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Contribution of Landsat data (MSS) to soil survey: application to the soil of southwestern Sinai (Egypt)

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Abstract. The first step of this study consisted of a visual analysis of Landsat images including contrast and colour analyses. This analysis helped us to locate four subimages (256 × 256 pixels). The processing of Landsat digital data consisted of several parts: (*a*) selection of the optimal channels for a multispectral classification of Landsat digital data: (*b*) determination of the thresholds, by different methods (frequency histograms, radiometric transects and radiometric characterization of the zones); (*c*) multispectral classification of digital data represented by a computer-assisted multicoloured thematic map; (*d*) drawing of a remotely sensed map of the soil surface. The computer map was used as a basis for mapping the soil surface conditions of south-western Sinai (Egypt).

1. Introduction

This research aims to present a complete method to exploit varied Landsat data as a tool for soil survey. This tool presents important assistance for soil surveying, because it allows:

(*a*) the drawing of a remotely sensed map of soil samples;
(*b*) the study of the spectral behaviour of different types of soil surface through different channels;
(*c*) the reduction of time and field work;
(*d*) increased efficiency of soil survey procedures;
(*e*) the production of a computer-assisted map, useful for mapping the soils and their surfaces.

Briefly, the study of Landsat information is an important preparatory step in soil surveying. It is also necessary for investigating the relationships between Landsat digital data and soil surface conditions (SSC).

2. Materials and methods

The area studied, located in the SW Sinai Egypt (figure 1, Egyptian Ministry of Education 1970), presents an ideal region favouring remote sensing studies due to the

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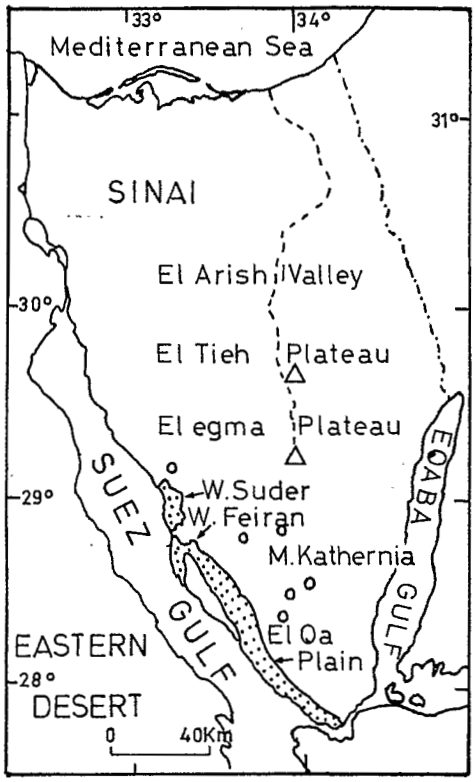

Figure 1. Location of the area studied.

absence of vegetation cover and low rainfall. This area lies completely in the Landsat scene 188–40, of 5 April 1981. The data have been studied in two successive stages: visual analysis, and the processing of MSS data.

During visual analysis the Girard method (1977) was extended to draw the contrast map. The coloured composition was analysed according to colour and structure (Babiker 1985).

Processing of the Landsat digital data consisted of three phases:

(*a*) Selection by scattergrams analysis of the most informative channels, that provide the maximal ground information.

(*b*) Determination by detailed analysis of the representative subimages of the thresholds of digital data classification. (256 × 256 pixels). This study includes three analyses: frequency histograms, transects and radiometric characterization of zones (10 × 10 pixels). This detailed study was carried out on an image display.

(*c*) Multispectral classification was carried out by the 'LOTERIE' method (ORSTOM 1978), a kind of hypercubic combination of the most discriminant channels, 4, 5 and 7. In this classification the pixels with the same digital data were grouped into 'cubes'. These cubes were then visualized and grouped into themes organized according to their radiometric values. Then this classification was represented on a computer-assisted map.

In the field the soil profiles and their surface conditions were described with special attention to the absence or presence (the abundance) of crusted-surfaces, sandy surfaces and surfaces covered with coarse elements (e.g. gravel, stones and rocks). The areas of these surfaces were estimated.

In the laboratory, the following analyses were carried out: distribution of particle size (ORSTOM 1972), total carbonates (Richards 1954), Dolomite (Peterson *et al.* 1966) and gypsum contents. The diagnostic values of FAO (1975) were used to determine the different textural types. These analyses allowed the grouping of the SSC classes into phases (Abd El-Hady 1987).

3. Results and discussion

3.1. *The visual analysis*

The visual analysis of the contrasts map and coloured composite image allowed the principal geomorphological units to be noted. Also, it provided some indications related to the spectral behaviour of different surfaces. This analysis determined the location of the four sub-images, which was based on the criterion of containing the maximal variations of colours and contrast values.

3.2. *Processing of Landsat digital data (MSS)*

3.2.1 *Selection of the most informative channels*

The channel scattergrams were traced (see figures 2 and 3). These scattergrams reveal that the pixels of channels 4 and 7 form a dispersed pattern (figure 2). This

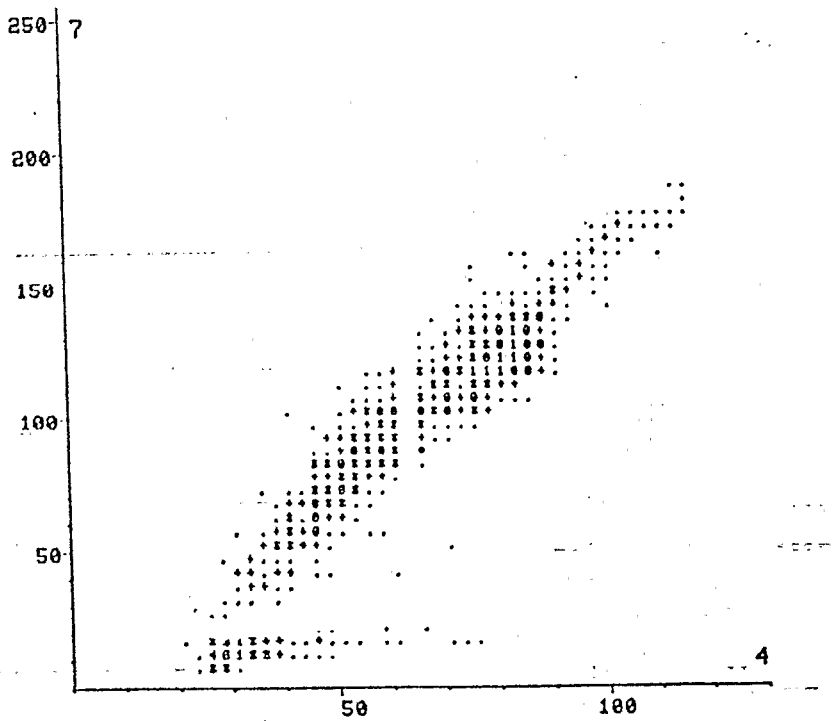

Figure 2. Scattergram of MSS 4-MSS 7.

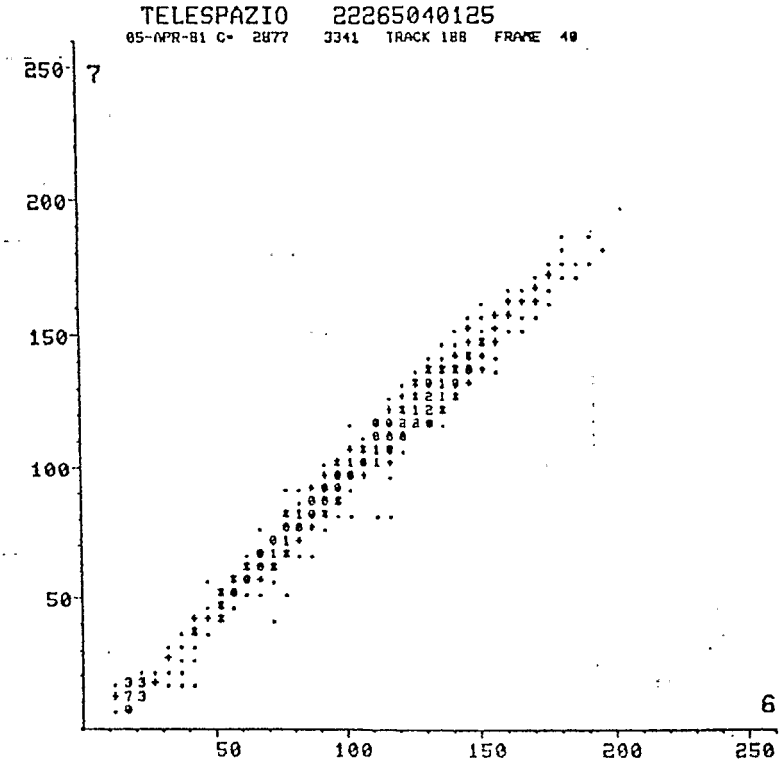

Figure 3. Scattergram of MSS 6-MSS 7.

distribution of points indicates that these two channels are less correlated with each other than are the other channels.

In remote sensing the notion of intercorrelated channels is interesting due to the use of these two channels (4,7) for:

(i) multivariable classification based on channel combinations;
(ii) studying the relationships between satellite digital data and parameters of soil surface conditions.

On the contrary, the scattergram of MSS 6-MSS 7 shows a narrow area of points (figure 3). This presentation proves the strong correlation between them. The other pairs of channels represented intermediate cases.

In conclusion, this analysis permitted the section of channels 4, 5 and 7 for data classification, Also, it reveals the importance of channels 4 and 7 for mapping the soil surface of arid regions.

3.2.2. *Determination of the thresholds by the detailed analysis of subimages.*

The determination of thresholds was carried out by a channel-by-channel study. This study included the following analyses:

(*a*) Frequency histograms were generated for every subimage. The obvious modes of the histograms and the calculation of the number of pixels in each spectral class made the segmentation easier.

(*b*) Radiometric transects. These are graphic representations that indicate the radiometric value (on the ordinate) and their positions across the transect (on the abscissa). These transects allow an estimate of the maximum and minimum values of each themes.

(*c*) Radiometric characterization of the test zones. Depending on the coloured composite images, 42 test zones were selected. Each zone might represent a distinct theme. These chosen zones were characterized radiometrically. The standard deviations (heterogeneity index), the averages and maximal and minimal values of these zones were extracted. The zones characterized by a high standard deviation were excluded from our study, while 40 spectrally homogeneous zones were chosen as observation sites.

These averages are important for multispectral classification, and also for the studying of the relationships between satellite digital data and soil surface conditions. The maximal and minimal values represented the spectral signature of the test zones.

3.2.3. *Multispectral classification*

The thresholds determined by the previous analysis were used to develop a semisuperized multispectral classification in which the spectrally similar points were packed into 'cubes'. Then they were grouped into 13 themes which were reconstitued as a computer-assisted map (figure 4). This map was used as a basis for mapping soil surface conditions (SSC).

3.2.4. *Remotely sensed mapping of soil*

The importance of the soil sampling map is due to the fact that the extrapolation of the results obtained forms the principal phase in the majority of remotely sensed studies. The validity of this extrapolation is principally dependent on the sampling scheme.

Landsat digital data allows elaboration of the remotely sensed soil map which is composed of sites of different digital data as follows.

Detailed analysis of radiometric transects and composite image was used to locate 42 test zones (sites of observation) that represent the different themes. The locations of these zones were used to map the soil sampling scheme (figure 5). Each zone contains 81 pixels (36 hectares). Every observation area is nearly four times more than the sample minimum area as estimated by Townshend (1981). The idea of the square sample shape was also respected. The orientation of the test zones was not parallel to the scan order (as it is advised). We preferred that the distribution of test zones followed the direction of slope of the area studied. This distribution offers the maximal internal homogeneity (within every zone) and the maximal heterogeneity (between the zones). This method of remotely sensed specified points was used throughout the characterization and mapping of SSC.

The field study distinguished the following main classes of SSC:

(*i*) crusted surface: gypsum and/or carbonates crust covering more 60 per cent of the zone area;

(*ii*) moderately crusted surface: 40 to 60 per cent of the zone area covered by crust;
(*iii*) sandy surface: surface free from the crust and coarse elements. The crust and/or coarse elements do not cover more than 20 per cent of the area;
(*iv*) gravelly and rocky surface: more than 40 per cent of the zone area covered by coarse elements.

The distribution of these classes was represented in figure 6, which shows that at the vallons of Baba and Suder crusted surfaces are completely absent while gravelly and rocky ones are dominant. Sand soil surfaces are widespread at the Feiran vallon and the northern part of the El-Qa plain. The superficial materials of the Cabliate Mountains cover the crusted surfaces of the surrounding region.

3.2.5. *Characterization and mapping of SSC*

This study revealed that superficial characteristics of the area studied are distributed as follows.

(*a*) The vallon of Baba is characterized by a moderately undulating surface, moderate slope, coarse texture (FAO 1975) high carbonates content, low gypsum content and strong salinity.
(*b*) The vallon of Suder is distinguished by an extremely undulating surface, severe slope, coarse to medium texture, low carbonate and gypsum content and moderate salinity.

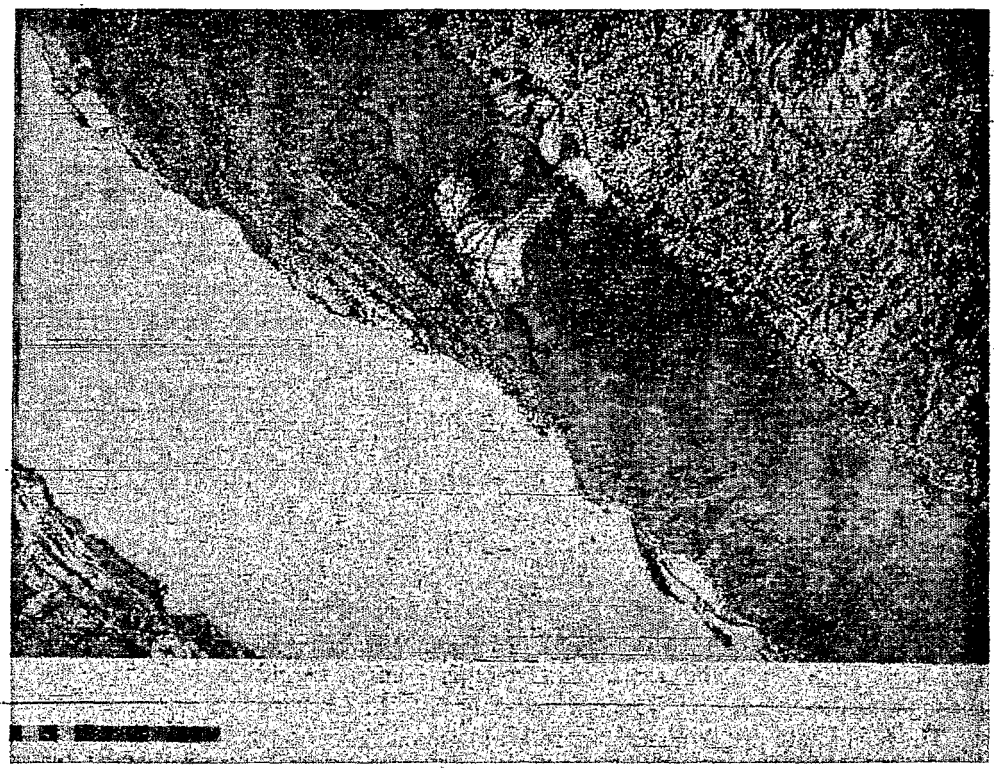

Figure 4. Computer map composed of 13 themes.

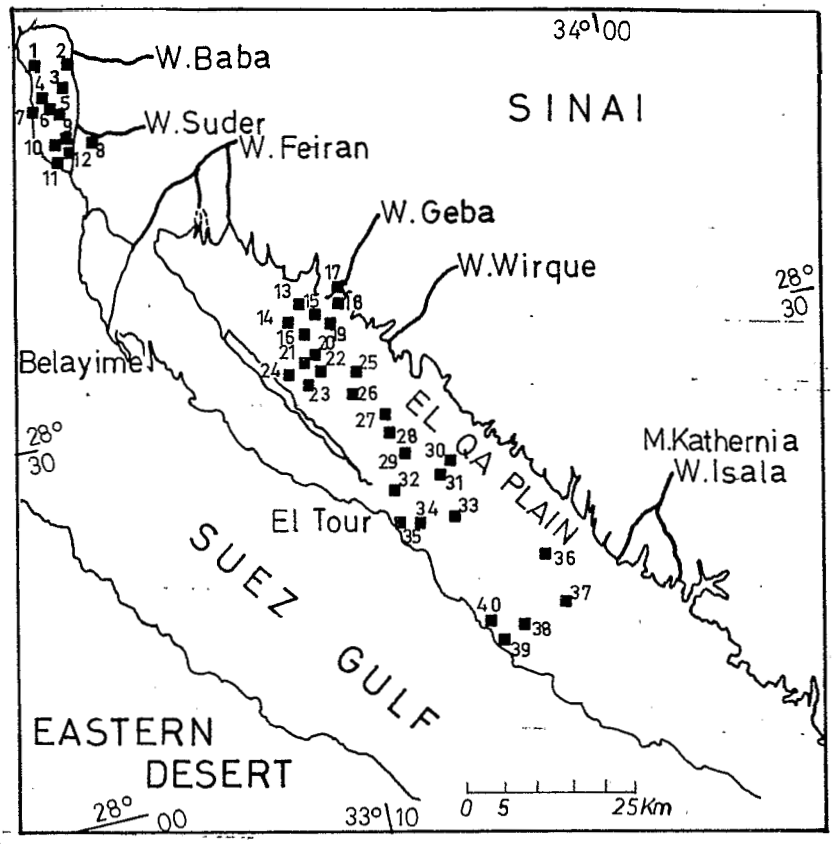

Figure 5. Remotely sensed soil sampling map.

(*c*) The vallon of Feiran is generally characterized by slightly undulating surface, gentle slope, medium texture, low carbonate and gypsum contents and weak salinity.

(*d*) The northern part of the El-Qa plain is characterized by slightly to moderately undulating surface, moderate slope, medium texture, high carbonate and gypsum contents and relatively strong salinity.

(*e*) The southern part of the El-Qa plain is distinguished by a plain surface, gentle slope, coarse texture, low carbonate and gypsum contents (with some exceptions in the north) and strong salinity.

3.2.6. *Assessment of the ability of MSS to map the SSC of the arid regions*

The comparison between the ground truth and the computer map shows that this map could not distinguish between the calcareous coarse elements and the granitic zones. On this map gravels and stones on a background of crust and/or sandy soil are similar. In the interior of some cartographic units, the distinctions between the three components (crust, sandy soil, coarse elements) have often disappeared.

This can be interpreted by the following facts:

(*a*) the surface roughness becomes the dominant factor affecting the pixels' grey levels;

(*b*) the pixels' grey levels integrate the opposite influence of the characteristics of the soil surface;
(*c*) the computer map neglects the slight difference of the pixels' grey levels.

This reminds one that the weak resolution of MSS restricts its ability to map the soil surface conditions. Accurate maps can be obtained in the regions that are characterized by distinct SSC. Also, the integrated interpretation helps to obtain accurate maps.

4. Conclusion

This study has led us to conclude that the visual analysis of satellite images permits us to trace the principal geomorphologic unit; it is also a good means of locating the subimages. Processing satellite digital data facilitates soil surveying, supplying us with a remotely sensed map for soil sampling that is an efficient guide for pedological prospection; a computer-assisted map as a basis for the mapping of soil surface conditions of the arid regions; a radiometric characterization of test zones, important for the study of relationships between satellite digital data and the SSC.

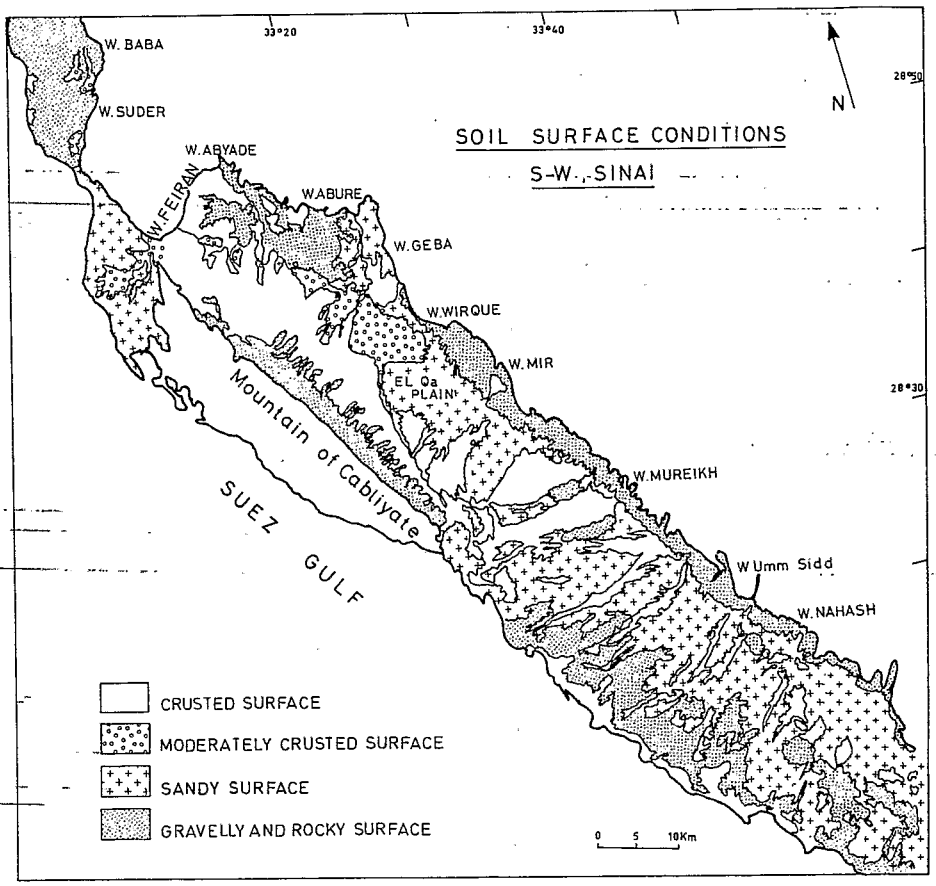

Figure 6. Map of the soil surface conditions (south-western Sinai).

In arid regions, the SSC can be grouped into four classes according to the surface composition (crust, coarse elements, sandy soil). Based on certain adaphological characteristics, these classes are subdivided into phases.

The characterization and mapping of SSC shows that the northern part of the El-Qa plain and the vallon of Feiran have higher agricultural potential in the south-western Sinai.

The relationship between the SSC and their underlying soils were physiographically established. Three great groups were differentiated; Gypsiorthids, Paleorthids and Salorthids. The two first great groups were also classified down to the family level (Abd El-Hady 1987).

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