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Multisensor Data Analysis of Urban Environments

The use of multisensor data sets, MSS and SAR, for urban and near-urban land-cover classification will provide more accurate results than either independent set of sensor data.

Introduction

Among the techniques used to improve remote sensing methods for obtaining accurate and cost effective information are changes in sensor spatial or spectral resolution as on the Landsat-4 thematic mapper; new sensors like the experimental systems on the second Space Shuttle flight and the proposed SPOT system; and different data processing strategies such as including ancillary data, for example slope or elevation, or registering remotely sensed data from different sensors. This study utilized the last technique of examining a multisensor data set to determine its effectiveness in improving classification. This study included data from synthetic aperture radar (SAR) and multispectral scanner (MSS) systems.

Abstract: *Ten data sets collected for the Los Angeles, California basin with multispectral scanner and synthetic aperture radar sensors were spatially registered to a common map base and examined to assess their utility for urban and near-urban land-cover delineations. Training sites for eight urban land-cover types were located and statistics were obtained for the ten data files. The training site statistics were examined using transformed divergence calculations to determine intra-class variability and the best channels for classification. The study indicated that the best classification results would be obtained by selection of data from each of the available major portions of the electromagnetic spectrum.*

Previous studies have combined radar and MSS data for different environments. Ulaby *et al.* (1982) conducted such an analysis for crop classification, Guindon *et al.* (1980) examined forests, and Wu (1980) used a similar multisensor data set to analyze several land-cover types, including forests and wetlands. These previous studies all indicated advantages in using the combined data set over either set independently. The intent of this study was to assess the utility of multisensor data for the study of urban and near-urban environments, land covers which are often difficult to accurately examine with remotely sensed data.

Rather than a visual analysis of images as has been done previously with similar data, this study examined the numerical data. The data were spatially registered to a common map base, thus allowing the extraction of data for the same surface features. The principal analytic tool used in this study was transformed divergence calculation. This calculation provides a quick and inexpensive indication of the ability to classify, numerically and correctly, different land covers. The following sections describe the data, study area, research methodology, and study results.

Data Acquisition and Preprocessing

L-band like- (horizontal-horizontal, HH) and cross- (horizontal-vertical, HV) polarized data were collected for the Los Angeles Basin in California on 7 March 1979 by the Jet Propulsion Laboratory of the California Institute of Technology. The L-band sensor was on a NASA Convair 990 aircraft flying at 10,000 m (33,000 feet) altitude with a due north look direction and depression angles varying from 42° near range to 14° far range. The L-band sensor wavelength was about 23 cm and had an inherent resolution of 12 to 14 metres per pixel or picture

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TABLE 1. DATA FILES EXAMINED

File Number	Data
1	X-band horizontal-horizontal polarization (X-HH)
2	X-band horizontal-vertical polarization (X-HV)
3	L-band horizontal-horizontal polarization (L-HH)
4	MSS 0.52-0.60 μm
5	MSS 0.63-0.69 μm
6	MSS 0.76-0.90 μm
7	MSS 1.00-1.13 μm
8	MSS 1.55-1.75 μm
9	MSS 2.08-2.35 μm
10	MSS 10.40-12.50 μm

element. The X-band sensor had a wavelength of 3.2 cm and an inherent resolution of 17 to 19 m. The like- (HH) and cross- (HV) polarization X-band data were collected by the NASA Johnson Space Center for the same area on 30 August through 2 September, 1979. This sensor was on an RB-57 aircraft flying at 18,300 m (60,000 feet) altitude, also with a due north look direction and depression angles varying from 49° near range to 30° far range.

The NS-001 multispectral scanner collected seven bands of data from a NC-130 aircraft flown at 6000 m (20,000 feet) altitude on 12 July 1980 over the Los Angeles, California basin by the NASA Johnson Space Center. The resolution of these data was 10 to 15 metres. Six of the MSS data bands were the same wavelengths as bands on the Thematic Mapper (TM) of Landsat-4. One band, 1.00 to 1.30 μm, collected by the NS-001 MSS was not one of the TM bands. Table 1 identifies the data files utilized in this study and Figure 1 contains images of the study area for selected data files. Because some of the analysis procedures utilized were limited to a maximum of ten data files, it was necessary to eliminate one of the original files. A previous study with the same four SAR data sets and training sites (Haack, 1984) indicated that the L-band cross-polarization data have little utility for urban land-cover delineations, so it was not included in this study.

The ten files of data were spatially reprojected to fit 15-m grid cells on a Universal Transverse Mercator (UTM) map projection. This reprojection, or registration process, involved the selection of line and column identified control points from a computer display of each file image and latitude and longitude coordinates of the same points from 1:24,000-scale topographic maps. The latitude and longitude locations were converted to UTM coordinates, and a mathematical relationship between the remotely sensed data and the UTM projection was established. Calculations were made for each data set of the best fit for the control points to determine the movement of all data elements to the projected map base grid (Clark, 1980; Bryant and Zobrist, 1977). This process provided a unique set of ten spatially registered multisensor remotely sensed data.

The reprojected 15-m resolution data were aggregated to 30-m resolution by averaging each four picture-element block to conform to some of the other data assembled for this and similar studies. This technique was also a smoothing function for the data. Averaging of pixel values to simulate resolution changes is simple and inexpensive but may not be truly representative of data obtained by different resolution sensors (Sadowski *et al.*, 1977). The effect of changing resolution by this simple averaging was to lower the standard deviations of statistics for each training site. For a subset of six sample sites and one radar data file, the change from 15 to 30-m resolution did not change the mean data values and lowered the standard deviation by an average value of under 2.

TRAINING SITES

A portion of the Los Angeles basin data was selected for this study. Those data were for the city of Glendale and portions of several surrounding cities in the north central portion of the basin. Twenty-one training sites for eight different land-cover types were selected using high altitude color infrared photography, topographic maps, and the remotely sensed imagery. Table 2 identifies the training sites, and Figure 2 locates them within the study area (see Haack (1984), Figure 2, for location of these training sites). Data file means and standard deviations for one training site from each cover type are contained in Table 3. The data in that table are useful for understanding some of the results in this study. One important initial observation is the large standard deviations of many of the data, particularly in comparison to Landsat MSS data. This variation is a function of the small pixel size in a complex urban environment.

Much of this study area consists of urban built-up area bordered by major freeways. There are some hills in the northeast, southeast, and west. There is also a large reservoir and a large railroad yard in the southern portion of the study area. On both the L- and X-band like-polarization images, the influence of street orientation on scene return is very apparent. In both of these images the scene is lighter toned in those areas where the street patterns are orthogonal to the look direction. Topographic shadowing in the northeast is evident in all of the SAR images.

Site 2 was a shallow reservoir which may be too small for an acceptable training site. Some variability in the amount of trees was evident in the four residential sites (3 through 7). This variability generally can be correlated to the age of the development or housing value. The freeway sites were

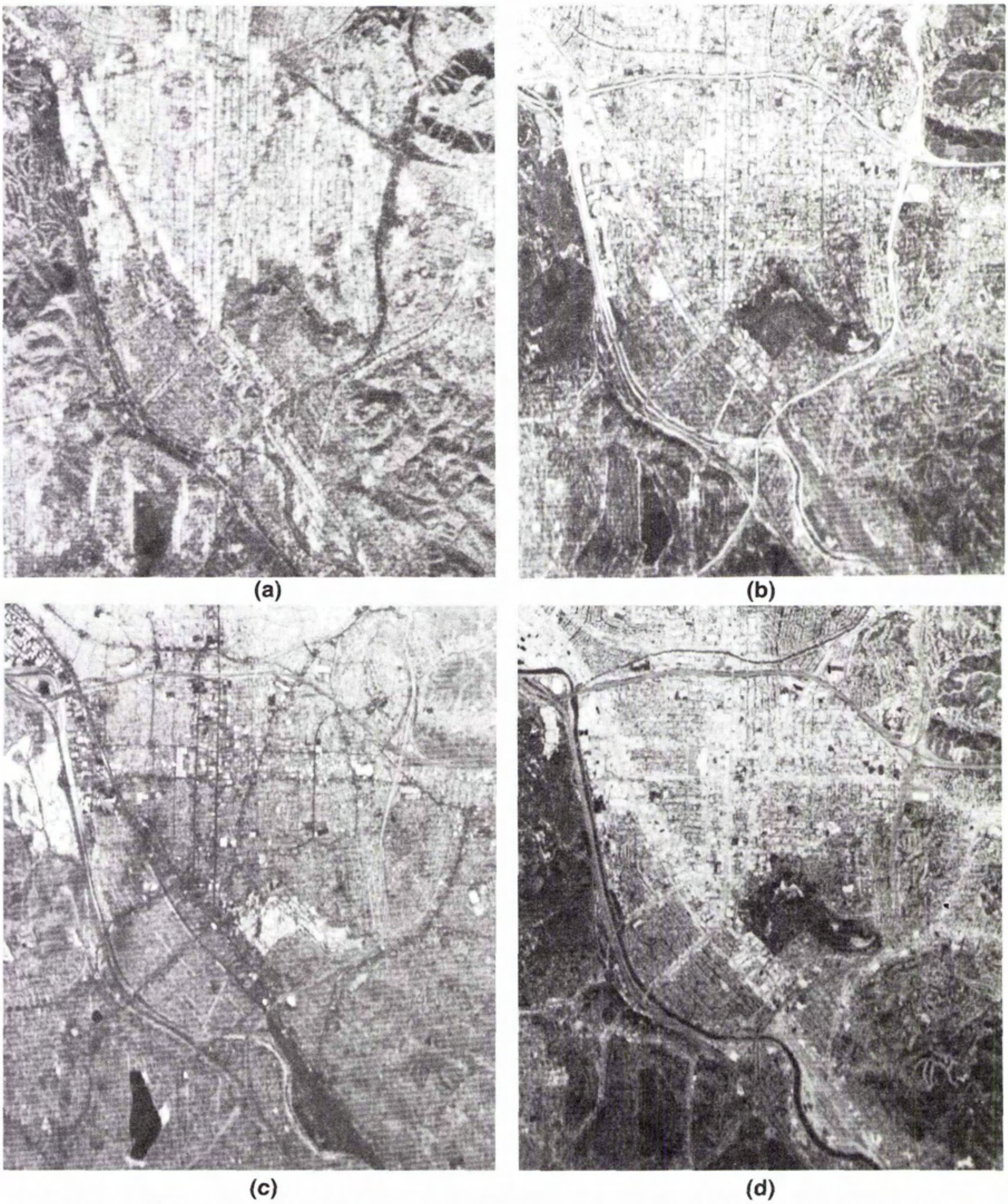

FIG. 1. Images of Glendale, California for selected data files. Approximate scale 1:100,000. (a) X-Band like polarization, (b) MSS 0.63 to 0.69 μm, (c) MSS 0.76 to 0.90 μm, (d) MSS 10.4 to 12.5 μm.

not very similar because they were interchanges where a variety of surfaces and amounts of shadow affected their spectral and radar responses. The freeways were too narrow to be effective training sites by themselves. Because this area of California is quite dry during summer, the urban vegetation is generally watered. Training sites from a golf course (11 and 12) and a cemetery (13 and 14) were selected to represent urban green areas or parks. These sites contained some trees as well as other

TABLE 2. TRAINING SITE DESCRIPTIONS

Site Numbers	Land Cover
1-2	Water
3-6	Residential
7-8	Transportation—railroad
9-10	Transportation—freeway
11-12	Grass—golf course
13-14	Grass—cemetery
15-17	Commercial—services
18-21	Industrial

features such as minor roads and tombstones. The commercial and service areas were quite representative of their land-cover class. The industrial sites consisted primarily of warehouses and were lacking in heavy industry and extensive stockpiling of raw materials.

ANALYSIS METHOD

Transformed divergence (TD) was the analytical tool used for this study. Transformed divergence, which is calculated from the means and covariance matrices of each spectral class or training site, is a measure of statistical distance between class or site pairs of interest and provides information on their "separability." This separability is an indirect estimate of the likelihood of correct classification between groups of different channel combinations (Swain *et al.*, 1971). Such an estimate provides information usually obtained by the time-consuming and expensive process of actual classification and accuracy evaluations. A discussion of transformed divergence, including some of its disadvantages, can be found in Swain *et al.* (1971), Swain and Davis (1978), and Latty and Hoffer (1980).

FIG. 2. Training site locations.

Transformed divergence can be used to examine intraclass variability and to determine the data channels most useful for classifying specific class pairs. A transformed divergence value of 1500 or greater in this analysis generally indicates an acceptable separability of classes. The maximum or saturated value is 2000.

INTRACLASS VARIABILITY

For each cover type in this analysis, a minimum of two training sites was selected. Transformed divergence values were obtained for all possible pairs of training sites in each cover type for all data files. The intent of these calculations was to assess intraclass variability for different data sets. This information is useful prior to classification because it identifies those cover types with no intraclass variability, thus indicating to the analyst those cover types which may be adequately represented by a single training site or that the training site statistics for that cover type can be merged. These transformed divergence calculations also identify when a cover type must be represented by several distinct training sites (those cover types with intraclass variability). The examination of this variability by data files also provides the analyst with information on those data files most likely to minimize intraclass variability and thus allows a reduction in the number of site statistics used in classification.

The results of the transformed divergence calculations for intraclass variability are contained in Table 4. Each class with a separable training site pair (a TD value greater than 1500) is indicated for the file where the separability occurs. The two water classes are separable in both the X-band like- and cross-polarization data. This separability is possibly a function of radar return varying because of different wave size or orientation on the two reservoirs. The MSS thermal data (10.40 to 12.50 μm) separability of the two water sites could be a result of different temperatures as a function of water depth. The difference could also have occurred when the data were aggregated to 30-m spatial resolution at site 2 because some non-water pixels were possibly included which would create errors.

The residential sites are separated in both the L- and X-band like polarizations. Closer examination of the separability values indicates that the separability only occurs between sites 3-4 and 3-5 in the L-band and sites 3-4 in the X-band. An examination of the aerial photography for these sites shows that site 3 has an orthogonal relationshp between street orientation and SAR look direction, which is not true for sites 4 and 5. Bryan (1979) demonstrated that

TABLE 3. MEAN DATA VALUES AND STANDARD DEVIATIONS FOR SELECTED TRAINING SITES*

Training Site Number and Cover	Data File									
	X-HH	X-HV	L-HH	0.52-0.60 μm	0.63-0.69 μm	0.76-0.90 μm	1.00-1.13 μm	1.55-1.75 μm	2.08-2.35 μm	10.40-12.50 μm
1 Water	187.2 (25.1)	158.4 (4.4)	41.2 (6.2)	70.0 (2.8)	39.6 (2.5)	23.9 (1.7)	22.4 (1.8)	21.7 (1.8)	31.5 (1.5)	15.3 (0.4)
6 Residential	240.7 (6.5)	206.1 (9.3)	79.3 (14.1)	137.9 (12.1)	115.9 (15.0)	118.0 (7.4)	127.6 (9.3)	113.5 (12.4)	73.2 (6.8)	154.5 (7.6)
8 Transportation Railroad	230.1 (11.3)	232.0 (9.9)	72.1 (16.5)	112.0 (6.4)	95.1 (7.5)	64.2 (5.3)	67.2 (6.3)	76.8 (8.4)	60.4 (5.2)	159.9 (6.3)
9 Transportation Freeway	203.3 (18.2)	192.0 (13.0)	48.6 (8.6)	134.0 (12.8)	113.4 (15.2)	89.7 (7.1)	92.0 (7.4)	96.4 (9.4)	71.2 (6.8)	120.5 (1.6)
11 Grass Golf Course	198.6 (10.4)	191.2 (10.8)	38.4 (7.1)	112.2 (16.1)	88.4 (15.2)	204.0 (12.9)	225.9 (12.5)	139.9 (13.3)	69.4 (7.2)	91.8 (2.1)
13 Grass Cemetery	215.5 (8.5)	198.2 (7.7)	44.9 (7.0)	103.2 (6.2)	80.6 (7.4)	144.5 (17.8)	166.5 (19.6)	115.6 (11.8)	61.2 (4.4)	94.8 (3.8)
16 Commercial Services	240.9 (7.4)	204.9 (12.6)	97.3 (25.0)	175.9 (19.0)	151.9 (19.9)	112.8 (14.2)	117.5 (15.2)	124.0 (16.2)	83.2 (9.0)	183.0 (7.6)
20 Industrial	225.8 (12.2)	216.2 (15.5)	58.5 (14.5)	155.1 (25.2)	133.7 (25.7)	94.2 (17.4)	102.0 (21.8)	112.7 (26.5)	80.0 (16.7)	171.7 (13.3)

* Mean (standard deviation).

the radar look direction will cause variations in return from similar cultural land covers. This variation in the angular relationship between street patterns and radar look direction is then the cause of the intraclass variability in these two radar bands for the residential sites.

MSS files 0.52 to 0.69 μm, 0.76 to 0.90 μm, 1.00 to 1.13 μm, and 1.55 to 1.75 μm also have separable residential training site pairs. This is not unexpected, because of the frequent variation in residential areas. The separability in these files is only between training sites 4 and 5. An examination of high altitude color infrared photos indicates more lawns and trees in site 5 than in site 4. This difference agrees with the indicated separable files, visible green and three near-infrared wavelength bands, where vegetation differences would be most evident.

The heterogeneity of the freeway sites for three MSS files is because of site differences, including the type of road surfaces, the amount of shadow from the interchanges, and the varied right-of-way sur-

TABLE 4. INTRACLASS SEPARABILITY*

Cover Type and Training Site Number	Date Files									
	X-HH	X-HV	L-HH	0.52-0.60 μ	0.63-0.69 μ	0.76-0.90 μ	1.00-1.13 μ	1.55-1.75 μ	2.08-2.35 μ	10.40-12.50 μ
Water (1-2)	X	X								
Residential (3-6)	X		X	X		X	X	X		
Transportation—railroad (7-8)										
Transportation—freeway (9-10)							X	X	X	
Grass—golf course (11-12)										
Grass—cemetery (13-14)										
Grass (11-14)						X	X			
Commercial-services (15-17)										
Industrial (18-21)										

* Cover type training sites with intraclass transformed divergence values greater than 1500 are indicated by an X for each data file.

TABLE 5. BEST DATA OR DATA COMBINATIONS AS DETERMINED BY TRANSFORMED DIVERGENCE CALCULATIONS FOR DIFFERENT NUMBERS OF INPUT FILES

	Number of Files			
	1	2	3	4
	7	7,8	1,4,6	1,5,6,10
	6	4,6	1,5,6	1,3,4,6
	10	5,6	5,6,10	1,3,4,7
	4	1,7	7,8,10	1,5,6,9
Best	5	7,9	1,4,7	1,7,8,10
Data	9	6,9	3,4,6	1,5,6,8
	8	1,6	3,4,7	4,5,6,10
	1	4,7	1,5,7	1,2,4,6
	2	5,7	1,7,9	5,6,7,10
	3	3,7	1,7,8	1,5,6,7

Data Identification: 1-XHH, 2-XHV, 3-LHH, 4-0.52 to 0.60 μ, 5-0.63 to 0.69 μ, 6-0.76 to 0.90 μ, 7-1.00 to 1.13 μ, 8-1.55 to 1.75 μ, 9-2.08 to 2.35 μ, 10-10.40 to 12.50 μ.

faces such as grass or soil. The separability in the near-infrared data files, 0.76 to 0.90 μm and 1.00 to 1.13 μm, for the four site grass cover class is not surprising. In these bands, variations in the amount of vegetation chlorophyll, which in this environment is often a function of the amount or timeliness of watering, is important. Some of the surprising information in Table 4 is the lack of separability in the commercial-services and industrial cover types. The information in this table was used in subsequent analyses. Those cover types without training site separability were merged to one statistical set of values in further examinations.

DATA FILE SELECTION

In addition to intraclass variability, divergence values are used for specific file selections. Table 5 lists the best data or data combinations for different numbers of input files. These values are for 13 classes identified from the analysis of intraclass variability. These classes are two water, four residential, two freeway, and combined classes for the other five cover types. In examining this table, it should be remembered that only the best ten combinations are listed out of those possible; there are, for example, 210 possible four-file combinations. Because of this, the range of separability or TD values between the combinations listed is often very small; the transformed divergence value difference between the first and tenth best four-file combination is only 14.

There is some surprising information in Table 5. Two of the near-infrared files, 6 and 7, are very useful in single and multifile classification while the two slightly longer wavelength infrared files, 8 and 9, are generally not very useful. The thermal file is also fairly useful as a single file classifier. This is not too surprising considering the thermal differences between water, grass, and built-up areas. The two near-infrared files, 7 and 8, being the most useful two file combination is not expected. It would seem more likely that files from different portions of the electromagnetic spectrum would be more useful as is the case with the other better two file combinations and the best 3 and 4 file combinations. Frequently, data from the same general portions of the electromagnetic spectrum are highly correlated, such as Landsat bands 4 and 5 or 6 and 7. Highly correlated data would tend not to provide additional discrimination. Thus, the best two file combination, 7 and 8, is surprising because of the wavelength similarity.

It is also evident that the better one- or two-file combinations are not always subsets of the best three- and four-file combinations. For example, file 7, the best single file, is not found in the best three- or four-file combinations nor is the best two-file combination in the best three- or four-file combinations. The second best single file (6) is, however, one of the files in the best three- and four-file combinations (1, 4, 6 and 1, 5, 6, 10) and the second best two-file combination (4, 6) is in the best three file combination (1, 4, 6).

It is apparent from Table 5 that for single file analysis the SAR data, files 1, 2, 3, provide very little useful information for urban land-cover delineations. However, as the number of files is increased, the SAR data, particularly the X-band like polarization data, become more useful when combined with other data files. The most useful combination of data files is frequently one which combines data from different portions of the electromagnetic spectrum. This is very evident in the best four-file combination which includes one each of the radar, visible, reflective infrared, and thermal infrared files.

An important utilization of transformed divergence calculations is the examination of the separability values for pairs of training sites because the average transformed divergence values from many pairs do not indicate classification confusions for specific site pairs. The matrix of paired transformed divergence values for the best four data files, 1, 5, 6, and 10, and the thirteen training site statistics identified only one classification confusion, value less than 1500, which was between two residential sites and therefore not a problem.

The average transformed divergence for the best four files was 1943, which indicates excellent separability of cover types and the likelihood of very good classification results. This calculation can be compared to a value of 1935 for the best four multispectral scanner data files and a value of 1705 for four SAR data files. The average divergence values are less for the individual sensor (MSS and SAR) calculations but more importantly, there was significant lack of separability between different cover types in the single sensor calculations. These results indicate advantages in classification with the multisensor data over the single sensor data.

Summary

This study has indicated that the use of multisensor data sets, MSS and SAR, for urban and near-urban land-cover classification will provide more accurate results than either independent set of sensor data. In particular, the best classification will occur when one data file is obtained from each major portion of the electromagnetic spectrum; visible, near-infrared, thermal infrared, and microwave. The transformed divergence values were useful in file selection and the examination of intraclass divergence.

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Erratum

In the article, "Assessing Landsat Classification Accuracy Using Discrete Multivariate Analysis Statistical Techniques," by Congalton *et al.*, which appeared on pages 1671-1678 of the December 1983 issue of *PE&RS*, the first two equations on page 1673 are incorrect. They should read as follows:

$$\hat{K} = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} x_{i+}\, x_{+i}}{N^2 - \sum_{i=1}^{r} x_{i+}\, x_{+i}}$$

$$\hat{\sigma}^2 [\hat{K}] = \frac{1}{N} \left\{ \frac{\theta_1(1 - \theta_1)}{(1 - \theta_2)^2} + \frac{2(1 - \theta_1)(2\theta_1\theta_2 - \theta_3)}{(1 - \theta_2)^3} + \frac{(1 - \theta_1)^2(\theta_4 - 4\theta_2^2)}{(1 - \theta_2)^4} \right\}$$