APPLICATION OF REMOTE SENSING TO MAPPING OF EXPANSIVE SOILS AND ROCKS IN OMAN

Anil K. Bagchi[1], Amer A. Al Rawas[2], Ali Al Barwani[3]
[1, 2, 3] Associate Professor, Lecturer and Undergraduate Student, respectively.
Department of Civil Engineering, Sultan Qaboos University, P.O.Box 33, Al-Khod, 123, Sultanate of Oman

Commission VII, Working Group 6

KEY WORDS: Remote_Sensing, Soil, Classification, Mapping, Multispectral.

ABSTRACT:

Presence of expansive soil increases cost and time for many civil engineering construction projects. Identification of the expansive soils and rocks using remote sensing, which involves less ground visits, should be useful. This has therefore been taken up as an ongoing research in the Civil Engineering Department of Sultan Qaboos University using the facility available in the Remote Sensing Center. The Center is equipped with a PC based system, consisting of a number of PC's, duly networked, and appropriate peripherals. The software in use is ERDAS.
A large scale geotechnical mapping program was carried out covering the entire country. The geotechnical information including the subsurface soil profile and soil characteristics were collected from more than seventy towns. A brief report on the ground situation is included.
The remote sensing phase of the investigation started with identification of a few training samples. Next job is to develop a signature, a rather elaborate exercise in finding statistical parameters which can represent the training samples. Identification of expansive soil is thereafter tried using the supervised classification technique, following the maximum likelihood decision rule. Success and applicability of one or the other of the methods depend upon the nature of the data structure, uniqueness of the signature, statistical distances between the signatures, nature of information class being sought, spectral bands used etc. All these were kept in view and studied at appropriate places.
All the three groups of spectral bands - visual, infra-red and microwave- have been applied for the investigation. The data source is restricted to the satellites JERS and Landsat TM. The final result of classification appears in the form of a classified map.

1. INTRODUCTION

Expansive soils and rocks are those which undergo volumetric changes upon wetting and drying. These materials swell when the moisture content is increased and shrink when the moisture content is decreased. The moisture change can be due to natural sources such as rainfall or manmade sources such as surface irrigation, broken water supply and sewers, and leakages from swimming and feature pools. These materials cause distress and damage to engineering structures founded on them. It was reported that the annual cost of damage from expansive soils in the United States alone exceeds $ 10 billion, Steinberg (1992).

Oman has experienced a tremendous urban expansion in the last two decades. This expansion was accompanied by a sharp increase in water consumption which means that considerable amounts of water are infiltrating into the ground. Several structures have suffered from various types of damage due to wetting of the foundation soil, from water ingress into the ground. The structural cracks are observed in different types of structures such as residential houses, garden walls, roads and open drainage channels. The pattern of cracks seems to vary depending upon the upward movement. As a consequence of the structural damage evidenced, the potential problems associated with the Omani expansive soils and rocks have been recognised and preventive measures are being incorporated into new designs and construction works.

Studies in the possibility of applying remote sensing technique to identify and map the expansive soils and rocks has therefore been undertaken in the remote sensing centre of Sultan Qaboos university of Oman. The Center is equipped with a PC based system, consisting of a number of PC's, duly networked, and appropriate peripherals. The software in use is ERDAS. It is an on-going research and the present paper is a status report.

2. EXPANSIVE SOILS AND ROCKS IN OMAN

The regional geology of northern Oman is dominated by the Oman mountains and is geologically distinct from the rest of the Arabian Peninsula. The problems of ground heave experienced in Oman are predominantly related to the presence of smectite clay minerals with mainly Tertiary rocks and Quaternary soils (Al-Rawas et al 1992).

It is widely recognized that the formation of the smectite group is greatly influenced by the composition of the parent rocks. Van der Merwe (1964) has indicated that the decomposition of basic and ultrabasic igneous rock can result in the formation of residual soils containing montmorillonite. Basic and ultrabasic igneous rocks are well represented in Northern Oman by the wide spread exposure of late Cretaceous Semail ophiolite (Figure 1).

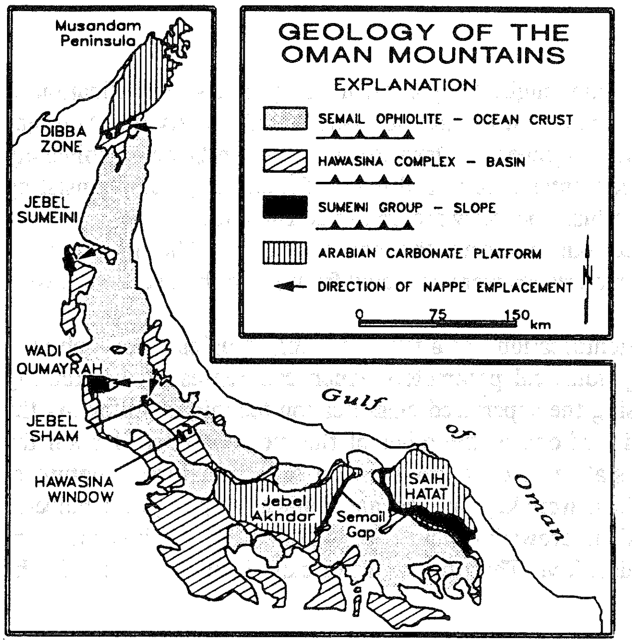

Figure 1. Geological Map of Oman Mountains Showing the Semail Ophiolite (Watts, 1990).

The Semail ophiolite has been weathered at various periods in geological time and the weathering products are now contained within a range of Tertiary rocks and Quaternary soils. Thus there are a number of materials in Northern Oman which may be identified as having swelling potential. These are Bentonitic Mudstones, Marls and Silty Mudstones, Argillaceous Dolomitic Limestones, Altered Conglomerates and Desert Fill. All of these materials, except the desert fill, tend to form impersistent bands within mainly Tertiary conglomerates and limestones.

The climate in Oman is arid, with evaporation rates higher than the annual rainfall, so that there is almost always a moisture deficiency in the soils and rocks. Supply of water from any source is thus liable to cause ground heave over any soils or rocks possessing swelling potential.

Al-Rawas (1995) reported that the mineralogical investigation conducted on samples from Al-Khod and Al-Murtafa'a has shown that smectite is the predominant clay mineral. Nevertheless, Kaolinite, illite and swelling chlorite clay minerlas are also present in these soils and rocks in small percentages. Chemical analysis has shown that Na and Ca cations are predominant while magnesium and potassium cations are present in small percentages. The microfabric tests conducted on the same samples revealed that the microfabric of the Omani expansive soils and rocks consists of dense clay matrices, although clay-granular matrices are observed occasionally.

3. SATELLITE DATA AND PRELIMINARIES

Data from two satellites have been used in the current phase of the research. They are Japanese Earth Resources Satellite (JERS) and Landsat (Thematic Mapper, TM). The pixel sizes of these images are 18m.sq and 30m.sq. respectively. The available spectral bands of JERS are tabulated below ; Landsat bands are well reported in literature and are not repeated here.

Table 1. Spectral Bands of JERS 1

Band	Central wavelength, µm	Band width,µm
1	0.56	0.08
2	0.66	0.06
3	0.81	0.10
5	1.655	0.11
6	2.065	0.11
7	2.190	0.12
8	2.335	0.13

The spectral response generally reported in literature for study of soils are of limited use in this case. This is because the type of information being sought is a buried phenomenon and there is no clear understanding of the resultant spectral response.

The soil sustains only a very specific class of vegetation. Also the surface takes a special look being subject to characteristic periodic minor and uneven swelling due to limited infrequent rainfall. All these- the soil, surface texture and vegetation- together are likely to result in a class which should permit multispectral classification.

3.1 Histograms

Histograms of all the bands were plotted to see if their distribution is suitable enough for application of the more important supervised classification technique, namely the maximum likelihood classification technique. These are given in Figure 2. The data structure seems good enough for the purpose. The distributions are however slightly skewed, for which apparently there is no explanation.

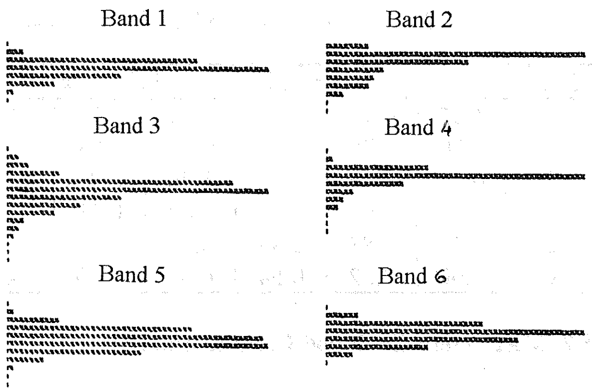

Figure 2. Structure of Brightness Values (TM)

3.2 Suitability of Bands

Brightness values of several points corresponding to the bands of both TM and JERS were read and their mean values plotted to find the spectral response characteristics. These are presented in Figure 3 (TM bands only). The response figures vary considerably from band to band which is encouraging. There are 6 bands of JERS and 7 bands of TM giving us a reasonable choice of bands.

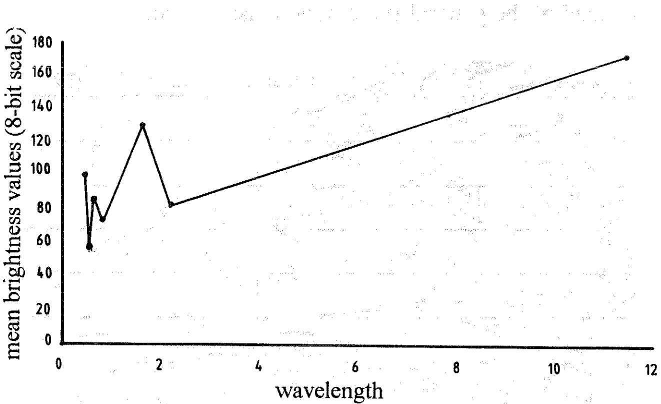

Figure 3. Mean Reflectance Against Corresponding Wave Length (bands of TM) - Expansive Soil (Sample 1)

3.3 Laboratory Analysis of Specimen

The minerals responsible for giving expansive characteristics to the expansive soils are generally found buried beneath the surface. In rare cases however they are found to be exposed to the surface. Some of them have been collected by the second author and four specimens were subjected to laboratory analysis for knowing the spectral characteristics. One of the response curves appear in Figure 4. The laboratory result could not be incorporated in the signature generation operation.

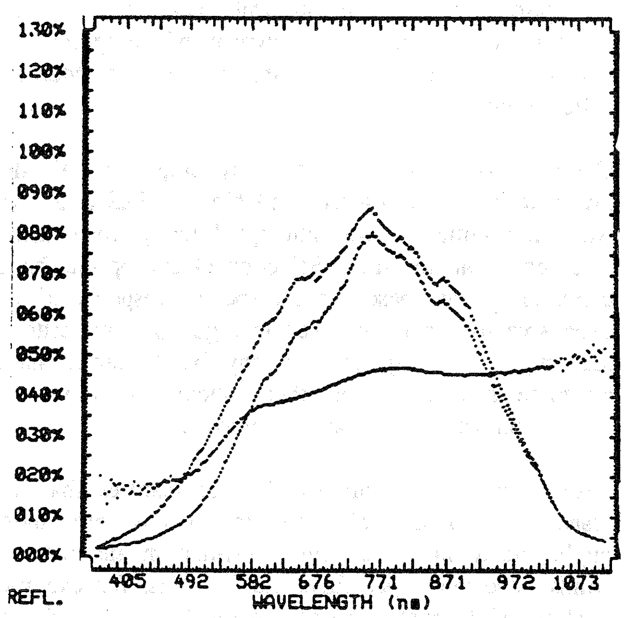

Figure 4. Spectral Characteristics of specimens

4. TRAINING SAMPLE

Extensive site investigations have been carried out in Muscat for construction purposes and for locating places suitable for development. Four such areas were selected as training samples. The sample patches vary in size; one of them, rectangular in shape, measure about one sq. km. Boundaries of these patches were surveyed using a hand held Global Positioning System (GPS). They were identified on the satellite images with the help of the GPS coordinates. For this the images had to be rectified beforehand using Ground Control Points (GCP) located and read on the available topographical map of the area. The mean values of the residuals indicate reliability of the rectification achieved :

$\delta E = 18.3$ m $\qquad \delta N = 24.8$ m

The GPS was used in single observation mode which is less accurate than the double observation mode. So this, together with the rectification error, contributed to the location uncertainty. But considering the fact that with limited number of drilling there is always an uncertainty of exact location of the boundary and further noting the fact that expansive soil is not a sharply defined land cover it can be said that sufficient accuracy has been achieved.

5. CLASSIFICATION

Classification accuracy depends upon the data quality, data structure (distribution type), number of features, noise in the data, the number of bands employed, correlation among the spectral data, classification technique employed etc. Employment of the appropriate strategy is therefore a matter of considerable deliberation.

Classification was done first by employing all the available bands separately available in JERS and TM. Next, the same job was attempted many times using three bands at any time. Selection of appropriate band combination was based on the spectral response to the expansive soil cover as given in Figure 3. Two criteria are important: response for any band should have adequate specificity and there should be minimum correlation between the bands employed.

Visible bands are more suitable for features that are visually distinguishable. Infrared bands are more applicable to moisture content estimation and thermal bands have very specialized applications, for example analysis of thermal content and regime etc. Success of identification of expansive soil in the arid areas of Oman is expected to depend on the visual characteristics, moisture content and also thermal properties. Combinations of all these groups have therefore been tried.

5.1 Signature Generation

The parameters that constitute a spectral signature are the mean and standard deviation of the brightness values (BV) and the variance-covariance matrix. These are extracted from the BVs of pixels situated in the training sample area. This is now a routine affair using a standard software. It is therefore possible to study the problem in depth. Thus the training sample No.1 which cover a rather big area was divided into nine sub-samples and signatures of each extracted . To check homogeneity of the cover represented by the sample, Euclidean distances between the sub-sample signatures were found. It was found that the training sample is homogeneous enough to be considered representative of expansive soil in arid Omani environment. A sample signature statistics is given in Table 2. Signature generation was repeated for each band combination.

Table 2. Signature Statistics Listings

Band	1	2	3	4	5	6
Min.	57	92	116	93	123	87
Mean	60.0	94.0	121.2	96.3	127.4	90.4
Stan.	1.0	1.5	1.8	1.3	1.3	1.2
Max.	64	100	130	103	133	94

Min. = Minimum, Stan. = Standard, Max. = Maximum

Table 2. Signature Statistics Listings (continued)

Band	Covariance Matrix					
1	1.05	0.10	0.12	0.04	0.16	0.00
2	0.10	2.25	1.40	0.99	0.83	0.22
3	0.12	1.40	3.21	1.26	0.98	0.54
4	0.04	0.99	1.26	1.64	0.53	0.32
5	0.16	0.83	0.98	0.53	1.78	0.30
6	0.00	0.22	0.54	0.32	0.30	1.46

5.2 Maximum Likelihood Classification

The standard classification method Maximum Likelihood Classification method was applied. This is the most widely used classification technique which presupposes that the spectral data is normally distributed. As given above this is indeed the case with reasonable accuracy. The exercise in the present research is to make a two-class classification. This can be done only if we specify a threshold. There is no clear guideline to decide the limit and hence it had to be decided rather arbitrarily, using trial and error method. The result of classification was presented in the form of a map of the area . The whole operation was repeated for each band combination using different satellites. Figure 5 is one of the several outputs, where six bands of JERS were used instead of the general three band classification.

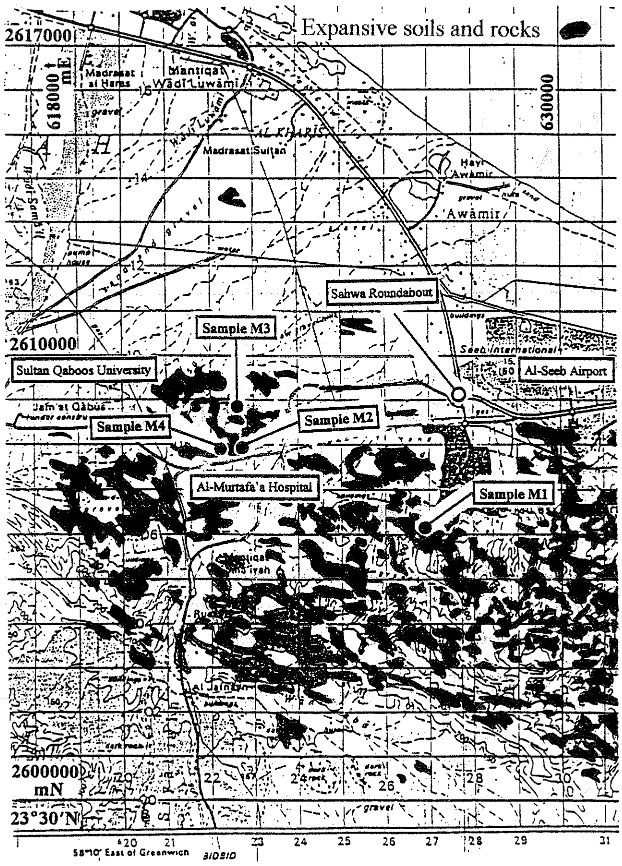

Figure 5. Gaussian Maximum Likelihood classification

5.3 Evaluation of the Result and Discussion

The four training areas were classified correctly by the computer. It also showed a large area as expansive soil. The area has been left open by the city authorities as unsuitable for construction purposes due to presence of expansive soil. Thus the classification looks correct. In addition, site investigation at a few additional places confirm the accuracy of the classification. However this cannot be taken as a satisfactory ground check which will need elaborate and expensive drilling. The authors do not have a clue on how this can be done. By applying several band combinations involving different satellites and using different classification routes it is hoped a satisfactory and stable solution at the remote sensing stage can be achieved. The results from different sources and through different techniques are to be combined for which a satisfactory algorithm has to be developed like the one in Wang and Civco (1994). Elaborate site investigation will then be attempted to establish reliability of application of the remote sensing technique to mapping of expansive soils in the arid environment of Oman. A final point is relevant: remote sensing is basically a surface investigation technique. Also it employs almost exclusively the only criterion , tone, whereas human pattern recognition could involve about nine parameters (Lucas and Frans, 1994). Expectation from remote sensing as a tool for solving the present problem should therefore be tempered with reality till we come across any smart system which will be able to incorporate other criteria in the pattern recognition process.

6. ACKNOWLEDGMENT

Laboratory reflectance studies of a few expansive materials specimens were done in Boston University under the guidance of Dr. Farouk El-Baz. This is acknowledged.

7. REFERENCES

Ali, M.M.A., (1995). Mapping of expansive soil using remote sensing technique. B.Sc. Project Report (unpublished), Civil Engineering Department, Sultan Qaboos University, Al-Khod, Sultanate of Oman.

Al-Rawas, A.A. and Woodrow, L.K.R., 1992. The Distribution of expansive soils in Oman. Proceedings of the Seventh International Conference on Expansive Soils, Dallas, Vol. 1, pp. 432-437.

Al-Rawas, A.A., McGown, A., Woodrow, L.K.R. and Sivakugan, N., (1995). The expansive soils and rocks of Oman. Proceedings of the Eleventh European Conference on Soil Mechanics and Foundation Engineering, Copenhagen, Vol. 3, pp. 3.1-3.6.

Lucas L.F. and Frans J.M. van der Wel, (1994). Accuracy assessment of satellite derived satellite land-cover data: a review. Photogrammetric Engineering and Remote Sensing, 60(4), pp. 419-426.

Steinberg, M.L. (1992). Controlling expansive soils: twenty Texas highways projects. Proceedings of the Seventh International Conference on Expansive Soils, Dallas, Vol. 1, pp. 392-397.

Van der Merwe, D.H., 1964. The weathering of some basic igneous rocks and their engineering properties. The Civil Engineer in South Africa, pp. 213-222.

Wang, Yeqiao and Civco, Daniel l., (1994). Evidential reasoning-based classification of multi-source spatial data for improved land cover mapping. Canadian Journal of Remote Sensing, 20(4), pp. 381-395.

Watts, K.F. (1990). Mesozoic carbonate slope facies marking the Arabian platform margin in Oman: Depositional history, morphology and palaeogeography. In the Geology and Tectonics of the Oman Region, edited by Robertson A.H.F., Searle, M.P. and Ries, A.C., Geological Society, London, pp. 139-159.