

Concentration and distribution of salinity in soils with hydrocarbons in “La Venta” Tabasco, Mexico

Chávez-Vergara BM¹, Beltrán-Paz O¹, Vela-Correa G^{2*}

¹Instituto de Geología, UNAM. Circuito de la Investigación Científica s/n. Ciudad Universitaria. C. P. 04510. Coyoacán. Ciudad de México.

²Universidad Autónoma Metropolitana – Xochimilco. Departamento El Hombre y su Ambiente. Laboratorio de Edafología. Calzada del Hueso 1,100. Colonia Villa Quietud. Coyoacán. C. P. 04560. Ciudad de México.

Email responsible: gvela@correo.xoc.uam.mx

ABSTRACT

This work was carried out in the so-called "ecological zone or environmental passive" of the "La Venta" Gas Processing Complex located in the state of Tabasco, Mexico. They were established as objectives: To determine the salt concentration and spatially represent its distribution in soils with presence of hydrocarbons. Sampling was performed considering a grid of 50 m per side, obtaining 28 soil samples at a depth of 0 - 30 cm, which were determined in the laboratory: color, density, porosity, pH, organic matter, cation exchange capacity (CEC) and exchangeable ions of Ca^{2+} , Mg^{2+} , Na^+ and K^+ ; Percentage of exchangeable sodium (PSI), electrical conductivity (EC) and concentration of anions and cations in solution. Subsequently, the soil classes were defined from the pH, EC and PSE values and their boundaries were plotted on a scale 1: 2,000. Among the results, the properties of the soils that have been modified are pH, electrical conductivity, and exchangeable sodium. The hydrocarbon distribution is heterogeneous, as is the concentration of salts such as NaCl , $\text{Ca}(\text{HCO}_3)_2$, CaCl_2 , KCl and MgCl_2 , and Na^+ . The EC has values that fluctuate from 0.61 to 117.8 dS m^{-1} and the PSE from 4.09 to 81.83 %. The properties of the soils that have been modified are pH, EC and Na^+ . The soils of greater relevance correspond to the Class II that occupies 52.96 % of the surface and are characterized by a high content of salts; followed by soils Class III that occupy 27.66 % of the surface and correspond to saline-sodic soils. Both classes cover 80.62 % of the total surface, while soils Class IV occupy 18.55 % of the surface and are characterized by their high in sodium.

Key words: contaminated soils, hydrocarbons, soil classes, Tabasco

RESUMEN

Este trabajo se realizó en la “zona ecológica o pasivo ambiental” del Complejo Procesador de Gas “La Venta” en Tabasco, donde se establecieron como objetivos: Estimar la concentración de sales y representar espacialmente su distribución con base en suelos con presencia de hidrocarburos. Se realizó un muestreo considerando una retícula de 50 m por lado obteniéndose 28 muestras de suelo a una profundidad de 0 – 30 cm a las cuales en laboratorio se le determinó: color, densidad, porosidad, pH, contenido de materia orgánica, capacidad de intercambio catiónico (CIC) y iones intercambiables de Ca^{2+} , Mg^{2+} , Na^+ y K^+ ; porcentaje de sodio intercambiable (PSI), conductividad eléctrica (CE) y concentración de aniones y cationes en solución. Posteriormente, se definieron las clases de suelos a partir de los valores de pH, CE y PSI y se representaron sus límites en un plano a escala 1: 2,000. La distribución de hidrocarburos es heterogénea, al igual que la concentración de sales como NaCl , $\text{Ca}(\text{HCO}_3)_2$, CaCl_2 , KCl y MgCl_2 , y Na^+ . La CE presenta valores que fluctúan de los 0.61 hasta 117.8 dS m^{-1} y el PSI de 4.09 a 81.83%. Las propiedades de los suelos que se han modificado son el pH, la conductividad eléctrica y el sodio intercambiable. Las clases de suelo de mayor relevancia son la Clase II que ocupa el 52.96 % de la superficie y se caracteriza por su elevado contenido de sales; seguida de los suelos de Clase III que ocupan el 27.66 % de la superficie y es donde se reciben y acumulan las sales y sodio provenientes de otras áreas. Ambas clases cubren el 80.62 % de la superficie total del pasivo ambiental.

Palabras clave: suelos contaminados, salinidad, hidrocarburos, clases de suelos, Tabasco.

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INTRODUCTION

Some of the sources of soil contamination are emissions, leaks, accidental spills, waste effluents and waste discharges derived from oil extraction activities (Pérez 2002). In the southeast of Mexico, there are numerous sites with different environmental impacts resulting from approximately fifty years of oil extraction operations of (Adams et al. 1999); Veracruz, Tabasco and Campeche states are the most exposed to the gradual increase in exploration and exploitation of this resource (IMP *et al.*, 2000). This contributes to the introduction of variable amounts of hydrocarbons into the environment, altering in one way or another the stability of terrestrial, lacustrine and palustrine ecosystems (Botello et al. 1993; Díaz et al. 1995).

Despite the fact that there are several refineries and petrochemicals that discharge wastewater to adjacent estates, only a handful of research has been done on soil salinization and sodification in these areas. Systems for the treatment of wastewater in these facilities are old and sometimes not suitable for controlling the flow of water passing through them; this causes contamination of discharge areas such as swamps, channels, rivers or lagoons. These waters commonly contain salts from the oil fields as well as significant amounts of hydrocarbons (Adams et al. 1999; Rivera et al. 2002).

Beltrán (1993) reports that approximately 7,200 hectares in Tabasco are affected by activities related to the extraction of petroleum and over 90% is located in low areas or marshes, where the soils are clayey with high amounts of organic matter. The Gas Processing Complex (GPC) La Venta belongs to Petroleos Mexicanos (PEMEX) and has carried out several activities to

deal with soil contamination from hydrocarbons and their possible bioremediation as Adams et al (1999) explain. However, in 2000 the Mexican Institute of Petroleum (IMP) made an assessment of the environmental condition caused by oil and gas extraction, separation and refinement facilities in Tabasco, concluding that pollution from these processes is local.

Navarrete (2005) carried out a study on heavy metals contamination, concluding that La Venta area had the highest values of heavy metals in soils; not only because of oil spills, but also because of the wastewater discharge. It is worth mentioning that until 1996 the water used for dehydration of crude oil had high concentrations of salts that were discharged to areas surrounding the facilities, causing their accumulation in the soil and affecting local vegetation. However, a lack of interest in reversing this process through the years, formed an "environmental passive" area; that is, a site contaminated with released hazardous materials or wastes which were not properly alleviated. Now it is a priority to rehabilitate this place (Russi and Martínez 2002), but the lack of information on the characteristics of soil salinity types and levels is a limiting factor for decision making towards recovery of the site. For this reason, the objectives of this research were: to determine the main salts found in soils; and to spatially represent the classes of soils affected by salinity in the "environmental passive" zone of GPC La Venta.

MATERIAL AND METHODS

Location of the study area

The study area is located in Chontalpa subregion, which forms part of the Southern Gulf Coastal Plain physiographic province that includes the Plains and Swams of Tabasco subprovince (CNA, 2002). Specifically, the “environmental passive” belongs to the La Venta Gas Processing Complex (GPC), which lies between 18°05'17" and 18°05'30" N and 94°02'41" and 94° W in Villa La Venta of the municipality of Huimanguillo in the state of Tabasco (Fig. 1), (INEGI, 1986).



Fig. 1. Location of the study area

"La Venta" Gas Processing Complex is divided in two sections: the first one is the industrial area with the absorption plant, the cryogenic plant, burners, warehouses, laboratories, and administrative areas. The second section, where this research was done, is an ecological area of 27 ha which contains the environmental passive (Fig. 2).

Climate is warm-humid with abundant rains in summer (Am), according to Köppen climate classification modified by García (1988); annual average temperature is 26.2 °C and total annual precipitation is 2,643 mm. Palma et al. (1996) and INEGI (1986) report Gleysolic soils poor drainage and high moisture favour reducing conditions. Vegetation in the site is a relic of medium-evergreen rain forest where *Scheelea liebmanna* Becc., *Sabal yucatanica* L.H. Bailey, *Thalia geniculata* L., and *Cyperus gardneri* Nees are dominant (Diego-Pérez et al. 2001).

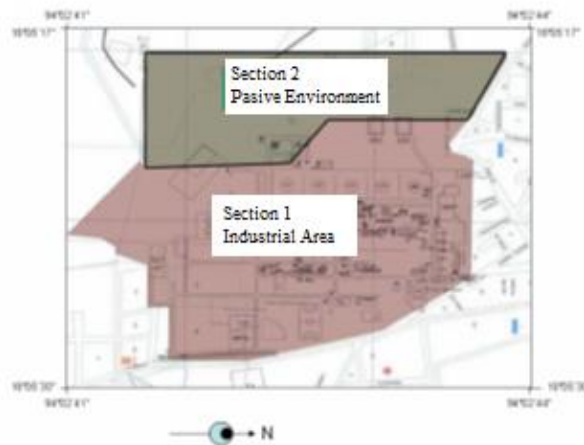


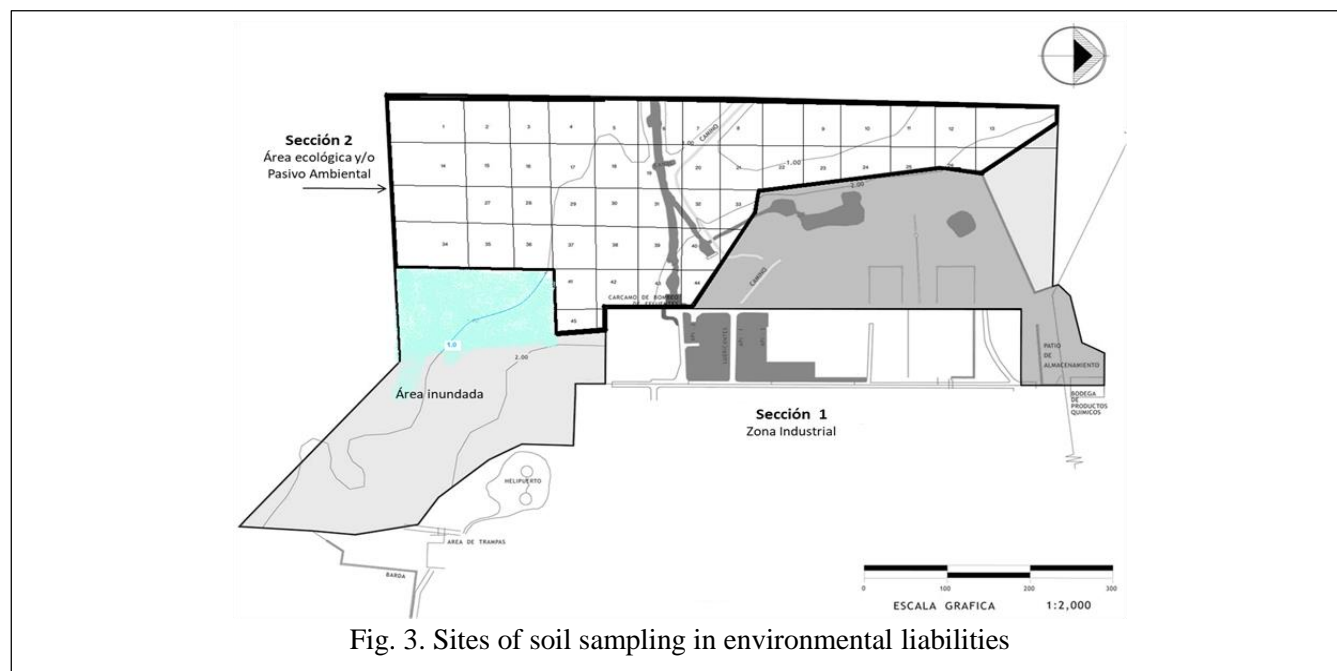
Fig. 2. Location of the study area in the GPC La Venta

Literature research and fieldwork

Literature related to the possible causes of soils salinization was reviewed. Afterwards, sampling was designed on a 50 x 50 m grid overlapping a 1: 2,000 topographic map (Fig. 3). In total, 28 samples, each with one kilogram of soil, were gathered, from the centre of each quadrant at a depth of 0-30 cm, for later analysis in the laboratory.

Laboratory work

Prior to laboratory analysis, the soil samples were dried at room temperature and sieved using a 2 mm diameter mesh, grinding larger lumps in a porcelain mortar. Subsequently, the sample was homogenized to avoid possible bias according to SEMARNAT (2002) and Corwin et al. (2003). Each soil sample was analysed for: colour by comparison with the Munsell tables (1994); actual and apparent density according to Soil Survey Staff (1999); porosity was estimated based on Baver (1973); electrical conductivity (EC) of the saturation extract was determined using a Corning 200 conductivity



meter. An extract of soil saturation was used to measure pH using a 1:2.5 H₂O ratio; organic matter (OM) and organic carbon were quantified following Walkley and Black (1947); CEC was determined by the versenate method (EDTA), 0.02 N; both exchangeable and soluble Ca²⁺ and Mg²⁺ were estimated after Jackson (1982); soluble and interchangeable Na⁺ and K⁺ were assessed using flame analysis with a Corning 400 flamometer; CO₃²⁻, (HCO₃)²⁻ and Cl⁻ were determined as indicated in SEMARNAT (2002). Base saturation and sodium absorption ratio (SAR) were calculated according to Richards (1985) and Velázquez et al. (2002). The interpretative classification of soils affected by salinity was elaborated with the criteria of Pineda et al. (2000) and SEMARNAT (2001) considering electrical conductivity (EC) and exchangeable sodium percentage (ESP). The values for each class are as follows: Class I has an EC < 4 dS m⁻² and ESP < 15; Class II has an EC > 4 dS m⁻² and ESP < 15; Class III has an EC < 4 dS m⁻² and ESP > 15; and Class IV has an EC > 4 dS m⁻² and ESP < 15. Each soil class was spatially represented in a 1:2000 scale map.

RESULTS AND DISCUSSION

Composition and concentration of salts in soils

Results show that predominant salts in the research area are composed by the chloride (Cl⁻) anion –such as NaCl and CaCl₂–, characterized for their solubility. For this reason, they can disturb vegetation that is not tolerant to sodicity and salinity (Table 1). Because there is a high concentration of salts in the soil solution, the increase in osmotic pressure causes root cells to use more energy for the absorption of the water molecules. Another effect is the collapse of plants due to the toxicity from the excess of absorbed ions, sodium, chlorides and sulfates that accumulate in their tissue and cells; this changes the metabolism of plants, affecting the synthesis of starch compounds, ATP, DNA and RNA (Richards 1985; Rowell and Pateras 2002).

They are ions CO₃ in low concentrations compared to HCO₃⁻. The relationship of soluble anions is Cl⁻ > HCO₃⁻ > CO₃²⁻, the latter found in sites with evidence of hydrolysis of mollusc heads.

Although slope is slight in the area where there is a higher elevation, HCO_3^{2-} are the predominant anions, whereas in the rest of the terrain the predominant ion is Cl^- reaching values of $129.63 \text{ mmol } (-) \text{ L}^{-1}$ due to residual saline water discharges and the solubility of this ion. When there is accumulation of soluble salts in the soil, exchangeable Na^+ content tends to increase so that it is in a favourable position to compete with Ca^{2+} and Mg^{2+} in exchange, EC values fluctuate between 0.61 and 117.8 dS m^{-1} , indicating a high variation in salt distribution due to water saturation and subsequent drying (Richards, 1985).

Table 1. Soluble soil ions at study zone.

| Sample | HTP | Cations | | | | Anions | | |
|-------------------------|----------|------------------|------------------|---------------|--------------|--------------------|------------------|---------------|
| | | Ca^{2+} | Mg^{2+} | Na^+ | K^+ | CO_3^{2-} | HCO_3^- | Cl^- |
| mmol(+) L^{-1} | | | | | | | | |
| 1 | 9,485.20 | 8.0 | 1.8 | 26.2 | 2.0 | 0.0 | 17.5 | 14.4 |
| 2 | 710.91 | 5.4 | 1.4 | 75.0 | 5.0 | 0.0 | 15.0 | 54.4 |
| 3 | 1,139.8 | 6.7 | 1.6 | 79.3 | 6.6 | 0.0 | 16.7 | 48.5 |
| 4 | 646.9 | 2.7 | 4.6 | 73.3 | 8.1 | 0.0 | 8.0 | 73.7 |
| 5 | 9,691.1 | 4.7 | 1.2 | 69.0 | 4.5 | 3.3 | 8.3 | 84.1 |
| 6 | 300.2 | 3.1 | 0.4 | 16.8 | 2.0 | 0.0 | 9.0 | 8.6 |
| 7 | 58.2 | 3.0 | 0.5 | 30.5 | 3.0 | 0.0 | 8.0 | 32.2 |
| 8 | 40.1 | 6.2 | 1.4 | 595.9 | 3.5 | 3.3 | 11.7 | 129.6 |
| 9 | 9.2 | 3.7 | 0.8 | 11.6 | 7.6 | 0.0 | 11.7 | 29.4 |
| 10 | 8.3 | 3.5 | 1.6 | 21.1 | 4.0 | 0.0 | 8.0 | 32.5 |
| 11 | 474.6 | 2.4 | 3.2 | 36.6 | 5.4 | 0.0 | 6.0 | 12.7 |
| 12 | 1,052.5 | 1.4 | 1.2 | 12.3 | 1.9 | 0.0 | 4.0 | 2.5 |
| 13 | 183.2 | 0.7 | 0.2 | 20.9 | 0.5 | 0.0 | 16.7 | 8.1 |
| 14 | 25.3 | 5.6 | 1.2 | 53.7 | 3.2 | 0.0 | 12.5 | 63.7 |
| 15 | 1,309.7 | 2.1 | 3.1 | 52.5 | 4.9 | 3.3 | 10.0 | 46.6 |
| 16 | 315.9 | 6.2 | 2.4 | 36.4 | 4.4 | 0.0 | 28.3 | 30.0 |
| 17 | 782.9 | 5.3 | 1.5 | 154.9 | 6.9 | 0.0 | 10.0 | 93.4 |
| 18 | 12.8 | 0.6 | 0.0 | 6.1 | 0.4 | 0.0 | 10.0 | 5.5 |
| 19 | 162.9 | 1.1 | 0.2 | 9.6 | 2.5 | 0.0 | 8.3 | 2.4 |
| 20 | 293.6 | 1.7 | 0.2 | 11.1 | 1.2 | 0.0 | 7.0 | 10.6 |
| 21 | 1,124.1 | 1.4 | 1.4 | 21.2 | 2.8 | 0.0 | 5.0 | 25.5 |
| 22 | 33.4 | 1.6 | 1.8 | 14.4 | 1.5 | 0.0 | 8.0 | 9.5 |
| 23 | 8.3 | 1.5 | 0.9 | 20.0 | 3.0 | 0.0 | 5.0 | 2.7 |
| 24 | 88.5 | 1.6 | 0.6 | 14.2 | 4.5 | 0.0 | 5.0 | 1.9 |
| 25 | 64.0 | 1.6 | 1.4 | 2.4 | 0.7 | 0.0 | 5.0 | 1.6 |
| 26 | 1,124.1 | 1.3 | 0.5 | 14.4 | 3.2 | 0.0 | 5.0 | 1.7 |
| 27 | 9.2 | 3.4 | 4.2 | 34.3 | 2.8 | 0.0 | 25.0 | 46.1 |
| 28 | 250.8 | 4.1 | 1.4 | 44.5 | 3.5 | 0.0 | 27.5 | 114.2 |

As the water table rises, salts dissolve and redistribute over the soil. This process is influenced by solubility of the salts and terrain slope causing highest EC values at the lower zones of the study area –where drainage is less efficient and favours salts accumulation and immobilization–. Another factor that reduces movement of soluble salts is the presence of petroleum hydrocarbons (PHCs). The effect of PHCs as reported by Pérez et al. (2002) shows in a decrease in the porous space of the soil ($\leq 50\%$), which favours salts to be exposed on the soil surface.

Samples with high EC have high concentrations of Cl^- and Na^+ ; this is explained by the increase in salts concentration caused by the discharge of residual salt water.

Influence of salinity on soil characteristics

Because of the high content of organic matter and hydrocarbons, the dominant colour in dry soils is dark brown (10YR 3/3) and very dark brown (10YR 2/2) when wet. Organic matter comes from non-degraded plant remains that are immobilized by anoxic conditions due to soil water saturation (gley conditions) characteristic of prolonged periods of flooding. This is consistent with a value of <5 in most soils in accordance to the redox conditions of partial or completely anaerobic conditions as Seoáñez (1999) and Gerrard (2000) describe.

Apparent density (D_a) shows a decrease in the areas with lower elevation in Section 2 of the GPC due to the accumulation of organic materials and hydrocarbons transported by surface water; in this zone, the minimum value -0.48 Mg m^{-3} – was recorded. Values of most samples are within the range of 0.50 to 1.00 Mg m^{-3} due to the accumulation of organic matter and hydrocarbons that remain restrained by water saturation during part of the year (Gerrard, 2000). High values of $D_a > 1.1 \text{ Mg m}^{-3}$ were noted in samples, with greater compaction due to wetting and drying processes, given the seasonality of the rainy season and their proximity to roads where the site was refilled and compressed. As organic matter content increases, D_a decreases, but Pérez (2002) mentions another factor. He indicates that electrical conductivity, the content of cations in solution and ESP have an effect on the density: while they increase, D_a decreases due to the possible dispersion of the soil caused by an increase in Na^+ .

The potential effects of a high EC, soluble cations and ESP diminished due to the high content of organic matter in the zones with greater accumulation of salts that can neutralize the harmful effects of exchangeable Na^+ , as described by Serrato

et al. (2002) and Corwin and Lesch (2005b). These authors state that soils with high OM and Na^+ can have a good condition since organic matter improves and prevents the deterioration of the physical condition of the soil through its interaction with cation exchange materials; also, because it is a resource for microorganisms that contribute to a stable aggregation of soil particles. The porosity decreases in certain areas of the study area, which is attributed to the presence of petroleum hydrocarbons (PHCs) that saturate soil pores decreasing its porosity (Martínez and López 2001). Soils are mildly acidic at pH 5.1 to 6.5. Although low parts of the terrain have a neutral pH (6.5-7.3), there are also some small but strongly acidic areas where pH ranges from 3.9 to 5.0 to the presence of high amounts of OM and its degradation generates organic acids that acidify the soil.

Arocena and Rutherford (2005), and Friedman (2005), mention that the ESP above 15% causes pH values to be between medium to strongly alkaline, but this was not the case in the study area since its soils do not reach high levels of alkalinity: This is due to the high content of OM, regardless the fact that in some areas partially it is partially restrained by water saturation of the land and the presence of PCHs and salts that inhibit biological activity. Therefore, the release of H^+ is not enough to completely counteract the effect of the cations on the exchange complex and the soluble salts in the soil; however, it is enough to mitigate the effect of the Na^+ on pH causing it to be from slightly acid to neutral. This is supported in the works of Richards (1985), Corwin and Lesch (2005b), Gerrard (2000), Auerswald et al. (2001), and Corwin and Lesch (2005c).

The soils are very rich in OM, but are considered to be immobilized, due to the reducing conditions caused by water saturation, as well as the presence of PCHs that fill the pores, making it difficult for oxygen to penetrate, and favouring a scarce aerobic decomposition in the soils (Adams et al. 2002, Olguín et al. 2007). In addition, OM

accumulation is influenced by flooding conditions and vegetation of the lower parts of the study area where it can move in the form of suspended particles on the ground and corresponds with places with the largest accumulation of salts and PCHs. In areas lacking vegetation cover, these have a direct influence on the physical properties of the soil, such as the presence of saline efflorescence, as well as a layer of disaggregated superficial soil of approximately 2 cm due to the high content of Na^+ and Mg^{2+} , which in turn do not allow the establishment of other plant species (Corwin and Lesch 2005b; Olguín et al. 2007).

Cation exchange capacity (CEC) is considered average, since it is in a range of 15 to 25 $\text{cmol}_{(+)}$ kg^{-1} . However, data obtained demonstrate the heterogeneity of this property, since there are areas where the values are between 5 - 15 $\text{cmol}_{(+)}$ kg^{-1} and therefore are considered to be low whereas other areas where the CEC is high in agreement with the content and availability of organic matter, have values between 25 - 40 $\text{cmol}_{(+)}$ kg^{-1} . Highest CEC values are found in the lower parts of the study area, where accumulation of PCHs and OM is highest; for this reason, both parameters are considered to form a larger colloidal surface that allows the absorption and replacement of cations (Vázquez -Alarcón 1997).

Because of the proximity of the research area to the sea it is influenced by a saline entry into the aquifer, a high water table and reduced drainage that naturally tends to accumulate cations with the consequent saturation of the exchange sites, whereby the saturation of bases (PBS) is greater than 100%. When it receives discharges from residual saline waters by the extraction of the crude, soils in the GPC La Venta modify the natural concentration of the cations in the exchange complex causing an increase and oversaturation of cations as described by Arocena and Rutherford (2005). This research also determined the relationship of cations present in the exchange complex, showing that the dominant relationship of the cations is $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$, although in some

sites it was found that there may be a dominance of Mg^{2+} over Ca^{2+} . Sites with a modified cation ratio lack vegetation probably because of the toxic effect of Mg^{2+} being a dominant cation in soils (Szabolcs 1989). Also, it was observed that a layer of approximately 2 cm of soil thickness was easily disaggregated; it is most likely the effect of Na^+ (Serrato et al. 2002; Corwin and Lesch 2005).

so it is considered that it is not affected by discharges of salt water that is used during the extraction of crude oil. They are located in the highest areas of the study area and closest to the channel that crosses the environmental passive. This channel was originally locating in the place where residual discharge of salt water was done and now is used as a drain facilitating the mobilization of salts from contiguous areas.

Class II soils or SALINES have a surface of 14.30 ha and they are the dominant class in the

Table 2: Physical and chemical properties of soils

| Sample | HTP Mg kg ⁻¹ | Density | | Porosity --- % --- | EC dS m ⁻¹ | pH(H ₂ O) 1:2.5 | OM % | CIC | Interchangeable cations | | | | SIP % | |
|--------|----------------------------|--------------------------------|------|-----------------------|--------------------------|-------------------------------|---------|-------|-------------------------|---------------------------------------|-----------------|----------------|----------|--|
| | | apparent Mg m ⁻³ | real | | | | | | Ca ²⁺ | Mg ²⁺ | Na ⁺ | K ⁺ | | |
| | | | | | | | | | | ----- Cm ol(+) kg ⁻¹ ----- | | | | |
| 1 | 9,485.20 | 0.5 | 1.5 | 66.7 | 13.8 | 6.8 | 48.93 | 20.38 | 39.6 | 9.1 | 2.8 | 0.4 | 13.7 | |
| 2 | 710.91 | 0.6 | 1.5 | 60.0 | 41.6 | 6.6 | 34.37 | 20.90 | 34.0 | 57.6 | 6.9 | 0.9 | 33.0 | |
| 3 | 1,139.8 | 0.6 | 1.8 | 66.7 | 36.6 | 6.4 | 28.25 | 21.32 | 27.2 | 46.0 | 7.6 | 0.9 | 35.6 | |
| 4 | 646.9 | 0.8 | 2.1 | 61.9 | 46.5 | 6.5 | 18.96 | 15.51 | 64.8 | 7.8 | 19.1 | 0.6 | 123.1 | |
| 5 | 9,691.1 | 0.9 | 2.2 | 59.1 | 61.8 | 7.0 | 14.19 | 13.72 | 29.4 | 4.7 | 3.3 | 0.5 | 24.0 | |
| 6 | 300.2 | 0.6 | 1.7 | 64.7 | 25.2 | 6.6 | 29.71 | 20.85 | 32.9 | 47.6 | 8.7 | 0.9 | 41.7 | |
| 7 | 58.2 | 0.8 | 2.1 | 61.9 | 117.8 | 5.6 | 10.79 | 38.31 | 37.2 | 7.9 | 6.0 | 0.5 | 15.7 | |
| 8 | 40.1 | 1.0 | 2.2 | 54.5 | 10.3 | 6.1 | 4.37 | 28.12 | 39.5 | 11.3 | 4.8 | 0.6 | 17.1 | |
| 9 | 9.2 | 0.9 | 2.2 | 59.1 | 1.0 | 4.5 | 5.32 | 15.34 | 13.4 | 12.3 | 1.2 | 0.3 | 7.8 | |
| 10 | 8.3 | 1.2 | 2.4 | 50.0 | 7.5 | 5.6 | 1.97 | 7.93 | 7.3 | 0.5 | 1.0 | 0.2 | 12.6 | |
| 11 | 474.6 | 0.5 | 1.8 | 72.2 | 48.4 | 6.6 | 28.36 | 25.48 | 58.1 | 13.4 | 8.6 | 0.8 | 33.7 | |
| 12 | 1,052.5 | 0.6 | 1.5 | 60.0 | 36.2 | 6.5 | 34.53 | 16.36 | 25.1 | 18.5 | 4.3 | 0.6 | 26.3 | |
| 13 | 183.2 | 0.9 | 1.1 | 18.2 | 50.5 | 6.5 | 13.00 | 10.35 | 27.7 | 16.6 | 2.4 | 0.4 | 23.2 | |
| 14 | 25.3 | 1.2 | 2.5 | 52.0 | 35.6 | 4.5 | 1.33 | 19.57 | 4.1 | 1.5 | 0.8 | 0.3 | 4.1 | |
| 15 | 1,309.7 | 1.2 | 2.4 | 50.0 | 18.7 | 6.8 | 4.38 | 32.86 | 10.3 | 2.8 | 1.4 | 0.2 | 4.3 | |
| 16 | 315.9 | 1.1 | 2.4 | 54.2 | 25.3 | 5.2 | 3.17 | 8.24 | 7.3 | 0.6 | 1.2 | 0.4 | 14.6 | |
| 17 | 782.9 | 0.5 | 1.4 | 64.3 | 18.2 | 6.0 | 22.91 | 29.14 | 62.1 | 11.7 | 2.3 | 0.6 | 7.9 | |
| 18 | 12.8 | 0.7 | 1.7 | 58.8 | 15.02 | 6.2 | 23.74 | 15.88 | 23.6 | 9.2 | 2.3 | 0.5 | 14.5 | |
| 19 | 162.9 | 1.1 | 1.9 | 42.1 | 11.03 | 6.8 | 13.94 | 22.60 | 21.4 | 4.2 | 2.9 | 0.3 | 12.8 | |
| 20 | 293.6 | 1.0 | 2.4 | 58.3 | 15.3 | 6.4 | 7.07 | 10.98 | 10.1 | 6.3 | 1.3 | 0.3 | 11.8 | |
| 21 | 1,124.1 | 1.2 | 2.4 | 50.0 | 19.3 | 6.2 | 2.15 | 21.42 | 13.1 | 0.6 | 1.1 | 0.2 | 5.1 | |
| 22 | 33.4 | 0.7 | 1.7 | 58.8 | 5.3 | 5.5 | 21.06 | 21.59 | 24.8 | 16.9 | 3.1 | 0.5 | 14.4 | |
| 23 | 8.3 | 0.9 | 1.9 | 52.6 | 35.6 | 5.1 | 9.58 | 14.27 | 19.2 | 2.6 | 2.0 | 0.4 | 14.0 | |
| 24 | 88.5 | 0.9 | 1.8 | 50.0 | 12.9 | 5.3 | 7.90 | 9.89 | 13.1 | 5.3 | 0.8 | 0.2 | 8.1 | |
| 25 | 64.0 | 0.9 | 1.5 | 40.0 | 15.0 | 5.6 | 15.06 | 32.88 | 18.2 | 4.1 | 2.3 | 0.5 | 7.0 | |
| 26 | 1,124.1 | 1.1 | 2.4 | 54.2 | 48.3 | 6.4 | 3.27 | 8.99 | 17.8 | 4.3 | 1.0 | 0.3 | 11.1 | |
| 27 | 9.2 | 1.1 | 2.4 | 54.2 | 25.3 | 4.0 | 3.19 | 7.29 | 10.0 | 6.4 | 1.9 | 0.3 | 26.1 | |
| 28 | 250.8 | 1.2 | 2.5 | 52.0 | 12.0 | 7.0 | 5.74 | 9.88 | 13.1 | 6.9 | 1.3 | 0.2 | 13.2 | |

HTP = Total hydrocarbons; EC = Electrical conductivity; OM = Organic matter; CEC = Cation exchange capacity; ESP = Percentage of exchangeable sodium.

Soils salinity classes

Class I soils or NORMAL have a surface of 0.10 ha do not show an increase in their EC or ESP,

environmental passive (Table 3). These soils have a higher concentration of soluble salts, but not of sodium, which is why draining these areas probably can reduce the concentration of the salts. These soils

are located in the central part of the study area, towards the southwest portion; this zone is not the lowest of the land, but receives washed salts from the high parts as well as areas that are flooded during the rainy season; for this reason, salts are redistributed seasonally through the field.

Tabla 3. Clases de suelos por salinidad

| Clase | CE | PSI | Superficie | Porcentaje |
|-------|-------------------|-----|------------|------------|
| | dSm ⁻¹ | % | Ha | % |
| I | <4 | <15 | 0.10 | 0.38 |
| II | >4 | <15 | 14.30 | 52.96 |
| III | <4 | >15 | 7.47 | 27.66 |
| IV | >4 | >15 | 5.13 | 19.00 |
| Total | | | 27.00 | 100.00 |

Class III corresponds to SALINE - SODIC soils, which occupy an area of 7.47 ha (Table 2). This is the area most affected by discharges of residual saline waters and, to be able to rehabilitate these soils, a proper drainage and the use of improvers for Na⁺ displacement from the cation exchange sites is necessary. These soils are located in the southeast portion of the lower areas where salts which cannot find an exit due to deficient drainage conditions and an elevated water table. There are also areas lacking vegetation cover with efflorescence and salt crusts, which coincide with sites with higher concentrations of hydrocarbons. These efflorescence's and crusts are due to hydrocarbons that reduce soil porosity and concentrates salts on its surface as it prevents them from descending.

Class IV corresponds to SODIC soils, which present an increase in exchangeable sodium concentration and cover an area of 5.13 ha. This Class of soils is located in the northeast area next to the fence that separates the study area from the industrial zone,

where there is a washing of salts that travel towards lower zones, while Na⁺ is retained in the exchange complex.

CONCLUSIONS

- Soils of the research area are subject to salinization and sodification processes, the main cause is discharge of residual saline waters that are released during dehydration process

- In the research area, the salts are distributed heterogeneously due to fluctuations in the water table; highest concentrations in lower parts of the site. Likewise, the presence of hydrocarbons influences salts immobilization and creates devegetated areas with superficial layers of saline efflorescence.

- Salts in the research area have high Na⁺ and Mg²⁺ toxicity that has a negative impact on vegetation, considering that NaCl is the most abundant, due to the solubility of its constituents.

- Soil classes that require more attention are III and IV due to high concentration of exchangeable Na⁺ and because both classes cover 48.8% of the total research area.

- Soils of Class II or SALINE, occupy the largest area of the environmental passive, followed by Class III or SALINE - SODIC, and Class IV SODIC.

ACKNOWLEDGEMENT

To the staff of the La Venta Gas Processing Complex for the facilities granted to carry out this work.

BIBLIOGRAPHY

- Adams R, Domínguez V, García L. 1999. Potencial de la biorremediación de suelo y agua impactados por petróleo en el trópico mexicano. *Terra* 17(2):159-174.
- Adams R, Domínguez V, Vinalay L. 2002. Evaluation of microbial respiration and ecotoxicity in contaminated soils representative of the petroleum producing region of southeastern Mexico. *Terra* 20(3):253-265.

- Arocena J, Rutherford P. 2005. Properties of hydrocarbon- and salt-contaminated flare pit soils in northeastern British Columbia (Canada). *Chemosphere* 60:567-575.
- Auerswald K, Simon S, Stanjek H. 2001. Influence of soil properties on electrical conductivity under humid water regimes. *Soil Science* 166(6):382-390.
- Baver, Gardner, W. H. y Gardner, W. R. 1973. *Física de suelos*. ed. Uthea, México. 529p
- Beltrán E. 1993. Los impactos del petróleo en Tabasco: realidad y perspectivas. Gobierno del Estado de Tabasco. México.
- Botello A, Díaz G, Villanueva F, Salazar L. 1993. Presence of PAH's in coastal environments of the southeast Gulf of Mexico, Polycyclic Aromatic Compounds. 3:397-404.
- Corwin D, Lesch S. 2005. Apparent soil electrical conductivity measurements in agriculture. *Computers and Electronics in Agriculture*. 46:11-43.
- Corwin D, Lesch S. 2005b. Characterizing soil spatial variability with apparent soil electrical conductivity: I. Survey protocols. *Computers and Electronics in Agriculture* 46:103-133.
- Corwin D, Lesch S. 2005c. Characterizing soil spatial variability with apparent soil electrical conductivity: II. Case study. *Computers and Electronics in Agriculture* 46:135-152.
- Corwin D, Kaffka S, Hopmans J, Mori Y, Van Groenigen J, Van Kessel C, Lesch S, Oster J. 2003. Assessment and field-scale mapping of soil quality properties of a saline-sodic soil. *Geoderma* 114:231-259.
- Díaz G, Cámara V, Botello A, Ponce G. 1995. Evaluación de hidrocarburos aromáticos policíclicos en suelos hidromórficos de la reserva de la biosfera "los Pantanos de Centra" en Tabasco, México, *Revista Internacional de Contaminación Ambiental* 12(1):15-21.
- Diego-Pérez N, Ramos-Álvarez CH, Martínez E. 2001. Un nuevo registro *Cyperus* para México. *Acta Botánica Mexicana* 55: 17-20
- Friedman S. 2005. Soil properties influencing apparent electrical conductivity: A review. *Computers and Electronics in Agriculture*. 46:45-70.
- García E. 1988. Modificaciones al sistema de clasificación climática de Köppen (para adaptarlo a las condiciones de la República Mexicana). Ed. Instituto de Geografía, Universidad Nacional Autónoma de México, México.
- Gerrard J. 2000. *Fundamentals of soils*. Routledge. London, U.K.
- IMP, UNAM, Batelle, PGPB y PEP. 2000. Diagnóstico de los efectos ambientales de la industria petrolera asociados a la región sur de PEP. Proyecto Ambiental de la Región Sur. No. Control INF-PARS-01. Instituto Mexicano del Petróleo, Universidad Nacional Autónoma de México, Instituto Batelle, Pemex Gas y Petroquímica Básica, Pemex Exploración y Producción. México, D.F.
- INEGI (Instituto Nacional de Estadística Geografía e Informática). 1986. Síntesis Geográfica, Nomenclátor y Anexo Cartográfico del Estado de Tabasco. Ed. INEGI. México 116 p.
- Jackson ML. 1982. *Análisis Químico de Suelos*. 4ta ed. Ed. Omega. Barcelona, España 662 p.
- Martínez V, López F. 2001. Efectos de los Hidrocarburos en las Propiedades Físicas y Químicas de un Suelo Arcilloso. *Terra* 19(1): 9 - 17.
- Munsell®. 1998. *Soil Color Charts*. Ed. Macbeth Division of Munsell Color. Baltimore, Maryland. USA.
- Navarrete M. 2005. Contaminación por metales pesados en tres unidades de suelo, ocasionada por derrames de petróleo en el Distrito de Agua Dulce Tabasco. Tesis Biología. Facultad de Ciencias, UNAM. México. 64 p.
- Olgún JE, El Hernández M, Sánchez-Galván G. 2007. Contaminación de manglares por hidrocarburos y estrategias de biorremediación, fitorremediación y restauración. *Revista Internacional de Contaminación Ambiental* 23(3): 139-154.
- Palma L, Cisneros J. 1996. Plan de uso sustentable de los suelos de Tabasco. Fundación PROCEDE Tabasco A.C. México.
- Pérez J, García G, Esparza F. 2002. Papel ecológico de la rizosfera en fitorremediación. *Avance y Perspectiva*. 21:297-300.
- Pérez O. 2002. Efecto de la aplicación de aguas residuales industriales en las propiedades físicas y químicas del suelo. *Agrociencia* 36(3):279-290.
- Pineda N, Elizalde G, Jaimes E, Ochoa G. 2000. Validación de una metodología para definir tipos de suelo en forma sencilla. *Agronomía Tropical* 50(3):477-498.
- Richards L. 1985. Diagnóstico y rehabilitación de suelos salinos y sódicos. Limusa. México.
- Rivera-Cruz M, Ferrera-Cerrato C, Volke-Haller R, Fernández-Linares V, Rodríguez-Vázquez LR. 2002. Poblaciones microbianas en perfiles de suelos afectados por hidrocarburos del petróleo en el estado de Tabasco, México. *Agrociencia* 36 (2):149-160.
- Rowell D, Pateras D. 2002. Diffusion and cation Exchange during the reclamation of saline-structure soil. *Geoderma* 107: 271 - 209.
- Russi D, Martínez-Alier J. 2002. Los pasivos ambientales. *Debates Ambientales* 24: 107 - 112
- SEMARNAT (Secretaría del Medio Ambiente y Recursos Naturales). 2001. NOM-023-SEMARNAT-2001.

- Norma Oficial Mexicana que establece las especificaciones técnicas que deberá contener la cartografía y la clasificación para la elaboración de los inventarios de suelos. Secretaría del Medio Ambiente y Recursos Naturales. Diario Oficial de la Federación. México.
- SEMARNAT. (Secretaria del Medio Ambiente y Recursos Naturales). 2002. NOM-021-SEMARNAT-2002. Norma Oficial Mexicana que establece las especificaciones de fertilidad, salinidad y clasificaron de suelos. Estudios muestreo y análisis. Secretaria del Medio Ambiente y Recursos Naturales. Diario Oficial de la Federación. México.
- Seoanez M. 1999. Contaminación del suelo: Estudios, Tratamiento y Gestión. Mundi Prensa. Madrid, España.
- Serrato R, Ortiz A, López J, Berúmen S. 2002. Aplicación de lavado y estiércol para recuperar suelos salinos en la comarca lagunera, México. *Terra* 20(3):329-336.
- Soil Survey Staff. 1999. Soil Taxonomy: A basic system of soil classification for making and interpreting soil survey. Second Edition. No. 436. Agriculture handbook. Ed. United States Department of Agriculture and Natural Resources Conservation Service., Washington, USA. 879 p.
- Szabolcs I. 1989. Salts-affected soils, C.R.C. Press Inc. Florida, U.S.A.
- Velásquez-Alarcón A. 1997. Guía para interpretar el análisis químico del agua y suelo. Departamento de Suelos. Universidad Autónoma Chapingo. México.
- Walkley A, Black IA. 1947. An examination of the deghthareff method for determining soil organic and a proposed modification of chromic acid titration method. *Soil Science*, no. 37, pp. 29-38.