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Remote Sensing of Informal Housing Settlements in Metropolitan Bangkok

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Abstract

In 1988 the National Housing Authority of Thailand estimated that about 10 percent of the population was living in 1300 slum or squatter settlements (officially designated as ‘congested communities) within the Bangkok metropolitan area. These settlements are located in a number of areas throughout the city, established on both public and private land and are consist of a variety of housing at very high densities (30 units per 1600 sq.m.). Due to the sometimes transient nature or these communities, or the speed with which they can develop, as well as the lack of information about the residents who occupy these locales, it is important to update and examine these neighborhoods on a regular basis. Determining the growth and extent of these communities, however, has been a time-consuming task as it has been done only through aerial photograph interpretation.

This study tests the application of Landsat Enhanced Thematic Mapper satellite imagery to identify, delineate, and assess the variability of land cover, associated biophysical characteristics, and distribution of Bangkok's ‘congested communities’. Unfortunately, digital image analysis of these sites produced spectral overlap with several other types of urban land use, which will result in imprecise identification and delineation. This appears to be the result of the resolution of the imagery and the low spectral variability of this type of ground cover, in any wavelength.

Keywords: urban remote sensing, slums, low-income housing

Remote sensing of urban areas

Satellite data are increasingly considered to be an essential data source for the appraisal of urban environments as they provide timely and valuable information for analyzing the landscape. Unfortunately these landscapes are composed of diverse materials (concrete, asphalt, metal, plastic, glass, shingles, water, grass, shrubs, trees, and soil) and arranged in complex ways, which produce spectral responses that are difficult to interpret (Jensen and Cowan, 1999). This is usually the result of land cover variability in close proximity produces a variety of reflectance characteristics that the satellite detects. The resulting image pixels are then comprised of different proportions of grass, trees, buildings, and roads, which can be difficult to differentiate (Forster 1985; Welch 1980).

Compounding these difficulties in Asia is that the patterns of land cover/land-use differ markedly in scale from their counterparts in North America. Street layout, buildings and structural materials, along with the size, amount and type of vegetation, make analysis of these places more complex. The resulting image pixels are then comprised of different proportions of grass, trees, buildings, and roads, which can be difficult to differentiate.

Most researchers have approached the task of characterizing an urban area by first accurately classifying the various land use types (which are a combination of land cover characteristics), and then identify the extent of the built up area and its internal variability. The main basis for this work is found in a variety of publications, but perhaps the most condensed version is in Haack, et al., 1997).

Identification and separation of urban-nonurban land use, with acceptable accuracy, is possible (e.g. Jensen and Cowan, 1999). Some specific topics that have been addressed include the separation of urban-nonurban land use (Jensen, 1983), population estimates (Forester, 1985; Haack, et al. 1997; Lo, 1986, Lo 1995; Lo and Welch, 1977), quality of life indicators (Curry 1997; Haack, et al. 1997; Lo and Faber, 1998), energy demand (Sutton, et al. 1997; Welch 1980), and meteorological data (Lo, et al., 1997).

In an environment similar to Bangkok, Lo (1981) has examined the capability of satellite data for mapping land use in Hong Kong. Iisaka and Hegedus (1975) were some of the first to undertake population studies of urban area in their study of the Tokyo's central business district, while Murai and Mastra (1987) used satellite data to identify preferential residential areas of Jakarta. However, there has been a notable lack of research on the type of housing examined in this study. This research will determine the utility of satellite imagery to help identify and delineate housing that occurs at densities that are far higher than the work noted above.

Although it has been possible to identify potential sites where this type of housing may occur, or where sites for public low-income housing may be located (author, 2000), satellite image analysis of established housing of this type has not yet been discussed in the literature in any detail. Part of the reason for this lack of discussion, may be due to lack of interest by scholars, but it is also likely that the coarser spatial resolution of the sensor, as well as the spectral similarity of these communities prohibits effective discrimination of this type of housing from other to other land cover types.

The capability of acquiring imagery in a single overpass of the satellite and the potential for assisting with spectral variation of these neighborhoods, however, are two valuable benefits that could potentially reduce the amount of time spent on performing basic tasks in detection and identification of these areas. The objectives of this study, therefore, are to determine the potential for using satellite imagery to identify and delineate Bangkok's 'congested communities' through multispectral image processing techniques rather than visual-spatial methods of aerial photo interpretation.

Study Area

The estimated 1995 population of Thailand was 57 million, with an average population growth rate of 1.7 percent (Ashakul, 1990). In 1980 about 82 percent of the population was still living in rural areas, but the majority of its urban population resided in Bangkok, which was growing at more than 11 percent a year, and faster than any other province in the country (Dowall, 1989). Between 1960 and 1986 the five contiguous provinces to Bangkok gained 4.9 million population, a compound annual growth rate of 3.6 percent; and this area is projected to reach 10.87 million by 2010 (National Economic and Social Development Board, 1992).

The rapid growth of Bangkok's population and economy in the past two decades, is clearly reflected in the changing patterns of land use. Between 1974 and 1984 approximately 35 sq. km. of land were converted annually from rural, largely agricultural use to urban activities (Dowall, 1989). Interpretation of 1989 satellite imagery (**Figure 1**) found that the total amount of land in the Bangkok Metropolitan Area (BMA) (1304, sq. km.) was about 75 percent agricultural, 17 percent residential, 5 percent commercial, and the remaining 3 percent designated as industrial factory sites (Chomchan, et al. 1992).

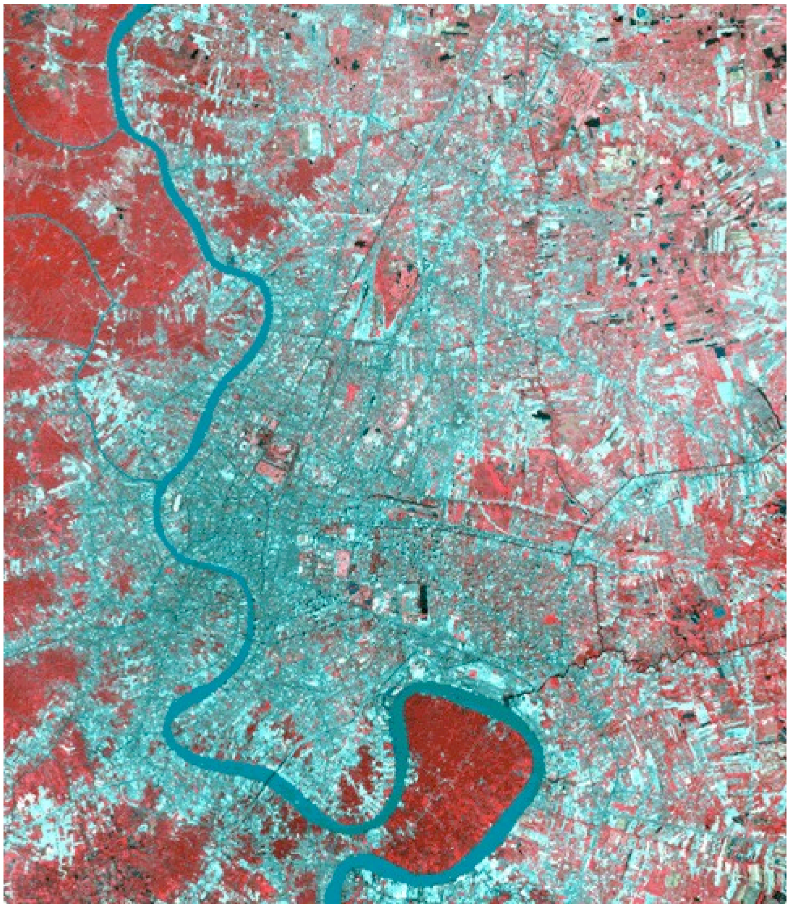

Figure 1.

Because the region is currently converting such a large amount of land into urban areas, one third of which is housing, the urbanized portion of the BMA increased by 50 percent in the decade (Dowall, 1992). This increased demand for housing is predominantly the result of the region gaining about 200,000 people per year. This increase has put tremendous pressure on the performance of the housing market, especially for low cost housing (Foo, 1992). It is estimated that between 40,000 and 50,000 dwelling units were needed each year.

Over the past two decades, traditional living accommodations in the less densely populated fringe areas of Bangkok have gradually been replaced by residential housing estate projects. However, the rapid increase in land prices in the late 1980s made housing a much more expensive and has restricted potential buyers to only those in the high-income bracket (Chanond, 1987). The only option open to the poor was to seek housing in slums or squatter settlements. Officially called ‘congested communities, these neighborhoods have densities of 80 or more persons per rai or 15 or more houses per rai (1600 sq.m.), and housing conditions that are considered harmful to the health and security of the residents.

Estimates indicate that there were 86 slums in 1940, 183 in 1950, 361 in 1960 and 678 in 1970. This grew to about 632 slums and 108 squatter settlements in 1974, increasing to 845 slums and 175 squatter settlements in 1984, and to some 1100 slums and 200 settlements in 1988 (National Housing Authority, various years). As a result of the rapid increase of these communities and the potential difficulty in regulating or providing services to them they are of substantial concern to local authorities *(See inset photos for examples of these settlements*). Unfortunately their size, locale, densities or other factors can make regulation of or providing serves to these areas difficult. Aerial photography has been of greatest value in the search of techniques to identify and monitor these sites, making it possible to calculate size, number and type of dwelling, as well as provide simple measures of housing quality. However, this process if very time consuming and obtaining suitable aerial photos is difficult, due to both the cost and restrictions placed on flying over the city.

Data sets and preparation

Three types of data used for this analysis, three sets of panchromatic aerial photos, a base map of the 'congested communities' (derived from aerial photography) and a Landsat Enhanced Thematic Mapper satellite image. The initial digital (vector) maps of the 'congested communities' were obtained from a 1:50,000 scale map compiled from 1:15,000 scale aerial photos taken in 1974, and updated using small format (35mm) aerial photography, with an approximate scale of 1:12,000, flow in 1985. House counts from the photos and data from local police precincts were also incorporated to produce the final map'. Additional aerial photography obtained in 1998, but at a scale of 1:50,000 was used to confirm the existence of communities identified with the earlier studies, but not to identify new sites.

Aerial photos

The film used for the 1974 photos had a resolution of 125 line pairs per millimeter. Using the standard formula for calculating ground resolution from an aerial photograph:

GRD = reciprocal of scale/system resolution

where GRD = ground resolution distance (usually measures in meters) and system resolution for aerial photographs is measured in line pairs per millimeter.

Thus, when flown at a scale of 1:15,000 the 1974 imagery produces photos with a ground resolution distance of @ 0.12m. [0.6 = (15000)/(125)(1000)]. Resolutions of approximately 0.12 meters were very suitable for both identifying and delineating these low-income communities, as well as for assessing physical characteristics including dwelling density, and in many cases, building materials, such as wood, zinc for roofing, and concrete- the major materials used in construction of these dwellings.

The 1985 small format photos yielded a ground resolution of approximately 3.0 meters, while the 1999 photos had a ground resolution of 1.25 meters. Unfortunately, due to restrictions placed on use of the 1974 and 1985 photos, it was not possible to provide examples of the 1974 and 1985 imagery. However, the basic information that can be detected is apparent in the 1998 photos, which although have a relatively coarse scale of 1:50,000 provide a great deal of detail if viewed using a zoom stereoscope. An example of the original photo and images that have been enlarged is provided in **Figures 2, 3, 4, and 5**. This conversion has been in order to simulate the greater detail that can be seen when viewing the analog image with greater magnification. The original photo was scanned using 150, 300, 600 and 1200 dpi.

Figure 2.

Figure 3.

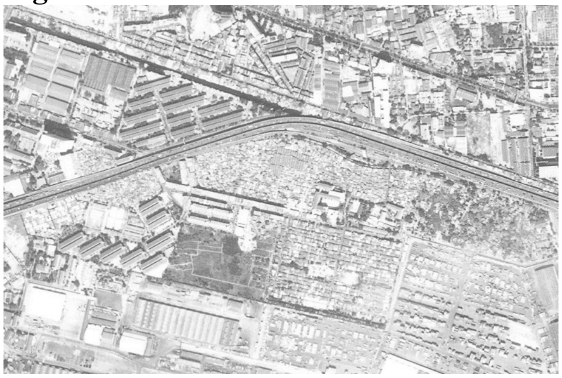

Figure 4.

Figure 5.

Satellite imagery

Complementing the aerial photography was a Landsat Enhanced Thematic Mapper scene acquired in December 2000. It was georeferenced to a Universal Transverse Mercator (UTM) coordinate system that produced a root mean square (RMS) error of less than .5 pixel or less than 15 meters. During preprocessing, the output pixel size for each of these images was reduced to 25 meters and a nearest neighbor algorithm was used for intensity resampling. Enlarging this imagery to try and achieve a different scale is not practical as it would only resulting in pixel duplication, making the image appear more coarse. In addition, a general spatial resolution rule for imagery comprised of pixels is that there needs to be a minimum of four pixels within an urban object for identification (Cowan et al., 1995; Welch, 1982). The differences in ground resolution between the 1200 dpi aerial photo, the 15-meter panchromatic image, and the 25-meter false color multispectral image are shown in Figures **5, 6** and **7**.

In order to extract multispectral information from each community, the digital vector map of the communities was overlaid upon each of the satellite images **(Figure 8)**. Because of the potential slight misregistration errors resulting from the various errors that could be produced from the base map compilation, georeferencing of the satellite image, and registration of the map to the satellite image, only those pixels that were at least one pixel inside the boundary of any community were used for this study. This would theoretically ensure that the digital value any pixel in a community would be a result of only the site of interest and not border or mixed pixels along the periphery.

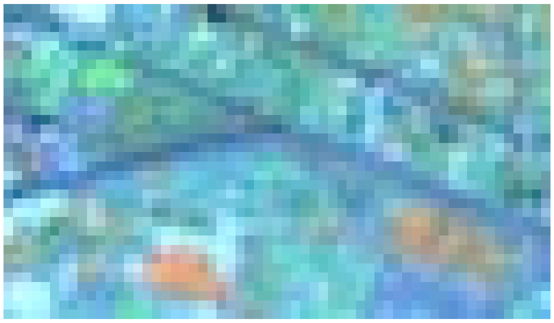

Figure 6.

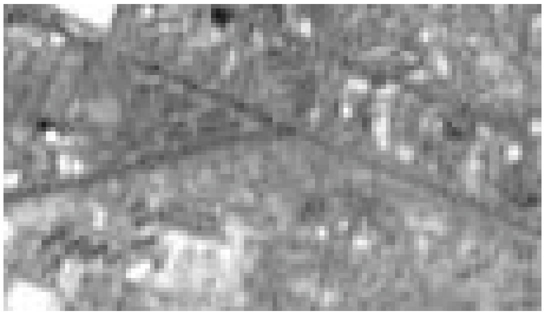

Figure 7.

The area of Bangkok that was examined for this study consisted of 1304, sq. km., although the 'congested communities' account only 2.1 percent of the total land use. The last verified study to assess the amount of various types of land use in the region (Chomchan, et al. 1992), determined that in the early 1990s, residential areas occupied about 17 percent of the land use in the city, although a current study by the author is suggesting that residential land use in this region now accounts for around 23-25 percent of the area. Which ever estimate of residential land use one uses, the fact that only 2 percent of land is given to these communities is remarkable given that published estimates of the proportion of the population living in this type of housing ranges from a low of 10 percent (NHA) to over 25 percent (Setchell, 1992).

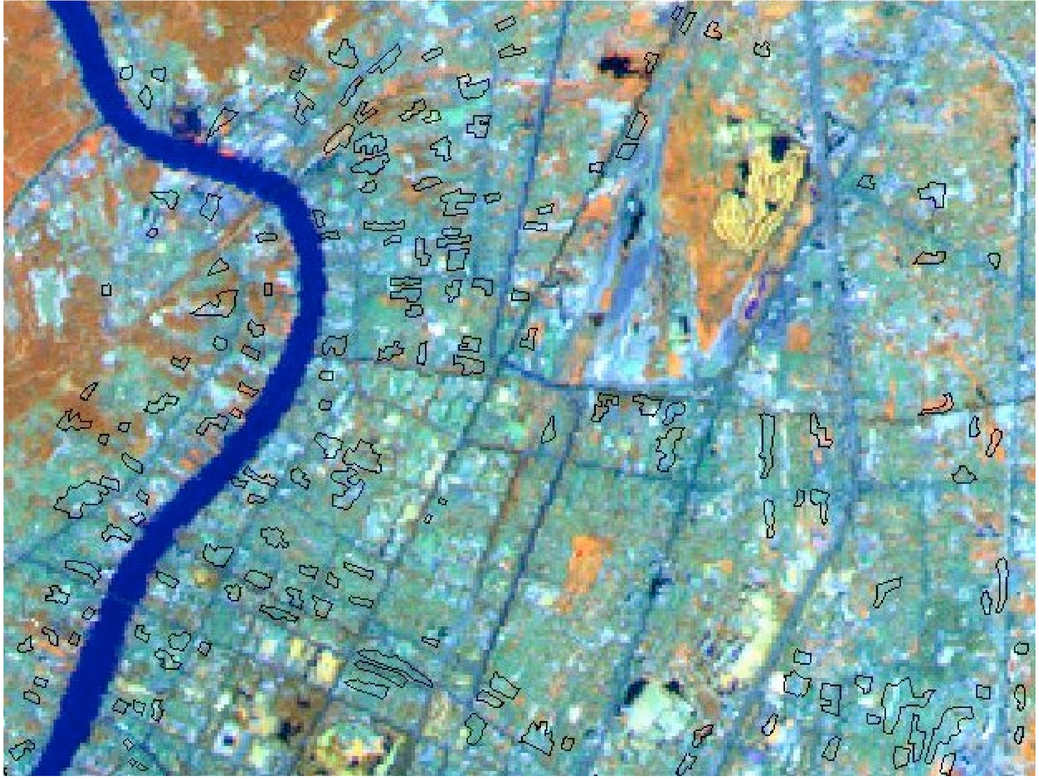

Figure 8

Analysis

Identification and delineation of the 'congested communities' from aerial photographs (as seen in the previous figures) was not a complicated process, however, it was very time consuming as land cover/use had to be interpreted individually from each photo. In addition, the inability to automate the process so that many photographs can be examined simultaneously makes the process more tedious. Satellite image analysis may overcome some these problems as an entire scene can be examined in a relatively short amount of time and once known reflectance values (spectral signatures) for specific types of ground cover are identified, the process can be automated for use with larger areas as well, and with additional scenes. The only major drawback is the relatively poor ground resolution that can be obtained, compared to the aerial photograph. This issue, however, is mainly important for visual analysis of an image, while the digital satellite imagery provides an exceptional method for concurrently examining multiple wavelengths, many of which cannot be detected on film.

The techniques for performing this analysis are statistical transformations of the digital data. The first step in this process is examining the spectral variability of the scene, and then deriving suitable 'training sites' that can be used to allocate all pixels to a specific cover type (class).

Spectral Variation

Clusters

The most important value of the satellite image is not for visual examination, but to conduct multispectral analysis. This was done using an unsupervised clustering routine (ISODATA-Iterative self-organized data analysis technique, using a minimum distance algorithm.) applied to all reflective bands of the multispectral image. Each pixel was allocated to one of 50 groups (the number of groups is arbitrarily chosen as this routine is usually performed using a large number of groups (@100) and then a smaller number of groups in order to determine how much spectral variability is found within a given scene. Through considering differences in spectral clusters that are produced using both the higher and lower figures, the analyst determines a suitable number of clusters that adequately represent the spectral variation in the scene for the purposes of the study (**Figure 9**).

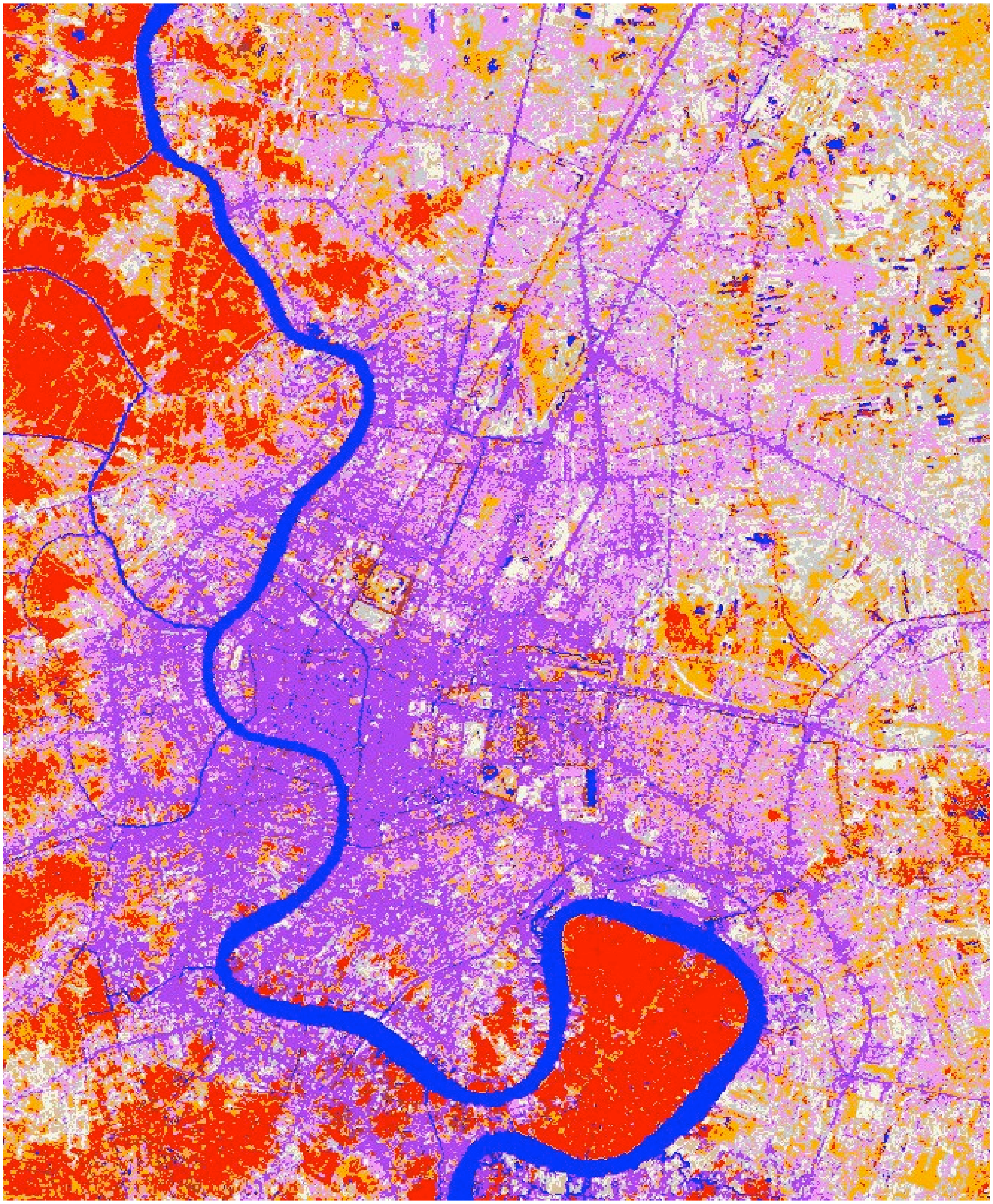

Figure 9

The results provide an informative summary of spectral variation within in the city. In order to assist with interpretation of this image, a bivariate scatterplot of these clusters was constructed **(Figure 10).** Two of the 6 reflective bands that help in distinguishing the greatest amount of spectral diversity in the scene were used to portray the variation of these clusters in two dimensions. The contrast between the red and near infrared wavelengths not only help to distinguish vegetation, but a large amount of literature over the years has discussed how the amount of soil and vegetation cover portrayed in this graph can be quantified and characterized (e.g. Deering, et al., 1975; Kauth and Thomas, 1976; Rouse, et al., 1973).

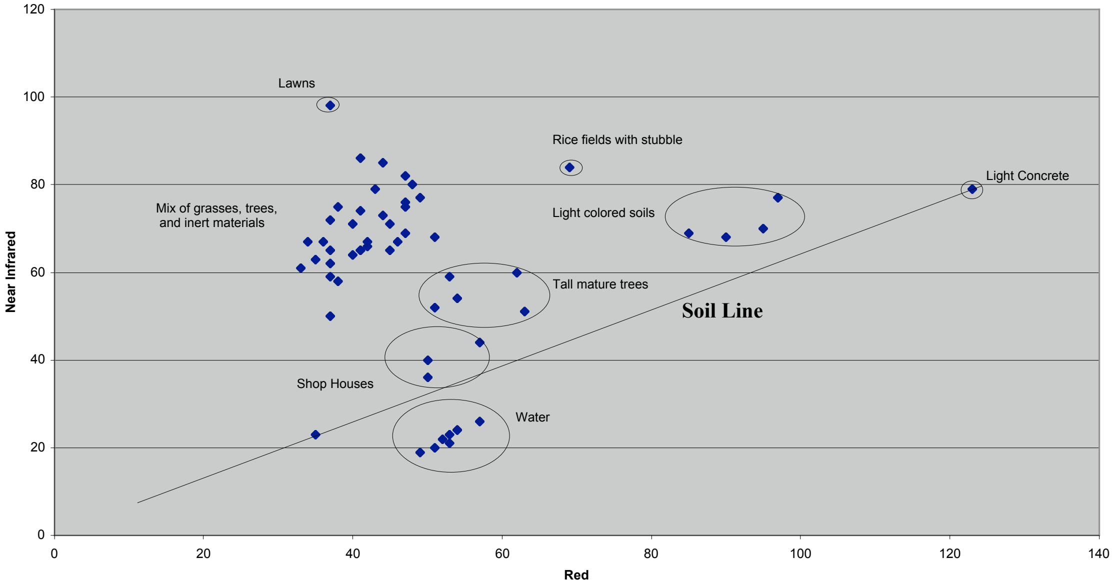

Figure 10

At the lower left corner of the graph, below the hypothetical soil line are clusters representing varying amounts of moisture and/or dark bare soil. Moving up and to the right, along the line, are clusters that represent material that is more reflectance in both the Red and NIR wavelengths and which has decreasing amounts of moisture. Cluster that are found the left the soil line are clusters that represent increasing amounts of healthy green vegetation as one moves further from the line.

Further examination of these clusters showed that they represent several groups of land cover. The group of clusters to the lower right of the soil line represents water, particularly the river. Three clusters representing the materials used in constructing shop housing are also found near the soil line at the less reflective end of the spectrum, while other concrete structures and roads, as well as dry soil, are found at the bright reflective end of the soil line. Trees are represented by the group of clusters found in the less bright portion of the spectrum moving toward an increase in greenness, while vegetation not as tall but with greater ground cover, is represented by clusters found at the brighter and greener portion of the figure. In between these two groups, tall trees and shorter vegetation, are clusters that represent ground cover with varying proportions of trees, shorter vegetation and inert material used in housing construction. Spectrally unique clusters, the ground cover of which does not appear to be similar to any of the other clusters, are fallow rice fields, and grasses with a high percentage of ground cover (lawns).

Spectral analysis of ‘Congested’ Communities

The spectral values for those pixels corresponding to the ‘congested’ communities were next examined. The vector map of the communities was used as a templet to extract only those pixels that fell within each community. Spectral variability of these pixels was then determined using the Isodata technique. These clusters were ultimately narrowed down to 9 specific signatures that fell into 2 main categories of land cover, inert materials that cover a range of soil types from light to dark and a combination of inert materials and very sparse vegetation (associated with medium to high density housing).

Figure 11 is the bivariate scatter plot, using the same Red and Near Infrared bands, for the 9 signatures for the 'congested' communities. The plot shows how close the clusters fall to the hypothetical soil line that runs along the diagonal from lower left to upper right. The most obvious aspect of this distribution suggests a general lack of vegetation within the communities, which is not surprising as previous figures of these communities show almost no vegetation present, except for sparse amounts along the periphery of some communities. A second notable aspect of the plot is how the distribution of clusters is distributed over a large range of the 'hypothetical' soil line that runs diagonally from lower left to upper right in the image, suggesting that reflectance of these communities has a similar distribution of inert surfaces from dark to light.

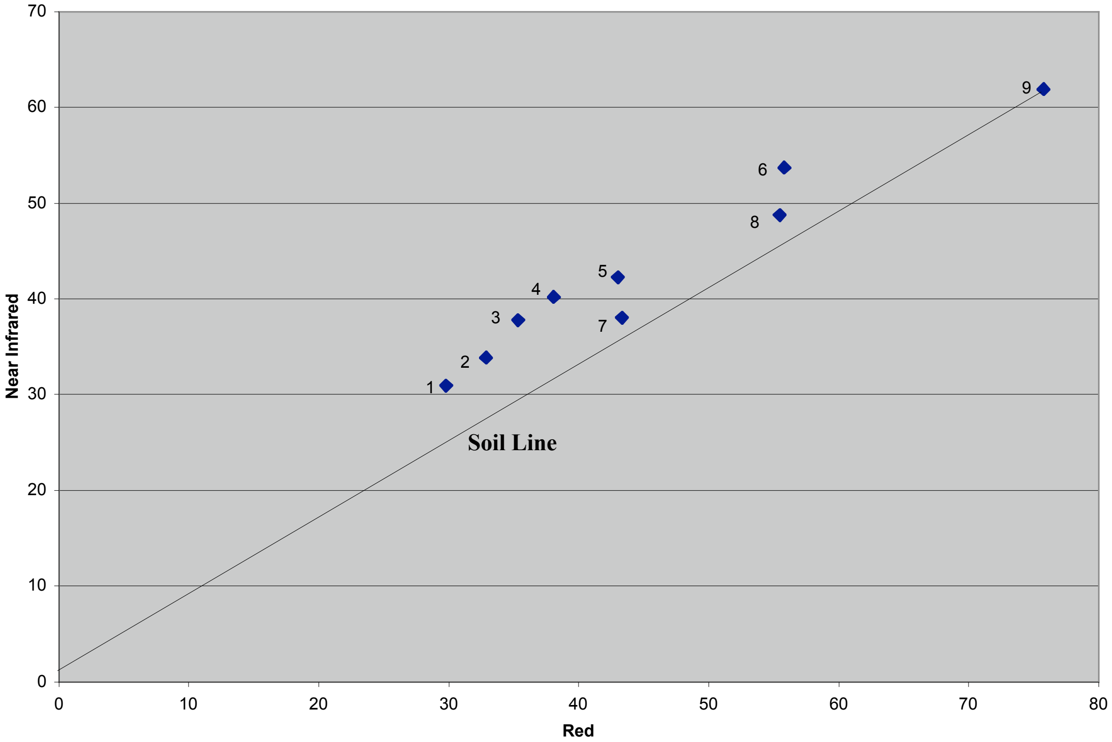

Figure 11

Unfortunately, there is no two-band combination that portrays any great variation of these signatures, which can be interpreted in a meaningful way. While ground cover for the any image is usually a combination of a multitude factors related to varying proportions of building materials, soil, vegetation, and water, these 'congested communities' are predominantly covered by either building materials or bare ground, with dwellings occupying over 80 percent of the ground surface. This lack of biophysical variation results in minimal amount of spectral variability for the communities.

Due to the lack of suitable aerial photography, it was not possible to determine the ground cover constituents associated with each signature. The spectral signatures of these communities were compared with other types of known land covers in order to determine the potential for distinguishing these communities from other types of land cover in a multispectral classification. As previously mentioned, ground cover of the communities is comprised of varying proportions of building materials and bare ground. The materials used for building are predominantly wood or concrete for the basic structure and wood or galvanized zinc sheets for roofing. Furthermore, as the galvanized metal ages, it also becomes covered by dust and will oxidize, turning slightly red over time.

The roofs of the dwellings in these communities would be the most important component in determining spectral reflectance that aerial or satellite imagery would detect, while bare ground, shadow, and the sides of the structures (in that order) would be much smaller contributors.

Each of the 9 spectral signatures was compared to ground cover types that were used to classify the entire image of the city. This comparison would help to determine the likelihood of separating the ‘congested’ community signatures from spectral reflectance of other land cover in the city. The nine clusters could be allocated into two categories, the first was comprised of a mix of land cover types (including some sparse vegetation) while the second was comprised of inert materials. **Figure 12** shows the spectral reflectance for the six ‘mixed’ signatures, while **Figure 13** depicts the signatures for the three signatures for inert material in the same wavelengths.

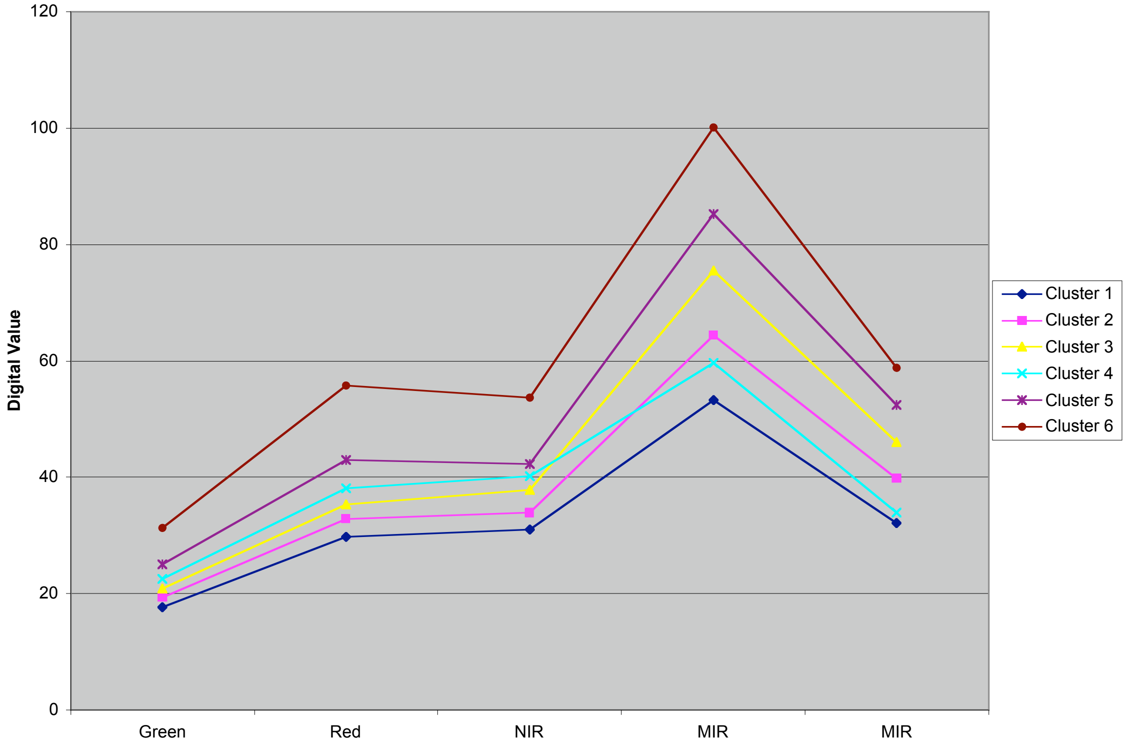

Figure 12

The six ‘mixed’ signatures showed an important distinction that was not present in three inert signatures, either a leveling in reflectance between the Red and NIR wavelengths that is not present in the three inert signatures, which show a marked decline. In order to more effectively interpret the distinctions between these signatures they were compared to reflectance values of known ground covers.

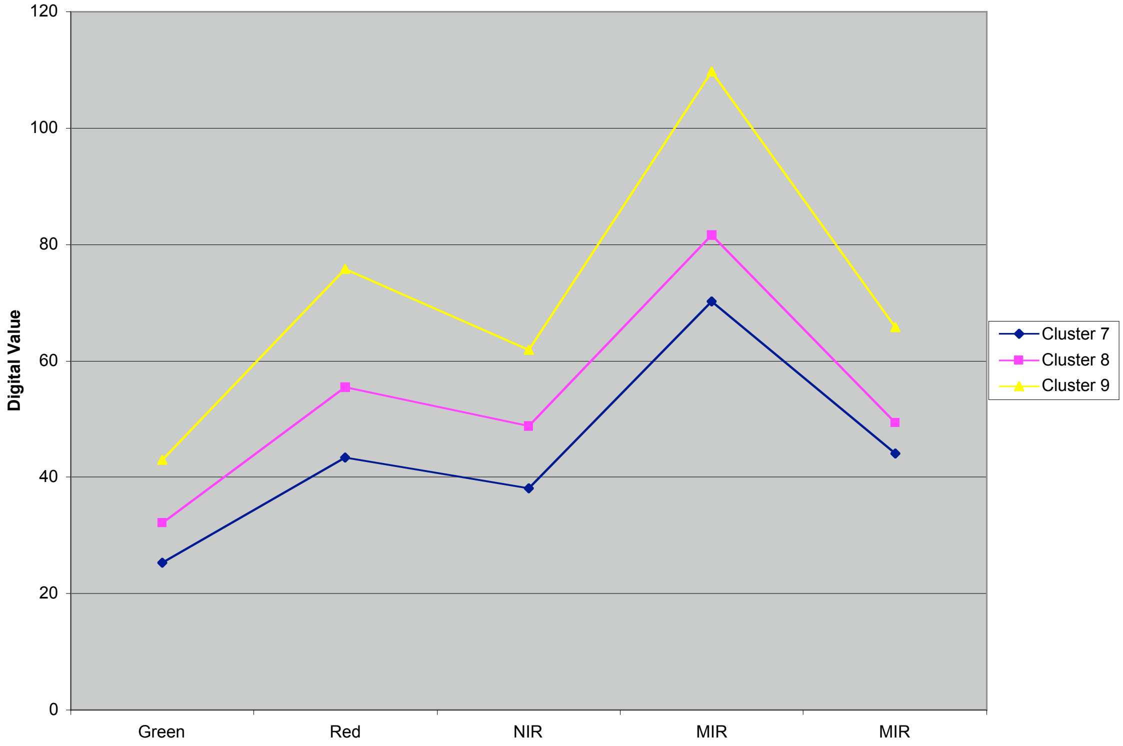

Figure 13

Table 1 is a comparison of the mean reflectance value for each of the nine community clusters to one or more of the known land covers. Signature 1 is similar to darker moist soils that are found in areas of the city with a high water table. Signatures 2 and 3 are similar to the longest established areas in the core of the city, where asphalt is used for roads or the concrete has been darkened through wear. Signature 4 is similar to bare ground with lighter soils and with very sparse vegetation <15% ground cover. Signature 5 is similar to the medium density areas of the city with larger homes, and some trees surrounding homes where vegetation is not established and there is a high proportion of bare ground. Signature 6 is also similar to a high-density urban area where concrete rather than clay based building materials dominate.

The three signatures for the inert materials are basically similar to the bright reflective surfaces from newer concrete and metal. Both signatures 7 and 8 are very similar to newer concrete while signature 9 is most similar to industrial areas where metal roofed warehouses dominate.

Further comparison of these mean digital reflectance values and the standard deviation of each signature revealed that there is essentially no difference between the informal settlement signatures and these other land cover types. In digital image processing it is important that a there be a notable difference in the values from at least one of the wavelengths in order to distinguish one land cover/use from another, which is not present for the settlements.

Table 1

	Wavelength				
	Green	**Red**	**NIR**	**MIR**	**MIR**
Cluster 1	17.67	29.80	30.96	53.20	32.11
Bare moist ground	19.81	33.95	38.92	65.01	29.26
Cluster 2	19.34	32.86	33.86	64.44	39.82
Roads in older urban areas	20.05	34.44	32.99	61.38	37.63
Cluster 3	20.79	35.32	37.77	75.45	46.08
High density urban-city core	22.96	39.57	39.08	76.26	46.28
Cluster 4	22.51	38.06	40.18	59.59	33.98
Bare ground, very sparse vegetation	25.2	41.56	42.92	66.04	29.94
Cluster 5	24.96	43.01	42.26	85.22	52.35
Medium density urban areas	25.45	45.07	46.95	93.01	54.38
Cluster 6	31.34	55.80	53.69	100.17	58.82
High density urban-concrete materials	33.12	58.87	56.15	94.66	53.72
Cluster 7	25.28	43.33	38.04	70.19	44.00
High density urban-concrete	22.96	39.57	39.08	76.26	46.28
Cluster 8	32.12	55.46	48.77	81.59	49.40
Newer roads in suburbs	29.76	51.99	47.98	77.86	45.42
Cluster 9	42.96	75.75	61.88	109.76	65.76
Metal roofed buildings-warehouses	45.18	79.99	65.07	115.38	68.72

The result of this examination is that due to the very similar spectral characteristics of the informal settlements to the more dominant land cover types within the city, these neighborhoods are not sufficiently ‘unique’ so as to distinguish them from other land cover types using only their spectral criteria. The basic biophysical factors related to this condition were not tested due to a lack of suitable imagery, but the most apparent hypotheses, which bears further examination, is that at 25 m, a single pixel covers an area equivalent to over 6 dwellings, and the spectral variability of this type of ground cover has low variability in any wavelength. It is also possible that using the newest 1m resolution Ikonos imagery, it may be possible to detect smaller areas, which can detect spectral variation between dwellings, rather than just a composite signature from many units.

Conclusion

While multispectral image classification has proven to be a valuable addition to distinguishing a variety of urban land cover, the potential for this technique to be of great value for the identification and delineation of very high density housing is not supported using only spectral information, at least when the spatial resolution of a pixel is larger than a dwelling. At present, it appears that manual interpretation of aerial photographs is still the most effective means for identifying these communities.

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