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A Comparison between Aerial Photography and Landsat for Computer Land-Cover Mapping

Computer analysis of a color infrared photograph provided more accurate land-cover estimates than Landsat when compared to a manual photointerpretation of an urban watershed.

Introduction

Researchers have applied a wide range of remote sensing techniques to provide accurate and timely land-cover information to resource planners and managers. These techniques range from multispectral scanners onboard satellites to aerial cameras on low flying airplanes. Several researchers have found Landsat imagery resolution inadequate to meet their mapping needs. Land-cover maps of either low accuracy or over simplified land-cover categories have been produced from Landsat imagery. This has led some authors[6-8] to attempt a quantitative or computer analysis of aerial photographs to provide land-cover information in resource studies. While these authors have found analysis of aerial photographs to be promising, others[9-11] have questioned its usefulness.

In this study a comparison is made between land-cover information provided from several sensors for an urbanizing area around Green Bay, Wisconsin. The area was chosen because of an ongoing research project funded by the Sea Grant Program. The project deals with determining the effects of urbanization on runoff and, consequently, on water quality in Green Bay. Land-cover information in this study is important as an input to the hydrologic models run by both the Wisconsin Department of Natural Resources (DNR) and the United States Geological Survey (USGS). Land-cover estimates from the computer analysis of Landsat and digitized aerial photography are compared to manual photointerpretations of black-and-white infrared and color infrared aerial photographs of the area within the watershed.

Abstract: *A comparison was made between computer analyses of color infrared film and Landsat imagery to provide land-cover information in an urban watershed. The results of the computer analyses were compared to manual photointerpretations of both black-and-white infrared and color infrared photographs. The computer analyses of both the color infrared and Landsat imagery produced comparable land-cover estimates and both were similar to the manual photointerpretations. However, the computer analysis of the color infrared photograph was found to provide a better representation of land cover within the area of the watershed.*

Area

The Highway 141 watershed lies southeast of the city of Green Bay, Wisconsin. The area of the watershed is quickly changing from a rural agricultural area with a few woodlots to a suburb of the city of Green Bay. The watershed covers approximately 4.1 square kilometres and is relatively flat. The maximum change of elevation is 43 m from the southwest to the northeast edges of the watershed. Kodak Aerochrome Infrared Film 2443 photographs of the site were acquired on 14 August 1979 from an altitude of 3700 m AMT with a Wild RC-8 camera equipped with a 152.4-mm focal length lens. A single 9 by 9 inch photograph at a scale of 1:24,000 encompassed the entire watershed. Due to meteorological conditions, the closest cloud free Landsat image of the area was taken on 5 September 1979.

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TABLE 1. LAND-COVER CATEGORIES CHOSEN FOR THE COMPARISON STUDY

Class	Description
1. Agricultural & Openland	Includes all agricultural, pasture, abandoned fields, lawns, etc.
2. Impervious	All areas covered by concrete, asphalt, or other impervious substances.
3. Disturbed	Includes all areas of disturbed top soil, typical in developing areas.
4. Forest	Includes all stands of trees and woodlots. Dominant species include White Oak, *Quercus Alba* and Shagbark Hickory, *Carya Ovata*.
5. Water	All water bodies.
6. Urban*	Areas containing a mixture of pervious/impervious surfaces (i.e., residential).

* Landsat only.

MANUAL PHOTO INTERPRETATION

For comparison purposes, a manual photointerpretation of the area was performed. The photographs chosen for the manual photo interpretation were a Kodak Infrared Aerographic Film 2424 photograph taken on 7 August 1978. The original photograph was at a scale of 1:20,000 while the photographic enlargement on which the manual photo interpretation was done was at a scale of 1:1200. A grid system was chosen for the manual photointerpretation in order to match the raster format of the digitized color infrared and Landsat images. A grid drawn on a mylar sheet was superimposed onto the black-and-white infrared photograph and a manual photo interpretation was performed by an experienced photo interpreter who had fieldwork experience in the watershed. Each grid cell corresponded to a picture element (pixel) representing a ground area of 63.6 by 63.6 m, or approximately 1 acre.

The land-cover classes used in this interpretation were agricultural and openland; impervious; disturbed; forest; and water. These land-cover classes are described in Table 1. For each cell the percentage of each of the land-cover classes was recorded. They were chosen because of their similarity to the land-cover classes used in the computer interpretation. This facilitated the comparison of interpretation results. A total of 1109 pixels were photo interpreted, with the results shown in Table 2.

Another manual photointerpretation was performed on the 14 August 1979 color infrared photograph in order to allow a further comparison between the methods. The same procedure was utilized with a grid of 48.0 by 48.0 m. A total of 1746 pixels were photo interpreted with the results also shown in Table 2. Both interpretations were compared to the results of the computer analysis. The manual photointerpretations based on the fieldwork within the watershed will provide the "ground-truth" for this study.

COMPUTER ANALYSIS

In recent years an extensive software system has been developed at the Environmental Remote Sensing Center (ERSC) on the University of Wisconsin-Madison campus. This software is used to analyze not only Landsat and thermal scanner data but also aerial photographs that have been converted into a digital format. An aerial photograph is converted into a digital format via a scanning microdensitometer. The microdensitometer scans the photograph three separate times through

TABLE 2. LAND COVER ESTIMATES, IN ACRES, FOR THE HIGHWAY 141 WATERSHED. BOTH MANUAL PHOTOINTERPRETATIONS AND DIGITAL INTERPRETATIONS WERE PERFORMED

	MANUAL		DIGITAL	
	Black-and-White Infrared (1978)	Color Infrared (1979)	Color Infrared (1979)	Landsat (1979)
Agricultural & Openland	793.51	709.22	689.23	654.43
Impervious	169.71	190.56	230.47	211.77
Disturbed	1.70	47.83	43.83	145.60
Forest	62.49	43.59	36.84	3.20
Water	3.15	3.08	2.84	0.00
Total	1030.56	994.28	1003.21	1015.00

narrow band interference filters centered at 0.45, 0.55, and 0.65 micrometers, respectively, which correspond to the approximate peak absorption wavelengths for the emulsion layers in color and color infrared film. The microdensitometer then records these data onto a computer compatible tape for transfer to mass storage files at the computer center. Due to the nature of photographic emulsion, these computer files of density levels from the microdensitometer must be corrected to exposures and for lens falloff to determine the relationship between the reflected energy from the ground and the resulting tone on the aerial photograph. This process and the theory of densitometric research has been described in detail by other authors[12-14]. These corrected computer files are then used in the ERSC classification software.

The computer analyses for Landsat images and digitized color or color infrared film are equivalent after these transformations are completed. As a first step, training sets representing the desired land-cover types are chosen from aerial photographs and fieldwork in the area. Second, these areas are located on density slices of the computer files. Then training statistics (i.e., mean vector, eigenvalues, etc.), are generated for each training set. These statistics are used in the classification procedures. Classification at ERSC is presently an iterative batch process run on a UNIVAC 1100/82 computer. The classification process runs until the resulting classification visually appears similar to the original image.

For this study, a color infrared photograph of the Highway 141 watershed was scanned on an Optronics P-1700 scanning microdensitometer following the procedure described above. Training sets were chosen and a minimum distance to mean classification was performed on the computer file. Simultaneously, the Landsat data tapes were obtained from the EROS Data Center. A similar process resulted in training sets being chosen from a much larger area for input into a maximum likelihood classifier. The only difference in the land-cover classes for the Landsat analysis was the addition of an urban class. This class was a mixture of impervious and pervious surfaces. Several residential areas were used as training sets for the urban class. With Landsat, impervious surface area was generally estimated from a land-cover category such as the urban class used in this study. The method used to estimate imperviousness from the Urban category has been documented by other researchers[15,16]. Land-cover classes chosen for the computer analysis were comparable to those for the manual photointerpretation and are described in Table 1. After several iterations the computer classifications produced for the digitized color infrared and Landsat images visually appeared to be a good representation of the actual land cover as it appeared on the aerial photographs.

Results

The results of both the manual photointerpretations and computer analyses are shown in Table 2. The number of acres of each land-cover type within the Highway 141 watershed are shown for the black-and-white infrared, color infrared, and Landsat images. in order to provide accurate information for the watershed, it's outline was drawn onto a 7.5 minute topographic sheet by a hydrologist at the USGS and digitized into Latitude-Longitude coordinates. These coordinates were converted to row-column coordinates for both manual photo interpretations and computer analyzed images by using control points and a two-dimensional affine coordinate transformation.

A comparison of the two manual photointerpretations reveals a noticeable difference in land-cover estimations. The amount of agricultural-openland is less and impervious and disturbed greater in the color infrared than the black-and-white infrared manual photointerpretation. Further examination of the two photographs shows the reason for these discrepancies. Since the watershed has urbanized quickly during the one-year period between the acquisition of the photographs, a significant amount of new development has occurred. It is interesting to note the close correlation between the number of acres in the water class for the manual photointerpretations and the computer classification of the color infrared. It is obvious that the water cover has not changed within the watershed during the time period between the two flights. This emphasizes the point that "ground-truth" should be coordinated closely with the acquisition of remote sensing data, especially in dynamic areas. Consequently, it was decided not to include the black-and-white infrared manual photointerpretation comparison in the study.

The comparison of the three remaining interpretations shows the digitized color infrared to be a closer approximation to the manual photointerpretation of the color infrared than the Landsat classification. The estimate of agricultural-openland acreage for the digitized color infrared and Landsat images are about equal, but lower than the value for the manual photointerpretation. The amount of impervious surface for the digitized color infrared and Landsat are very close, but higher than the manual photo-interpretation. In particular, the disturbed class's acreage estimate from the color infrared analysis is similar to the manual photointerpretation of the color infrared, but not as large as the Landsat estimate. The Landsat estimate is definitely due to misclassification. Apparently, the Landsat classification is misclassifying some inpervious surfaces as disturbed due to their similar spectral signatures. A reclassification of the Landsat scene should decrease the amount of the disturbed class, but would also result in an increase in the urban class and, consequently, the amount of imperviousness. This would increase the amount of overestimation of impervious surface from the Landsat analysis.

A comparison of the forest class for both digitized color infrared and the manual photointerpretation of the color infrared is similar to the previous discussion. However, the Landsat class seems to underestimate the amount of forest canopy in the watershed. The reason for this is that the small woodlots and oak openings are not large enough to significantly influence the spectral reflectance within a Landsat pixel. The last land-cover category, water, shows approximately the same acreage for both color infrared interpretations. The Landsat scene indicated no water bodies within the watershed even though training sets were taken from water bodies throughout the scene. This underestimate was again due to the inability of the watershed's water bodies to influence the spectral signature from the land-cover within the Landsat pixel. An additional comparison step was then attempted.

In order to compare the results of the computer analysis to the manual photointerpretation, a Chi-square analysis was performed. However, in order to perform a Chi-square analysis the zero entry for the Landsat water class must be altered to a non-zero entry. The method chosen to perform this operation was a pseudo-Bayes estimator[17]. This method, described in Table 3, has three steps. First, "a priori" probabilities (λ) were selected for each of the entries in the table. These probabilities were based on the table entries themselves. Secondly, a weighting factor (K) was computed. The weighting factor is dependent on the table entries and their probabilities. In the last step a new entry was computed for each entry in the table based on the present value of a particular entry, it's probability, and the weighting factor. The results of this procedure are shown in Table 3. Note that the number of acres for agricultural-openland under the manual photo interpretation of the color infrared has changed from 709.22 to 703.56. Overall, very minor changes have occurred to the entries in the table; however, the water entry for Landsat is no longer zero. This allows us to proceed with the Chi-square analysis.

A Chi-square analysis allows us to compare the results of the computer analysis to the color infrared manual photointerpretation and determine if there is a significant difference between them[18]. The Chi-square analysis is shown in Table 4. The null hypothesis was that there is no significant difference between the estimations of acreages for both computer analyses and the manual photointerpretation of the color infrared photograph. In

Table 3. Land Cover Estimates from Table 2 Adjusted Using a Pseudo-Bayes Estimate of Cell Probabilities

pseudo-Bayes estimator:

$$M_{ij} = \frac{N}{N + K}(X_{ij} + K\lambda_{ij})$$

where

N = sum of the row and column totals

$$\lambda_{ij} = N^{-2}X_{i+}X_{+j}$$

X_{i+} is a row total
X_{+j} is a column total

$$K = \frac{N^2 - \sum X_{ij}^2}{\sum_{i,j} X_{ij} - \frac{2}{N}\sum_{i,j} X_{ij}X_{i+}X_{+j} + \frac{1}{N^2}\sum_{i} X_{i+}^2 \sum_{j} X_{+j}^2}$$

	Manual	Digital	
	Color Infrared	Color Infrared	Landsat
Agricultural & Openland	703.56	688.52	661.88
Impervious	194.13	226.86	212.17
Disturbed	53.67	50.54	133.15
Forest	40.59	35.12	7.99
Water	2.84	2.70	0.40
Total	994.79	1003.74	1015.59

Source: Discrete Multivariate Analysis by Bishop, Fienberg, and Holland.

TABLE 4. RESULTS OF THE CHI-SQUARE ANALYSIS USING THE MANUAL PHOTOINTERPRETATION OF THE COLOR INFRARED PHOTO AS "TRUTH"

Chi square

Ho: No difference in the estimates of land cover.
Hi: Digital analysis of the color infrared is most like the "truth."

$$\text{Statistic: } \chi^2 = \frac{(fo - fe)^2}{fe}$$

where

fo = observed frequency
fe = expected frequency

	Digital	
	Color Infrared	Landsat
Agricultural & Openland	0.64	4.43
Impervious	4.90	0.99
Disturbed	0.24	112.07
Forest	0.83	27.00
Water	0.01	2.15
Total	6.62	146.64

Degrees of Freedom

$$df = K - 1$$
$$df = 4$$

Results

$\alpha = 0.001$ reject *Ho* if $\chi^2 > 18.465$

We must accept *Ho* for the color infrared analysis but reject *Ho* for Landsat.

Source: *Social Statistics* by Blalock.

this case the manual photointerpretation of the color infrared photograph is used as the standard. Using the proportions of the five land-cover categories from the manual photointerpretation to obtain the "expected frequencies" for each land-cover category in the computer analysis, and the acreages from each computer analysis category as the "observed frequencies," the Chi-square statistic was calculated. The results in Table 4 show a Chi-square statistic for the computer analysis of the color infrared of 6.62 and for Landsat of 146.64. If we compare that to the expected value of 18.465 for a significance level of 0.001, we find we must fail to reject the null hypothesis for the computer analysis of the color infrared but reject it for the Landsat analysis. This means that there is a statistically significant difference between the land-cover estimates from the manual photointerpretation and Landsat but none between the same manual photointerpretation and the digitized color infrared image; or the land-cover estimates between the color infrared manual photointerpretation and the computer analysis of the color infrared are more alike than the same manual photointerpretation and the Landsat estimates.

A further step was taken to obtain an estimation of the amount of dissimilarity between the manual photointerpretation and the computer analyses. In this test the absolute acreage differences between the proportion of a land-cover category from the manual photointerpretation and this proportion in each of the computer analyses was calculated. The differences in acres are shown in Table 5. As an example, based on the proportion of water in the manual photointerpretation of the color infrared (0.0031) the absolute difference for the computer analysis of the color infrared and Landsat was 0.27 and 3.15 acres, respectively. Overall, the absolute number of acres needed to be changed for the computer analysis of the color infrared was 76.41, while Landsat would require 228.06 acres to be changed. This means that, in order for the land-cover categories in the computer analysis of the color infrared to be in the same proportions as the manual photointerpretation of the color infrared, 76.41 acres must be changed for all five land-cover types. In the Landsat classification 228.06 acres must be changed.

TABLE 5. RESULTS SHOWING THE AMOUNT OF DISSIMILARITY BETWEEN THE MANUAL PHOTOINTERPRETATION OF THE COLOR INFRARED PHOTO AND THE DIGITAL ANALYSIS OF BOTH THE COLOR INFRARED PHOTO AND LANDSAT

	Manual	Digital			
	Proportions	Color Infrared	Δ	Landsat	Δ
Agricultural & Openland	.7133	689.23	26.36	654.43	69.57
Impervious	.1916	230.47	38.25	211.77	17.30
Disturbed	.0481	43.83	4.42	145.60	96.78
Forest	.0438	36.84	7.10	3.20	41.26
Water	.0031	2.84	0.27	0.00	3.15
Total	1.0000	1003.21	76.41	1015.00	228.06

Conclusions

This study has shown that computer analysis of a color infrared photograph provided more accurate land-cover estimates than Landsat when compared to a manual photointerpretation of an urban watershed. This is based on both Chi-square and dissimilarity analyses. Color infrared photography, unlike Landsat, can be acquired on any cloud-free date and provides a higher resolution when converted to a computer compatible format. This study also indicates that computer analysis of color infrared photography can be used as a substitute for a manual photo-interpretation. This would permit a quick, accurate interpretation over large areas at a higher resolution than achievable by a photo interpreter. Additionally, the results would be available to a computer data base. This study also demonstrates the importance of the date of "ground-truth" acquisition, especially in rapidly changing areas. The results of this study are presently being used as input to hydrologic models run by the Wisconsin DNR and USGS. These models will help determine runoff and sediment load from this and other watersheds in the Green Bay area.

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