LARS Information Note 031276

NASA CR-147788

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(NASA-CR-147788) AN ANALYSIS OF METROPOLITAN LAND-USE BY MACHINE PROCESSING OF EARTH RESOURCES TECHNOLOGY SATELLITE DATA (Purdue Univ.) 12 p HC $3.50 CSCL 08B
N76-28627
Unclas
G3/43 44503

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Purdue University, West Lafayette, Indiana

1976

PROCEEDINGS

of the Association of American Geographers

RALPH D. VICERO
Editor

Volume 6

1974

AN ANALYSIS OF METROPOLITAN LAND-USE BY MACHINE PROCESSING OF EARTH RESOURCES TECHNOLOGY SATELLITE DATA

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The technology available at Purdue University's Laboratory for Applications of Remote Sensing (LARS) to classify earth surface features from multispectral data is sophisticated. This paper describes the results of a successful application of state-of-the-art remote sensing technology in classifying an urban area into its broad land-use classes. This research proves that numerous urban features are amenable to classification using ERTS multispectral data automatically processed by computer. Furthermore, such automatic data processing (ADP) techniques permit areal analysis on an unprecedented scale with a minimum expenditure of time. Also, classification results obtained using ADP procedures are consistent, comparable, and replicable; hence many spatial analysis problems caused by human errors or decisions are eliminated. The results of classification are compared with the proposed U. S. G. S. land-use classification system in order to determine the level of classification that is feasible to obtain through ERTS analysis of metropolitan areas. (Anderson, Hardy, and Roach, 1972, 6).

DATA ACQUISITION AND DATA PROCESSING

On August 9, 1972, ERTS collected imagery over a large area in the Middle West from an orbit that averaged approximately 915 kilometers above the earth's surface. This imagery was collected by the ERTS multispectral scanner, which records reflected energy from earth surface features and converts it into electronic signals. The resolution of the ERTS multispectral scanner is approximately 80 meters. The scanner receives data from four portions of the electromagnetic spectrum: 0.5 to 0.6 μm (micro-meters range of band 4), 0.6 to 0.7 μm (band 5), 0.7 to 0.8 μm (band 6), and 0.8 to 1.1 μm (band 7). As the ERTS scanner "scans" an area on the earth's surface, four simultaneous signals are received for any given area and are stored on magnetic tapes at one of NASA's receiving stations. Work performed in this study was accomplished at LARS where ERTS data received are reformatted for use with the laboratory's data processing system.

There is similarity between the two visible bands (four and five), and between the two infrared bands (six and seven). The visible bands allow ready distinction between the highly urbanized areas, suburbia, major transportation routes, and the outlying agricultural regions. The infrared bands, on the other hand, most clearly differentiate the central, older part of the metropolitan area from the suburban and agricultural areas.

Significant amounts of information may be deduced from studying spectral data from a single band; however, it is of greater value to combine the bands of data in order to obtain a single, integrated land-use classification of a metropolitan area. System analysts at LARS have implemented a package of computer programs which allow the investigator to identify earth surface features by automatic pattern recognition techniques (Phillips, 1973).

After a study area was classified, programs were used to display the results. Interpretation of selected aspects of the classes delineated in the Milwaukee County and other Midwestern study areas (Chicago-Gary, Madison, Rockford, and Indianapolis) was performed using data from the urban land-use classification displayed in the synthesized photographic and alphanumeric print-out forms.

THEORETICAL CONSIDERATIONS

The broad land-use classes used in the ERTS analysis of Midwestern metropolitan areas can be divided into two types of spectral responses, herein designated as homogeneous and heterogeneous. A land-use class with a relatively homogeneous spectral response is characterized by a single phenomenon or a group of spectrally similar phenomena providing the overwhelming influence in the total spectral response that is obtained from the multispectral scanner.

The resolution of multispectral data from space, for instance, tends to make the identification of subclasses of green vegetation very difficult, since the spectral responses from the various botanical forms are similar. Hence, in a small-scale or highly generalized classification of land use it is initially easiest and most accurate to consider green vegetation as a mixture of phenomena with similar (homogeneous) spectral responses, rather than attempt to analyze a large number of subclasses of vegetation, each characterized by a unique spectral signature.

The land-use classes of an urban study area as viewed by low-resolution scanner are usually comprised of two or more distinctly different types of spectral responses which generally indicate that a mixture of diverse phenomena is present in a given class. Land-use classes of this nature are termed heterogeneous. For example, the classes "commerce/industry," "inner city," "suburban," and "wooded suburb," represent the relatively heterogeneous earth surface features classified in this study.

The heterogeneous classes of land use were comprised of various proportions of a minimum of two spectrally diverse groups of phenomena. The class "suburban" was predominantely a mixture of rooftops (asphalt), sidewalks (concrete), roads (asphalt and concrete) and green vegetation (grass and trees). Although an individual roof, tree, lawn, or sidewalk cannot be identified at the resolution attained by ERTS, the combined spectral response from the various proportions of all phenomena present in the area may permit the differentation of one urban phenomenon from another. The class "suburban", for instance, which is primarily a mixture of rather highly reflective materials (i.e. concrete), materials of low to very low reflectance (i.e. asphalt), and materials of variable reflectance dependent on which ERTS channel is used (i.e. green vegetation), should have response characteristics (using all ERTS bands) different than the class "commerce/industry" which is comprised primarily of concrete and other rather reflective materials complimented by lower response materials such as asphalt. The class, "commerce/industry," has a different overall spectral nature than that of class "suburban" because of the difference in the proportions of material that comprise each class. Thus, frequently it is feasible to define broad classes of urban phenomena based on the proportions of groups of spectrally different phenomena that comprise each class (LeBlanc, Johannsen, and Yanner, 1972, 70–73).

METROPOLITAN LAND-USE CLASSES

Several metropolitan land-use classes were identified through analysis of ERTS spectral data (Table 1). Each land-use class has its own distinct combination of relative spectral responses which permits accurate differentiation of one earth surface feature from another when machine-processed.

A determination of the approximate accuracy of land-use class identification was attempted for two versions of the ERTS Milwaukee County classification. Alphanumeric printouts of the classifications were superimposed on topographic quadrangles (supplemented by information from recently published land use maps) of the study area. Comparisons between the known land-use patterns and the land-use patterns identified through spectral analysis of ERTS data indicate that more than 90 percent of the classes "commerce/industry", "inner city", and "suburban" were identified correctly. Water classes were identified correctly with an accuracy of nearly 100 percent. The more rural classes of land-use in metropolitan Milwaukee were not identified correctly with as high a degree of accuracy (65 percent) in the classification that identified very successfully the most highly urban land-use classes.

TABLE 1. RELATIVE SPECTRAL RESPONSES OF EARTH PHENOMENA IN MILWAUKEE COUNTY

	Relative Spectral Responses Class X's			
Class	bd 4	bd 5	bd 6	bd 7
Commerce/Industry	38.71	37.53	35.80	14.77
Inner City	30.98	26.88	37.87	18.42
Wooded Suburb	24.94	18.66	40.24	22.91
New Suburb*	29.52	24.20	49.27	27.85
Suburban, Other	39.17	37.09	53.12	26.99
Trees	20.47	12.27	50.49	32.38
Grassy*	27.15	20.16	53.24	31.43
Rural	23.15	14.29	53.88	33.62
Water 1	35.20	21.41	9.94	1.49
Water 2	24.23	10.37	5.40	0.69
Water 3	19.71	9.42	5.86	1.10
Water 4	21.47	13.85	12.65	3.34
Water 5	46.83	46.50	23.83	2.83
Cloud	71.55	69.50	89.08	44.38
Shadow	17.70	9.45	16.15	6.75

* New Suburb and Suburban, Other are commonly displayed as one class. Grassy and Rural are often displayed as one class.

Source: Compiled by the authors from LARS STATISTICS Program.

A second version of Milwaukee County classification derived from analysis of ERTS spectral data was made which concentrated most on identifying correctly less strongly urban phenomena. In this classification version over 90 percent of the more rural land-use classes were identified correctly. The accuracy of identification of the most highly urbanized classes deteriorated to less than 70 percent in the classification version that identified very successfully all other county land-use classes. Further work must be attempted to combine the advantages of two classifications into one; however, at this time it takes two classifications to identify each one of the metropolitan land-use classes (Table 1) with an accuracy that approaches or exceeds 90 percent.

The Milwaukee County classification data were used to help classify the Chicago-Gary, Rockford, and Madison Metropolitan Areas. The exact degree of classification success was not determined in these metropolitan areas; however, it was evident from comparisons between the classification results and published maps of the areas that the quality of classification of these urban areas was similar to that of Milwaukee County. Classification data that were used to analyze the Kansas City Metropolitan Area were used successfully to classify Milwaukee County. These examples indicate that transferability of classification results (i.e. the spectral signature of "suburban" in Milwaukee County can be used to classify suburban areas in other cities) within and among ERTS frames obtained during similar times of the year is a possibility in selected cases. Monitoring of urban land uses for large numbers of metropolitan areas is simplified if transferability of classification data proves to be common.

A CONTRIBUTION OF ERTS TO THE PROPOSED U.S.G.S. LAND USE CLASSIFICATION SYSTEM IN METROPOLITA AREAS

Land-use evaluation from analysis of ERTS spectral data in Milwaukee County, and to a lesser extent in other Midwestern urban areas, was compared with the proposed national land-use classification system (U.S.G.S.) in order to determine the contribution ERTS can make in the identification of metropolitan area phenomena (Todd and Baumgardner, 1973, 2A 23–29). The land-use classes that are commonly subject to identification in metropolitan areas are reproduced (Table 2) in tabular form (Anderson, Hardy, and Roach, 1972, 6).

TABLE 2. COMPARISON BETWEEN U.S.G.S CLASSIFICATION SYSTEM AND ERTS ANALYSIS FOR SELECTED MIDWESTERN METROPOLITAN AREAS

LEVEL I and Level II	Agreement
01. URBAN AND BUILT-UP LAND	YES
01. Residential	yes
02. Commercial and services	yes
03. Industrial	
04. Extractive	no
05. Transportation, communications, utilities	no
06. Institutional	no[1]
07. Strip and clustered settlement	no[2]
08. Mixed	no
09. Other and open	yes
02. AGRICULTURAL LAND	YES
03. RANGELAND	NA[3]
04. FOREST LAND	YES
05. WATER	YES
01. Streams and waterways	yes[4]
02. Lakes	yes
03. Reservoirs	yes
04. Bays and estuaries	yes
05. Other	yes
06. NONFORESTED WETLAND	NA
07. BARREN LAND	NA
08. TUNDRA	NA
09. PERMANENT SNOW AND ICEFIELDS	NA

[1] Classified as Commercial/Industrial.
[2] Classified as New Residential.
[3] Not applicable to study areas.
[4] Identification obtained through spatial analysis of spectral data.

Source: Anderson, Hardy, and Roach, 1972, 6.

All four of the classification level I land uses found in Midwestern metropolitan areas can be differentiated from one another through machine-processing of ERTS multispectral data (Table 2). The authors of the proposed national land classification system expected satellite imagery to be the sole source of information for land uses at level I. This study verifies the ability of satellites to obtain data that permit accurate identification of level I land uses in metropolitan environments without resorting to additional sources of data.

Level II land uses were anticipated to be identified through the use of high-altitude and satellite imagery combined with topographic maps. This study used spectral data from ERTS solely to attempt to identify level II land-use features in metropolitan environments. Photography and topographic maps were used to estimate accuracy of classification; however, the use of these other data sources was not a part of land-use identification initially. It is certain that the combining of three sources of data (satellite, photography, and topographic maps) will lead to the identification of level II land uses; however, this research indicates that from satellite data alone it is possible to identify several level II land-use classes. Additional research may result in the accurate identification of virtually all level II metropolitan area land uses from analysis of ERTS spectral data combined with a minimal use of supplementary data.

An excellent study of the San Francisco Bay Metropolitan Area that used machine-processing of ERTS spectral data (Ellefsen, Swain, and Wray, 1973, 2A7-22) arrived independently at many results and conclusions similar to those presented in this analysis of Midwestern metropolitan areas. The broad similarity of results among two studies independently developed is encouraging because the liklihood of successful ERTS classification of metropolitan areas in general is enhanced.

CONCLUSION

Real and potential advantages of using ERTS data automatically data processed for developing broad land-use inventories of metropolitan areas are: (a) speed and accuracy in classification of earth surface features; (b) comparability and transferability of classification from one area to another; (c) versatility in the processing of spectral data; (d) economical acquisition of broad land-use patterns information; (e) feasibility for obtaining accurate land-use data in selected under-developed parts of the world.

Small-scale land-use inventory classification can be obtained through *spectral* and *spatial* analysis of ERTS data. All level I and many level II categories of the proposed U. S. G. S. land-use classification system are possible to identify accurately through machine-processing of ERTS multispectral data. Additionally, the use of ERTS makes possible for the first time in history, frequent and regular *temporal* analysis of earth surface features. Under ideal conditions, a SMSA or any other earth surface area can be analyzed spectrally and classified into land-use types every eighteen days. The impact of this ERTS characteristic for potential users is great since the quality, accuracy, and detail of land-use classification improves as the number of "scans" at different dates increases. The proven value of ERTS data in evaluating metropolitan land uses in selected Midwestern areas suggests that this source of information will be invaluable for many urban regional specialists.

ACKNOWLEDGEMENT

This research was supported by NASA under Grant NGL 15-005-112.

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