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VEGETATION ANALYSIS IN DESERT ENVIRONMENT USING SAR IMAGERY

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Abstract: Orbital synthetic aperture radar (SAR) C-band data acquired by ERS-1/2 in vv-polarization and Radarsat in hh-polarization during the period from 1996 to 1999 were used to evaluate their combined information potential for classification of land cover in the arid environment of Kuwait. Individual SAR scenes were orthorectified using a digital elevation model (DEM) of Kuwait, radiometrically adjusted for incidence angle effects, and mosaics were generated for the whole country. Thirteen classes of the joint ERS-1/2 and Radarsat images were identified based on Bhattacharya distance and geospatial pattern. The high degree of correlation between the C-band radar backscatter observed by ERS and Radarsat made unambiguous classification of surface material difficult when using C-band data alone. However, the physical data collected at the ground verification sites were used to assign nominal categories to the radar clusters that resulted from unsupervised classification. This categorization or relabeling of the clusters then provided the basis both for the generation of thematic maps and for accuracy assessment. Backscatter is shown to be related to the percent cover by annual vegetation for ERS, while its influence appears to be somewhat less for Radarsat. Backscatter was observed to be positively related to the percent cover by perennial vegetation. Radar backscatter is more highly correlated with total vegetation volume for ERS than for Radarsat, and is probably a consequence of both the lower angle of incidence for ERS and its vv-polarization. In addition to vegetation cover, the C-band radar data were found to be related to surface roughness, percentage of coarse material in the surface layer, and moisture conditions.

Keywords: SAR; ERS, Radarsat; C-band, Arid environment; Vegetation cover; Land classification, Image processing; Kuwait

1. Introduction

The majority of synthetic aperture radar (SAR) imagery applications in land use and land cover mapping have been related mainly to vegetation identification and biomass estimation. It is well known that the type and quantity of vegetation cover can exert considerable influence on the quantity of radar backscatter from terrain (Dobson et al. 1995, Lo 1998). Radar is sensitive to vegetation type with respect to the geometry or architecture of plants as defined by the size of woody and foliar elements relative to wavelength, shape and orientation. Vegetation serves to both scatter the incident field, some of it in the backscatter direction, and also attenuates the field, which can result in reduced scattering from the surface layer—generally causing a reduced sensitivity to surface properties such as roughness or soil moisture. Thus, vegetation can either increase backscatter relative to a soil surface or decrease backscatter depending upon the type of vegetation, its quantity per unit area and also its moisture content. Vegetation type, quantity and moisture content are not static variables, but are highly variable in time—especially in arid regions with strong seasonal influences. The coverage and quantity of both annual and perennial vegetation are strongly influenced by annual variability in temperature and precipitation. Seed establishment, germination and the availability of soil moisture are the primary limiting factors. Grazing pressure and timing can also reduce vegetation cover, perhaps in a selective fashion due to the feeding preferences of herbivores. Greeley and Blumberg (1995) reported clear distinctions between grazed and ungrazed desert in the southwestern United States using SIR-C data.

In this study, C-band vv-polarized (ERS) and hh-polarized (Radarsat) SAR data are evaluated for mapping terrain classes, land use patterns, surface roughness variations and vegetation type and cover in the desert environment of Kuwait. After supervised and unsupervised classification methods, the physical data collected in the field are used to assign nominal categories to the radar clusters. This categorization or relabeling of the clusters then provides a basis both for the generation of thematic maps and for accuracy assessment. This paper focuses on the analysis of vegetation type and cover percent using ERS, Radarsat and field measurements.

The State of Kuwait is characterized by a desert type of environment with scanty rainfall, and a dry, hot climate. Summer is very hot, especially July and August, with a mean temperature of 37.4°C and a maximum mean temperature of 45°C. The average total yearly potential precipitation recorded the past 50 years is 115 mm, and occurs mainly between October and May. The potential evaporation rate is 16.6 mm day per day.

Kuwait's vegetation consists of undershrubs, perennial herbs, forbs, and spring ephemerals. Because of the desert nature of the environment, vegetation is quite sparse and rarely exceeds 2 m in height. The vegetation types are controlled by four major ecosystems, i.e., sand dunes, desert plain, desert plateau, and salt marshes and saline depressions (Halwagy and Halwagy 1974). The predominant plant communities are *Stipagrostis plumosa, Cyperus conglomeratus*, and *Haloxylon salicornicum* (Omar et al. 2001). Kuwait’s vegetation cover has deteriorated and the distribution pattern has changed considerably over the past 30 years because of unrestricted overgrazing and other forms of land degradation. In general, natural vegetation is denuded in desert areas except in fenced or restricted areas where vegetation cover may attain a potential ground cover of 25 to 50% (Halwagy et al. 1982, Omar 1990). In rangeland areas, vegetation cover rarely exceeds 5%. Vegetation distribution is quite variable and depends on rainfall, landform and biotic factors. Variations in the quantity and distribution of vegetation cover observed in satellite images of Kuwait are directly related to the amount of rainfall that occurs between October and April, overgrazing, and other forms of land degradation (Kwarteng and Al-Ajmi 1996). Wadis or dry drainage channels have the tendency to support more vegetation than the surrounding areas because of the relatively high moisture content of sand trapped in the channels.

2. Methodology

Nine ERS-1/2 and six Radarsat S4 beam mode images of Kuwait and surrounding areas recorded between 1996 and 1999 were used in this study (Table 1). The data were radiometrically corrected and orthorectified to the universal transverse mercator (UTM) projection, zone 38 and WGS 1984 ellipsoid over a digital elevation model (DEM) of Kuwait generated from hypsography vectors. Each orthorectified scene was verified to be accurate to within 2 pixels (i.e., 50 m) overall from comparison with digitized road vectors dataset. The ERS and Radarsat datasets were radiometrically corrected for local angle effects, different acquisition dates, and mosaics were generated for the whole country (Kwarteng 2000). An adaptive spatial filter was used to increase the number of effective independent looks prior to generation of feature vectors based on SAR backscatter power values.

Both supervised and unsupervised classification techniques were used in this study. The fuzzy K-means clustering algorithm was selected for data analysis and investigation. For a complex landscape, fussy K-means is most preferred for ground cover classification as the results appear to be most closely related to the ground data (Duda and Canty 2002). In the fuzzy K-means algorithm, pixels are clustered using a maximum likelihood approach that assumes Gaussian distributions for each cluster. The cluster centroids are computed as the weighted average of all of the membership value-weighted pixels. A cluster optimization procedure performed on the ERS, Radarsat, and combined ERS/Radarsat mosaics, resulted in image classifications with 20 spectrally and geographically dissimilar clusters.

A three-week-long intensive ground sampling campaign was conducted from March 31, 2000 through April 16, 2000, to collect data for cluster-class assignment and to assess the accuracy of the combined ERS/Radarsat unsupervised fuzzy K-means clustered image. Over

250 sampling sites were selected by the methodology of Congalton and Green (1999). The sites were selected taking into consideration the accessibility (primary and secondary roads, and trails) and security (restricted and areas along the borders) of the areas. Each pre-selected site was located in the field to within better than 20 m using a global positioning system (GPS). The following information was collected for each site:

1. GPS reading with a hand-held GPS receiving unit;
2. Two photographs, using digital cameras, to show mid-range panoramic general overview of a recorded look direction of the terrain, and a close-up to show detail ground surface material;
3. Description of near-surface soil including grain sizes and percentages, soil layer type, soil texture, density (loose or compact), and soil color using the Munsell Rock Color Chart;
4. Local and regional soil roughness including grain size distribution, percentage and net volume of stones and general roughness;
5. Vegetation cover including, type, total percentage cover, and size (height and width) of perennials and annuals, and names of dominant species, if known;
6. Soil moisture and depth to moist soil; and
7. Miscellaneous measurements including relative topography, general geomorphology (e.g., flat, hummocky, etc), presence of sabkhas and nebkahs, origin of pebbles and gravels, and presence or absence of dunes, as well as their relative sizes and orientations.

Table 1. SAR data for Kuwait used in this study.
(*a*) ERS

Spacecraft	Orbit	Frame	Acquisition date	Time	Product type	Pass direction
ERS-1	17137	2997	25 Oct 1994	10:25	PRI	Descending
ERS-1	25230	2996	12 May 1996	10:25	PRI	Descending
ERS-1	25230	3014	12 May 1996	10:26	PRI	Descending
ERS-1	25230	3032	12 May 1996	10:26	PRI	Descending
ERS-2	05557	3015	13 May 1996	10:26	PRI	Descending
ERS-1	25459	3014	28 May 1996	10:23	PRI	Descending
ERS-1	25459	3032	28 May 1996	10:23	PRI	Descending
ERS-2	20358	3015	13 Mar 1999	10:28	PRI	Descending
ERS-2	23128	3015	22 Sep 1999	22:13	PRI	Ascending

(*b*) Radarsat beam mode S4

Orbit no.	Acquisition date	Time	No. of looks	Resolution (m)	Sensor configuration
5310	10 Nov 1996	05:49	4	12.5	Descending
5410	17 Nov 1996	05:45	4	12.5	Descending
5489	22 Nov 1996	17:51	4	12.5	Ascending
7025	10 Mar 1997	05:49	4	12.5	Descending
7125	17 Mar 1997	05:45	4	12.5	Descending
7204	22 Mar 1997	17:51	4	12.5	Ascending

3. Results and discussion

Each of the 20 clusters generated from the combined ERS/Radarsat fuzzy K-means unsupervised clustering was examined with information provided by the ground sample database. The clusters were reduced to a final set of 13 distinct radar surface classes aggregated on the basis of Bhattacharya distance and spatial pattern (Figure 1).

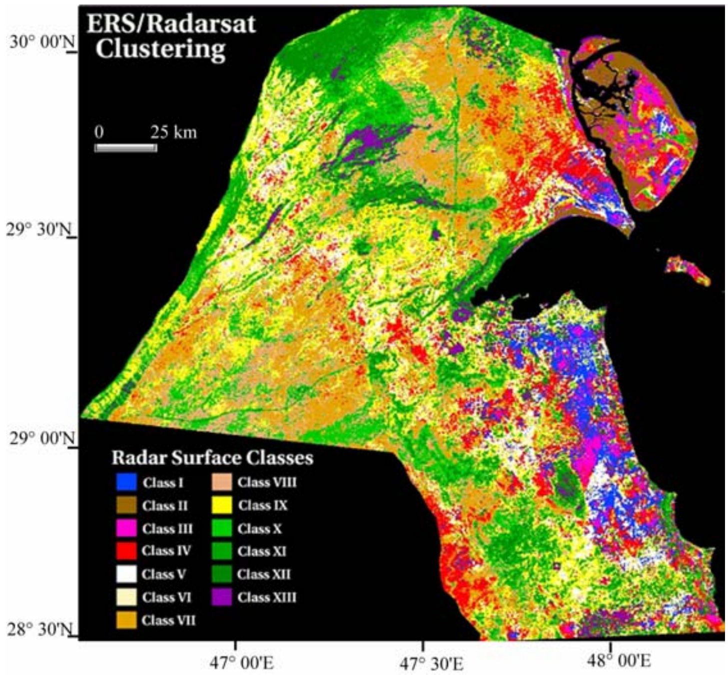

Figure 1. Image of Kuwait showing the final 13 surface classes generated from the ERS and Radarsat datasets.

Radar backscatter depends upon surface geometric properties such as roughness, the dielectric constant of the surface layer which is mainly related to moisture content and density, and the quantity and type of vegetation cover. Through the development and validation of theoretical scattering models, how each of these components affects radar backscatter is generally well understood. Inverse models that estimate a scene's physical properties from radar backscatter have been constructed and successfully used for certain applications. In order to be successful, such models typically require simultaneous radar observation with greater frequency and/or polarization diversity than that afforded by the C-band ERS-1/2 and Radarsat data used in this study. Hence, this approach was not taken since the dataset is under-determined and will yield non-unique solutions. However, the physical data collected at the ground verification sites were used to assign nominal categories to the radar clusters that result from unsupervised classification. This categorization or relabeling of the clusters then provides a basis both for generation of thematic maps and for accuracy assessment.

While most of the properties recorded in the field were not measured with great precision, they are sufficient to generate some coarse indices and to permit the calculation of some derivative quantities, such as an estimate of vegetation volume. Vegetation volume is defined as the product of the percent cover and the average height (in centimeters). For example, if the total percent cover is 40% and the average vegetation height is 10 cm, then the vegetation volume would be 4 cm. Further analysis in this paper is limited to vegetation characteristics.

The types and relative abundance of vegetation were observed in April 2000 at each of the approximately 250 sites checked in the field. These observations do not necessarily correspond to the conditions prevalent during the times of radar data acquisition by ERS and Radarsat. The field data were purposely obtained during the spring period in order to observe conditions at or near vegetation maxima—as inevitably reduced by grazing. However, the vegetation cover for each spring season depends upon the amount and the rainfall period.

The average characteristics (percent cover, height and volume) of annual vegetation types are compared for the various radar classes in Figure 2. Class II was devoid of annuals, and the cover fractions for Classes VI and XIII were less than 1%. Rangeland Classes I, III, V and VII all had cover fractions that often exceeded 10%. Other classes had cover fractions ranging from 2 to 10%, and were often heavily grazed by herds of sheep and/or camels unless fenced (e.g., within the Burgan oil field and Kuwait Institute for Scientific Research (KISR) Sulaibiyah Research Farm) or occupied by sabkhas. The average maximum heights of annual vegetation were typically less than 10 cm at the time of observation. The average vegetation volume vary between 0 cm for Class II and approximately 2 cm for Classes I and VII, which had little, if any, perennial vegetation present. Of the vegetation attributes measured in the field, vegetation volume and height are perhaps the least likely to bear a close correspondence to the conditions existent at the times the radar data were obtained by ERS and Radarsat.

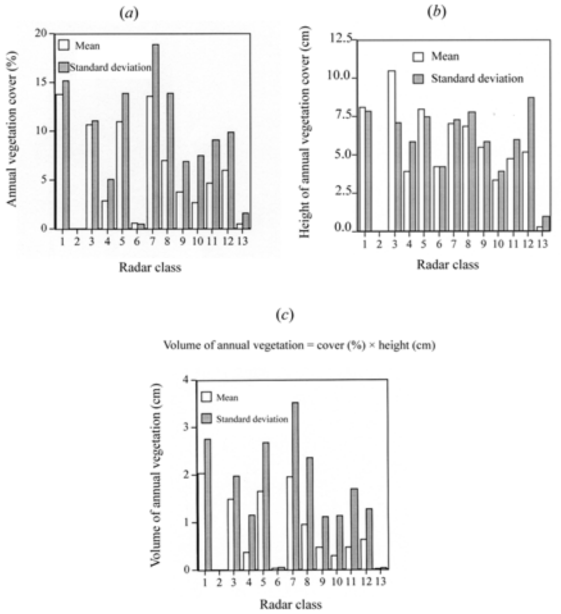

Figure 2. Histograms of annual vegetation cover, the average height of annual vegetation, and the volume of annual vegetation for the 13 radar classes.

The relationship between radar backscatter and annual vegetation cover is depicted in Figure 3, which shows the 13 radar class centroids annotated with the percent cover of annual vegetation. Backscatter is shown to be related to the percent cover by annual vegetation for ERS, while its influence appears to be somewhat less for Radarsat. This is probably explained by two factors: (1) the sparse nature and short height of the vegetation cover and (2) the vv-polarization of ERS, which is more sensitive to vegetation than the hh-polarized Radarsat, even though Radarsat is at a much higher angle of incidence and, therefore, the path length through the vegetation is much greater.

The average characteristics (percent cover, height and volume) of perennial vegetation types are compared for the various radar classes in Figure 4. Class II was devoid of perennials, and the cover fractions for Classes IV and IX were almost negligible. The greatest cover fractions were found in Class XIII and were dominated by sabkha vegetation. The other classes were typified by a general absence of perennials (except *Cyperus conglomeratus*), except for sabkhas, where the coverage of perennials could be quite high. The average

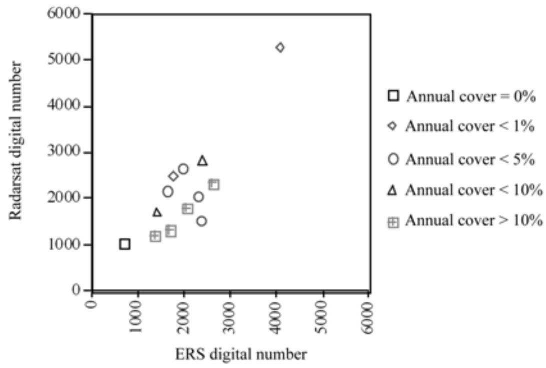

Figure 3. Radar class centroids annotated to show the average percent cover of annual vegetation for the 13 radar classes.

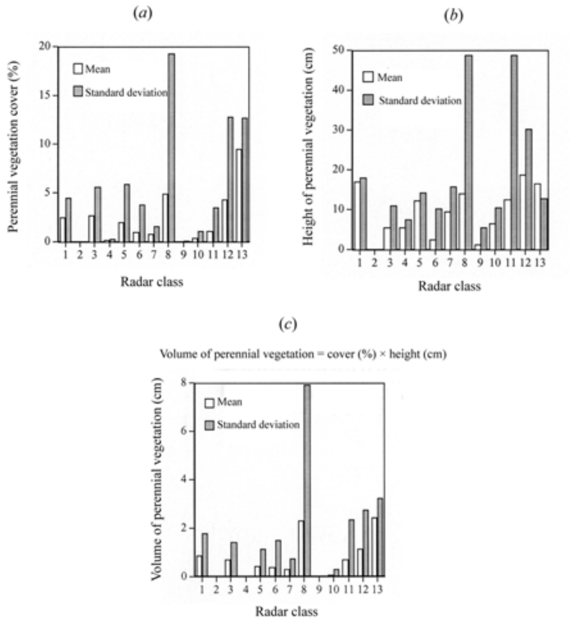

Figure 4. Histograms of the perennial vegetation cover, the average height of perennial vegetation, and the volume of perennial vegetation for the 13 radar classes.

maximum heights of perennial vegetation were typically less than 10 cm at the time of observation, except for sabkhas. The average vegetation volume varies between 0 cm for Class II and approximately 2 cm for Classes VIII and XIII. As was the case for the annual vegetation types, vegetation volume and height were probably the least likely to bear a close correspondence to the conditions existent at the times the radar data were obtained by ERS and Radarsat. Backscatter was observed to be positively related to the percent cover by perennial vegetation.

The combined effects of both annual and perennial vegetation are perhaps best examined by considering the total volume of vegetation. The relative means and standard deviations of the 13 radar classes are compared in the histogram in Figure 5. The effects of total vegetation volume on radar backscatter are shown in Figure 6. Radar backscatter is more highly correlated with total vegetation volume for ERS than for Radarsat, and is probably a consequence of both the lower angle of incidence for ERS and its vv-polarization.

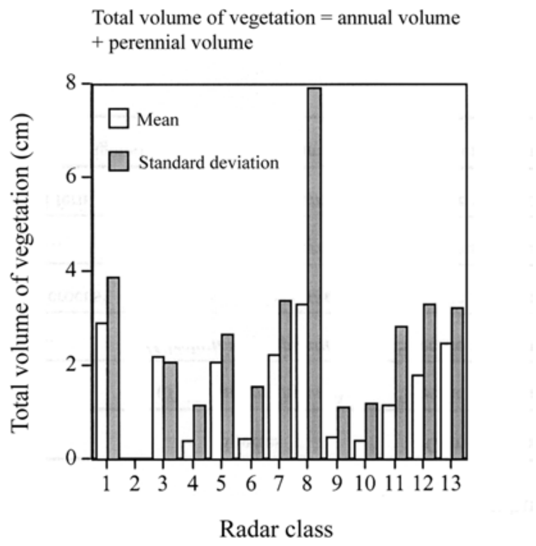

Figure 5. Histogram of the total vegetation volume (annual + perennial) for the 13 radar classes.

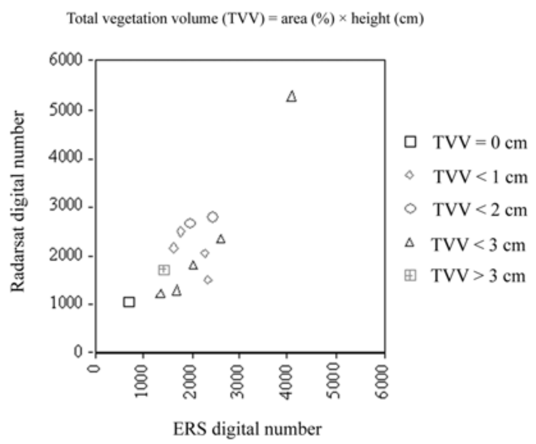

Figure 6. Radar class centroids annotated by the average total volume of vegetation.

4. Conclusions

In this study, SAR orbital datasets consisting of ERS and Radarsat were utilized in land-cover and land-use assessment of the terrestrial part of Kuwait which characterized by a desert environment with scanty rainfall and a hot, dry climate. The SAR scenes were orthorectified using a DEM image of Kuwait and were radiometrically adjusted for viewing angle effects. ERS-1/2 and Radarsat standard beam mode S4 mosaics were generated for the whole country. The data were co-registered as multi-channel composites with associated GIS overlays of vectors for roads, hydrology, soils and vegetation. An adaptive spatial filter was used to increase the number of effective independent looks prior to generation of feature vectors based on power. Class labels were assigned to the final 13 radar clusters using a supervised to approach with maximum likelihood techniques incorporating field measurements. Physical data collected at the ground verification sites were used to assign nominal categories to the radar clusters that resulted from unsupervised classification. This categorization or relabeling of the clusters then provided a basis both for generation of thematic maps and for accuracy assessment.

Backscatter is shown to be related to the percent cover by annual vegetation for ERS, while its influence appears to be somewhat less for Radarsat. Radar backscatter is more highly correlated with total vegetation volume for ERS than for Radarsat, and is probably a consequence of both the lower angle of incidence for ERS and its vv-polarization. Other factors that also modulate radar backscattering include surface roughness, surface material type and moisture content. However, these factors are not considered in this paper. Since only C-band data were available for surface classification, it was difficult to uniquely relate backscatter to each of these competing effects separately. It is obvious that only two (ERS and Radarsat) somewhat correlated feature vectors will be insufficient to resolve the ambiguities of what is basically a three-component inverse problem as defined by surface geometry, vegetation characteristics, and moisture/dielectric properties.

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