THE URBAN GROWTH MANAGEMENT INITIATIVE: CONFRONTING THE EXPECTED DOUBLING OF THE SIZE OF CITIES IN THE DEVELOPING COUNTRIES IN THE NEXT THIRTY YEARS – METHODS AND PRELIMINARY RESULTS

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ABSTRACT

Procedures are overviewed and preliminary results are presented for a project addressing urban growth mapping for a sample of 120 metropolitan areas from a universe of 2,719 cities having populations in excess of 100,000 in the year 2000. A modified unsupervised classification approach applied to Landsat imagery serves as the basis for urban cover mapping. At the time of the preparation of this paper, work had been completed for 54 cities, and another 37 were in various stages of completion. The average annual urban growth for a sample of 31 metropolitan areas was 5.1 percent, based on an average temporal difference between T_1 and T_2. Accuracy for a sample of seven of the classifications for the completed metropolitan areas yielded an overall mapping accuracy of 88.3 percent for both for T_1 and T_2. It is expected that classification and accuracy assessment for T_1 and T_2 Landsat data for all cities will be completed by Spring 2005. The urban classification maps developed in this project, as well as summary data, will be made available to the scientific community via the Internet.

INTRODUCTION AND BACKGROUND

According to the most recent United Nations projections (United Nations, 1999), the urban population of the developing countries is now growing at the annual rate of 2.3%. At this rate, it will double in 30 years, from 1.94 billion in 2000 to 3.88 billion in 2030. While the metropolitan areas in industrialized countries will only add 12% to their population during this period, their counterparts in developing countries will add 100% to their existing populations. Based on current settlement practices, this implies that, on average, cities in the developing countries will most likely double their built–up areas to accommodate the doubling of their present populations. Accounting for increasing per capita incomes, their built–up areas are likely to more than double during this period, but there is little systematic data to estimate, let alone to explain, current and future levels of urban expansion.

In the industrialized countries, recent concerns with urban sprawl (Gordon and Richardson, 1997; Geddes, 1997; Mills, 1999; Cooper, 1997), often in the absence of rapid population growth, have led to planning initiatives focused on urban growth management and on "smart" growth (Weitz and Moore, 1997). Corresponding initiatives in the developing countries (that are still experiencing rapid *population* growth) are rare. Few governments in the

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developing countries are actively engaged in realistic minimal preparations for growth: securing the necessary public lands and public rights–of–way necessary to serve future urban growth, protecting sensitive lands from building,[5] or investing in the minimal infrastructure necessary to accommodate and direct urban development. Instead, they sometimes focus on ambitious utopian master–plans that are never meant to guide development on the ground, take many years to produce, and are usually shelved shortly after their publication. At other times, they simply refuse even minimal planning, hoping against hope that their overcrowded cities will stop growing. As a consequence, urban expansion has taken place on lands that should be left undisturbed, and newly built–up areas now lack adequate roads, sufficient land for public facilities, and even rudimentary open spaces.

It is more expensive to provide urban infrastructure in built–up areas, especially in areas developed by the informal sector, than to provide such services, or at least to protect the rights–of–way needed for such services, before building takes place. While there are many reasons for neglecting to prepare for the inevitable future growth of cities, the absence of even minimal preparation for urban expansion is, no doubt, an inefficient, inequitable and unsustainable practice, imposing great economic and environmental costs on societies that can ill afford them. The fact that such practices are now ingrained does not mean that they cannot be changed or moderated. The mistakes of the past need not be repeated. Humanity has indeed been given a second chance: we now need to build yet again new urban areas equivalent in size to the cities that we have already built, we need to do it better, and we need to do it in a very short time.

The two complementary objectives of the Urban Land Management Initiative are therefore:

1. *Studying the causes and consequences of urban expansion*: Alerting local and national governments, as well as the international academic community to the magnitude of recent urban spatial expansion and its virtual inevitability; measuring urban land `expansion on a global scale and establishing global norms; and explaining the causes and consequences of this expansion by focusing on remote sensing, census and other data collection in a global stratified sample of 120 cities; and
2. *Preparing viable models of minimalist urban growth management*: Alerting governments worldwide to the urgent need to manage urban expansion properly by (a) providing and disseminating state-of-the art information on urban growth management; and (b) by studying minimalist growth management strategies in three pilot cities, with a view to creating viable models for wider use.

Work on the Initiative began in early 2004. By the end of 2004 several important steps had been completed: (a) the selection of a stratified random sample of 120 metropolitan areas from the universe of 2,719 urban areas with populations in excess of 100,000 in the year 2000 has been completed; (b) for most metropolitan areas in the sample, administrative boundaries (level 2 or higher), and their corresponding populations in two recent census periods have been obtained; (c) Landsat TM or ETM image data for these two time periods have been obtained, and the classification of these images into urban and non–urban land use is now at an advanced stage, to be discussed further below. The construction of various measures of urban land expansion and the preliminary statistical modeling of the data, using available economic and demographic data to explain variations in these different measures, will be undertaken in Summer 2005.

Preparations are now being made for collecting data on the ground in each city. This will proceed by completion of: (a) design of a data gathering protocol, focused on data collection by a local consultant in each of the 120 metropolitan areas in the global sample by January 2005; (b) pilot testing of this protocol in an initial sample of 10 cities by April 2005; (c) recruitment of a local consultant in each metropolitan area by April 2005; and (d) data gathering, including ground truth data at several designated points in each city, information on housing conditions and prices, as well as information on the local planning policies, in the global sample of 120 cities during Summer 2005. The data gathered on the ground will be used to evaluate and, where possible, improve the land cover classification in each city. The data collected will also be used in efforts to improve the explanatory power of the preliminary models based on available census data and classification, as well as make possible the construction of new models that explain some of the consequences of urban expansion, and particularly its effect on various measures of shelter deprivation.

[5] In some cases — Greater Cairo is an example — it is also necessary to limit the incursion of the urban area into agricultural lands.

METHODS

Creating a Global Sample of Cities

A stratified sample of 120 cities was obtained from the universe of identified cities with metro-area that had a population in excess of 100,000 in the year 2000. Two sources of data were used to construct the sample. The first was the matrix of city data prepared by Dr. Vernon Henderson of Brown University, as part of a World Bank research project entitled "Successful cities: Determinants of City Growth Rates." This matrix provided information on the urban population in the period 1950–2000 for 2,719 cities that had populations in excess of 100,000 in the year 2000.[6] The information on the cities contained in this matrix was used to construct the strata of cities that were sampled for study. The second was the sample of 353 cities (and a sub–sample of 35 cities) recently selected by an expert group for the UN Global Urban Observatory (GUO). The sample of 120 cities selected for the study was chosen from the UN Urban Observatory sample of 353 cities, and included 32 of the 35 cities in its sub–sample.

Individual cities or metropolitan areas, rather than their populations, constitute the units of observation in this sample. Some analyses undertaken may seek to estimate relationships that hold for the world urban population, and other relationships that hold for cities per se. Therefore, the sampling procedure will make available weights for the sample that reveal, for each city, the appropriate weight as a sample of the total urban population and a separate weight as a representative observation in a sample of all cities. These weights will be used in estimating measures of urban expansion for the universe of cities. Using these weights, different measures of urban land consumption will be estimated for each city.

The selected sample of 120 cities was a stratified sample. Three important characteristics were used to define the strata: (a) the world region in which the city is located; (b) city population size; and (c) its level of economic development, measured by national per capita income. The universe of cities was divided into nine regions, four size categories, and four per–capita income groups. To the extent possible, within the budgetary limitation on the number of cities to be sampled, an attempt had been made to include cities in the sample in as many regional, size, and income categories as possible.

(a) Geographic region categories: The UN Global Urban Observatory provides a breakdown of countries into nine regions, and it is this regional classification that was used for constructing the study sample. The nine regions are: (1) Europe, including both Western and Eastern Europe, as well as the Russian Federation; (2) East Asia and the Pacific, including China, Korea, and Mongolia; (3) Latin America and the Caribbean; (4) Northern Africa; (5) Other Developed Countries, including the United States, Canada, Japan, Australia and New Zealand; (6) South and Central Asia, including Iran; (7) South East Asia; (8) Sub–Saharan Africa; and (9) Western Asia, including Turkey. A minimum of eight cities was selected from each of these nine regions. Five of these nine regions have approximately 15% each of the global urban population. Sixteen cities were selected from each of these five regions. Two of the regions had 5–10% each of the global urban population, and 12 cities were selected from each one of them. A comparison of the universe of cities and the sample of cities appears in Table 1.

(b) City size categories: The 2000 population in the universe of 2,719 cities with populations in excess of 100,000, in the matrix provided by Henderson, varied from 26.4 million in Tokyo, Japan to 100,000 in Kinesma, Russian Federation. The universe was divided so that the total urban population in each size category was equal. The total population in the universe was 1.815 billion. This population was divided into four classes, so that each size category contained approximately 454 million people. This resulted in the following size categories:

1. Size class 1: cities with populations between 100,000 and 528,000 (1,982 cities);
2. Size class 2: cities with populations between 528,000 and 1,490,000 (498 cities);
3. Size class 3: cities with populations between 1,490,000 and 4,180,000 (190 cities); and
4. Size class 4: cities with populations in excess of 4,180,000 million (49 cities).

To the extent possible, the cities in each of the nine regions were sampled so that there will be an equal number of cities in each size category. For example, in Latin America and the Caribbean, a total of 16 cities were sampled, four cities in each size category. The sample of 120 cities will therefore contain approximately 30 cities in each size category. As a result, although the sample will contain only 120 cities (4.4% of the total number of cities), it will contain 397 million people (22% of the world's urban population). Because urban land consumption is expected to

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[6] This universe of cities in Henderson's matrix now appears to be incomplete. According to UN Habitat, the UN Human Settlements Programme, there are more cities in the 100,000–or–more category. The research team is in the process of obtaining the more complete list and the sampling procedure used by UN Habitat, to detect any systematic bias in the sampling procedure adopted here.

be closely related to the urban population, the proposed sample will examine approximately one–fifth of the built–up area in urban use.

Table 1. Comparison of the study sample with the universe of cities

		The Universe of Cities			The Sample of Cities		
		Number	Population 2000		Number	Population 2000	
No.	Region	of Cities	Total Urban	% of Total	of Cities	Total Urban	% of Total
1	Europe	624	289,059,052	15.9%	16	58,094,854	14.6%
2	East Asia	282	315,465,095	17.4%	16	38,749,537	9.8%
3	Latin America & Caribbean	424	262,457,151	14.5%	16	69,876,732	17.6%
4	Northern Africa	64	41,355,071	2.3%	8	21,239,133	5.4%
5	Other Developed	401	315,960,542	17.4%	16	66,958,996	16.9%
6	South and Central Asia	346	272,666,966	15.0%	16	67,992,645	17.1%
7	South East Asia	188	106,051,972	5.8%	12	36,940,787	9.3%
8	Sub-Saharan Africa	271	136,977,906	7.5%	12	19,105,243	4.8%
9	Western Asia	119	75,568,300	4.2%	8	17,836,183	4.5%
	Total Urban 2000	2,719	1,815,562,055	100.0%	120	396,794,110	100.0%

(c) Per capita income categories: The World Bank's World Development Report provides a regular breakdown of countries into four annual Gross National Income (GNI) per capita categories. The 2003 Report, entitled "Sustainable Development in a Dynamic World," (page 243) was used to obtain the classification of the universe of cities into four 2001 per–capita income groupings. This resulted in the following per–capita income categories:

1. Per–capita income category 1: cities in countries with annual per–capita income of $9,206 or higher (38 cities in the sample with 128 million people);
2. Per–capita income category 2: cities in countries with annual per–capita income between $2,976 and $9,205 (14 cities in the sample with 66 million people);
3. Per–capita income category 3: cities in countries with annual per–capita income between $746 and $2,975 (37 cities in the sample with 106 million people); and
4. Per–capita income category 4: cities in countries with annual per–capita income of less than $745 (31 cities in the sample with 98 million people).

(d) The sampling procedure: The nine geographical regions, four size categories, and four income categories were used to define the strata to be represented in the sample. This resulted in a total of 144 cells, of which 60 cells were found to contain at least one city. For each of the 60 strata that could be represented, we selected a number of cities in each so that the combined population of the cities selected for that stratum would be approximately proportional to that stratum's share in the global urban population. Where possible, we selected randomly among the cities in the UN Urban Observatory sub–sample of 35 cities (because considerable additional data are being collected and made available for this subsample). Where the subsample was not sufficiently well-represented, cities were selected at random from the larger UN Urban Observatory sample of 335 cities. Cities for which no national development indicator data exist at the World Bank, as well as cities for which no census data exist in the period 1984–2003, or cities for which no *Landsat* images are available (for dates roughly corresponding to the census dates) have been excluded from the sample. This resulted in selection of 117 cities. Three urban areas (which are outside the UN Urban Observatory sample but for which Landsat and World Bank are available) were randomly chosen from appropriate strata to complete the sample. The locations of the sample of 120 cities are shown Figure 1.

Measuring and Explaining Global Urban Expansion

The data being collected will permit us to calculate a variety of spatial measures of land consumption and urban structure. The spatial measures that will be calculated for each metropolitan area in the sample will include:

1. Average built–up area per person (and its reciprocal, the average population density in the built–up area) at the present time;
2. Average annual consumption of new urban land per person over the past decade;

3. The compactness (or constrained compactness)[7] of the built–up area at the present time;
4. Increase (or decrease) in average population density during the last decade;
5. Increase (or decrease) in the compactness of the built–up area during the last decade;

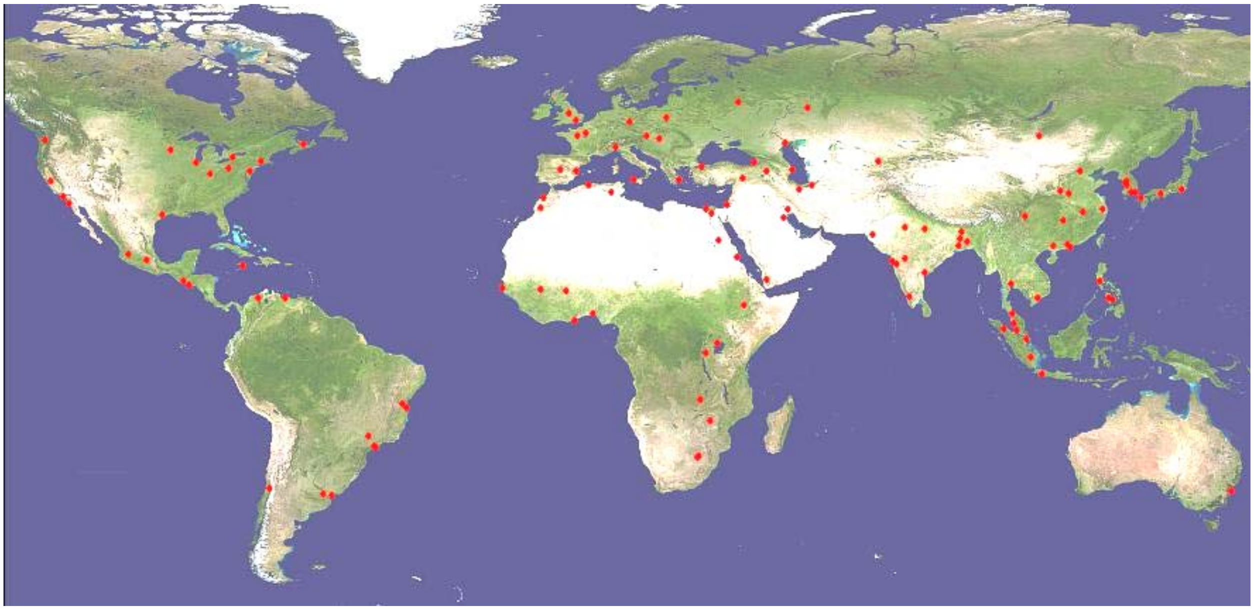

Figure 1. Location of the 120 sample cities. (Base image from ***The Blue Marble***, NASA Earth Observatory)

Our initial analysis will focus on the factors that influence these measures of land consumption and urban structure. We will estimate the relationship that holds between these measures and variables that represent economic and demographic pressures for urban expansion. These variables will include the following seven measures (and possibly others as well, e.g. fuel prices and vehicle ownership):

1. Gross national income per capita in purchasing power parities in the year 2000(+);
2. The city rank in the overall national urban system in the year 2000(+);
3. The city population in the year 2000(–);
4. The number of kilometers of paved roads per 1,000 people in the country in the year 2000 (+);
5. The percent of the country's population living in urban areas in 1960(–);
6. Annual city population growth between 1960 and 2000(+); and
7. The average household size in the country in the year 1990(–).

For each variable, the sign of the expected impact on total land consumption is indicated as either positive (+) or negative (–). In order to explore the potential explanatory power of the above measures in explaining variations in the built–up areas of cities, two preliminary multiple regression models were constructed, using cross–sectional data for the built–up area and city population of 45 world cities collected by Bertaud (Malpezzi and Bertaud, 2002). Logarithmic forms of (a) gross national income per capita, (b) city rank, (c) the number of kilometers of paved roads per 1,000 population in the country as a whole, and (d) city population explained 79 percent of the variation in the log form of built–up areas of cities in the Bertaud sample. Similarly, log forms of (a) gross national income per capita, (b) city rank, and (c) the number of kilometers of paved roads per 1,000 explained 71 percent of the variation in the log form of urban land consumption per capita in the cities in his sample. These initial results suggest that, using similar or improved models, the data to be obtained in the global sample of 120 cities can provide a model whose results can be extended to the universe of cities.

Two projected outputs of the proposed research are (a) to use the city sample described earlier to estimate the relation between measures of urban land consumption and economic and demographic variables for which data are

[7] Measures of compactness and constrained compactness (compactness given geographical constraints, such as steep slopes or bodies of water) will be discussed in greater detail in the body of the proposal.

available worldwide; and (b) to use these estimated relation to estimate these measures of urban land consumption in all world cities.

We will use the estimated statistical relationship between urban land consumption measures and economic and demographic data now available worldwide to produce, for most of the urban center in the world having population greater than 100,000 persons, several estimates that are presently not available on a comparative global scale:

1. Average urban land consumption per capita (and its reciprocal, the average population density in the built–up area) at the present time;
2. Annual consumption of *new* urban land per person at the present time;
3. The compactness (or constrained compactness) of the built–up area at the present time;
4. Increase (or decrease) in average population density during the last decade; and
5. Increase (or decrease) in the compactness of the built–up area during the last decade;
6. An estimate of the *additional* land area that would be required to accommodate a doubling of the current population; and
7. An estimate of the increase in total urban land area required if current rates of population growth continue for the next 30 years.

For the first time, it should be possible to estimate urban land consumption on a global scale: for the world at large, for different regions, for different countries, for different stages of economic development, and for different sizes of cities. These estimates will contribute towards several important policy objectives:

1. They will help policy makers better understand the relation between economic development and urban land consumption;
2. They will provide information on the stability of relationships between land consumption and socio-economic conditions, enabling evaluation of the hypotheses of "exceptionalism" where urban policy makers hope or expect to deviate in a radical way from the usual observed patterns of urban expansion and development;
3. They will help establish global norms of expected land consumption patterns for different types of cities, allowing cities to determine whether they are close to the expected norm or whether they are outliers given the expected norms;
4. They will help policy makers identify and estimate needs for technical assistance and infrastructure investment in preparation for accommodating the projected urban growth in the coming years in all cities, countries, regions, and in the world at large.

Selection of Landsat Imagery

Moderate resolution land cover data are available for much of the globe for *circa* 1990 and 2000, in the form of EarthSat's *GeoCover LC (Land Cover)* product,[8] however, not all of the study cities have been completed. Further, an inspection of a sample of those cities which are covered by EarthSat's *GeoCover LC* data revealed that, while perhaps appropriate for general urban land cover mapping, were inadequate for this study. It was decided, therefore, to proceed with classifications tailored to meet the spatial and informational needs of this project. Landsat Thematic Mapper and Enhanced Thematic Mapper-Plus data were selected as the basis for image analysis and land cover classification. Landsat scenes available through EarthSat's *GeoCover Ortho Landsat TM* database[9] were identified and previewed via the Earth Observing System Data Gateway.[10] If the scenes in the *GeoCover-Ortho Stock Scenes* archive were both cloud-free, especially within the area of interest surrounding the cities, and were acquired on a date within two years of the respective country's population census, they were selected as appropriate for analysis. For those cities for which either there was excessive cloud cover or were more than two years from the census date, a search of other Landsat 4/5 and 7 data was conducted with the USGS Global Visualization Viewer (GLOVIS).[11] These additional scenes were acquired from USGS EROS Data Center (EDC) through EarthSat, which produced a *GeoCover-Ortho Custom Projection* product conforming to the specifications of the original NASA contract for the GeoCover Ortho Landsat TM product. In several instances, suitable Landsat data for one or both dates for several cities was not available, requiring a modification of the original sample of 120 cities.

[8] http://www.geocover.com/gc_lc/index.html
[9] http://www.earthsat.com/ip/prodsvc/gcolandsat_prod.html
[10] http://edcimswww.cr.usgs.gov/pub/imswelcome/
[11] http://glovis.usgs.gov/

Image Classification Protocol

Each full-scene Landsat was subset to just the area required to cover each city. This was done to facilitate data management, processing, and storage, as well as to reduce the overall area to be classified to the minimum coverage required, thereby allowing the analyst(s) to focus on the urban features. An unsupervised classification approach was chosen for the classification of T_1 and T_2 Landsat imagery (Figure 2). The ISODATA clustering algorithm was used to partition the T_1 subset scenes into 50 spectrally separable classes. Using the Landsat data themselves, along with independent reference data when available, each of the 50 clusters was placed into one of seven pre-defined cover classes: water, urban, vegetation, barren (including bare soil agriculture), clouds/ shadow, snow/ice, and "undetermined". The latter class was one reserved for those pixels for which a clear determination could not be made on the first clustering. Only those pixels for which the land cover class was certain were labeled. The "undetermined" class typically consisted of pixels confused between urban and barren. Those pixels labeled as such were extracted from the T_1 and submitted to a second clustering in an attempt to maximize the separability among those spectrally similar classes. The clusters from this second iteration were labeled into one of the six informational classes. Because per-pixel, spectral data-alone classification methods often encounter difficulty in discriminating between urban and barren cover types, confusion still remained after this second pass. The classification maps were carefully scrutinized to detect obvious misclassifications by comparing results with the source image, through a careful, section-by-section examination of the Landsat imagery. On-screen editing of regions of pixels obviously misclassified was performed through *heads-up* digitizing.

Accuracy Assessment

Accuracy assessment was performed independently for the T_1 and T_2 land cover classification for the two categories of urban and non-urban. For each land cover map, an equalized, random set of test points was selected, using the T_1 land cover as the basis. The test points within a sample were further randomized to avoid bias in the reference labeling of those pixels. Additionally, the pixel located at a randomly generated easting and northing was used, rather than the 'majority' option offered by some algorithms. This set of points was exported into an ASCII file and used as the same set of test points to assess the accuracy of the T_2 classification. Ideally, it would be desirable to use an independent source of reference data of higher precision and known accuracy for validating the classifications, however, such data were, and are, not generally available. Therefore, the source Landsat imagery was used as the basis for assigning reference labels to each classified test pixel. Standard measures of producer's accuracy, user's accuracy, overall accuracy, and kappa were generated (Congalton and Green, 1999).

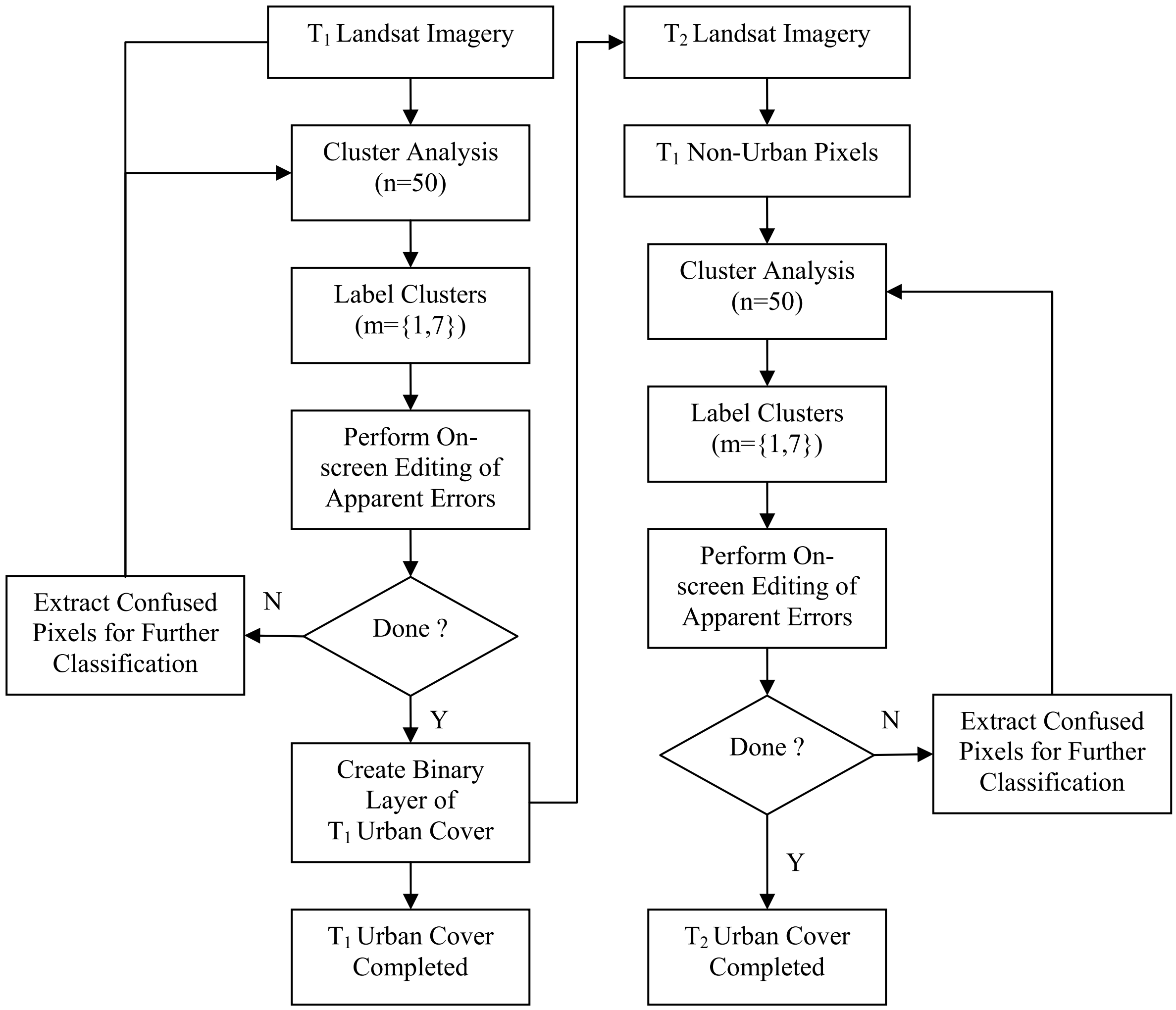

Figure 2. Protocol for T_1 and T_2 urban land cover classification

RESULTS AND DISCUSSION

Classification

The classification protocol overviewed previously generally performed well in extracting land cover information. The identification of the clearly, spectrally separable classes of vegetation, water, clouds/ shadow, and snow/ice was quite efficient. However, problems were encountered with the spectrally similar classes of urban, barren, and bare-soil agriculture. These confusions were resolved by way of either a second-pass clustering of the "undetermined" class, or, and perhaps more useful, through on-screen editing of apparent errors (*i.e.*, heads-up digitizing). Most, but obviously not all, conflicts among these spectrally related classes were eliminated. Figures 3, 4, and 5 are examples of classification results and the parent Landsat images for Guanzhou (China), Moscow (Russia), and Madrid (Spain), respectively.

Urban Land Cover Change

At the time of this paper's preparation, the classification for 54 cities for both T_1 and T_2 had been completed, and another 37 were in various stages of production. Table 2 lists, alphabetically, a sample of 31 of those cities fully classified, reporting the date of T_1 and T_2 Landsat imagery, the total urban land area within the area of interest, the total change in urban extent, and the annual growth of urban lands, normalized over the period T_1 to T_2. Total urban growth ranged from a minimum of 10 percent over a 10.8 year period of observation for Kingston, Jamaica to as much as 194 percent over (Kigali, Uganda). The average growth among these 31 cities was 59 percent. The average annual urban growth for this sample of 31 cities was 5.1 percent, based on an average temporal difference between T_1 and T_2 Landsat data of 11.6 years. Figure 6 portrays the annual percent urban growth based on the period of observation for each city.

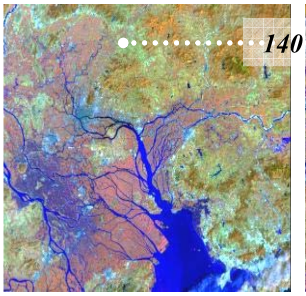

Figure 3a. Landsat TM Image, 13-Oct-90

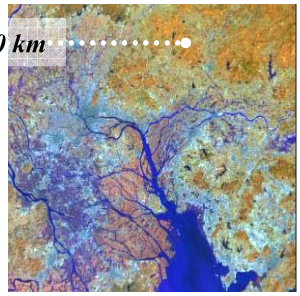

Figure 3b. Landsat TM Image, 14-Sep-00

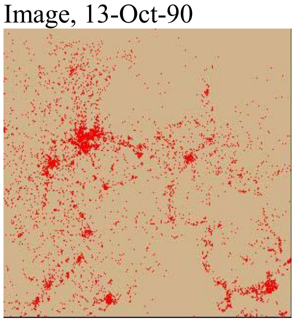

Figure 3c. T_1 Urban land cover classification
Producer's Accuracy: 86.7%
Consumer's Accuracy: 86.7%

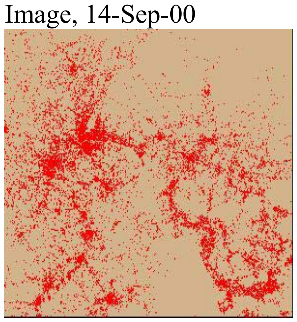

Figure 3d. T_2 Urban land cover classification.
Producer's Accuracy: 88.24%
Consumer's Accuracy: 93.75%

Figure 3. Guanzhou, China

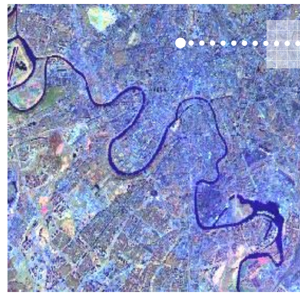

Figure 4a. Landsat TM Image, 08-Oct-91

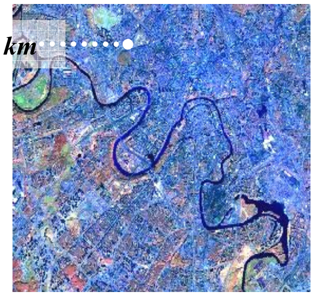

Figure 4b. Landsat TM Image, 14-Oct-02

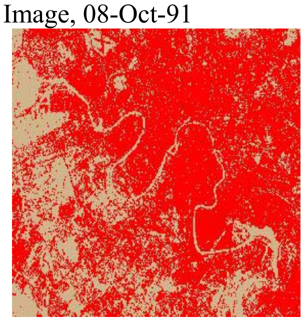

Figure 4c. T_1 Urban land cover classification
Producer's Accuracy: 92.31%
Consumer's Accuracy: 80.00%

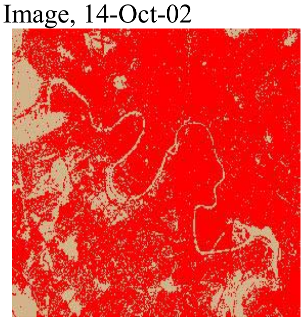

Figure 4d. T_2 Urban land cover classification
Producer's Accuracy: 92.86%
Consumer's Accuracy: 86.7%

Figure 4. Moscow, Russia

Urban Land Cover Accuracy

Table 3 presents preliminary accuracy assessments based on a sample of seven completed cities. Data reported include Producer's Accuracy (related to errors of omission), User's Accuracy (related to errors of commission), and Overall Kappa (related to chance agreement). Since the urban class is of principal interest, accuracy assessment was conducted on the binary urban/non-urban classification maps. The poorest accuracies for T_1 were for both Bamako (Mali) and Sao Paulo (Brazil), at 84.6% and 73.3% for producer's and user's accuracy, respectively. Highest T_1 accuracies were for Madrid (Spain) at 93.7% and 100%. For T_2, lowest producer's accuracy was for Sao Paulo (Brazil) at 85.7% and lowest and user's accuracy for Accra (Ghana) at 80.0. Highest T_2 producer's accuracy was for Madrid at 100%, and for both Guangzhou (China) and Madrid at 93.7%. Overall mapping accuracy (OMA) for these test cities was 88.3 percent for both for T_1 and T_2, a highly acceptable and well-balanced level to meet the needs of this project.

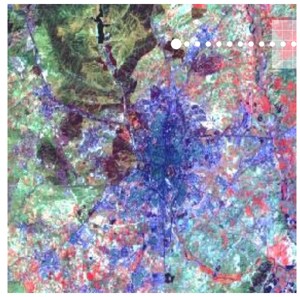

Figure 5a. Landsat TM Image, 25-May-89

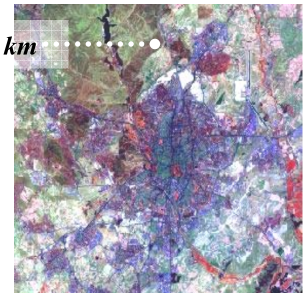

Figure 5b. Landsat TM Image, 22-Aug-00

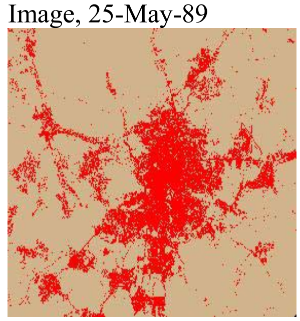

Figure 5c. T_1 Urban land cover classification
Producer's Accuracy: 93.75%
Consumer's Accuracy: 100.00%

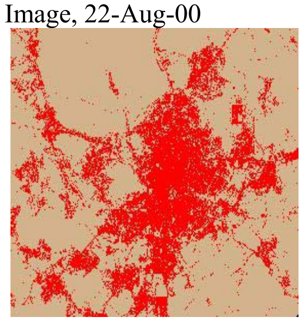

Figure 5d. T_2 Urban land cover classification
Producer's Accuracy: 100.00%
Consumer's Accuracy: 81.25%

Figure 5. Madrid, Spain

Table 2. Urban land area and percentage change for 31 cities

City	T_1 Date	T_2 Date	T_1 Urban Land Cover Area (ha)	T_2 Urban Land Cover Area (ha)	Urban Area Percent Change	Annual Percent Urban Change
Accra	06-Mar-85	04-Feb-00	13,253	34,076	157	10.5
Addis Ababa	21-Jan-86	05-Dec-00	10,907	16,246	49	3.3
Bamako	14-Nov-86	25-Oct-99	6,981	13,177	89	6.9
Beijing	25-Dec-88	01-Jul-99	128,725	157,294	22	2.1
Buenos Aires	13-Apr-87	20-Dec-00	122,145	138,196	13	1.0
Casablanca	06-Jan-87	20-Jan-01	8,060	11,438	42	3.0
Chicago	30-Jun-89	11-Sep-01	439,167	509,311	16	1.3
Cincinnati	06-Jun-88	16-Aug-99	70,144	93,905	34	3.0
Guanzhou	13-Oct-90	14-Sep-00	96,671	238,787	147	14.8
Jaipur	09-Oct-89	13-Sep-00	9,691	18,900	95	8.7
Jequie	22-Aug-88	12-Apr-01	1,883	3,714	97	7.7
Johannesburg	07-Apr-91	23-Apr-00	113,538	133,578	18	2.0
Kigali	20-Jun-84	08-Jul-99	1,556	4,573	194	12.9
Kingston	12-Mar-91	13-Jan-02	10,896	11,953	10	0.9
Madrid	25-May-89	22-Aug-00	33,009	44,782	36	3.2
Manila	01-Apr-93	01-Apr-02	55,141	84,029	52	5.8
Mexico City	07-Mar-89	21-Mar-00	69,219	92,030	33	3.0
Minneapolis	22-Sep-92	05-Jul-01	125,425	173,288	38	4.3
Montevideo	19-Mar-89	06-Dec-00	16,249	20,030	23	2.0
Moscow	08-Oct-91	14-Oct-02	84,482	123,186	46	4.2
Mumbai	09-Nov-92	25-Oct-01	39,430	51,767	31	3.5
Ougadougou	18-Nov-86	14-Jul-01	6,029	13,799	129	8.8
Paris	09-May-87	24-Aug-00	229,393	270,848	18	1.4
Pittsburgh	05-Oct-87	12-Sep-99	110,214	131,150	19	1.6
Pretoria	07-Apr-91	23-Apr-00	53,175	61,520	16	1.7
Ribeirao Preto	27-Sep-88	23-Mar-01	10,544	13,115	24	2.0
Santiago	17-Mar-89	31-Mar-00	32,403	40,674	26	2.3
Sao Paolo	12-Sep-88	17-Jun-00	140,682	178,920	27	2.3
Singapore	17-Apr-90	11-Nov-02	18,536	25,721	39	3.1
St. Catherines	12-Jun-92	12-Sep-99	23,605	28,282	20	2.7
Valledupar	30-Dec-89	04-Oct-01	2,004	2,705	35	3.0

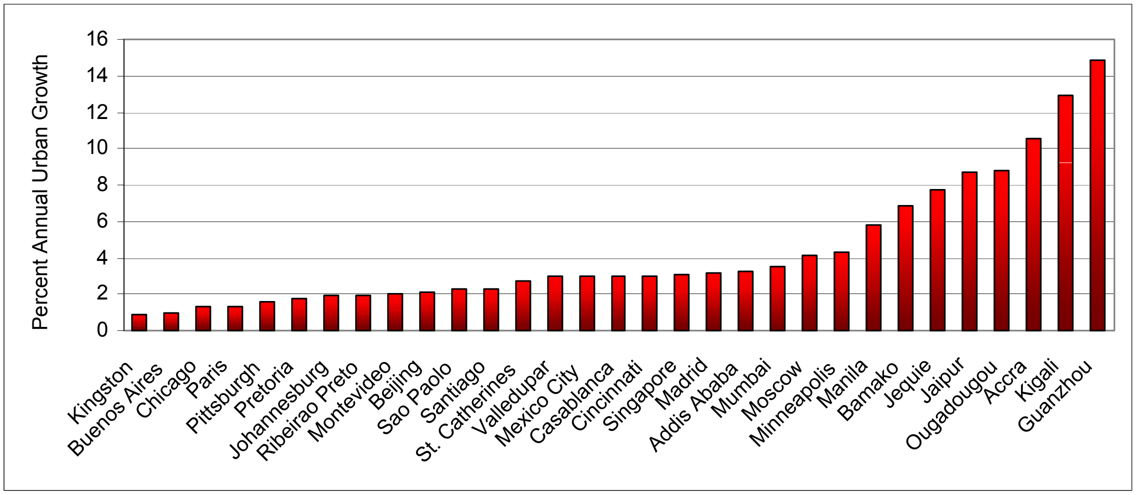

Figure 6. Percent annual urban growth based on analysis of T_1 and T_2 Landsat imagery

Table 1. Preliminary accuracy assessment for seven city sample. Cities tested thus far include Accra, Bamako, Beijing , Casablanca, Guangzhou, Madrid, Moscow, and Sao Paulo.

T_1	Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
	Non-urban	109	105	94	86.2%	89.5%
	Urban	101	105	90	89.1%	85.7%
	Totals	240	240	212	88.3%	OMA
	Overall Kappa	0.7524				

T_2	Class	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
	Non-urban	102	97	88	86.3%	90.7%
	Urban	108	113	99	91.7%	87.6%
	Totals	240	240	212	88.3%	OMA
	Overall Kappa	0.7622				

Figure 7 portrays the annual percent urban growth for the 31 cities completed to-date. Small green circles represent 0 to 5%, medium yellow circles from 5.1 to 10%, and large red circles from 10.1 to 15%. Four of the moderate to large growth metropolitan areas are located in Africa, two in Asia, and one in South America. For North American cities, annual growth was from 1.3 to 4.3 percent, and for the three European cities in this initial sample, the average urban growth was 2.9 percent. Though the analysis is far from complete, and the results are not fully-conclusive, an early observation is one that reveals higher then average urban expansion in the Sub-Sahara region of Africa.

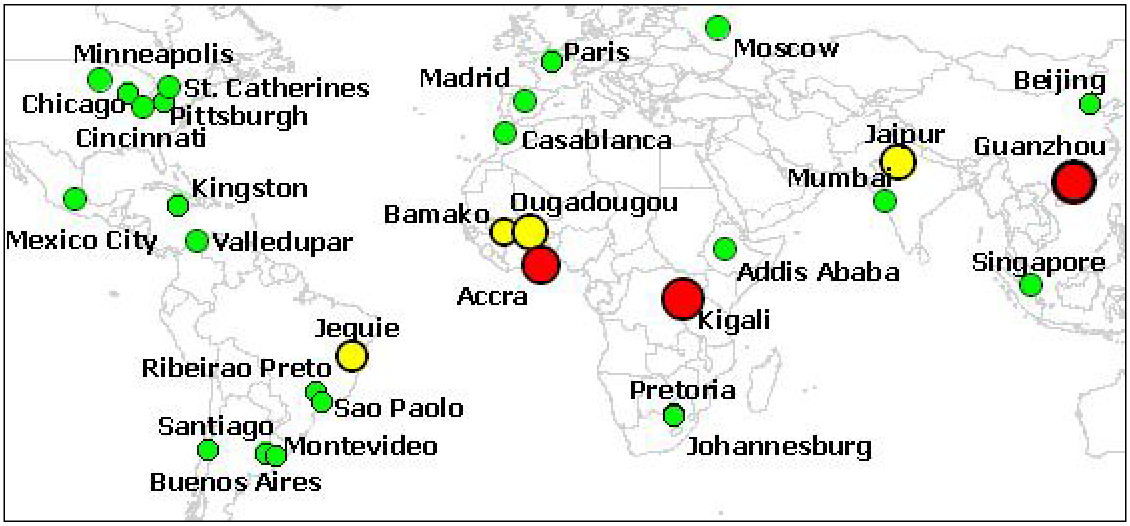

Figure 7. Annual urban growth (Green = 1 to 5%, Yellow = 6 to 10%, Red = 11 to 15%)

FUTURE EFFORTS

At the time of this paper's preparation, work is still underway, with classification of nearly half of the 120 metropolitan areas completed or underway. It is expected that classification and accuracy assessment for T_1 and T_2 Landsat data for all cities will be completed by Spring 2005. Completion of this phase of the project will lead into the pursuit of another objective of estimating global urban land consumption. With the help of statistical models, these investigators will use the sample results to estimate preliminary measures of urban land consumption for all the cities with populations in excess of 100,000 in 2000, so as to establish the present global norms of urban land consumption for different types of cities. This will be followed by yet another major goal to examine land consumption and urban poverty; using the census data in the sample, statistical models will be constructed to examine the relationships between different dimensions and patterns of urban land consumption and four key dimensions of urban poverty, overcrowding, access to piped water and sewerage, and access to home ownership. The urban classification maps developed in this project, as well as summary data, will be made available to the scientific community via the Internet, likely in Fall 2005.

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