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Original article

The geological environments in the accumulation of heavy metals in soils of Pinar del Río

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ABSTRACT

The research was carried out in the South Plain of the Pinar Río province with the objective of integrally evaluating the geological environments of soil formation and their influence on the processes erosion-sedimentation-contamination by heavy metals (HMs), in localities destined to tobacco crop. To this end, two units with different degrees of intervention were selected: the erosive surface (Consolation of the South unit) and the erosive - cumulative surface (units of Pinar Río, San Juan and Martinez and San Luis). The pedological prospecting work identified four main types of soils. They were at depths of 0-20 cm described and sampled, to characterize the main properties that influence the accumulation of HMs in soils. The analysis carried out indicated that natural conditions do not exert a marked influence on the accumulation and availability of HMs, where the reference values of Cd, Pb, Cu, Zn, Fe, Mn, Ni, Cr and Co are, lower than the standards of quality established for Cuban soils.

Key words: tobacco, pollution, soil formation, soil degradation

INTRODUCTION

Heavy metals (HMs) are naturally present in soils. The increase in its concentrations can occur due to natural processes or due to anthropogenic activities [1,2]. The total natural concentration of HMs in soils depends, mainly, on the source material, the formation processes and the proportion of the components of the solid phase, this concentration is less evident in soils that originate from sediments [3,4].

The natural concentration of HMs in soils has two main origins: the weathering of the parent material in a tropical environment modulated by different manifestations of erosion (current and geological) and the degradation processes generated by human activity, especially agriculture [5]. Increases in concentrations due to natural causes are determined by the chemical-mineralogical composition of the underlying stone material, as well as the dynamics of the pedogenesis-morphogenesis processes [6,7] where fixation by clay minerals and complexation by organic matter play a role a fundamental role [8,9] (Table 1).

Table 1. Ranges of heavy metal concentrations in the most abundant rock types

Heavy metals	Igneous rocks			Sedimentary rocks		
	Ultra basic	**Basic**	**Granites**	**Limestone**	**Sandstone**	**Schist**
Cd	0.12	0.13-0.2	0.09-0.20	0.028-0.10	0.05	0.20
Co	110-150	35-50	1	0,1-40	0,30	19-20
Cr	2000-2980	200	4	10-11	35	90-100
Cu	10-42	90-100	10-13	5.5-15	30	39-50
Hg	0.004	0.01-0.08	0.08	0.05-0.16	0.03-0.29	0.18-0.5
Mn	1040-1300	1500-2200	400-500	620-1100	4 – 60	850
Ni	2000	150	0.50	7-12	2-9	68-70
Pb	0.10-140	3-5	20-24	5.7-7	8-10	20-23
Sn	0.50	1-1.5	3-3.50	0.5-4	0.50	4-6
Zn	50-58	100	40-52	20-25	16-30	100-120

Source: [9]

In this context, the genetic regularities and links of the sedimentation and contamination processes remain to be with the manifestations of soil erosion specified, whether of a geological nature in environments that are little disturbed or induced by agricultural activity [10]. Taking into account the previous antecedents, this work has the objective of comprehensively evaluating the geological environments and their influence on the processes of erosion-sedimentation-contamination by HMs in the soils of the Southern Plain of Pinar del Río.

MATERIALS AND METHODS

The research was carried out in the Southern Plain of the Pinar del Río province (Figure 1). In the region known as "Macizo Tabacalero de Vuelta Abajo", in which two representative units of the historical-natural formative environments were selected at the local level of the soils in little disturbed localities: the erosive surface (Consolación del Sur unit) and the erosive-cumulative surface (units of Pinar del Río, San Juan y Martínez and San Luís).

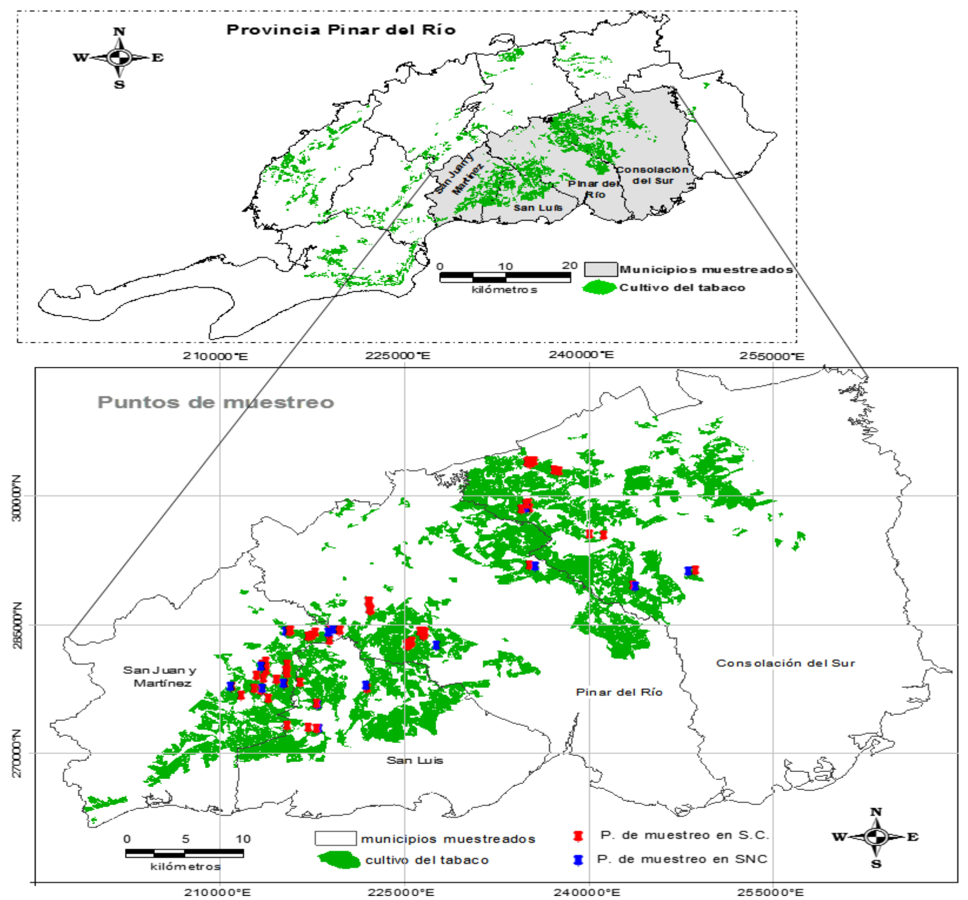


Figure 1. Spatial distribution of the soil sampling points in the Southern Plain of Pinar del Río, Cuba

Twelve main profiles were characterized in them and soil samples were taken in the upper, middle and lower sectors of the micro-relief flexures. This is in order to examine by means of the descriptive-comparative method at the depth of 0-20 cm, the dynamics, manifestation and intensity of morphogenetic processes, in correspondence with geological - geomorphological variations and agricultural use, which influence the accumulation of HMs in soils (Table 2). For the chemical analysis and pseudo-total concentrations of HMs, 60 samples were collected in the same number of sampling points, in five groups of uncultivated soils in areas covered by spontaneous vegetation or forest fragments with a certain level of morphogenetic balance. The final sample of 1 kg of soil was obtained from 20 sub-samples taken in the form of a zig-zag; which were air dried, crushed and sieved to a diameter of 2 mm.

Table 2. Classification of the soils of the investigated sub-region of the Southern Plain of Pinar del Río, Cuba

Nº	Extension superficial (ha)	Percentage of the total area	Genetic Classification Soils of Cuba (11)	Classification of Soils of Cuba (12)	World Soil Reference Base (13)
1	10 026	59.5	Leachate Yellow Quartzite Ferralitic	Leachate Yellowish Ferralitic	Chromic acrysol,
2	2 608.2	5.12	Leachate Reddish – yelow ferralitic	ABA yellowish red	Acrisol Alumic
3	1 609.2	15.5	Quartzite sandy	Arenosols	Arenosols
4	1 237.2	9.54	Alluvial	Fluvisol	Fluvisol
5	863.4	7.34	Bronw with carbonates	Bronw	Eutric Cambisol

Source: Own elaboration

The analyzes were carried out in laboratories of the Institute of Agronomy of the Federal Rural University of Rio de Janeiro, Brazil, between 2016 and 2018, according to criteria and guideline values of soil quality (14). The pH was determined with a potentiometer in relation to soil water 1: 2.5. The organic matter (OM) was by oxidation with potassium dichromate (0.2 mol L^{-1}) in an acid medium determined, the excess being valued with ammoniacal ferrous sulfate. Interchangeable calcium and magnesium were extracted using a 1-mol L^{-1} KCl solution and the analysis was carried out by the complexometric method with EDTA.

Extraction of assimilable phosphorus and exchangeable potassium was carried out using a Mehlich-1 solution (HCL 0.05 mol L^{-1} and H_2SO_4 0.025 mol L^{-1}). The reading was with a photocolorimeter for phosphorus made and a flame photometer for potassium. The evaluations were according to the Rio de Janeiro State Subscriber and Liming Manual carried out (15). To determine pseudo-total concentrations of HMs, 1 g of the sieved soil sample was taken, digested by heating with the MARS Xpress® Digester, USEPA Method 3051A using inverted royal water (16). The resulting extracts were by EAA analyzed in a VARIAN-55B kit where the metallic elements Cd, Pb, Zn, Fe, Mn, Ni, Cu Cr and Co were quantified. For statistical analyzes, the arithmetic mean and standard deviation were used; the means were compared using the ANOVA and Tukey tests (p <0.05).

RESULTS AND DISCUSSION

Influence of geological-geomorphological conditions on the accumulation of heavy metals in the soils of the Southern Plain of Pinar del Río

The edaphic cover "archives" traits and properties inherited from past climatic and geological phases, which are not in balance with current edaphogenic processes [17], where the geological structure influences the origin of the MPs present today in the soils according to its zonal - spatial distribution (Table 3).

Table 3. Main rocks and mineralogical composition of the investigated regions

Formation	Lithology/diagnostic	Age	Thicknesses
Guane (gne N_2^2 Q_1^1)	Siliceous sands, sandy clays, gravels (angular and subangled), weakly cemented by clays with an indefinite lenticular layering.	Upper Pliocene - Lower Pleistocene	It can reach up to 50 m.
Guevara (gv Q_1^{1-2})	Plastic clays (montmorillonite and montmorillonite - kaolinitic), siliceous sands, fine gravels, fragments of ferritic shells (hardpan) with an indefinite, parallel stratification.	Lower-Middle Pleistocene.	It does not exceed 50 m.
Alluvial and marshy deposits (alQ_2 and pQ_2)	The alluvial deposits (alQ_2) are associated with the valleys and river terraces of rivers and streams, consisting mainly of quartziferous sands. Clay sands and sandy clays are also with intercalations of gravels of varied composition and dimensions documented. The marsh sediments (pQ_2) are only in the coastal zones distributed; clays and carbonaceous silts with vegetal remains represent them.		

Source: (18)

A significant characteristic of the soils is their transit to the basal material or underlying weathering crust, which is associated with the elution of the clays through the profile in an environment of greater stability (concave flexures of the micro slopes), confirmed dynamics in the morphologist - genetic observations made, corroborating what was stated [19]. In some cases, these weathered sediments, either due to their location in the micro-relief or having a higher proportion of clays, are enriched with HMs, so that the soils can be classified as "contaminated" [10]. However, these concentrations were found naturally or of low anthropic activity, due to the presence of these elements in the constituent minerals of the rocks and elluvio-deluvial deposits characteristic of the geological formation environments, coinciding with studies carried out in similar regions [3].

Pedogonesis–morfogenésis dynamic and its influence in heavy metal accumulation

Through a comprehensive analysis, the current stage of morphogenesis is examined and, in a broader sense, the dynamics of some of the properties of soils that, due to their low content of organic matter and sandy texture [20]. Among other characteristics, they are very erodible ones, together with traditional management practices that have led to the progressive decline of their chemical, physical and biological fertility [21].

In this context, two sub-regions were from the interpretation of the landforms differentiated and in particular the pedogenesis-morphogenesis balance Northeast (erosive-cumulative surface) and South (cumulative surface). It is characterized by a different and complex paleo-geographical evolution both the geological-geomorphological conditions, as well as by the conditions of use that at the same time have influenced the zonal - spatial distribution of the HMs (Figure 2). It presents variations in the edaphic cover, in which the alitic soils with low activity stand out red-yellowish clay (ABARA), Ferralitic Yellowish Leachate (FRAL) and Arenosols, among other types such as Fluvisol and Arenosol according to what was reported [12].

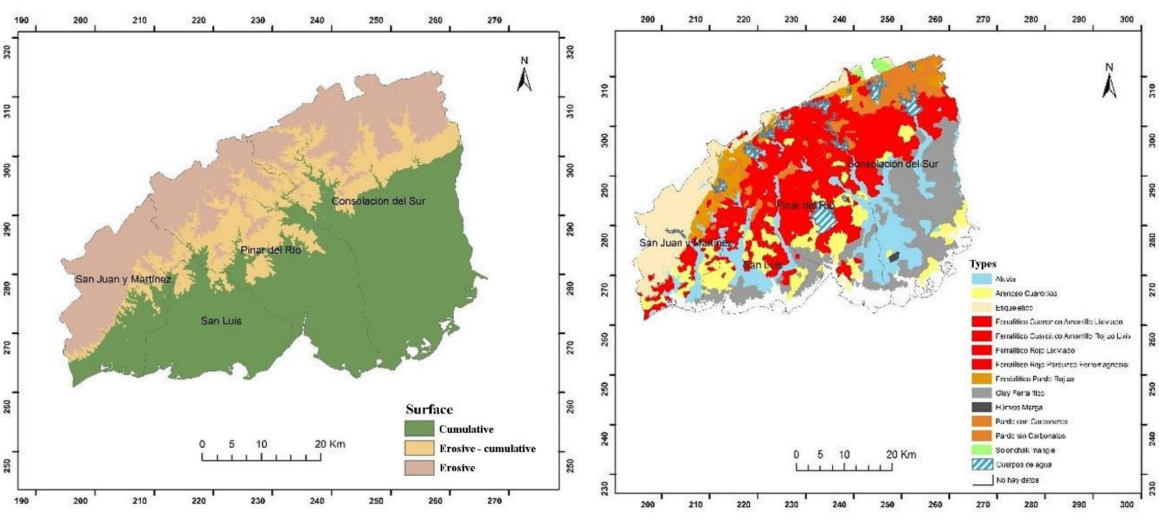
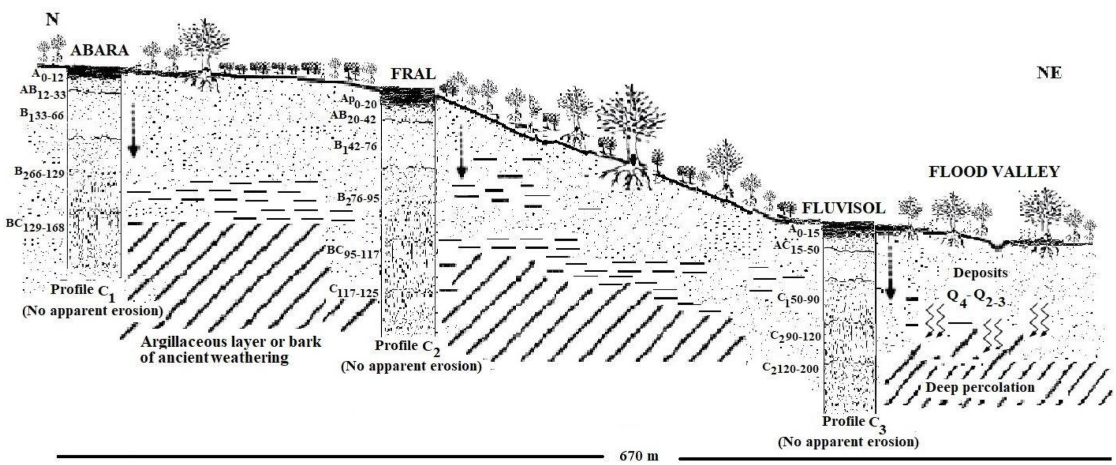


Figure 2. Soil distribution in the main geological-geomorphological surfaces in the Southern Plain of Pinar del Río, Cuba

Erosive - cumulative surface. Upper sector of Consolación del Sur unit

In it, the most accentuated slopes are located, both for the position it occupies in the context of the province and for the dissimilar processes that take place (Figure 3). They are classified as a scattering surface for creeping [22], where the weathering-erosion processes have given rise to redeposited automorphic bark of the kaolinite-alitic-ferric type at a depth between 40-60 cm, associated with clay mantles, whose main morphological features conform to a lightly textured, generally acidic edaphic horizon Low humidification, low cation exchange capacity, desaturated with ferruginous concretions.



Automorphic surface. Transient - unstable

∅=10 % Erosion due to areal runoff and trenches H=50-100 m

Vertical dismemberment = 2.5-25 m/km^2

Horizontal dismemberment = 1 m/km^2

Soil dominance ABARA

Natural vegetation: Marabou, aroma and grasslands

Deliver of porous sediments that descend towards areas of greater geomorphological stability

Semi-hydromorphic accumulation surface

∅=8 % Erosion due to areal runoff and trenches H = 45-25 m

Vertical dismemberment = 2.5-25 m/km^2

Horizontal dismemberment = 1 m/km^2

Fluvisol soil prevalence

Natural vegetation: Marabou, aroma and grasslands

Clay-sandy sediment receptor in depresional zones

Figure 3. Distribution of the main soils in the Consolación del Sur Unit. Pinar del Río, Cuba

The development of the profile has been influenced by natural causes and anthropogenic factors, which have sometimes interrupted the evolutionary-sequential process described, leading to a combination of soils at the genetic level: Alitic with low red-yellowish clay activity (ABARA), Ferralitic Yellowish Leachate (FRAL) and Fluvisol, where the pedological differentiation is highly contrasting. It is revealed by the changes in the chemical-mineralogical composition of the underlying stone material and the degree of evolution, attending to the topographic enclave they occupy.

Therefore, the ABARA and FRAL soil profiles are in a wavy relief distributed (Figure 3). The spatial configuration of the slope shapes are less stable (∅=8-10 %; H=50-100 m). Fluvisol soils are basically confined to the flood valleys of rivers and flat sectors of the territory (∅=2-4 %; H=300-50 m), with contributions of non-native materials and HPs in the upper thickness being common of the profiles that coincide with the results obtained [(23)] in the Southern Plain of Pinar del Río.

In relation to physical properties, soils generally have a light texture, with a percentage of clay between 5-30 % at the level of the genetic horizons A+B0-50 cm. They are the most important for tobacco cultivation (Table 4), where 70–95 % of its mass is of sandy fractions made up, fundamentally kaolinite of good crystallization and in a lesser proportion illite and vermiculite, with traces of chlorite, being a regular increase in said minerals in depth according to the position they occupy in the micro-relief. This illuvial horizon eventually emerges on the surface when erosion is very strong.

Table 4. Physical properties of the main soils in little disturbed environments. Towns of Consolación del Sur municipality

Horizon/ Depth (cm)	Percentage of fractions in mm					Mg m^{-3}		Munsell Color
	A. Gross 2 - 0.2	A. Fine 0.2 - 0.02	Slime G. 0.02 - 0.01	Slime F. 0.01 - 0.002	C < 0.002	Density From soil	Density Solid phase	
				Profile C$_1$ (No apparent erosion)				
				- ALYTICAL LOW ACTIVITY CLAY RED-YELLOW –				
A$_1$ $_{(0 – 12)}$	0.30	76.10	4.82	5.18	13.60	1.49	2.62	7.5YR 5/7
AB$_{(12 – 33)}$	2.70	65.80	3.60	6.60	21.10	1.48	2.63	5YR 4/6
B$_1$ $_{(33 – 45)}$	3.40	53.88	4.12	5.80	32.80	1.49	2.64	7.5 YR 6/8
$_{(45 – 66)}$	1.60	49.40	5.30	5.90	37.90	1.50	2.66	2.5YR 5/7
B$_2$ $_{(66 – 96)}$	0.10	46.42	5.72	7.53	38.87	1.52	2.67	2.5 YR 6/8
$_{(96 – 129)}$	0.30	47.68	5.72	7.10	39.20	1.51	2.66	2.5 YR 6/8
BC$_{(129 – 168)}$	0.10	40.50	7.20	7.22	47.00	1.52	2.67	2.5 YR 5/8
				Profile C$_2$ (No apparent erosion)				
				-- FERRALYTIC YELLOW LEACHATE --				
Ap$_{(0- 20)}$	31.63	33.47	8.78	10.54	13.56	1.42	2.62	10 YR 6/4
AB$_{(20 -42)}$	23.23	41.77	8.45	11.13	13.42	1.43	2.63	10 YR 7/5
B$_1$ $_{(42 -76)}$	20.59	39.29	10.26	11.94	17.90	1.50	2.65	10 YR 7/8
B$_2$ $_{(76 -95)}$	34.61	26.04	8.71	12.83	17.81	1.45	2.67	10 YR 6/8
BC$_{(95 – 117)}$	44.59	23.63	7.77	12.69	19.30	1.48	2.67	10 YR 7/6
C$_{(117 – 125)}$	48.36	25.45	6.54	12.46	21.19	1.50	2.70	7.8 YR 7/6
				Profile C$_5$ (No apparent erosion)				
				- FLUVISOL -				
A$_{(0 -15)}$	11.02	81.78	0.80	3.50	3.90	1.40	2.67	10 YR6/8
AC$_{(15 – 50)}$	9.72	74.28	11.10	2.40	2.50	1.42	2.67	10 YR7/9
C$_1$ $_{(50 -90)}$	13.02	68.28	5.30	0.90	12.50	1.46	2.66	10 YR6/9
C$_2$ $_{(90 – 120)}$	10.12	67.38	5.12	2.38	15.00	1.42	2.65	10 YR6/10
C$_3$ $_{(120 – 200)}$	11.03	60.41	5.82	2.73	20.01	1.42	2.67	10 YR6/10

The analysis of the physical-chemical and chemical properties (Table 5), denotes an average value of organic matter of 3.44 %, qualifying on average according to [15], where the ABARA soil presents the lowest value as a manifestation of the development and maintenance of the aspects, degree of erodability and use indicated. The cation exchange capacity shows an average value of 15.69 cmol$_c$ kg^{-1} (low) in correspondence with the percentage of clay and the pH in the first horizons, together with the average contents of the exchangeable bases (mainly Ca and Mg) and sandy texture [23].

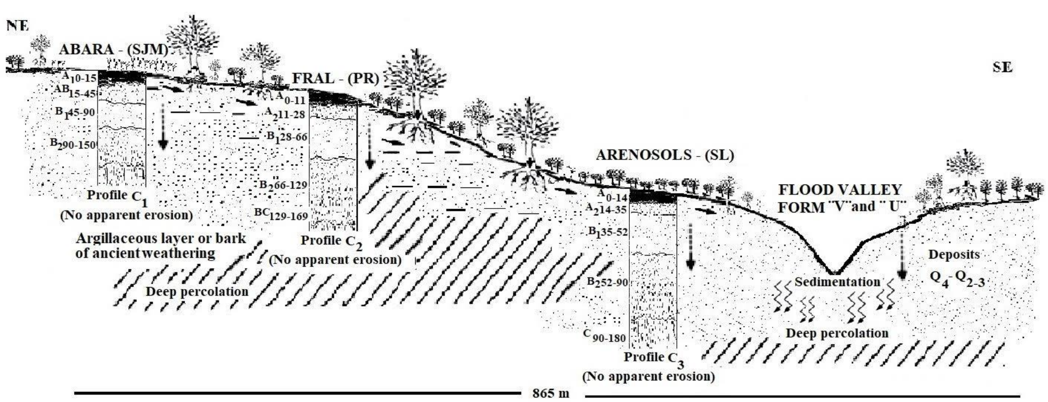
Table 5. Physico-chemical and chemical properties of the soils in little disturbed environments in the Southern Plain of Pinar del Río, Cuba

Parameters	pH	Ca	Mg	K	CIC[1]	M.O[2]	P_2O_5	Clay
	(H_2O)	------------- $cmol_c kg^{-1}$ -------------				%	Mg kg^{-1}	%
FRAL (n = 24). Consolación del Sur–San Juan y Martínez units								
Average	6.1	6.83	1.85	0.74	15.68	3.07	95.24	5.9
ABARA (n = 12). Consolación del Sur–San Juan y Martínez units								
Average	7.36	8.2	1.67	0.6	13.38	2.85	45.43	5.3
ARENOSOLES (n = 6). Unidad San Luís								
Average	7.33	10.8	2.8	0.73	17.09	3.22	57.99	4.6
FLUVISOL (n = 18). Consolación del Sur Unit								
Average	6.99	10.93	1.52	0.76	15.1	4.63	37.48	9.1
Average (n=60)	6.95	9.19	1.96	0.71	15.31	3.44	59.04	6.23
St Dev..	0.59	2.01	0.58	0.07	1.54	0.81	25.57	1.99

[1]Exchange cation exchange capacity, 2 organic matter, Std. Std - standard deviation

Cumulative area. Middle-lower sector Pinar del Río, San Juan y Martínez and San Luís units

This surface shows differences in soil properties mainly determined by the spatial configuration of the slopes at the meso and micro relief levels (Figure 4), which from a geological point of view are associated with the Guane + Guevara Formation [(24)].



Automorphic surface. Transient - unstable
Provides sediment. May present covered karst
∅= 10 % Areal runoff erosion creep H=30-50 m
Vertical dismemberment = 2.5-5 m/km^2
Horizontal dismemberment = 1 m/km^2
Soil dominance ABARA
Natural vegetation: Marabou, aroma and grasslands, which acts as a geological barrier
Semi-hydromorphic accumulation surface
Accumulation of sandy-clay sediments
∅=2-6 % Erosion due to areal runoff and sedimentation in flood valleys H=20-30 m
Vertical dismemberment = <1 m/km^2
Horizontal dismemberment: 0.5 m/km^2
Predominance of soils Arenasols
Natural vegetation: Marabou, aroma and grasslands
Clay-sandy sediments (undifferentiated)

Figure 4. Distribution of the main soils. Pinar del Río, San Juan y Martínez and San Luís Units, Cuba

It covers the units (SJM and PR), with a hypsometry between H=30-50 m; where the sediments are characterized by their morphological and textural similarities, but with different ages given the joint action of the processes of erosion - transport - sedimentation, with interrelated functions that represent a geomorphological barrier. It has led to a differentiation of synthesis and decomposition of organic matter, promoting the formation of the ABARA, FRAL and Arenosols soils with a marked contrast and in close relationship with the lithogeomorphological conditions, a dynamic that corresponds to those studied for some authors [(25)].

On the other hand, the ABARA and FRAL soils of the lower-middle sector occupy the largest area (Table 6), where the forming materials are a consequence of the redeposition of weathered eluvia containing certain amounts of mica, from the quartzite shale of the highest regions. While the Arenosols are at heights between 20-40 m distributed and they are characterized by a pedological differentiation of the cover layer at the meso relief level in the river flood valleys (interfluvial spaces 250-450 m) that they intercept the territory.

Table 6. Physical properties of the main soils in little disturbed environments. Municipalities of Pinar del Río, San Juan y Martínez and San Luís

Horizon/ depth (cm)	Percentage of fractions in mm				$Mg\ m^{-3}$ Density		Munsell Color
	A. Gross 2 - 0.2	A. Fine 0.2 - 0.02	Slime 0.02 - 0.002	Clay < 0.002	From soil	Solid Phase	
Profile C$_1$ (No apparent erosion) - LOW ACTIVITY ALITHITIC CLAY RED-YELLOW-(SJM)							
A$_1$ $_{(0-15)}$	10.08	62.29	13.33	13.31			7.5YR 5/7
AB$_{(15-45)}$	31.57	37.26	7.59	23.62			5YR 4/6
B$_1$ $_{(45-90)}$	5.90	42.12	7.83	44.15			7.5 YR 6/8
B$_2$ $_{(90-150)}$	4.05	35.07	8.72	52.16			2.5 YR 6/8
Profile C$_2$ (No apparent erosion) - LEACHATE YELLOW FERRALITICAL–(PR)							
A$_{(0-11)}$	1.30	75.10	9.00	12.60		2.60	10 YR 6/4
A$_2$ $_{(11-28)}$	2.60	65.90	10.40	21.10	1.50		9.5YR 7/5
B$_1$ $_{(28-44)}$	3.45	53.44	10.01	33.00	1.66	2.66	9 YR 7/8
$_{(44-66)}$	1.50	49.39	11.10	38.00			10 YR 6/8
B$_2$ $_{(66-96)}$	0.11	48.39	12.30	38.60	1.67	2.67	10 YR 7/6
$_{(96-129)}$	0.29	48.8	12.11	39.17			
BC $_{129-169}$	------	39.5	15.50	45.00	-----	------	7.8 YR 7/6
Profile C$_5$ (No apparent erosion) - ARENOSOLS–(SL)							
A$_1$ $_{(0-14)}$	0.40	84.6	5.50	9.50	1.54	2.55	10 YR6/8
A$_2$ $_{(14-35)}$	0.50	88.1	4.40	7.00	1.59	2,60	10 YR7/9
B$_1$ $_{(35-52)}$	0.40	86.9	4.20	8.50	1.60	2.60	10 YR6/9
B$_2$ $_{(52-90)}$	1.90	72.3	6.40	19.40	1.60	2.63	10 YR6/10
C$_{(90-180)}$	1.90	72.4	3.10	22.60	1.65	2.65	10 YR6/10

In depth, a reduction in the diameter of the pores is manifested as it becomes more compact, caused by the accumulations of the finest fractions (<0.002 mm) in the profile that occupy the poral space from 50 cm depth (Table 6). It limits the penetration of the roots or does so by coating the aggregates, compressing, behavior reported in tobacco plots [(26)].

Accumulation of heavy metals and their spatial distribution in the main soils of the Southern Plain of Pinar de Río

Regarding the origin of the main metallic elements, it has been strategic to consider the paleogeographic evolution of the Southern Plain of Pinar del Río, to know the origins of the current geochemical behavior of the main soils. A frequent feature is the abrupt transit of the B horizon to the old (ferralitized) weathering crust, either *in situ* or redeposited, which regularly constitutes the C horizon of the soils [(27)], generally of little biological activity and in most of the reclining cases between 120-150 cm deep.

The low natural concentrations of HMs (Table 7) are because these soils are supported mainly on transported materials of siliceous origin and kaolinized clay that do not retain a large amount of metal cations, due to the low content of clay and organic matter [(28)]. Since highly evolved soils formed under strong weathering processes present low natural concentrations of HPs, a criterion that coincides with similar investigations carried out [(29)].

Table 7. Natural values of MPs in soils in little disturbed environments in the Southern Plain of Pinar del Río, Cuba

	Cd	**Pb**	**Cu**	**Zn**	**Fe**	**Mn**	**Ni**	**Cr**	**Co**
	------------------ mg kg^{-1} ----------------				**------- g kg^{-1}------**		**----------mg kg^{-1}-----------**		
FRAL (n = 24). Consolación del Sur – San Juan y Martínez Units									
Media	0.02ª	7.40cd	8.29a	26.72ª	9.86c	0.42ab	11.09ab	16.39b	7.06a
Desv. Est.	0.22	4.53	2.49	15.46	2.72	0.41	6.01	6.10	7.46
ABARA (n=12). Consolación del Sur – San Juan y Martínez Units									
Media	Nd	14.62bc	10.30ª	32.41ª	14.67bc	0.63a	15.15ab	22.46b	5.60a
Desv. Est.		3.19	1.48	3.12	2.41	0.15	1.50	1.94	0.81
ARENOSOLES (n = 6). San Luis Unit									
Media	Nd	1.72d	9.27ª	32.17ª	19.90b	0.69a	16.02a	19.46b	6.23a
Desv. Est.		2.67	5.31	14.45	6.40	0.20	3.31	24.41	1.42
FLUVISOL (n = 18). Consolación del Sur Unit									
Media	0.31ª	15.29b	12.06ª	40.36ª	15.22bc	0.34ab	12.72ab	27.22b	5.79a
Desv. Est.	0.41	0.28	1.48	5.14	3.17	0.11	2.56	3.11	1.00
[1]CUBAN SOILS. (n = 33)									
Average	0.6	50	83	86	-	-	170	150	25

[1]Average natural values of Cuban soils [(15)], Means with equal letters in the same column do not differ from each other. (Tukey; p <0.05)

Cr, Ni, Cu, Co and Zn are associated with primary minerals or co-precipitated with other secondary ones or strongly linked to Fe, Mn and Al oxides, they also accumulate in areas where depositions of soils removed by water erosion processes occur where metallic compounds are leached, a dynamic that corroborates the investigations carried out in similar regions (30).

In the case of Cd, the concentrations are very low; only certain accumulations are in the FRAL, ABARA and Fluvisol soils observed, with values less than unity (Table 7). When comparing the concentrations of this element with the natural average values reported for Cuban soils (31), it is noted that the soils of the Consolación del Sur municipality have lower concentrations of this element. Cu and Zn presented the highest values in Fluvisol without differences with the rest of the soils, so it can be stated that the behavior of both elements is similar.

The Pb shows a heterogeneous behavior, in accordance with the Fe and Mn oxide contents given its strong capacity to adsorb this element. Something similar occurs with organic matter and high pH conditions that favor the formation of stable Pb chelates, resistant to leaching (32). The FRAL soil has the lowest values of this element, a situation that is also expressed in its spatial distribution (Figure 5). The ABARA (14.62 mg kg^{-1}) and Fluvisol (15.29 mg kg^{-1}) soils present similar contents, in the Consolación del Sur - San Juan and Martínez units, respectively, due to the similarities between the characteristics of these two groupings in both surfaces.

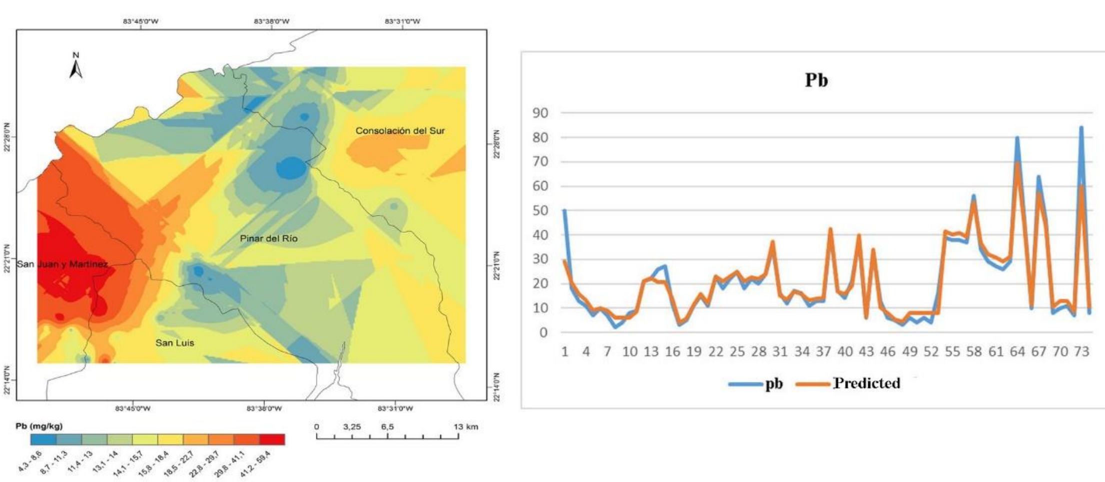


Figure 5. Spatial behavior of Pb in the soils of the Southern Plain of Pinar del Río, Cuba

That is to say in ABARA soils due to the possible influence of the weathering crust of montmorillonite and montmorillonite-kaolinitic composition, which sometimes appears or appears close to the surface due to erosion. In Fluvisol soil, it is the result of accumulation of sediments with a sandy - clayey and clay - sandy texture with gravel intercalations of varied composition and dimensions, given their location in the depression areas as indicated. While Fe and Mn showed high and different values according to the type of soil (Figures 6 and 7), especially high concentrations in FRAL soils due to the nature of the source material and the formation process; where these elements are found mainly in the form of oxides, hydroxides or oxyhydroxides and are present in almost all soils [33].

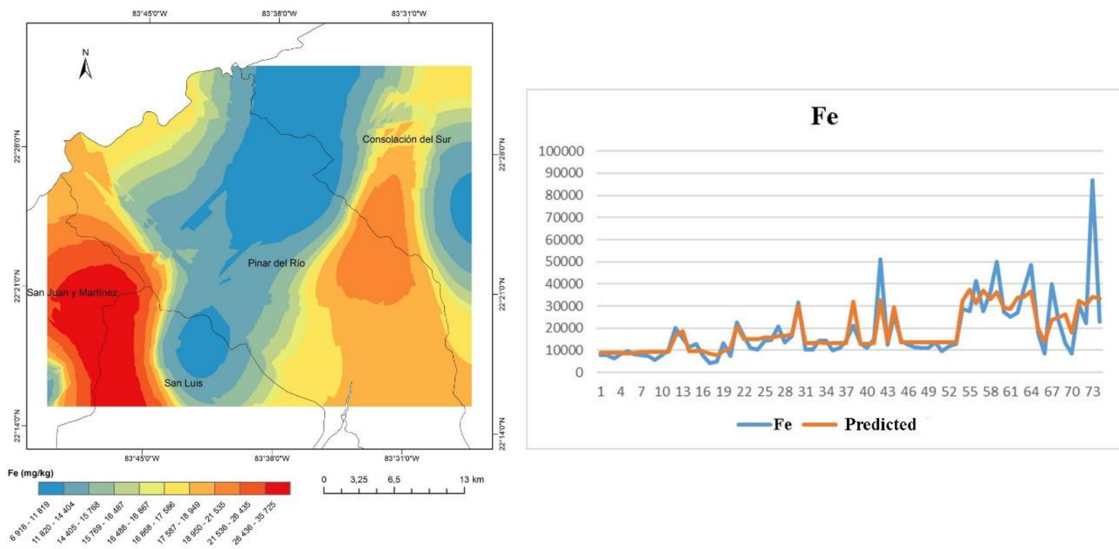


Figure 6. Spatial behavior of Fe in the soils of the Southern Plain of Pinar del Río, Cuba

Regarding their spatial distribution in the soils, the MPs Fe and Mn present similar behaviors in both sectors of the Southern Plain, as they are on materials supported with a similar chemical-mineralogical composition.

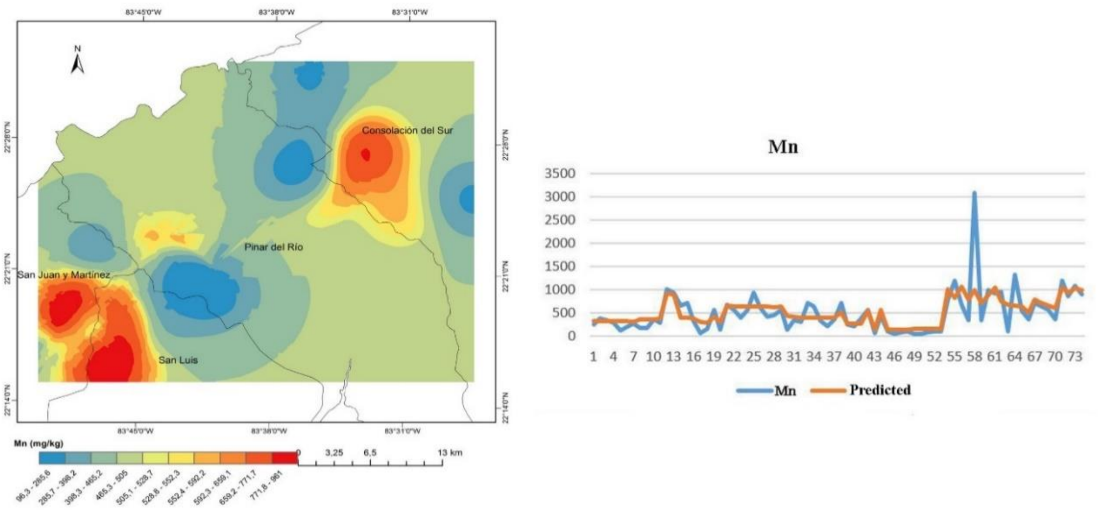


Figure 7. Spatial behavior of the Mn in the soils of the Southern Plain of Pinar del Río, Cuba

This geological-geomorphological conditioning offers a favorable environment for environmental equilibrium, if agro-ecological strategies for soil management are adopted. However, recultivation has been a common practice among farmers in the "Macizo Tabacalero Vizo Abajo ", which consists of collecting sediments from the slopes near the rivers and applying it upstream. These sediments are generally enriched with PMs, toxic organic compounds, nutrients and organic matter, which could activate the retained toxic compounds, putting the quality of the productions and human health at risk, which is corroborated by what was reported in other regions of the country [34].

CONCLUSIONS

- The geological environments in the Southern Plain of Pinar de Río have exerted a notable influence on the composition, spatial distribution and accumulation of heavy metals, both in the current context and in the geographical palaeo, which generally show low natural concentrations compared to soils of other regions of the country.
- The results of this work constitute an approach to design more balanced management systems in risk scenarios of the tobacco massif of the Southern Plain of Pinar del Río and for others with similar edaphoclimatic and productive characteristics.

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