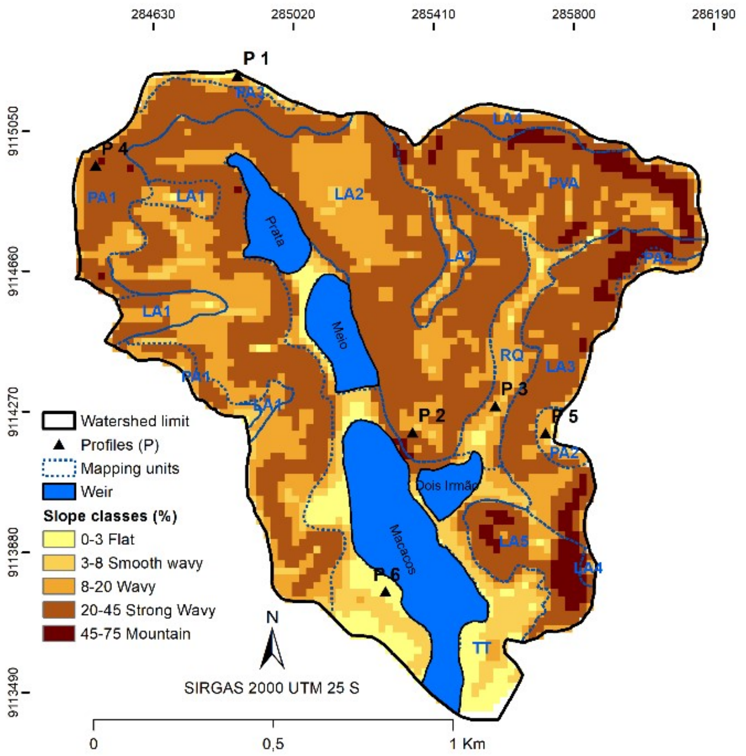


FIGURE 5. Overlapping of soil and slope maps of the Prata watershed.

TABLE 6. Result of the intersection between the slope classes and the mapping units with their respective areas in the Prata watershed.

Mapping Units	Slope classes (%)									
	0 – 3		3 – 8		8 – 20		20 – 45		45 – 75	
	ha*	%**	ha*	%**	ha*	%**	ha*	%**	ha*	%**
LA	0.32	0.33	3.48	3.51	30.68	30.89	59.68	60.06	4.56	5.21
PA	0.16	2.65	1.00	7.50	4.64	28.49	9.68	57.55	0.36	3.81
PVA	0.04	0.65	0.36	2.33	4.16	21.81	11.64	60.17	2.84	15.04
RQ	0.24	8.13	1.40	12.26	2.72	50.36	1.48	29.25	0.00	0.00
TT	7.64	36.52	7.76	37.09	3.52	16.83	1.80	8.60	0.20	0.96

*ha – hectare (1 ha = 10,000 square meters); ** Percentage based on the total area of each mapping unit

It can be seen in Table 6 that the Latossolos (Ferralsols) and Argissolos (Acrisols) occur mainly in the strong undulating relief, while the areas with Type of Land are concentrated in the lower parts, flat and close to the water, due to the facility for human occupation.

Still in Table 6, the values found for Type of Terrain occurring in Strong Wavy and Mountainous reliefs, are inconsistent, which can be explained by the fact that the pixels of the raster image, due to their resolution, are extrapolated to areas that do not contain the attribute represented by them. Other computer programs could have been used, testing algorithms, but this was not the objective of this work.

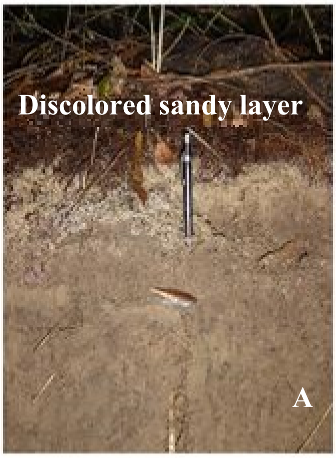
Due to the time of existence of the dams, the flooding condition favored the appearance of gley horizons, typical of the Gleissolos (Gleysols). However, in many places these soils could not be characterized, decreasing their percentage of occurrence, due to the areas that should be favorable to them, having been significantly altered by human occupation. They are areas modified from their natural condition due to constructions and earth movement, as a result of cutting and filling operations. Through the auger drilling carried out in the field during the soil survey, it was possible to verify the mixture of soil materials.

The construction of the dams and, consequently, the stagnation of the water in their hydraulic basins, provided the development of algae and aquatic plants, which at the end of their cycles, have contributed to the silting up and even formation of some islands, as is the case from Macacos island located in the weir of the same name. In these situations, organic soils may occur, not mentioned in this work. A strong indication for this formation is the confirmation of the A Histic horizon that occurs in the Gleissolo (Gleysol).

In almost the entire area, the soils showed a moderate horizon A, with thickness ranging from 15 to 60 cm. Exception occurred in the Gleissolo (Gleysol) with a superficial horizon classified as Histic which presented a thickness varying from 20 to 40 cm and whose organic matter content was sufficient to characterize it as Histic.

It was observed in almost all the areas located in irregular relief, slopes and tops, the presence of a whitish sandy horizon, with 5 to 10 cm of thickness (Figure 6A), positioned between the superficial organic layer and the horizon A of the soils.

With regard to depth, the soils varied from deep to very deep, and this characteristic may have been underestimated, in some cases, by the presence of stones (Figure 6B) constituting an impediment to the auger.



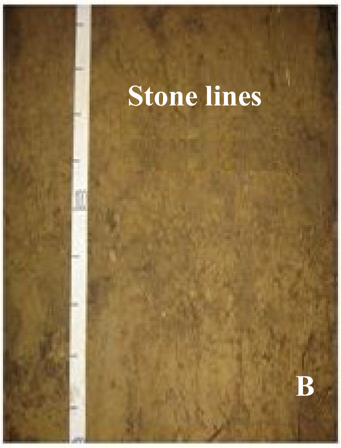


FIGURE 6. Details of the sandy horizon (A) and the stone line (B) in the profile of Argissolo Amarelo (Xanthic Acrisol).

This sandy horizon can be constituted in a type in which there was maximum eluviation or in a layer originated by geological processes. If the origin is geological, such a sandy layer may have had its shape pronounced from a supposed differential and lateral erosion, provided by the topography moved.

The formation of a whitish or albic subsurface horizon with a sandy texture has been reported in the literature under the name podzolization (Silva et al., 2013; Nunes et al., 2019), in which the coldest climate and a specific type of vegetation, particularly conifers, would favor such an event. In this case the process is governed by the formation of organic acids on the surface that would assist the movement of iron, aluminum and organic compounds downwards, giving rise to the formation of a spodic B horizon. According to Santos et al. (2018), the albic horizon can, in rare cases, be the superficial horizon due to truncation of the soil, but it usually occurs in subsurface, having at least 1.0 cm of thickness and almost always precedes a spodic B horizon, a textural B horizon, a plintic horizon, a gley horizon, a fragipan or waterproof layer.

Analyzing works such as Biondi et al., (2011) and Santos et al. (2018) regarding soils that occur in the Zona da Mata of the state of Pernambuco, no mention was found in the literature of the occurrence of this whitish and superficial sandy horizon, nor how it could interfere in the classification of soils in which it occurs. In addition, there is the fact that there is no appropriate designation for this type of horizon, as verified specifically in the document "Description and notation of horizons and soil layers" by Embrapa (1988a) nor in the Brazilian Soil Classification System - SiBCS published by Santos et al. (2018).

It was also observed in the soil profile, as already commented above, mainly through road cuts, the presence of deserted stone lines, with widespread occurrence throughout the area, appearing at varying depths (Figure 6B). In some places the stones are on the surface, denoting the existence of possible past erosive processes or that the stones were promptly deposited in this position. According to Biondi et al., (2011), lines of stones can appear in the soil profile between horizons A and B, or B and C, with thicknesses ranging from centimeter to meters and with extensions from tens to hundreds of meters. They can be interpreted as detritic desert pavements formed in drier conditions, implying a polygenetic character of the soil. If the presence of a textural B horizon occurs, it suggests the presence of evolved paleosols over reworked material.

Vanzela et al. (2020) state that color and pedoform (soil + topography) constitute important field tools in the identification of certain soil attributes, which in many cases can be more relevant than laboratory analyzes. According to this statement, an attempt was made to make a relationship between the red and yellow colors of the soils, dominated respectively by the iron oxides hematite and goethite, with the slopes of the sunny and norwegian types in which they occur, however, no correspondence was found in this current work.

There was little evidence of the existence of soils with cohesive horizons, as found in soils of the Coastal Tablelands (Tabuleiros Costeiros) according to works by Biondi et al., (2011). According to field observations and clod tests, the necessary cohesion was observed only in Profile 4 of Argissolo Amarelo (Xanthic Acrisol). In the work of the aforementioned author, it is commented that in the Coastal Tablelands locations, where the cohesive horizon occurs, the relief varies from flat to gently undulating. In the Prata basin, wavy to strong wavy reliefs predominate, a condition possibly unfavorable to the formation of the cohesive horizon, due to the lateral loss of finer materials than those forming the “soil skeleton”, not favoring the process of illuviation.

CONCLUSIONS

The soils are quite acidic and have a very low natural fertility, with the Latossolos (Ferralsols) predominating in the landscape, with the Amarelos (Xanthics) ones being the highest percentage observed, predominantly at altitudes between 20 and 50 meters, particularly in the lower third of the slopes.

The silt and clay fractions of the studied Argissolos (Acrisols) and Latossolos (Ferralsols) presented quartz and kaolinite as the main component. In the profile of Neossolo Quartzarênico (Arenosol) only quartz was identified as a component of the silt and clay fractions.

The kaolinitic mineralogy of the clay fraction is consistent with the environment of its formation, that is, hot and humid.

There is no relationship between the colors of soils and their exposure to the sun on the slopes where they occur.

The occurrence of a sandy and whitish horizon between the litter and the A horizon, is not foreseen in the norms and criteria adopted in the Brazilian Soil Classification System – SiBCS.

Despite the anthropic pressure exerted in the watershed, with respect to fauna and flora, mainly by the population established in its northwest limit, there is little loss of soil materials in this ecosystem, as evidenced by the crystallinity of the water, even in rainy season, particularly in the Prata and Meio weirs.

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