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ORIGINAL ARTICLE

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Spatial variability of soil quality in the surroundings of a saline lake environment

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Abstract The spatial variability of the quality of the soil on the shores of a lagoon affected by hydromorphy and/or salinity can be identified (Laguna de Villacañas, Castilla La Mancha) by the use of multitemporal Landsat images in order to analyse these changes. For this purpose, TM and ETM images along with field observations and certain edaphic laboratory parameters are used. In order to identify saline-hydromorphic soils, the spatial variability of chemical and physical properties of a transect, which includes from Solonchaks to Regosols and Cambisols, have been correlated with the Normalised Difference Vegetation Index (NDVI). This index, chosen for specific dates, has proven to be very useful in detecting halophytic vegetation and relating it to the variability of the quality of these soils.

Keywords Soil quality · Salinity · Landsat images · La Mancha · Spain

Introduction

Soil quality, defined as "the functioning capacity of a specific soil", can be determined by measuring a minimum amount of data from the soil properties in order to estimate the capacity of the soil to perform its basic functions. Over the last decades there has been a clear tendency to search for an index or indicators that combine and define the different edaphic characteristics in terms of "quality": Doran et al. (1994), Hortensius and Welling (1996), Bouma (1997), Gilley et al. (1997), Karlen et al. (1997), Kettler et al. (2001), Norfleet et al. (2001), Gajda et al. (2001), Doran (2002), etc. The reason behind this trend is to provide a simple terminology that can be applied to the management of the terrain.

The USDA (1999) was among the first to design a widely used index that defines soil quality as "the capacity of a specific soil to function".

In the region of Castilla La Mancha (Spain), research is being carried out to determine the main indicators that situate soils in a specific position on a soil quality scale. Between the different categories of quality, saline soils are obviously in the lowest position because they are not appropriate for agricultural use. In this region, part of the saline soils is located in humid areas, e.g. The National Park " Las Tablas de Daimiel" or the "Lagunas de Ruidera", comprising as many as 50 lakes spread over the provinces of Toledo, Ciudad Real, Cuenca, Albacete and Guadalajara.

The intense historic agriculture and livestock farming in La Mancha has resulted in the natural vegetation being confined to a relatively small area, which for various reasons has remained unfarmable: steep hillsides, excessive salinity, lack and poor quality of soil, frequent floodings, etc. Despite the existence of forests, it is not usual to find some areas with an isolated *Quercus rotundifolia*, without shrubbery or grasses, which are characteristic of Mesomediterranean vegetation.

In these "unique or intrazonal" environments the natural vegetation has been relegated to numerous humid areas and riverside vegetation. Therefore, the predominant species belong to the saline Mediterranean soils, which are formed by *Salicornias, Suaedas, Salsolas, Scirpus, Schoenus nigricans, Microcnemun caralloide, Juncus maritimus, Limonium* sp., etc. and other species (*Tamarix* sp, *Cladium mariscus*, *Phragmites australis, Populus alba, Arundo donax*, etc.). Detailed research work has been done by Cirujano (1980) and Cirujano et al. (1992) on hygro-halophytic vegetation of each of the lakes of La Mancha.

Moreover, the situation has been aggravated by the careless behaviour of people in many of these humid areas, especially if the soil is saline and inappropriate for agriculture. In this way, in many towns this kind of soil becomes a rubbish dump or drainage pond for sewage.

The southern part of the Spanish ‘‘meseta’’ presents a series of geomorphological, hydrological and climatic features that favour the development of salt-affected soils (Gumuzzio et al. 1995). The purpose of this study is to learn the spatial variability of soil quality in one of these environments using satellite images, a technique used by numerous authors for edaphic research work (Mougenot and Pouget 1993; Verma et al. 1994; Sharma et al. 1994; Pulido et al. 1997; Pérez González et al. 2000; Zinck 2001; Al-Khaier 2003).

A pilot salt-affected humid area located in Toledo and Ciudad Real provinces and defined by the geographical coordinates 39°39′N–3°23′W and 39°22′N–3°4′W (Fig. 1) has been selected for analysis.

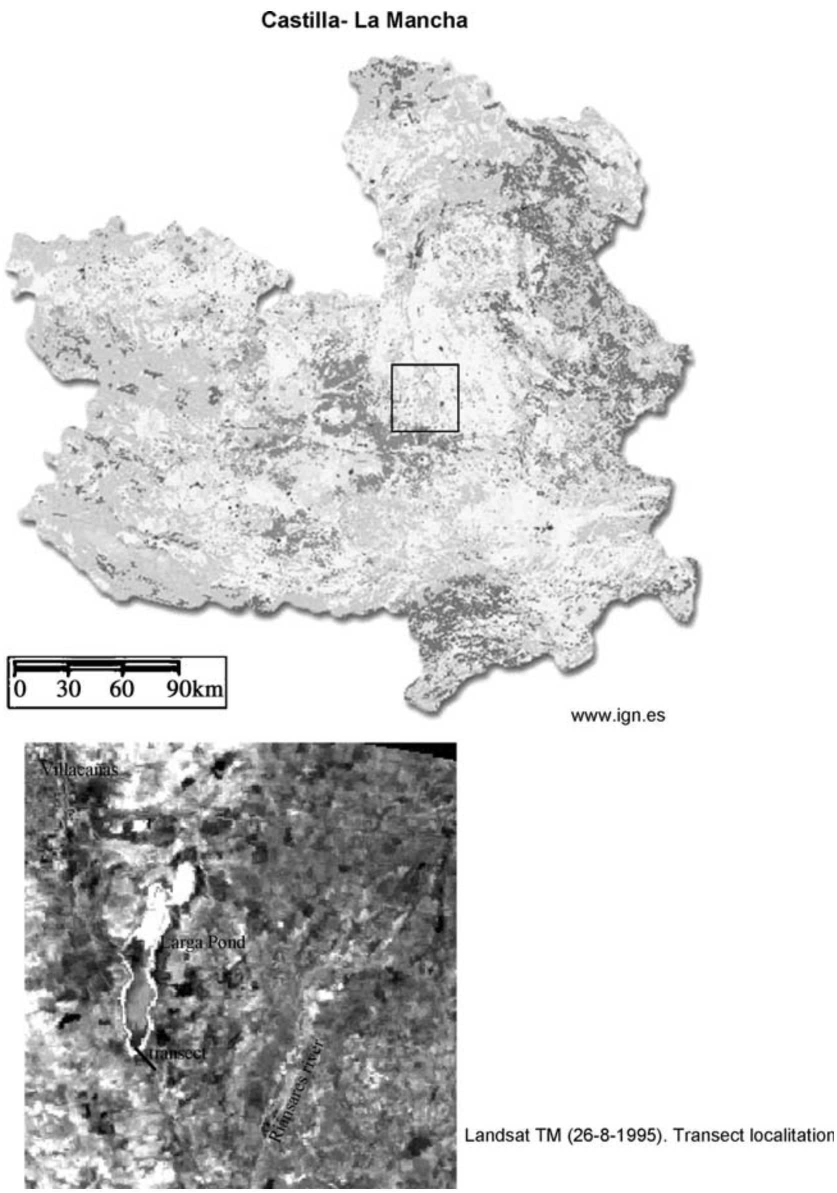


Fig. 1 Location of the study area and the transect: Corine Land Cover Image and TM Landsat 5 Image

Materials and methods

In order to identify the saline soils, six Landsat TM and ETM images from different dates were selected on the basis of ease of soil identification. The TM images are floating miniscenes (between orbits 200/32 and 200/33) dated 5-11-1992, 26-8-1995, 20-2-1997 and ETM scenes (orbit 201/32) from 6-6-2001, 10-9-2001 and 25-6-2002. These images have been georeferenced to UTM coordinates and have been radiometrically and spectrally corrected by ERDAS Imagine 8.6. The six scenes were visually analysed in visible and infrared non-thermal channels, both separately and mixed together in order to detect the surfaces occupied by saline soils.

Different indexes have been applied to every image, the most remarkable being the halophytic vegetation and the maximum extension of saline soils. Specifically the Normalized Vegetation Index (NDVI, B4-B3/B4 + B3) has been selected because it best detects saline conditions.

Once the soil in humid regions was identified, samples were taken from the pilot area from a transversal transect on the shores of the "Laguna Larga" (Villacañas) at 10 m intervals from the edge of the lake to the surrounding vegetation through the soil which have turned to Solonchak (Pérez González 1995). This is the type of soil containing halophytic vegetation.

Altogether, 15 samples were collected and analysed in the laboratory to determine the following parameters: pH in water (1:2.5), electrical conductivity (1:5), texture (Robinson's pipette), carbonates (Bernard's calcimetry), organic matter (Walkley and Black method, 1949) and colour (Munsell tables). The different parameters (physical and chemical) of the soil have been correlated with NDVI values. Initially, the main inconvenience in using the NDVI lies in the weak answer of the halophytic vegetation due to the lack of aerial appearance and spatial coverage. Therefore, when some crops are compared with the halophytic vegetation, especially in irrigated lands, this type of vegetation tends to be overlooked. Only samples coinciding with the dates of maximum halophytic plant blossoming contrasted with field findings allow for the identification and cartography of the salt-affected soils.

Results and discussion

In La Mancha the salt-affected soils in humid regions are mainly distributed concentrically around the lake areas. These are affected lagoons and lacustrine areas of azonal ecosystems. The greater salt content in the profiles is the result of superficial and underlying sediments and especially of subsuperficial and subterranean water movements in depressed areas. The distribution and extension of the saline-hydromorphic soils in La Mancha lagoons can be represented by the exemplary transect of the Laguna Larga (Villacañas), from the water layer to approximately 100 m, coinciding with the point where the soil is farmed.

The following spatial distribution appears:

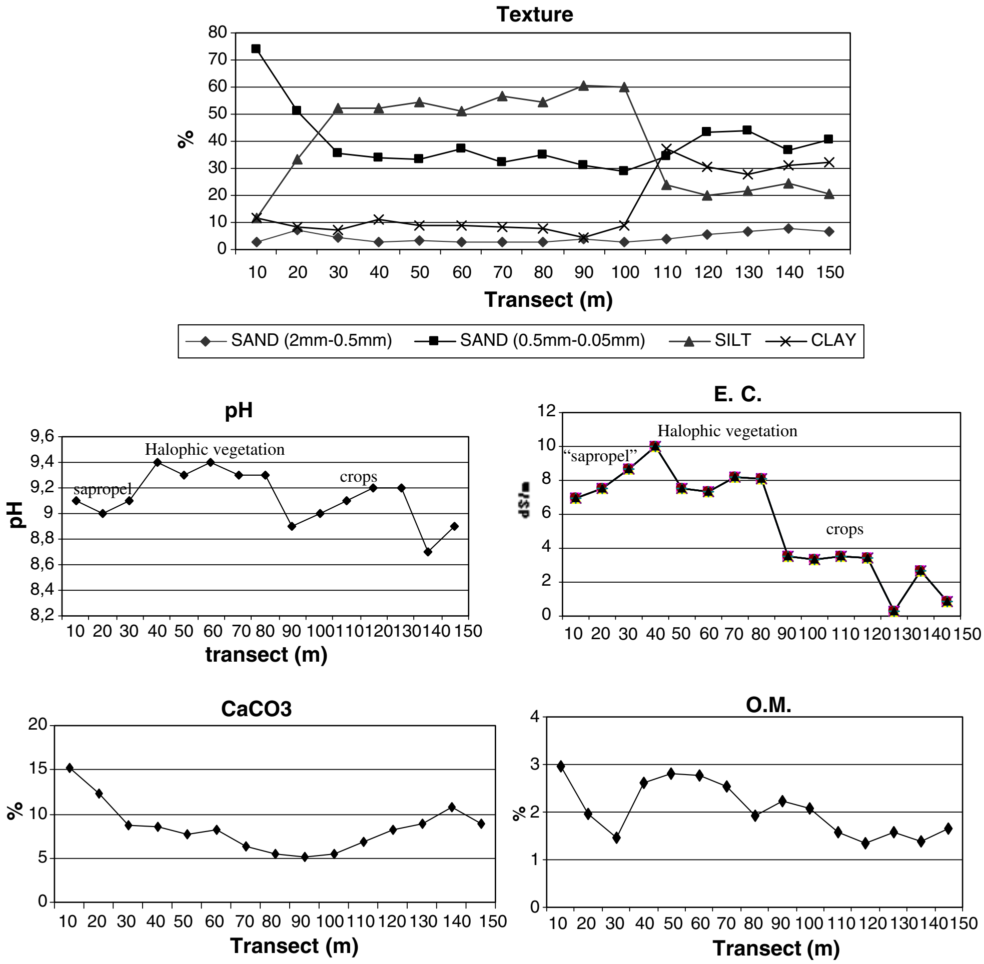
- Saline-hydromorphic soils on the lagoon shore, water saturated with noticeable salinity and a high organic matter content, and greyish colouring similar to "sapropel".
- Saline soils with unclear signs of gleization with dense hygro-halophytic vegetation. The proportion and density of the halophytic plants decrease in reverse proportion to the distance from the lagoon. In the proximity the predominant species are: *Salicornia,*

Table 1 Soil samples characterization of the studied soils transect

Sample	Dry colour	Wet colour	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	pH (H_2O)	EC (dS/m)	OM (%)	$CaCO_3$ (%)
1	2.5 Y 6/2	2.5 Y 4/2	3.0	74.1	11.5	11.4	9.1	6.97	2.96	15.2
2	10 YR 5/3	2.5 Y 3/2	7.1	51.2	33.2	8.5	9.0	7.48	1.97	12.3
3	5 YR 4/3	5 YR 4/4	5.1	35.5	52.4	7.4	9.1	8.64	1.46	8.6
4	5 YR 4/4	5 YR 3/3	3.1	33.7	52.0	11.2	9.4	10.03	2.61	8.5
5	5 YR 4/4	5 YR 3/3	3.3	33.3	54.2	9.2	9.3	7.40	2.80	7.7
6	5 YR 4/6	5 YR 3/4	2.6	37.4	50.8	9.2	9.4	7.31	2.77	8.2
7	5 YR 4/6	5 YR 3/4	2.8	32.0	56.9	8.3	9.3	8.22	2.55	6.3
8	2.5 YR 4/6	2.5 YR 3/6	2.9	35.0	54.5	7.6	9.3	8.10	1.94	5.4
9	2.5 YR 4/6	2.5 YR 3/6	4.1	30.9	60.5	4.3	8.9	3.51	2.23	5.2
10	2.5 YR 4/8	2.5 YR 3/6	2.7	28.7	60.0	8.6	9.0	3.35	2.07	5.5
11	2.5 YR 4/8	2.5 YR 3/6	4.2	34.6	23.9	37.3	9.1	3.57	1.59	6.8
12	5 YR 5/6	5 YR 4/6	5.9	43.3	20.2	30.6	9.2	3.39	1.34	8.2
13	5 YR 6/6	5 YR 5/6	7.0	43.7	21.5	27.8	9.2	0.26	1.56	8.8
14	5 YR 5/4	5 YR 4/6	8.0	36.6	24.3	31.1	8.7	2.70	1.37	10.7
15	5 YR 5/4	5 YR 4/4	7.0	40.6	20.4	32.0	8.9	0.85	1.65	8.8

EC electrical conductivity, *OM* organic matter

Fig. 2 Analytical soil data for the fine earth (< 2 mm) fraction



Microcnemum, Suaeda, Salsoda, Schoenus nigricans, Scirpus, etc. As the water saturation and salt concentrations in the soil decrease this kind of vegetation combines with *Limonium, Lygeum* and *Elymus*.

- Salt-deficient or salt-free soils used for low-profit cereal crops of the fields farthest from the lake are used for irrigation farming.Table 1 shows the main physical and chemical parameters for the soil surface in this transect.

The colour of the soils is more varied along the transect. The first two samples show grey colouring with a remarkable change to dark red shades derived from Triassic materials (samples 3–11). The samples taken from the farmed soils are reddish brown and yellowish red but are considerably lighter than the samples taken from mesozoic soils.

From the textural data (Fig. 2) we can deduce that the majority of the samples consist of very fine sand and silt. Only in soils formed from tertiary materials (samples 12 and 15) is the texture more clay-like. Along the whole transect coarse sand is barely present. The two samples corresponding to materials similar to sapropel (samples 1 and 2) have more sand than silt, but the sand calibre is less than 0.08 mm, approximately the size of silt. Soils developed on Triassic sediments have a silty texture.

The pH and electrical conductivity data show a close relationship with the soil coverings. Samples 1 and 2 have very high EC values, which is characteristic of saline soils. Samples 3–8, with very high pH and EC values can only sustain halophytic plant life. From sample 9 onwards the EC is lower than 4 dS/m, thus the soil classification is non-saline. Consequently, these soils are farmable.

The calcium carbonate content establishes a clear distinction between the two samples from the lagoon shore, the saline-Triassic and tertiary materials. The highest content corresponds to the lagoon shore and the lowest to the mesozoic materials, becoming lower the further we get from the lagoon. From sample 11 on the transition to tertiary materials, the carbonate content increases.

The highest organic matter content is in the lagoon shore and it decreases abruptly in the following two samples (samples 2 and 3). Later it increases again when the halophytic vegetation covers the soil (samples 4–7). In the farmable tertiary materials these percentages logically decrease considerably.

The influence of the hydrological regime on the soil regime moisture and soil salinity is clear because the water movement is the main vector of exchange and transport of salts between the lagoons and the surroundings (Batlle 1995).

TM and ETM Landsat images enable us to clearly discern the spatial variability of the soils and their vegetation. From several analyses the best images have been selected to show the spectral response of the soils with vegetation. The halophytic species, with poor spatial cover and height, can be distinguished spectrally by NDVI index. Date verification has been done in order to discriminate them and find the best date, which in this case is November. The values corresponding with autumn (the flowering season for *Salicornias*, *Suaedas*, etc.) slightly rise above the rest of the plants around them; this fact makes an easier visual and digital discrimination of the halophytic vegetation. The NDVI image (Fig. 3) allows the recognition of a white border around the saline humid area, but not in the area next to the water which is occupied by sapropel and has higher contents of humidity, a fact that is shown in grey colours. Therefore, although saline soils have low values, they can be digitally discriminated in autumn. Despite the high values of organic matter, sapropel does not show a positive reply in the NDVI index. The high contamination of the wetland in summer is reflected by the highest values of NDVI.

Since dry land crop area is in a marginal sector it is not cultivated every year, nor does it present vegetation in autumn/winter. For this reason the NDVI values are very low both in November and February.

In Fig. 4 the relationship between the electrical conductivity data and NDVI is represented along the transect which is the object of the study (pond of Villacañas). This reveals the transition from saline to non-saline soils. A high correlation exists between the different coverings and the conductivity values in autumn and winter, but not in summer. These data could be extrapolated to other lagoons delimiting from TM images, the extension of the halophytic vegetation and therefore of the saline soils.

Because autumn is the best period to obtain a better discrimination of the saline soils, spectral profiles of the different samples have been done for the visible and infrared near and medium channels of the transect (Fig. 5). The curve corresponding with the lagoon shows

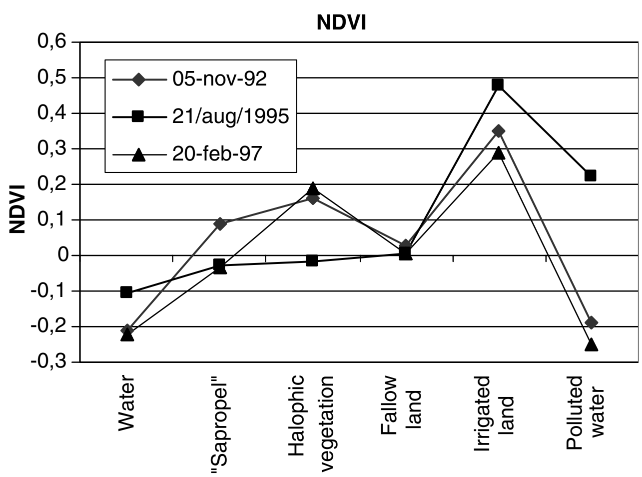


Fig. 3 Normalised Difference Vegetation Index values

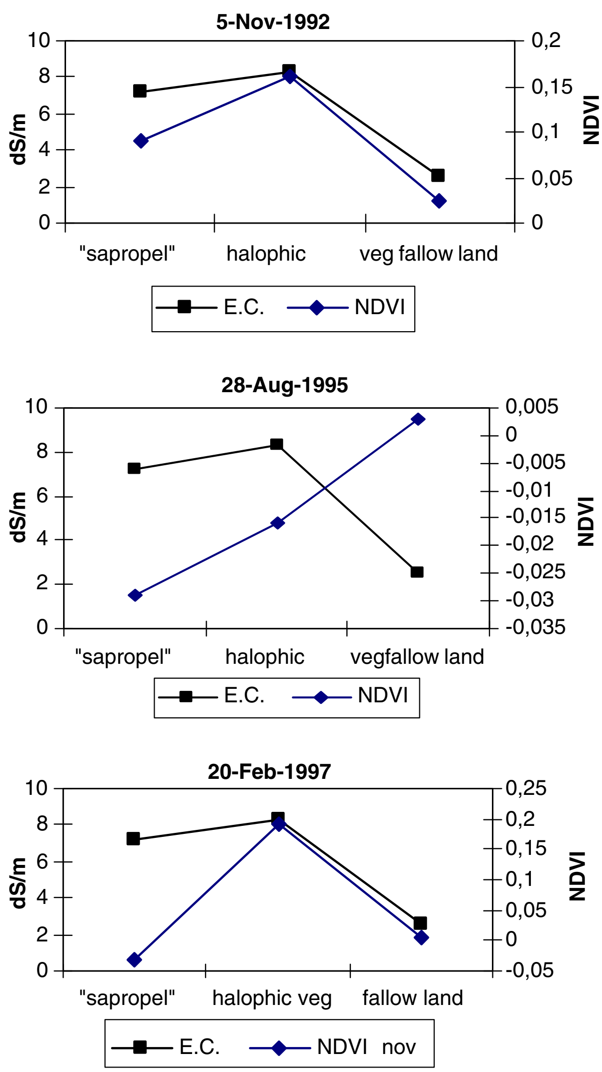


Fig. 4 Relationship between EC and NDVI

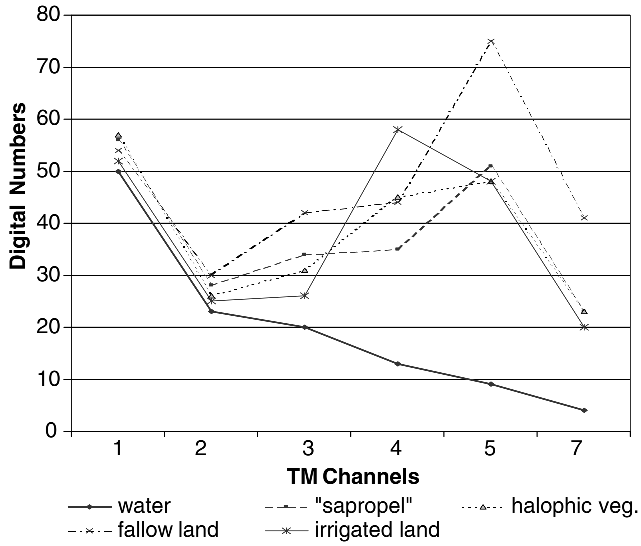


Fig. 5 Spectral profiles in saline soils

low values with minimums in the infrared bands with which it is possible to discern the extension of the water surface. The surfaces occupied by crops are also well separated spectrally because the irrigated lands have a high relation between the bands 4/5 and 4/3 whereas the dry land crops show a high response in the band 5. The sapropel has a similar curve to the bare soils but with values remarkably lower due to the high content in humidity and the dark colours given by the organic matter. The halophytic vegetation can mainly be recognized from the rest of the spectral classes because of the high relation between the bands 4 and 3. Therefore, the vegetation reveals a zoning that is related to the morphology and salinity of the soils of the environment.

Conclusions

In central Spain and specifically in the region of La Mancha there are endorrheic areas in the Mediterranean semiarid climate where shallow lagoons have salinity problems but related to seasonal changes.

Landsat images allow the identification and mapping of soils with a low agriculture quality sequence, which are periodically affected by flooding and salinity processes.

At first, the summer images give a maximum distribution of saline efflorescences but these cannot always be associated with saline soils. The highest values of reflectivity correspond to very dry soils rich in carbonates and/or sulphates. In order to delimitate saline soils it is necessary to include other elements like the type of vegetation and the water movements in the soil.

Halophytic vegetation differs from other spectral classes in the high relation between bands 4 and 3, thus in their vegetation indexes. The ideal times to discriminate these species from the images are autumn and winter because in these periods the chlorophyllic activity is higher, as shown in the vegetation indexes.

The saline soils and sediments present high digital numbers in the visible channels. On the other hand in the proximal and medium infrareds, if the materials have high humidity (over land capacity), water absorption leads to very low values disguising the salts.

The comparison of these data with the one obtained in the laboratory allows us to differentiate between the spatial variability of the soils, thus around 100–110 m of distance from the lagoon is where a higher change can be appreciated. This change reflects a clear difference in the soil quality. So vegetation distribution and soil quality are related to soil salinity levels.

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