

PANSHARPENED LANDSAT 7 IMAGERY FOR IMPROVED URBAN AREA CLASSIFICATION

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Recent advances in the area of remotely sensed image sharpening or fusion have resulted in the complete retention of original multispectral data characteristics together with improved spatial resolution. Same-sensor sharpening of Landsat data has been possible since the launch of Landsat 7 in 1999 due to the addition of a 15-metre panchromatic band. Three image fusion methods (PCA, RGB-IHS, and PANSHARP) are compared, with the PANSHARP results being further evaluated in an urban change detection analysis. Regular monitoring is necessary to assess the impacts that a continuing urban population shift and its associated development have on cities and their surrounding regions. The extent of expansion and redevelopment in the Toronto (Canada) area is evaluated during a 3-year period from 1999 to 2002. The region continues to grow rapidly, despite sometimes challenging economic conditions in recent years. A yearly average of 10.6 km² of new development was observed. Pansharpened data allowed for finer details to be distinguished than was previously possible with other Landsat imagery and the overall classification accuracy figure of almost 96% is approximately 5-10% higher than previous urban change detection results.

Les progrès récents dans le domaine de l'affinage ou de la fusion d'images de télédétection ont eu pour résultat la conservation complète des caractéristiques des données multispectrales originales et une meilleure résolution spatiale. L'affinage de données du même capteur Landsat a été possible depuis le lancement de Landsat 7 en 1999 grâce à l'ajout d'une bande panchromatique de 15 mètres. Trois méthodes de fusion d'images (PCA, RGB-IHS et PANSHARP) sont comparées, les résultats de PANSHARP étant évalués plus à fond dans une analyse de détection du changement urbain. Une surveillance régulière est nécessaire pour évaluer les impacts qu'un changement démographique urbain continu et son développement associé ont sur les villes et leurs régions environnantes. L'étendue de l'expansion et du réaménagement dans la région de Toronto (Canada) est évaluée sur une période de 3 ans de 1999 à 2002. La région continue de croître rapidement, malgré des conditions économiques parfois difficiles ces dernières années. On a observé une moyenne annuelle de 10,6 kilomètres carrés de nouveaux développements. Les données de PANSHARP ont permis de distinguer des détails plus fins que ce n'était possible auparavant avec les autres données d'imagerie Landsat et la précision de la classification globale de presque 95 % est d'environ 5 à 10 % supérieure aux résultats antérieurs de détection des changements urbains.

1. Introduction

Data from the Landsat series of satellites have been utilized for land cover classification since the launch of the first Earth Resources Technology Satellite (later renamed Landsat-1) in 1972. In the past, most of the uses for the data could be found in natural area management. There has, however, been a recent trend toward the analysis of urban environments [Arthur *et al.* 2000; Chen 2002; Chen *et al.* 2000; Favretto and Jürgens 2003; Hostert and Diermayer 2003; Masek *et al.* 2000; Yeh and Li 2001]. Urban forms were not previously studied as intensively due to the fact that 80-m Multispectral Scanner (MSS) and 30-m Thematic Mapper (TM) data could not provide the level of detail required for some types of studies (e.g. building information). The data could however be used to analyze the extent of urban development in relation to surrounding regions [Masek *et al.* 2000; Hostert and Diermayer 2003].

Image Fusion or Sharpening

The concept of image fusion or sharpening is not a new one, but the methods used have not always been successful or provided meaningful results. MSS bands 4, 6, and 7 were improved from 240-m to 80-m spatial resolution using the 80-m resolution band 5 [Cheng *et al.* 2000]. In addition, multispectral TM data have been combined in the past with SPOT panchromatic data [Chavez *et al.* 1991; Zhang 2001] as well as Indian Remote Sensing (IRS) satellite data. The successful launch of Landsat 7 in 1999 has provided the Landsat data user community with an opportunity to utilize the data from this satellite in an enhanced form. While there have been previous satellites such as SPOT where same-sensor image fusion was possible, with Landsat 7 the opportunity

exists to enhance data over a much wider part of the electromagnetic spectrum.

There are many methods to perform image fusion. However, until now they were all limited by certain drawbacks. Red-Green-Blue-Intensity-Hue-Saturation (RGB-IHS) transformation yields enhanced imagery but the spectral characteristics of the data are destroyed [Cheng *et al.* 2000]. Other techniques such as Principal Component Analysis (PCA) and Synthetic Variable Ratio (SVR) also provide enhanced data but have problems such as colour distortion. In addition, they are very operator and dataset dependent with different operators producing varying results using the same datasets [Zhang 2002]. Another problem is that there is inevitably a difference in the time of acquisition between images obtained from different sensors. Zhang [2001] had a gap of over 2 years between Landsat TM and Spot panchromatic data that were used for image fusion. There would have been some land use change in this time period, which would cause problems with the accuracy of the fused results.

Urban Change Detection

Using image radiometry is the best method to determine urban change [Ridd and Liu 1998; Masek *et al.* 2000]. With most image analysis applications, the goal is to produce classified end products through either supervised or unsupervised methods. The problem with using either of these methods over a time-series of imagery is that the classification errors will propagate over the length of the analysis period [Masek *et al.* 2000; Yang and Lo 2002]. It is

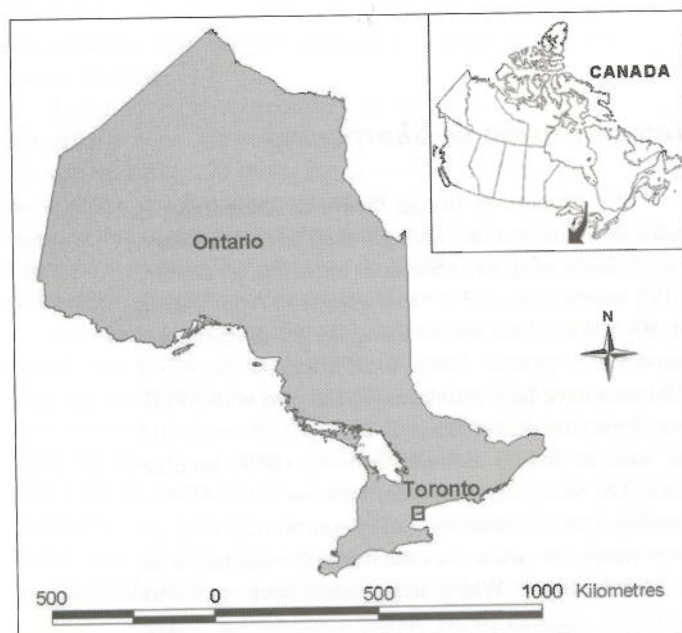


Figure 1: Location of the Toronto Study Area.

therefore more efficient to use radiometry directly, which should be relatively constant if the image acquisition dates are consistent (e.g. year to year) and the data are from the same satellite platform.

The methods of radiometric analysis include: band-by-band image differencing, image ratioing, change vector analysis, and vegetation index differencing. Jensen and Toll [1982] as found in Masek *et al.* [2000] were able to detect with reasonable accuracy, the urban growth of Denver, Colorado using Landsat MSS (Band 5) data. Ridd and Liu [1998] utilized similar techniques with Landsat TM data (Band 2) and found that they produced a much more accurate account of urban land cover change. Masek *et al.* [2000] used MSS and TM data in a Normalized Difference Vegetation Index (NDVI) subtraction approach for successful urban change detection. Fused Landsat and Spot data were applied in detecting 'big building' change in Shanghai, China by Zhang [2001]. Hostert and Diermayer [2003] utilized unsupervised classification procedures employing a constraint linear spectral unmixing approach for detecting urban change in Berlin, Germany.

2. Study Area

Toronto, Ontario (Figure 1) is the largest city in Canada and since January 1, 1998 is known (to the citizens of Toronto at least) as the "megacity." The "reinvented" city contains nearly a quarter of the population of the entire province of Ontario. The latest census figures from 2001 show that Toronto is the second fastest growing major city in Canada [Statistics Canada 2002]. The Census Metropolitan Area (CMA) has a population of approximately 4.68 million people. Toronto offers an interesting place to study urban development. A recession during the early 1990s slowed housing starts and construction [Donald 2002], but the more recent economic slowdown (2001 to the present) appears to have had little effect on the rate of growth in the region. Building permits hit new highs in 2002 and new home construction continues to be a healthy sector of the economy [Statistics Canada 2003].

A new official plan has been developed which should guide how the city grows over the next 30 years. It is a difficult task considering that nearly 100,000 people per year move to Toronto. This places additional burden on housing stocks, ageing infrastructure, and causes even more traffic congestion.

3. Data

Landsat 7 Enhanced Thematic Mapper (ETM+) imagery was acquired for the study area.

The dates of image acquisition were:

- September 3, 1999 (Path 18, Row 30)
- September 19, 1999 (Path 18, Row 29)
- August 20, 2000 (Path 18, Row 30) (discarded for the full analysis due to cloud problems)
- August 10, 2002 (Path 18, Row 29-shifted 80% south)

4. Methods

The first task was to assess various data fusion or sharpening methods and compare the results to original 30-metre resolution Landsat imagery from 1999. Functionality within the PCI Geomatica and Erdas Imagine image processing software was used for the data fusion processes. An RGB-IHS transformation (RGBFUS algorithm) and pansharpening (PANSHARP algorithm) were performed using PCI, while the PCA fusion process was undertaken with Erdas Imagine (Resolution Merge model). The outcomes (Figure 2) were very different depending on which process was employed. The RGB-IHS results show that the spatial resolution was indeed improved however, severe colour distortion and alteration of the original multispectral values is apparent. This can be seen when the original 30-m imagery is compared to the RGB-IHS image. The PCA image is unsatisfactory as the digital numbers are altered so that the original spectral variability is not retained. This is particularly noticeable when looking at the agricultural fields in the original and PCA fused images. The values or digital numbers are more similar, and variability that is present in the original image is lost. Since PCA is a data reduction technique, this seems to be a logical outcome. Additionally, variable results will always be obtained because the technique depends on the spectral values contained within each independently analyzed image. The PANSHARP results retain the multispectral variability of the original image. This is evident when looking at the fields and the urban areas within the image. Since this is an automatic process, the two main problems of colour distortion and operator/data dependency are eliminated. The approach is based on least squares and was developed to best approximate the grey-value relationship between the original multispectral/panchromatic data and the fused results to achieve a best colour representation [Zhang 2002]. For Landsat TM and ETM+ data, reference multispectral bands (Green:2, Red:3, Near IR:4) are employed that span the range of the panchromatic band. The PANSHARP algorithm overcomes the weaknesses of

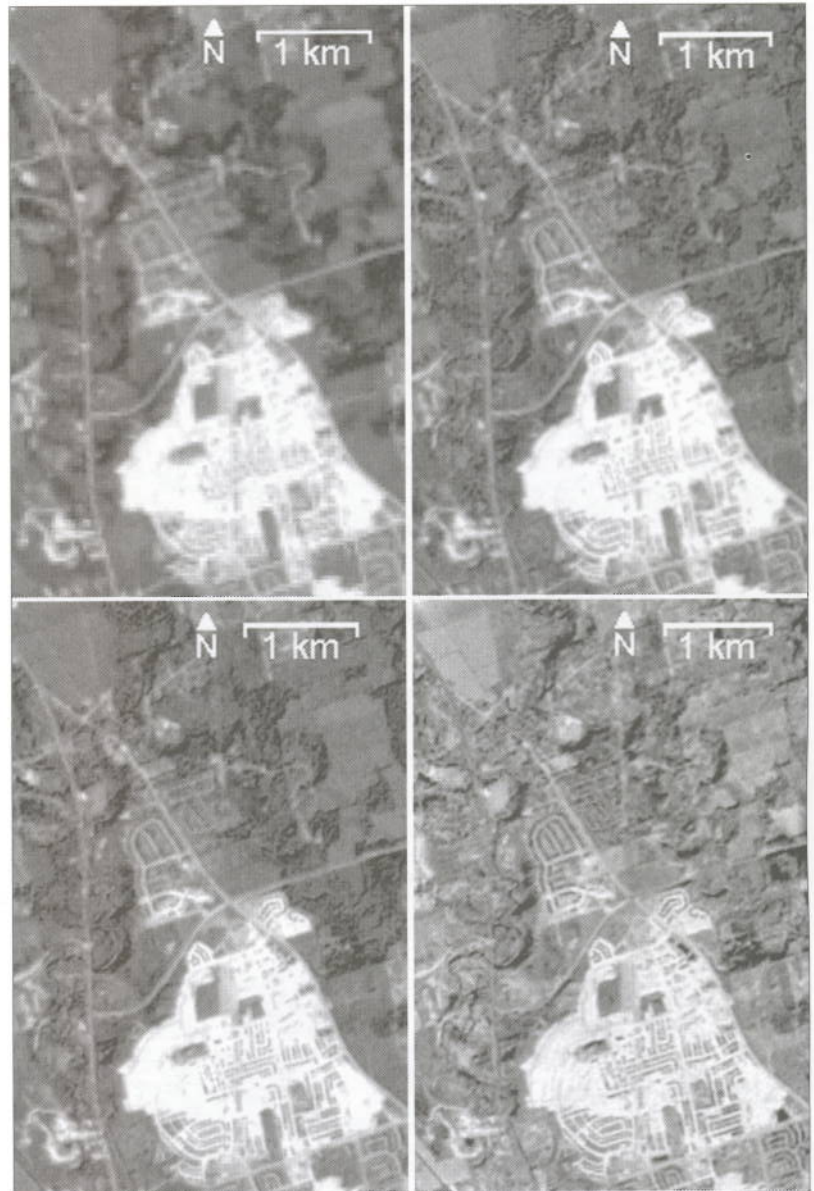


Figure 2: Data Fusion results (greyscale)—clockwise from the top left: original 30-m Bands 3,2,1; PCA method; RGB-IHS method; and PANSHARP method.

the other methods in that the original digital number values are preserved. A more detailed discussion of the PANSHARP algorithm can be found by referring to Zhang [2002] and PCI [2003].

Data Processing

All of the images were fused (using PANSHARP) to a 15-m resolution. The 1999 images had been previously orthorectified to the NAD83 (GRS1980) UTM Zone 17 projection. They were then mosaiced and the resulting image was used as a base image to which the 2000 and 2002 images were registered. Root Mean Square (RMS) errors

of under 0.25 pixels in both the X and Y directions were achieved which translates to a maximum error of 3 to 4 metres on the ground.

A combined radiometric band differencing and unsupervised classification approach was used to distinguish true urban development from change that occurs due to other factors such as agricultural crop rotation and forestry practices. Examples are provided for a subset of the imagery although a larger area was analyzed. The images portraying bands 3, 2, and 1 for each year are presented in Figure 3.

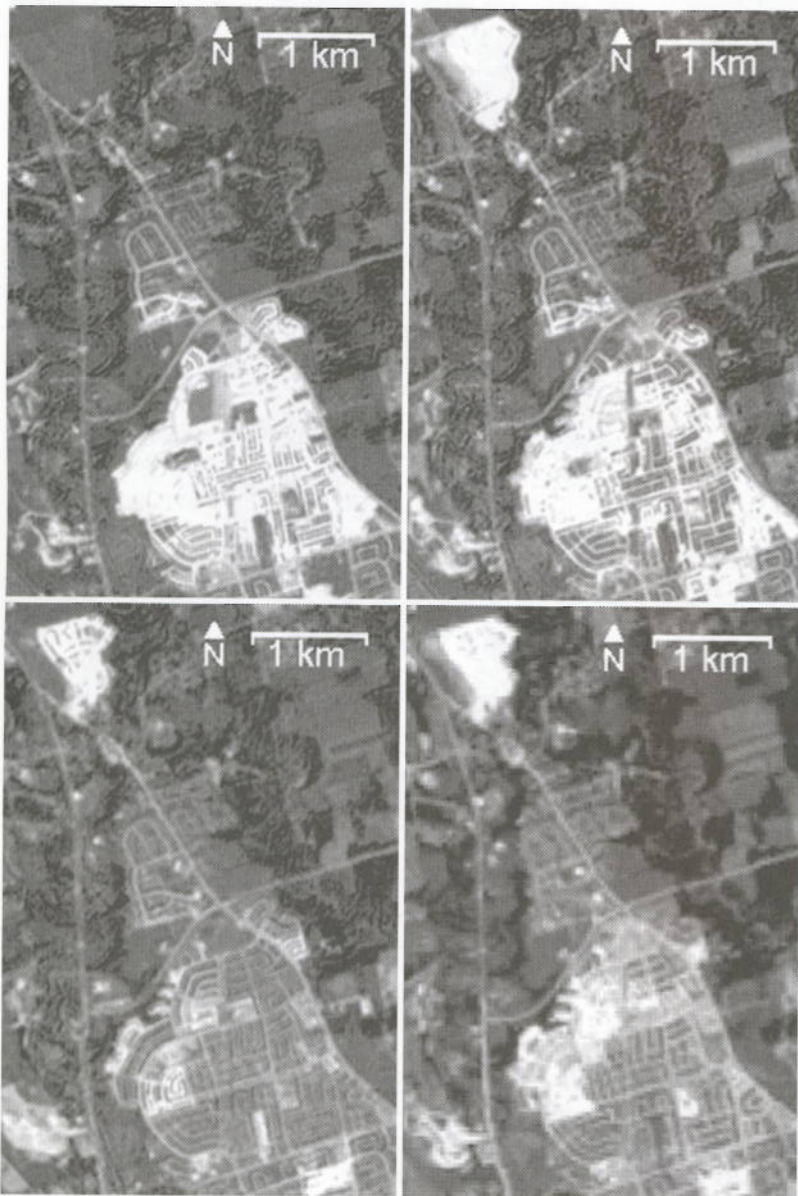


Figure 3: Bands 3, 2, and 1 (greyscale) for 1999, 2000, 2001, and 2002 (clockwise from the top left)–The 2000 image was not utilized for the full analysis due to cloud problems.–The Landsat 5 TM (2001) image has a 30-m spatial resolution, but together with the 2000 image illustrates the continuous change that has occurred from 1999 through 2002.

Previous studies [Steinnocher 1997; Masek *et al.* 2000; Shaban and Dikshit 2001; Yeh and Li 2001] have shown that a number of features derived from the original satellite bands can be useful in distinguishing urban features. Figure 4 represents the results for Normalized Difference Vegetation Index (NDVI) analyses that measure the amount of biomass in imagery. Progressive increases from dark (black) to white shades represent increasing levels of vegetation.

In addition, Principal Component (PC) analysis as an input into classification procedures can provide useful information for class identification. In Figure 5, newly disturbed areas for urban development are indicated by darker tones.

Image texture can assist in defining urban classes and helps to separate classes where agricultural crop rotation may be mistaken for urban change [De Kok *et al.* 2003; Schleicher *et al.* 2003; Shaban and Dikshit 2001]. De Kok *et al.* [2003] suggest that similar texture results will be obtained using any of the original multispectral bands or principal components. Chen [2002] found that texture derived from TM band 5 was the best for distinguishing separate urban features and urban features versus bushland. Zhang [2001] states that TM band 5 and the first Principal Component (PC1) help to distinguish features more clearly. Steinnocher *et al.* [2003] and Schleicher *et al.* [2003] suggest using PC1 for image texture analyses. Figure 6 shows the results of image texture analyses (homogeneity option 7x7 window) performed on ETM+ band 2. The results were very similar for a number of texture operations that were performed on individual bands and Principal Components. It is, however, interesting to note that texture derived using band 2 did not distinguish golf course fairways, while when texture was derived from PC1, the fairways were highlighted in much the same way as excavated areas being prepared for new urban development (Figure 7). Since this analysis seeks to define urban areas, the choice of band 2 texture measures helps to distinguish developed areas from green (including golf course) areas. It also provides a better measure of newly excavated areas.

5. Results and Discussion

An aggregate classification is necessary to use as a mask for defining urban areas and new urban development. It was performed on the most recent image data (in this case 2002) and developed from 255 original unsupervised K-means classes. While

Masek et al. [2000] found 22 classes sufficient for distinguishing image features using an ISODATA unsupervised approach, this method did not provide satisfactory results using the current datasets. Instead, the methodology utilized by Forsythe [2002] provided the necessary degree of separation between classes. The 255 figure represents the maximum number of classes available for the unsupervised classification option of the PCI software. The high number of classes helps to distinguish between cases where recently ploughed fields could be misinterpreted as land disturbed by recent urban development. The layers included in the classification were: bands 1-5 and 7, PC2, NDVI, and texture (derived from band 2). These results were then aggregated to greenspace, water, and developed classes (Figure 8).

Figure 9 represents the results of image differencing operations using band 2 from the pansharp-ened imagery and seven change classes that were derived from this result. Some interesting features in the first image are that white tones generally represent areas where previous agricultural or forested land has been replaced by excavated land being prepared for building. Darker (black) areas generally represent where housing developments have replaced excavated land (created to be built upon). It is noteworthy that ploughed fields exhibit the same characteristics as the white areas mentioned previously and thus it is necessary to have the unsupervised classification results as a mask to minimize classification errors. Rather than running trials to determine the digital numbers of new urban development, an ISODATA unsupervised classification was performed on the differencing image. Seven classes was the optimal number that distinguished greenspace versus urban areas and also allowed for newly developed and recently excavated areas to be identified.

The data layers were exported as Erdas Imagine (.img) files from PCI Geomatica for further analysis in ArcGIS. The aggregated change class results (Figure 9) were combined (added together) with the aggregate 2002 classification (Figure 8) using the Raster Calculator to produce the change results. This layer was then reclassified to define greenspace, water, developed, new developed, excavated, and no data classes. The areas for each class were calculated using ArcGIS and are presented in Table 1. The final result map (Figures 10 and 11) was then exported in an Erdas Imagine format for accuracy assessment.

Of particular interest is the figure of approximately 10.6 km² per year of New Developed land, which is slightly higher than the 9.15 km² average

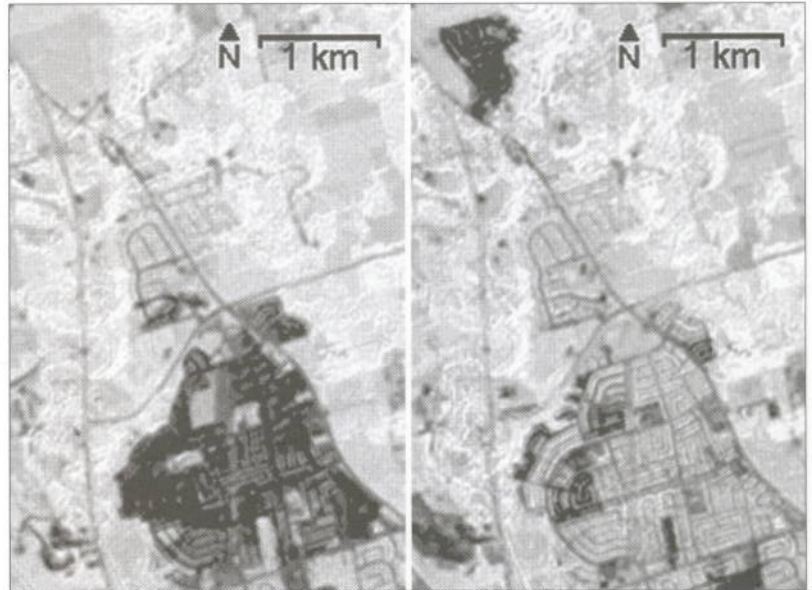


Figure 4: NDVI for 1999 (left) and 2002 (right).

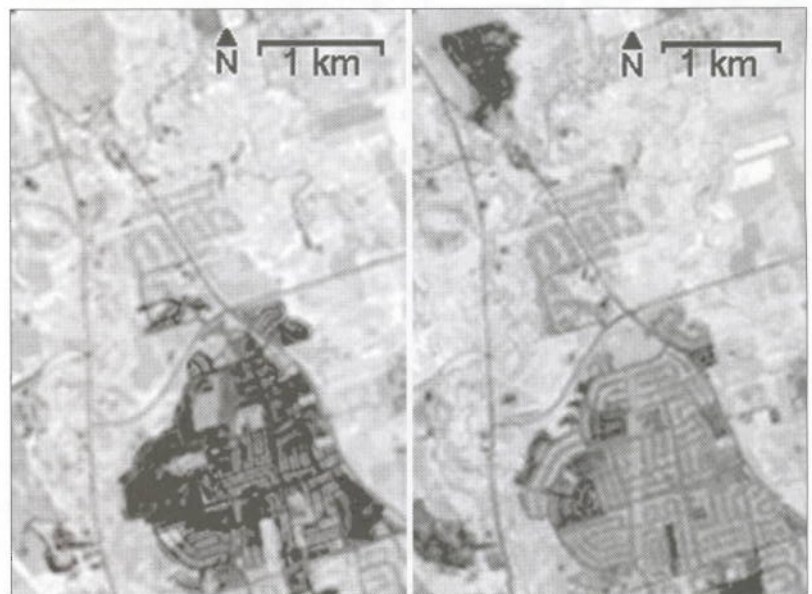


Figure 5: PC2 for 1999 (left) and 2002 (right).

Table 1: Class Areas 2002–1999.

Class Name	Area (km ²)
Greenspace	1700.213625
Water	1142.9271
Developed	973.432125
New Developed	31.755375
Excavated	145.279575
No Data	0.000225
Total area analyzed: 3993.60825 km ²	

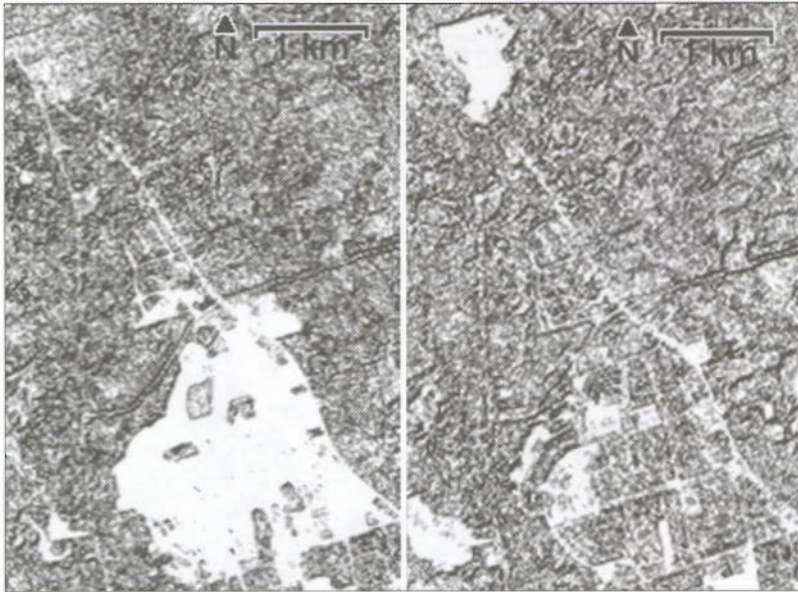


Figure 6: Image Texture (derived from band 2) for 1999 (left) and 2002 (right).

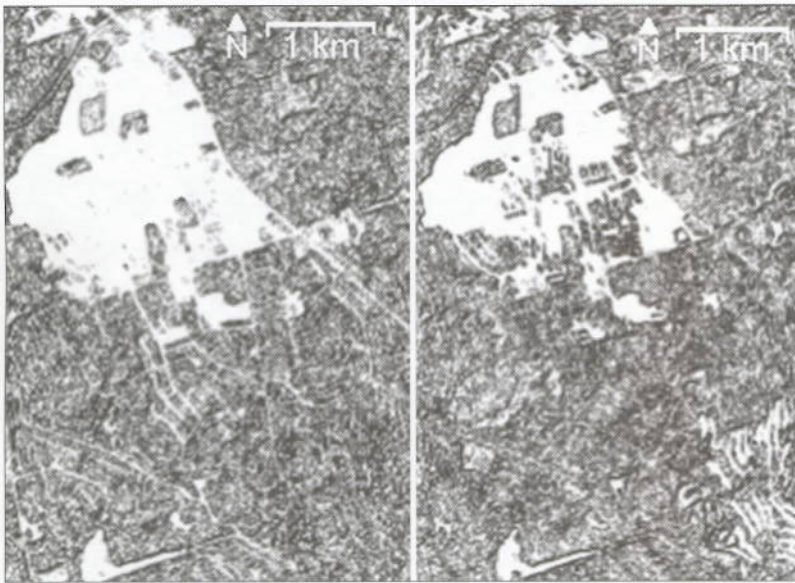


Figure 7: Comparison of Image Texture (1999 image) derived from Band2 (left) and derived from PC1 (right)—Golf course fairways are clearly delineated (white stripes) in the lower right corner of the PC1 image.

that Forsythe [2002] found when comparing growth in the Toronto region from 1974 to 2001. With record building permits issued in 2002 [Statistics Canada 2003], it seems very likely that these results indicate that the permits were turned into housing starts. The amount of excavated land is interesting as building does not always occur immediately after excavation and not all excavated land is used for development. However in the context of this paper, excavated land is still developed land, although a small portion of the total area can be attributed to some gravel and sand operations in the area.

6. Accuracy Assessment

To assess the reliability of the classification results, accuracy assessment was performed within PCI Geomatica. A random sample of 300 points was generated for the three classes of Greenspace, Water, and Developed. The accuracy statistics are presented in Tables 2a and 2b.

The New Developed and Excavated classes were grouped together with the Developed area for this procedure as the generation of enough random sampling sites was difficult for these smaller areas.

The accuracy of the classification was also assessed with reference data from a set of 1999 digital orthophotos. In addition, the author performed field research to determine the reliability of the results. Some confusion between gravel and sand operations as discussed above and the effect of varying lake levels as seen by the inclusion of the excavated class on lake shorelines were noted. Generally however, the classified image represented the area very well.

7. Conclusion

Pansharpened Landsat 7 imagery allows for changes in urban structure to be readily identified. The results from analyses such as this one allow for the creation of inputs for further analysis in Geographic Information System (GIS) software where the total amount of urban development can be determined.

The overall accuracy figure of almost 96% is approximately 5-10% higher than previous Landsat change detection results reported in the literature. The producer's and user's accuracy figures for the greenspace and developed classes are very good, with averages of approximately 94% and 92.5% respectively. The low cost (US\$600 per scene), broad swath, wide multispectral coverage, and general availability of Landsat 7 data make analyses such as this one possible for many organizations involved with urban and regional planning. The creation of up-to-date databases will enable urban planners and other users to see how cities are developing over time.

The question of whether urban sprawl into suburbia and exurbia should be allowed to continue will be one of the questions that needs to be answered as we move forward in the 21st century. The identification of available land for future growth must consider previous land use decisions. Goals should be set that seek to minimize the

Table 2a: Accuracy Statistics.

Overall Accuracy: 95.67% - 95% Confidence Interval (93.20% 98.14%)					
Overall Kappa Statistic: 0.93% - Overall Kappa Variance: 0.00%					
Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Greenspace	96.00%	(92.17% 99.84%)	93.75%	(89.17% 98.33%)	0.8929
Water	100.00%	(99.42% 100.58%)	100.00%	(99.42% 100.58%)	1.0000
Developed*	91.01%	(84.51% 97.52%)	94.19%	(88.66% 99.71%)	0.9173

Table 2b: Accuracy Statistics - Error (Confusion) Matrix.

Classified Data	Reference Data			Totals
	Greenspace	Water	Developed	
Greenspace	120	0	8	128
Water	0	86	0	86
Developed*	5	0	81	86
Totals	125	86	89	300

* includes Developed, New Developed, and Excavated Classes



Figure 8: Aggregate Classification for 2002 (grey = greenspace, white = developed) The water class is not present in the subset image.

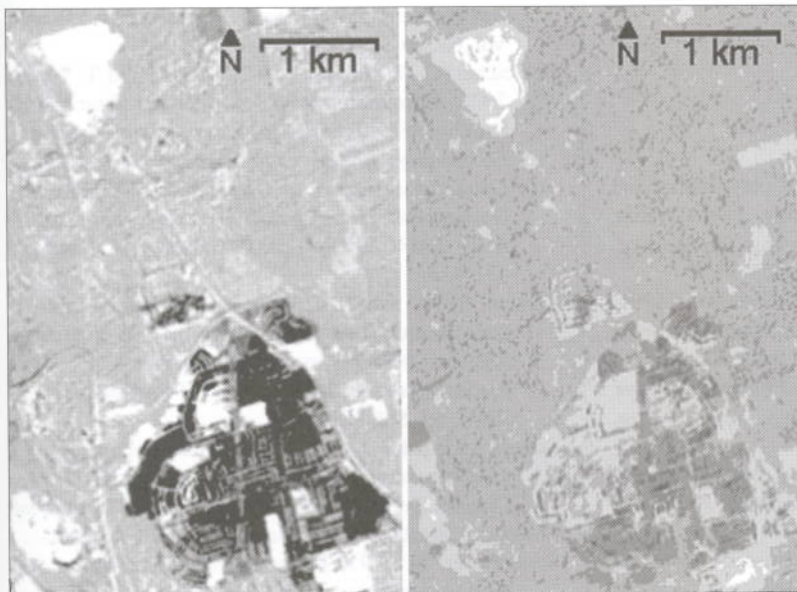


Figure 9: Band 2 Differencing for 2002 minus 1999 (left) and the seven aggregated change classes (right).



Figure 10: Classification Results (subset) (For legend refer to Figure 11.)

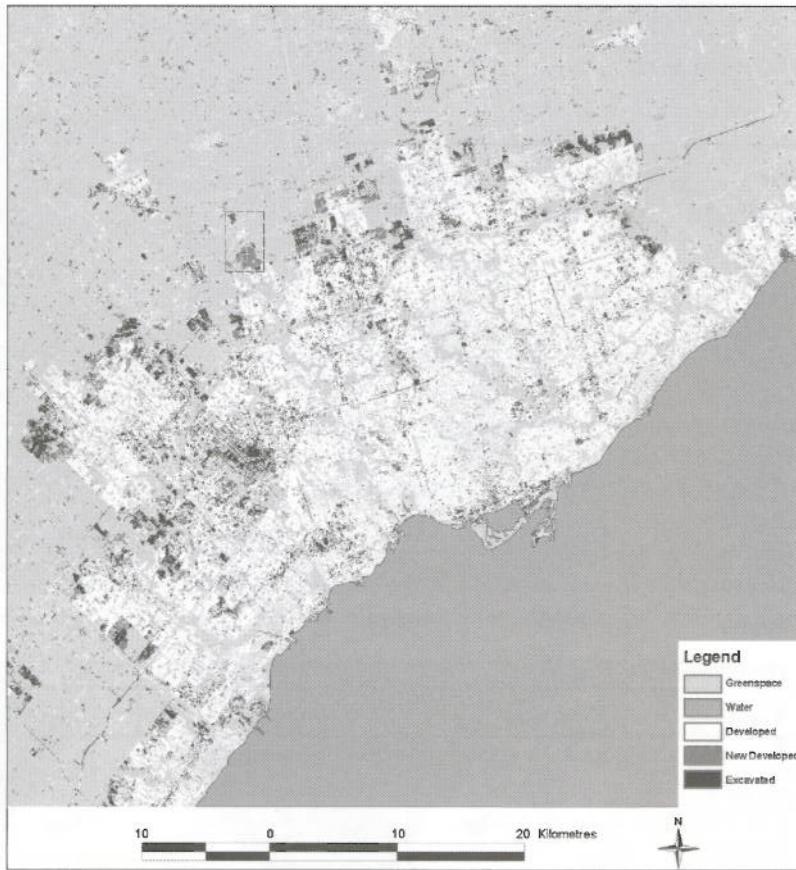


Figure 11: Results for the entire analysis area (Dashed box indicates the location of the subset images from Figures 3 - 6, and 8 - 10).

impact on the landscape and environment and reduce the loss of prime agricultural land. In this respect, remotely sensed data can be a valuable information source.

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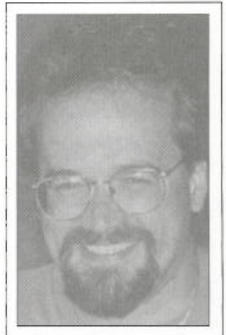
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