

THE APPLICATION OF REMOTE SENSING TO IDENTIFY AND MEASURE SEALED AREAS IN URBAN ENVIRONMENTS

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ABSTRACT:

Numerous studies have used satellite images for mapping urban land cover and land use along with modelling green spaces and surface impermeability. Recently, monitoring the percentage of sealed soils in urban environments is of great interest as a key indicator of sustainable land use. The aim of this research is to identify an appropriate methodology to classify sealed soil and green space surfaces in urban environments with the use of satellite remotely sensed data. The study area is the city of Cambridge, UK. The percentage of sealed soils, within 18 randomly selected sample segments (250 x 250 m), was interpreted visually from the aerial photography and the Ordnance Survey (OS) MasterMap polygons attributed accordingly; the percentage was limited to a precision of 25%, i.e. 0, 25, 50, 75 and 100%. The results were compared with a maximum likelihood classification of Normalised Difference Vegetation Index (NDVI) images derived from QuickBird data integrated with the OS MasterMap and summarised using confusion matrices. The overall mapping accuracy was estimated to be approximately 75%. The low map accuracy is due to coarse precision of the aerial photo interpretation (API) and the use of pixel based classification procedures. The described methodology are the preliminary results of an on going research study. In the future, object-based classifiers (eCognition) will be investigated to provide an objective approach of the visual interpretation and improve efficiency and accuracy. eCognition is also anticipated to be used as the main classifier of the satellite image analysis.

1. INTRODUCTION

1.1 Soil sealing

The characterisation of the environmental quality of urban landscapes, such as the density and growth of the built environment, the climate quality, the proportion of green spaces and impervious surfaces, are key indicators for sustainable development. Impervious surfaces are generally understood to be any material, natural or man-made, that prevents the infiltration of surface water to the underlying strata. As a result, impervious surfaces not only indicate urbanization but are also major contributors to the environmental impacts of urbanization. A suitable qualification of whether a soil is sealed or not is to assess whether it is permeable. There are hardly any internationally recognised definitions of soil sealing (Burghardt *et al.*, 2004). The European Union (EU) accepts that "soil sealing refers to changing the nature of the soil such that it behaves as an impermeable medium and describes the covering or sealing of the soil surface by impervious materials by, for example, concrete, metal, glass, tarmac and plastic" (EEA glossary, 2006). In addition to the EU definition, Burghardt *et al.* (2004) describe soil sealing by three different means: (i) following a systems approach: "Soil sealing is the separation of soils by layers and other bodies from totally or partly impermeable material from other compartments of the ecosystem, such as biosphere, atmosphere, hydrosphere, anthroposphere and other parts of pedosphere", (ii) according to a purpose related approach: "Soil sealing is the covering of the soil surface with an impervious material or the changing of its nature so that the soil becomes impermeable, such that soil is no longer able to perform the range of functions associated with it" and (iii) by including natural characteristics: "Changing the

nature of the soil such that it behaves as an impermeable medium. This definition includes compaction of soils or sub-soils which may affect larger areas than the sealing as defined in definition (ii)". Grenzdoerffer (2005) considered a soil to be sealed when it is covered by an impervious material and categorised sealed areas as either built-up or non-built-up areas. He also defined partially sealed surfaces as partly permeable surfaces such as open celled pavers that allow a reduced growth of plants.

1.2 Monitoring soil sealing

During the last few years, a variety of projects have been undertaken in Europe to detect soil sealing at European, national or regional scales such as the *SoilSAGE* project, the GMES Urban Services (GUS) project, the GMES Service Element (GSE) Land monitoring project, the Monitoring Urban Dynamics (MURBANDY) project and the Monitoring Land use/cover Change Dynamics (MOLAND) project. Soil sealing has also been investigated by the Technical Working Groups (TWG) of the Soil Thematic Strategy described by Burghardt *et al.* (2004) and Burghardt, Banko *et al.* (2004).

Furthermore, Deguchi and Sugio (1994) evaluated the use of medium resolution satellite images (20-80 m) to estimate the percentage of impervious areas in urban environment by mapping urban growth. Dousset (1995) analysed a set of SAR images to derive soil moisture. The analysis of the SAR images was done by using a multi-spectral SPOT image, classified with the joint distribution of the visible and infrared channels.

He concluded that in areas devoid of construction there is a limit on estimating roughness or soil moisture. Ridd (1995) developed a conceptual model for analysing urban land cover types within urban areas. The vegetation-impervious-soil (V-I-

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S) model was presented as a possible aid for urban ecological investigations through remote sensing technology by offering new inputs to morphology, ecology, energy, moisture, vegetation and human responses. The V-I-S model was later used by Ward *et al.* (2000) for monitoring urban growth and Phinn *et al.* (2002) to monitor the composition of urban environments. Herold, *et al.* (2003) simulate and compare Landsat data (30m resolution) and IKONOS data (4m resolution) using hyperspectral airborne data (AVIRIS) to identify the optimum waveband positions for classifying the built environment. In an unpublished manuscript, Herold, *et al.* (2003) used near-infrared (NIR) waveband combinations and vegetation indices (i.e. NDVI) for monitoring useful indicators of unsealed soil. Coe *et al.* (2005) developed a hybrid method of an object-oriented and a pixel-based classification approach to detect impervious surfaces at multi-scales by using Landsat, IKONOS satellite data and Lidar ancillary data to discriminate buildings from other urban objects like parking lots and roads. Accuracy assessments for Landsat and IKONOS data have not been published but they argued that object-based classification and the addition of Lidar has the potential to be very effective to identify urban classes. Grenzdorffer (2005) used a combination of Landsat TM and SPOT images with high resolution aerial photographs to identify sealed surfaces and the degree of sealing with the help of eCognition software. The NVDI index was also used to discriminate vegetated and non-vegetated surfaces. He argued that based on visual accuracy assessment sealed areas could be identified with an average accuracy of 85-90%. It is worthy of note that some attempts have been made to classify urban land cover with the use of object-based classification techniques. Examples include Darwish, *et al.* (2003); Wang, *et al.* (2004); Guindon *et al.* (2004); Frauman & Wolf (2005); Greiwe & Ehlers (2005); Harayama & Jaquet (2005); Blaschke, *et al.* (2005). These either attempt to classify amalgamated blocks of the built environment to map urban growth or they use airborne sensors with spatial resolutions better than that possible from space. Similarly, the Senate Department of Urban Development in Berlin, Germany, used Landsat-TM satellite imagery and Colour Infrared (CIR) aerial photographs to estimate the degree of sealing at the level of housing blocks (Department of Urban Development web-site). Lastly, the Office for Urban Drainage System in Dresden, Germany, sanctioned the mapping of sealed areas by aerial image mapping. Ortho-rectified aerial photography (1:50,000 scale) were digitized stereoscopically and interpreted with an overlay of the Authoritative Topographic Cartographic Information System (ATKIS) to include soil sealing values for the whole city. The mapping was carried out with a positional accuracy of <0.2 m. The work of Meinel & Hernig (2005) was an inspiration to this research study.

The aim of this research is to identify an appropriate methodology to classify sealed soil and green space surfaces in urban environments with the use of satellite remotely sensed data. The scope is to evaluate the possibility of mapping soil sealing within UK cities in detail (i.e. back gardens of each house) and not in residential blocks.

For that purpose, sealed soil surfaces were considered to be caused by infrastructural sealing and not by crusting capping or compaction in public green spaces. In addition, the discrimination between vegetated and non-vegetated urban surfaces seems to provide a good surrogate for making initial assessments of the degree to which an area is either sealed or unsealed. Consequently, vegetated surfaces were equated to unsealed soil, and non-vegetated surfaces were equated to sealed soils. Bare soil was accepted to be a non-vegetated

surface and, therefore, was visually classified as unsealed. But due to the infrequency of the "bare soil" class within the urban environments, this class was considered negligible for the statistical analysis and accuracy assessment of the research.

2. DATA AND METHODS

The study area is the city of Cambridge, UK. Eighteen sample segments (250 x 250 m) were randomly drawn from the region to provide a basis for the air photo interpretation (API). The data sources acquired for the analysis consisted of: (i) QuickBird satellite imagery (2.8 m MS and 0.7 m PAN spatial resolution), (ii) ortho-rectified aerial photography, 0.125 m resolution, and (iii) Ordnance Survey (OS) MasterMap ancillary data at a scale of 1:1250.

2.1 Baseline map production

A baseline map was produced by developing and implementing a key interpretation of the selected aerial photography which comprised a visual segmentation and classification of the eighteen sample segments. For that purpose, the OS MasterMap, which contains baseline polygons that delineate transport network infrastructure and residential and commercial buildings, was overlaid onto the aerial photography of Cambridge. Each land parcel in the topographic data was allocated a proportion of the following land cover types: (i) sealed surfaces, (ii) vegetation surfaces, (iii) trees, (iv) bare soil and (v) water. The proportions were estimated visually and limited to a precision of 25%, i.e. 0, 25, 50, 75 or 100%. As mentioned before, sealed surfaces were considered to be caused by infrastructural building and not by soil crusting, capping or compaction. Figure 1 shows an example of the map production displaying the percentage of sealing using the API information for one of the eighteen sample areas. This procedure was repeated for all the eighteen segments.

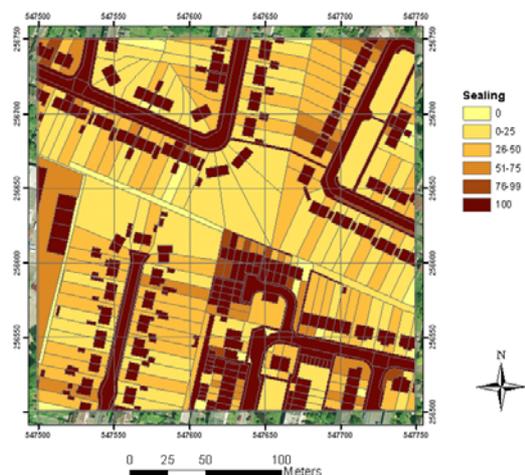


Figure 1. The visual classification of one of the sample areas according to sealing

2.2 Satellite Image classification

The satellite imagery was classified as either vegetated or non-vegetated as this was considered an acceptable surrogate for unsealed and sealed soils, respectively. The use of image band combinations from the red and near infrared wavelengths

provides the greatest opportunity for discriminating vegetation (Jensen, 2000). Such band combinations are typically referred to as vegetation indices, the most popular being the normalised difference vegetation index, or NDVI, and is calculated as:

$$NDVI = \frac{\rho_{IR} - \rho_R}{\rho_{IR} + \rho_R} \quad (1)$$

where
 p = the pixel reflectance value
 ρ_{IR} = the pixel reflectance value in the near infrared (IR) waveband
 ρ_R = the pixel reflectance value in the red (R) waveband

The NDVI image classification comprises three stages: (i) definition of a land cover typology, (ii) “training”—the production of signatures by extraction of sample satellite image pixels from locations of known land-cover and the actual image classification, and (iii) accuracy assessment

2.2.1 Land cover typology: The land cover typology was derived by the land cover types (i.e. roofs, roads, car parks, gardens, trees etc) observed in the high resolution aerial photography, and their membership was assigned to either the sealed or unsealed classes. At the end, a simple two class grouping of sealed vs. unsealed land was provided.

2.2.2 Training the classifier: The district of the city of Cambridge was sub-divided into a number of 250 m x 250 m segments; from a total of 650 possible segments, 15 (c.2.5%) were randomly drawn. The ortho-rectified aerial photography of Cambridge was used to select training pixels in QuickBird imagery (i.e. the seed points forming a cross shaped pattern of five pixels) and to create the signature classes for the supervised classification by using the ERDAS Imagine software (Figure 2).

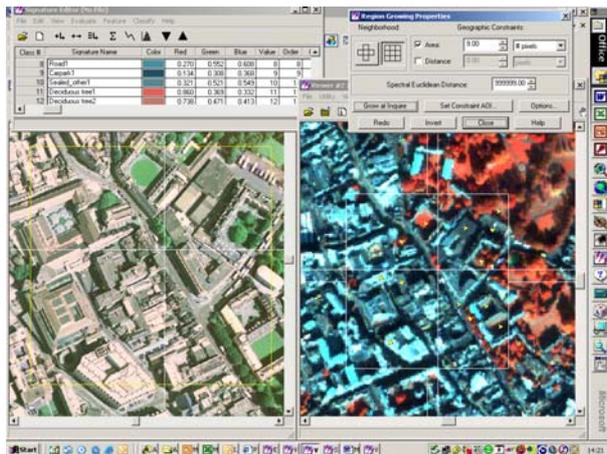


Figure 2. The aerial photograph (right) was used to locate the seed points onto the QuickBird imagery (left)

Finally, the NDVI image was classified with a maximum likelihood supervised classification. The image was reclassified according to the binary format sealed-unsealed and was exported into GIS to be joined with the OS MasterMap data. The topographic data were used to mask all the “Manmade”

infrastructure (i.e. roads, roadsides and buildings) with a percentage of 100% sealing.

2.2.3 Accuracy assessment

The accuracy of the classification was assessed by comparison with the baseline maps that were produced by visually interpreting the ortho-rectified aerial photographs, for the 18 sample segments, as described in section 2.1.

3. RESULTS-DUSCUSSION

Eighteen segments, 250 x 250 m, have been visually classified from 0.125 m resolution ortho-corrected aerial photography. An example of one of the classified map segments is presented in Figure 3. This particular segment has 561 individual polygons. Given all 18 segments, 8086 polygons were available to test the correspondence between the classification and the API



Figure 3. Comparison of (1) the aerial photograph classification, and(2)the supervised image classification

The results of the two classification methods were analysed with the confusion matrix approach. A confusion matrix (Table 1) cross-tabulates the frequency of class combinations, 0%, 25%, 50%, 75% and 100% sealed, in the digital classification with the equivalent sample survey from the API classification. This process is analogous to overlaying the two maps in Figure 3, and comparing classes, but for all 18 segments. The diagonal axis represents agreement between the two observations. Off-diagonal values represent mis-classification errors. Of importance to users of the classified maps is an idea of the overall mapping accuracy and the accuracy for the individual classes.

In Table 1, the overall accuracy is 69%. The numbers in brackets represent a weighted accuracy estimate that takes into account the probability that the API observations may contain some level of uncertainty. The digital classification provides maps of sealing on a continuous scale from 0 – 100%. The API classes, however, are discrete classes within that scale (i.e. 0%, 25%, 50%, 75% and 100%). To take into account the level of human interpretation error, ‘fuzzy’ boundaries were applied to the confusion matrix interpretation. The dashed box outlines represent a tolerance of one class either side of the expected class. According to the assumptions given, a 25% weight is given to the values either side of the diagonal, and 50% to the diagonal. The effect is to increase the estimated accuracy. For example, the overall accuracy increases from 69% to 75%. The adjusted accuracies are indicated in brackets and have been applied to the overall estimate and the user accuracy.

		CLASSIFICATION (Satellite + topographic)					Total	Producer
		0	25	50	75	100		
API	0	475	134	50	36	140	835	57%
	25	288	267	94	53	66	768	35%
	50	149	124	88	53	107	521	17%
	75	111	47	28	50	150	386	13%
	100	523	143	120	123	4683	5592	84%
Total		1546	715	380	315	5146	8102	
User		31%(40%)	37%(55%)	23%(39%)	16%(44%)	91%(92%)	69%(75%)	

Table 1. The confusion matrix indicates correspondence between the digital classification and the API classification of sealing

4. CONCLUSIONS AND OUTLOOK

In this paper we have presented an approach for the automated mapping of sealed soils in urban environments using QuickBird images. The automated classification was compared with the air photo interpretation approach and the overall accuracy calculated to be 75%. The accuracy estimate could be an 'under'-estimate, due to the nature of the visual interpretation which classified sealing into 25% intervals. The low mapping accuracy also comprises the use of pixel based classifiers which are well known for their mapping accuracy limitations. A better assessment could be achieved by using more refined intervals. Future work will explore the potential of using object-based classifiers (i.e. eCognition software) to produce an objective and more efficient visual interpretation for increasing the overall accuracy. The methodology will be validated against three additional urban areas which will be (i) 'less green' than the city of Cambridge, (ii) of different sizes and (iii) located in different parts of England. Furthermore, eCognition will be used to classify the QuickBird imagery and the results will be compared with the pixel based approach. Finally, an operational approach for routine soil-related monitoring in the built environment will be recommended.

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