ESTIMATING IMPERVIOUSNESS USING NDVI AT MULTIPLE RESOLUTIONS FOR URBAN CATCHMENTS IN SYDNEY, AUSTRALIA

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1. INTRODUCTION

Land cover changes associated with urbanisation such as the removal of natural vegetation and its replacement with impervious surfaces such as buildings, roads and other paved areas result in increased runoff during storm periods and decreased infiltration resulting in lower base-level stream flows, and also decreases in water quality. Remote sensing has been found to be an effective tool for mapping urban growth, and methods to map impervious areas include the use of the Vegetation-Impervious-Soil (VIS) model [1] which usually incorporates the spectral mixture analysis (SMA) of medium resolution data, deriving impervious cover from high-resolution data [2], and other methods including the use of NDVI (Normallised Difference Vegetation Index) [3] and land surface temperature [4]. Environmental scientists and engineers use a range of hydrologic models to model the potential impacts of imperviousness (e.g. flooding) [5]. These models are complex and their inputs and outputs vary, but in models that are designed for urban catchments, an estimate of the impervious area is frequently included. However, even in models which utilise spatially distributed parameters, imperviousness is often input as a single ratio that represents all suburban areas as having identical ratios of impervious to total areas, rather than detailed spatial information. Many models allow input at subcatchment scale and could utilise spatially differentiated estimates of imperviousness if they were readily available. This study examined vegetation index data at multiple resolutions to determine if a useful relationship existed between the index and the ratio of impervious to total areas at a subcatchment scale.

2. METHODS

The study area was a north-south swath of approximately 50 square kilometres across the northern suburbs of Sydney, Australia. The swath extended from the urban-bushland interface in the north to close to Sydney Harbour in the south. The area was divided into two sectors (north and south) which had differing urban characteristics: in the northern area houses were on relatively large blocks of land; in the south the houses were built on smaller blocks of land, resulting in a higher fraction of man-made surfaces. Both areas had a stable housing pattern and were predominantly suburban but included commercial and small industrial areas.

The following datasets were acquired: Quickbird multispectral data with 2 m resolution (2003), SPOT5 data with 10 m resolution (2003), Landsat TM data with 30 m resolution (2005), and MODIS EOS data with 250 m resolution (2003). Remotely sensed data were rectified, converted at-satellite reflectance using calibration constants supplied by the distributors, and NDVI values were calculated. DEM data at 25 m resolution were also acquired and subcatchments in the study area were identified using ArcGIS Hydro Tools. The zonal statistics function in ArcGIS was used to determine the mean NDVI value for each subcatchment (Figure 1).

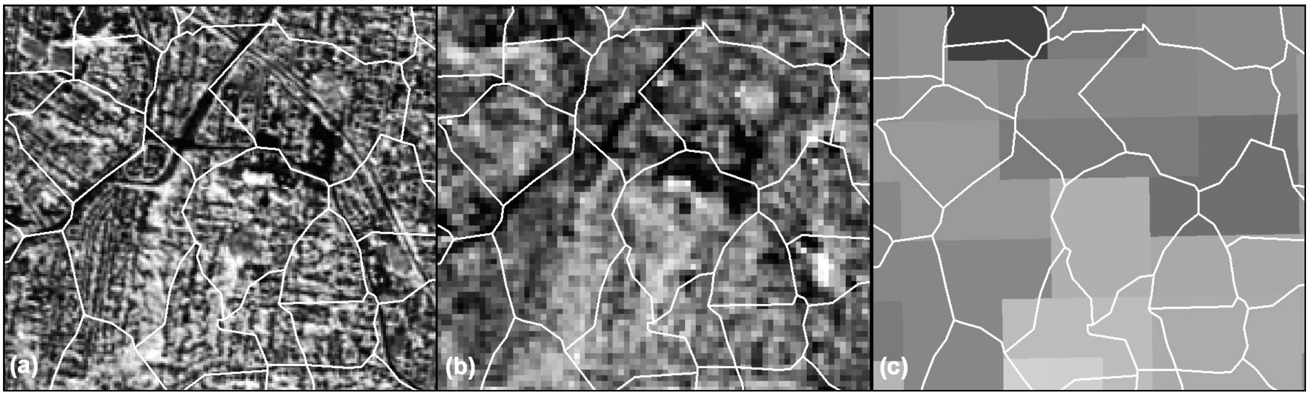

Figure1. NDVI and catchment boundaries for SPOT5 (a), Landsat TM (b) and MODIS EOS data (c).

The high resolution Quickbird imagery was used to map land uses to enable imperviousness to be estimated. A number of techniques to enhance the identification of the land uses were trialled. These included: image segmentation, unsupervised and supervised classification, and maximum likelihood (MLC) and spectral angle mapping (SAM) classifiers. The accuracy of the outputs from each method was assessed using 245 ground points which were located randomly but allotted according to class size. In this urban area, many ground points were on privately owned property therefore a number of methods (including high resolution aerial photography) were used to collect field data.

Spatial cross tabulation of the subcatchment layer with the land cover classification provided the fractional area of each land cover within each subcatchment. Land covers were identified as pervious, impervious or partially pervious. E.g. urban vegetation located around houses was a mix of pervious areas such as grass and gardens, and impervious areas such as driveways and roads, and observations indicated it was ~50% pervious. The fraction of each subcatchment which had an impervious surface was estimated from these data. To assess the effects of uncertainty in the nature of the land covers, high and low values were also derived.

Data describing the physical characteristics of an environment are often spatially clustered because neighbouring areas are similar in nature, therefore the Moran's I statistic was used to assess spatial correlation. The percentage of impervious land cover in the subcatchments was found to be clustered and two methods were trialled to reduce the influence spatial autocorrelation: (a) a random subset of catchments which was not spatially clustered was selected and the relationship between impervious land cover and NDVI was assessed using these subcatchments; and (b) geographically weighted regression (GWR) as implemented in ArcGIS was used to provide a local model of the relationship between impervious land cover and NDVI.

3. RESULTS

The classification method that resulted in the highest overall accuracy was a supervised classification using MLC. The overall accuracy was 69% (kappa=0.61), owing partly to the heterogeneous nature of the urban study area and the number of classes that were required to characterise it. Spectral confusion between two classes that were both pervious or impervious, e.g. confusion between roofs and roads or car-parks had no impact in this study. As expected, there was a higher percentage of impervious land covers in the southern sector (Table 1).

Table 1. Overall characteristics of the two sections of the study area

	Wooded areas (%)	Grass (%)	Urban vegetation (%)	Roofs & concrete (%)	Roads & car-parks (%)	Shadow (%)
Northern sector	34	10	18	8	17	12
Southern sector	23	15	21	10	22	9

A total of approximately 200 subcatchments ranging in size from 5 to 95 hectares were identified for the study area. The range of fractional impervious area for subcatchments in the northern sector was 9 to 78% with a mean of 40%, whereas those in the southern sector were less variable with a range of 17 to 72% and a mean of 46%. Using the high and low estimates of imperviousness, the variation in individual subcatchments was 5 to 15%. The spatial distribution of imperviousness gave a Moran's I value of 0.129 and there was a less than 1% chance that this had happened by chance. A subset totalling 80 subcatchments (50 in the northern sector and 30 in the southern sector) was chosen such that the Moran's I statistics indicated clustering was not important.

The results of the linear regression analysis using these subsets and GWR showed that NDVI was highly correlated with percent imperviousness at multiple scales (Table 2). For the medium resolution datasets both regression methods found a very strong relationship. For the low resolution MODIS data the relationship found by GWR was stronger than that found using linear regression on a subset of subcatchments. The strength of the relationship was not sensitive to changes in assumed imperviousness of particular land covers but the coefficients in the predictive equation changed. Subcatchments with the least accurate predictions using GWR were examined for any factors which repeatedly affected accuracy. Two general trends were found at all resolutions: predictions were less accurate in subcatchments with a small area, and in those with a high vegetation fraction.

Table 2. R^2 values from the linear and GWR regression analyses of NDVI and fractional impervious cover. (The number of subcatchments in each analysis is included in parenthesis.)

	SPOT (10m)		Landsat TM (30m)		MODIS (250m)	
	Linear	GWR	Linear	GWR	Linear	GWR
Northern sector	0.92 (50)	0.95 (131)	0.94 (50)	0.94 (131)	0.68 (48)	0.89 (119)
Southern sector	0.92 (30)	0.94 (73)	0.94 (30)	0.95 (73)	0.72 (30)	0.85 (70)

4. CONCLUDING COMMENTS

A robust relationship has been found between NDVI and fractional impervious cover. The results indicate that NDVI could provide accurate estimates of imperviousness for the land covers in this study area. Additional studies in areas with differing vegetation will be useful to confirm these results. Calculation of NDVI from medium resolution data is cost effective and straightforward compared to some other methods for determining imperviousness (e.g. spectral mixture analysis). The relationship between NDVI and fractional impervious cover is potentially extremely useful for providing estimates of fractional imperviousness to characterise urban areas and for use in hydrologic modelling.

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