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A cost-effective approach for improving the quality of soil sealing change detection from Landsat imagery

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Abstract
The aim of this study is to develop a cost-effective approach for soil sealing change detection integrating radiometric analysis, multi-resolution segmentation and object-based classifiers in two study areas in Italy: Campania region and Veneto region. The integrated approach uses multi-temporal satellite images and CORINE Land Cover (CLC) maps. A good overall accuracy was obtained for the soil sealing maps produced. The results show an improvement in terms of size of the minimum mapping unit and of the changed object (1,44 ha in both cases) in respect to the CLC. The approach proves to be cost-effective given the data which are provided at low or no cost and as well as the level of automation achievable.
Keywords: Object based analysis, monitoring, automated feature detection, map updating.

Introduction
In the last century, accelerated ecosystem transformations have been identified as one of the major environmental problems at the global scale (e.g. Millennium Ecosystem Assessment) mainly depending on urbanization, industrialization and land abandonment of rural areas. The human impact on the environment is very relevant because it is related to phenomena leading to social changes, landscape fragmentation, biodiversity loss, soil pollution, hydrological risks [Johnson, 2001; Salvati and Zitti, 2005; Capotorti et al., 2013].
In particular soil sealing is regarded as one of the most severe processes of land degradation in Europe as well as elsewhere in the world [Eckelmann et al., 2006; Salvati et al., 2013]. The European Commission, in the Communication “Towards a Thematic Strategy on Soil Protection” (COM(2002) 179), has also identified soil sealing as one of the main threats the EU is confronted with when referring to the sustainable management of soils (http://ec.europa.eu/environment/soil/index_en.htm).

For these reasons monitoring soil sealing (or its degree, otherwise defined as imperviousness) and its expansion is critical. In the land cover datasets produced at sub-national and national level, soil sealing is mostly analyzed in relation to land cover classes identified as ‘artificial areas’. However, in these cases, artificial areas mapping does not correspond precisely to the detection of surfaces covered with artificial impervious materials. Depending on the scale of restitution and minimum size of the objects analysed, artificial areas may comprise portions of vegetated areas, which should be excluded from the calculation of the total area sealed. This is certainly the case of CORINE Land Cover (CLC), one of the few available sources for assessing diachronically soil sealing in the EU.
Since 2008 the USGS Landsat archives provide free access to multi-spectral satellite imagery, which therefore constitute a valuable and inexpensive source of information for a variety of multitemporal analyses concerning land cover monitoring [Foody, 2003; Kumar, 2011; Gargano et al., 2012] as well as soil sealing monitoring [Alberti et al., 2004; Lu and Weng, 2004; Stathakis et al., 2012]. Regarding remote sensing data classification, the object-based image analysis (OBIA) [Blaschke et al., 2008] is receiving an increasing attention in the identification of land cover objects [Conchedda et al., 2008; Duveiller et al., 2008; Hay et al., 2005] also in the context of impervious surfaces [Myint et al., 2011]. In addition to this, seasonal changes can improve the distinction between sealed surfaces and vegetation coverage, for instance by means of trends of vegetation indices over time, which can be used in the OBIA analysis.
Within this context, the aims of this study are: i) to produce a soil sealing change detection from Landsat archive imagery combining radiometric analysis, multi-resolution segmentation and OBIA [Ceccarelli et al., 2013]; ii) to develop a cost-effective approach for soil sealing change detection which improves on the products attainable from the CLC alone; iii) to test the repeatability of the procedures in space and time and their automation in two areas in Italy which differ substantially in landscape heterogeneity and land cover dynamics: the Campania region and the centre-eastern plain of the Veneto region.

Study areas

The Campania region

The Campania region is located in southern Italy (Fig. 1), covering an area of approximately 13,600 km^2. The landscape is characterized by a complex topography consisting of mountain ranges, volcanic areas and wide plains. Land cover is characterized by agricultural areas (55%), above all arable lands (24%) prevailing in the wide plains, and natural and semi-natural areas (38%), most of which are forests covering hills and mountains (28%). Artificial areas (7%) consist almost entirely of urban areas located above all along the coast and around the city of Naples.

The centre-eastern plain of the Veneto region

The second study area is located in the centre-eastern plain of the Veneto region, in the north-east of Italy (Fig. 1). It covers an area of about 4,650 km^2. The landscape is characterized by a wide plain, except for the hills in the western part. In the eastern part is located the Venetian Lagoon. The study area is mainly occupied by agricultural areas (73%) and artificial surfaces (12%). The natural and semi-natural areas (4%) are distributed in the hilly territories and the wetlands (3%) in the lagoon.

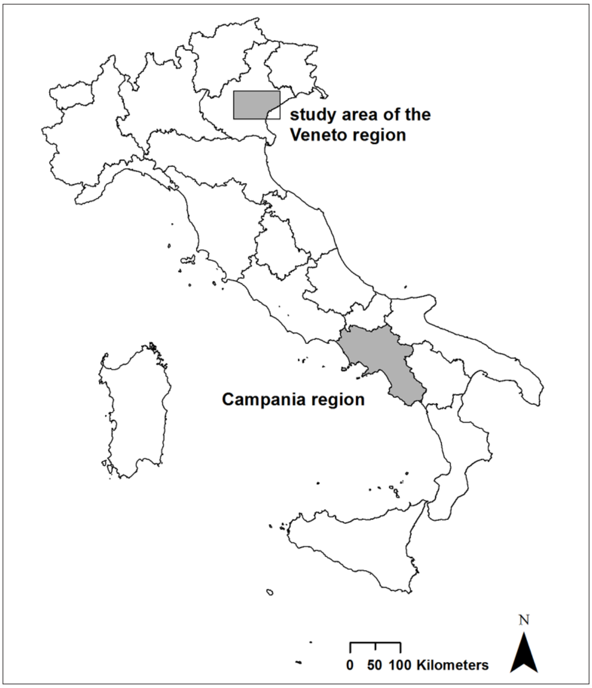

Figure 1 - The study areas (the region of Campania and the centre-eastern plain of the Veneto region).

Reference data

Landsat images

To derive the land cover classifications for the two study areas we used Landsat images freely available from the Landsat archives (http://edcsns17.cr.usgs.gov/NewEarthExplorer/). The classification is based on multi-temporal dataset (Tab. 1). As for the Campania region for any given period (reference and up-dating) a mosaic composed by two scenes was created in order to cover the whole study area. The 2 scenes (path 189, row 031 and 032) are along-track images acquired at almost the same time and in the same atmospheric condition. Top-of-atmosphere image layers were mosaicked without any kind of matching algorithm between different scenes.

Table 1 - Scenes (path/row) and acquisition date of the reference and up-dating periods for Campania region and Veneto region.

	path/row	reference	up-dating
Campania region	189/31 - 189/32	Landsat 7 ETM+ 2001-05-01 2001-09-22	Landsat 5 TM 2010-07-21 2010-08-22 2010-09-23
Veneto region	192/28	Landsat 7 ETM+ 2001-02-15 2001-08-26	Landsat 5 TM 2011-08-14 2011-10-01

Land cover maps

The land cover maps used are the CLC (CORINE Land Cover, 2000) of the Campania region and the Veneto region, and the CUAS (Carta dell'Utilizzazione Agricola dei Suoli) of the Campania region (2001). The CLC is a product of the CLC project (http://www.eea.europa.eu/publications/COR0-landcover) carried out by the European Environment Agency (EEA) to provide pan-European land cover maps. The CLC has a nominal scale of 1:100,000 and a minimum mapping unit (MMU) of 25 ha. The CUAS map, structured in accordance with the CLC nomenclature, was made available by the Agricultural Department of the Region of Campania. The CUAS map has a nominal scale of 1:50,000 and a MMU of 1 ha. For the purpose of this study only the first level of the nomenclature was used: 1 - Artificial surfaces, 2 - Agricultural areas, 3 - Forest and semi natural areas, 4 - Wetlands and 5 - Water bodies.

The CLC maps have been used in the segmentation process, whereas the higher resolution CUAS map has been used for the accuracy assessment of the reference map of the Campania Region. As for the Veneto region the available high resolution land cover maps are not comparable in time, therefore, for the accuracy assessment of the reference map, a visual interpretation of the satellite imagery was performed.

Methods

The proposed methodology for the identification of the sealed areas, i.e. the surfaces covered with impervious materials, integrates radiometric analysis of multi-temporal satellite imagery datasets, multi-resolution segmentation and OBIA classification. In order to test the repeatability and the automation of the procedure in space and time the procedure was initially calibrated for the Campania region and then applied to the Veneto region.

Regarding the region of Campania, the procedure can be divided into the following steps:

I) Realization of a reference map (2001):

a) pre-processing of the Landsat images (two mosaics of 2001), including radiometric calibration, derivation of the NDVI (Normalized Difference Vegetation Index) and tasselled cap transformation;

b) segmentation of the pre-processed images and of the CLC map;

c) classification of the segmented images based on radiometric properties and integration with textural properties and vegetation indices by means of an OBIA classification;

d) evaluation of the classification results against a reference land cover map (CUAS).

II) Up-dating (2010):

a) pre-processing of the Landsat images (three mosaics of 2010), including radiometric calibration, derivation of the NDVI and tasselled cap transformation;

b) segmentation of the pre-processed images and of the reference map 2001;

c) classification of the segmented images based on radiometric properties and integration with textural properties and vegetation indices by means of an OBIA classification;

d) evaluation of the classification results by expert judgment.

Regarding the region of Veneto the procedure has been replicated replacing the Landsat images and the reference map with the relevant image layers and reference map.

Pre-processing of satellite data

Radiance and reflectance calibration

When using Landsat data acquired over large and different areas and with reference to different time periods, it becomes crucial to minimize variations in the sun-earth distance, the solar geometry, and exo-atmospheric solar irradiance. This is achieved with radiance and reflectance calibration [Song et al., 2001]. In the present study the Digital Number (DN) was first converted to radiance and then to Top-of-atmosphere (TOA) reflectance [Chander et al., 2009].

DN values for each band (b) are converted to radiance values (L) using the calibration coefficients gain and offset supplied in the imagery report file, according to the equation:

$$L_b = Gain_b \, x \, DN_b + offset_b \qquad [1]$$

Conversion from radiance to sensor TOA reflectance were obtained according to the formula:

$$\rho_\lambda = \pi L_\lambda d^2 / Eo_\lambda \cos\theta_s \qquad [2]$$

where ρ_λ is the TOA reflectance (unitless), L_λ is the TOA spectral radiance (W m^{-2} sr^{-1} μm^{-1}), d is the earth-sun distance (astronomical units), Eo_λ is the mean TOA solar spectral irradiance (W m^{-2} μm^{-1}), and θ_s is solar zenith angle at the centre of the Landsat acquisition (radiants).

Vegetation indexing

Greenness indices derived from satellite images are commonly used to characterize the type, amount and condition of the vegetation within the scene [Wylie et al., 2002; Pettorelli et al., 2005; Beck et al., 2006]. For this study they can be usefully applied to distinguish vegetated and non-vegetated areas within artificial surfaces. The NDVI (Normalized Difference Vegetation Index) is typically used to characterize the phenological state and the seasonal dynamics of vegetation [Zhang et al., 2003; Ahl et al., 2006]. The NDVI is computed as the normalized ratio between the reflectance in the Red and Near InfraRed (NIR) spectral bands and ranges from -1 to 1, where the negative values refer to non-vegetated areas, while positive low values indicate sparsely vegetated zones and values close to 1 indicate densely vegetated zones.

Tasselled cap transformation

The tasselled cap transformation is a useful tool for compression of spectral data in a few bands associated with physical scene characteristics [Crist and Cicone, 1984]. The tasselled cap converts the six highly correlated spectral bands in six bands arranged almost orthogonally. Most of data variance is concentrated in the first three bands, while the noise and atmospheric effects are concentrated in the last three bands [Crist and Cicone, 1984].

The procedure is based on a linear transformation of data from the original image into three new axes which become features of the transformation and may be described as follows:

a) Brightness: shows surfaces with little or no vegetation (a measure of soil surfaces);

b) Greenness: indicates areas with vegetation that are obviously shown in green (a measure of vegetated surfaces);
c) Wetness: defines the "soil plan" and represents the primary feature (interrelationship of soil and canopy moisture).
In this study the tasselled cap transformation has been applied to at-satellite reflectance due to the fact that a large part of the impact of illumination geometry could be normalized by converting DN to at-satellite reflectance [Huang et al., 2002].

Segmentation
Image segmentation is the partitioning of raster images into spatially continuous, disjointed and homogeneous regions, i.e. segments, based on pixel values and locations [Jensen, 2004]. Pixels having similar feature (textural and spectral) values that are spatially connected are grouped in single segments or objects, minimizing their heterogeneity. In this research , the image segmentation was used as a preliminary step of the classification. The segmentations were performed based on the software eCognition®. The multi-resolution segmentation was carried out in order to minimize the objects heterogeneity and to maximize the detection of the smallest impervious elements. A good compromise has been reached with the identification of objects bigger than 16 pixels. Regarding the region of Campania, the image segmentation for the reference data (2001), was based on the following feature variables:
a) Top-of-atmosphere reflectance image layers for all bands of both dates (2001-05-01, 2001-09-22);
b) NDVI for both dates of 2001;
c) Tasselled cap (brightness, greenness and wetness) for both dates of 2001;
d) CLC map.
In this phase the CLC map allows to get useful information to better discriminate sealed and not sealed areas in the classification process afterwards.
The segmentation process has been performed by a visual inspection approach on two levels:
I) First level (parameters: scale factor 25, shape 0.1, compactness 0.5):
a) Image layer: NDVI 2001-05-01, NDVI 2001-09-22, pancromatic band 2001-05-01 and panchromatic band 2001-09-22;
b) Thematic layer: CLC map.
II) Second level (parameters: scale factor 100, shape 0.1, compactness 0.5):
a) Image layer: none;
b) Thematic layer: CLC map.
The second level supports the object identification process. It allows to set classification rules based on the thematic layer which permit to better discriminate sealed and not sealed areas.
The Table 2 shows the weight associated to each feature variable used in the segmentation process.
The segmentation process has been replicated for the up-dating replacing the image layers with those of 2010 and the CLC map with the reference soil-sealing map of 2001.
The same process was performed for the Veneto region replacing the image layers and the thematic layers with the appropriate ones.

Table 2 - The weight associated to each feature variable used in the segmentation process.

Image layer	Weight
TOA image 2001-05-01	0
TOA image 2001-09-22	0
NDVI 2001-05-01	1
NDVI 2001-09-22	1
PANCROMATIC 2001-05-01	2
PANCROMATIC 2001-09-22	2
BRIGHTNESS 2001-05-01	0
GREENNESS 2001-05-01	0
WETNESS 2001-05-01	0
BRIGHTNESS 2001-09-22	0
GREENNESS 2001-09-22	0
WETNESS 2001-09-22	0
Thematic layer	**Usage**
CLC	Yes

Object based classification

The object oriented classification technique combines radiometric and textural properties as well as vegetation indices, tasselled cap transformation and CLC maps. This approach allows the identification of the sealed areas in a strict sense, that is only the covering of the soil surface with impervious materials, contrary to the CLC nomenclature that is based on the concept of prevailing land cover (e.g., the "artificialized" CLC class 1.1.2 includes a certain amount of vegetated surface). The classification model was developed using the eCognition® object-oriented algorithms.

In this classification, objects originated from the segmentation are evaluated instead of individual pixels. The classification discriminates the image objects into two classes: sealed or unsealed. Each class is described combining class descriptors for the different feature variables by means of fuzzy-logic operators and the objects are then grouped and located in the corresponding classes (Tab. 3).

Table 3 - An example of fuzzy-logic operators for the "Sealed areas" within class 1 of the CLC map.

Feature	Membership function
Mean NDVI 2001 05 01	0.08 - 0.15
Mean NDVI 2001 09 22	0.08 - 0.15
Mean Brightness 2001 05 01	85 - 90
Mean Brightness 2001 09 22	85 - 90
Rel. area of super object class 1 CLC	0.5 - 0.7

Specific object features from the above-mentioned variables are used in the classification rule-set of sealed and unsealed classes, as summarized in Table 4. An example of rule-set for the class "Sealed areas" of the Campania region is shown in Table 5.

Table 4 - Key object features utilized in the integrated classification of sealed and unsealed classes.

Class	CLC classes	GLCM contrast PAN	NDVI		Brightness		Greenness		Wetness	
			2001-05-01	2001-09-22	2001-05-01	2001-09-22	2001-05-01	2001-09-22	2001-05-01	2001-09-22
Sealed	X	X	X	X	X			X	X	X
Unsealed	X				X	X	X	X		

Table 5 - An example of rule-set for the class "Sealed areas".

Sealed areas	
Sealed areas within class 1 of CLC map	**Sealed areas outside class 1 of CLC map**
And (min) Mean NDVI 2001-05-01 Mean NDVI 2001-09-22 Mean Brightness 2001-05-01 Mean Brightness 2001-09-22 Rel. area of super object CLC class 1	And (min) And (min) GLCM Contrast PAN (all dir.) Mean NDVI 2001-05-01 Mean NDVI 2001-09-22 Mean Brightness 2001-05-01 Mean Brightness 2001-09-22 Mean Greenness 2001-05-01 Mean Greenness 2001-09-22 Or (max) Rel. area of super object CLC class 2 Rel. area of super object CLC class 3

The class "Sealed areas" is composed by the union of the two sub classes "Sealed areas within class 1 of the CLC map" and "Sealed areas outside class 1 of the CLC map". While the first class allows the extraction of sealed areas within urban areas according with CLC nomenclature, the latter identifies sealed areas smaller than the minimum mapping unit (MMU) within land cover classes 2 and 3 (Fig. 2). Class descriptions were defined based on their ability of discriminating among the different classes. This was achieved by means of the eCognition® "sample editor", inspecting image values of the features in relation to classes with similar properties. Regarding the up-dating of the soil sealing maps (2010 for Campania region and 2011 for Veneto region), the analysis was focussed only on surfaces which became sealed over the period considered. It was considered that the opposite trajectory (reduction of sealing) is marginal or non-existent during this period in the two study areas. The objects were classified using the criteria listed in Table 4. Subsequently they have been compared to the classifications of 2001 to obtain a number of cases in the soil sealing change detection matrix (Tab. 6).

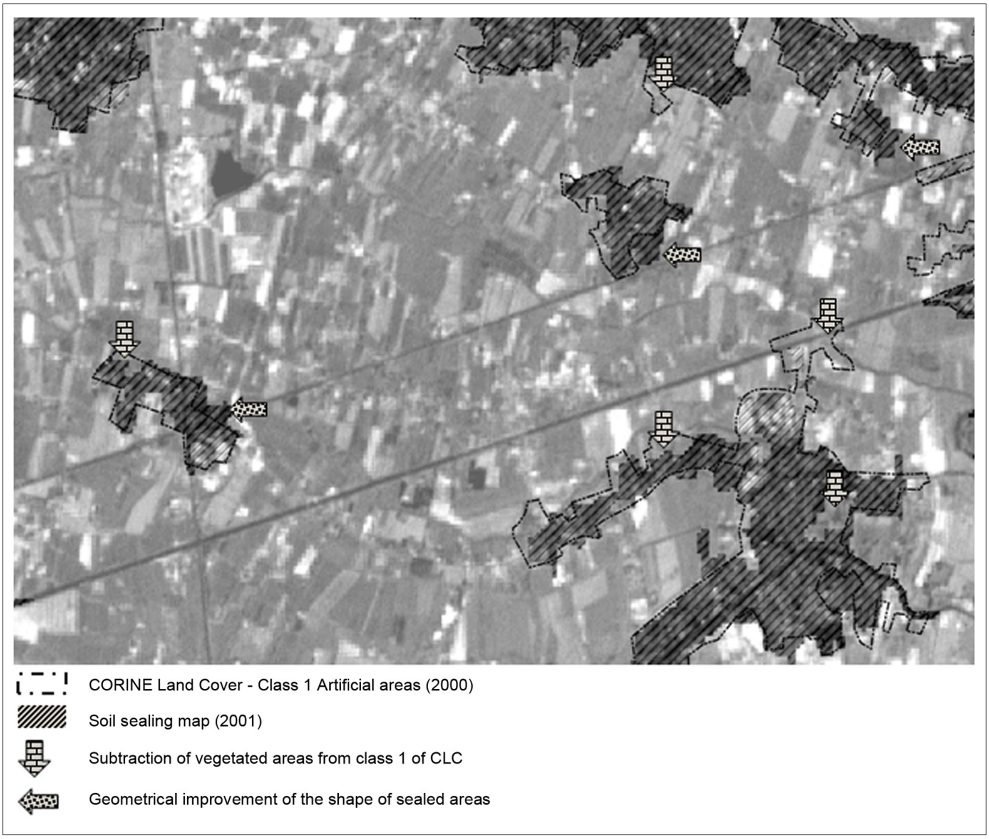

Figure 2 - An example of the identification of sealed areas within class 1 of the CLC map and sealed areas within land cover classes 2 and 3.

Table 6 - Change detection matrix of sealed and unsealed areas.

	up-dating	
2001	**Sealed**	**Unsealed**
Sealed	Unchanged	Not applicable
Unsealed	Changed	Unchanged

Accuracy assessment of the classifications

As for the Campania region, the quality of the classifications obtained was assessed by two different methodologies: the reference soil sealing map was evaluated by means of a confusion matrix according to the CUAS land cover map. The soil sealing map of 2010

instead was assessed by visual interpretation due to the lack of a temporally comparable map.
A set of test samples was randomly extracted and used for evaluating the accuracy of 2001 soil sealing map. The training samples covered approximately 8% of the surface of the Campania region. The confusion matrix was constructed against a reclassified land cover map where the sealed surface class corresponds to class 1 - Artificial areas (except for "green urban areas") and the unsealed class corresponds to classes 2, 3, 4 and 5. Regarding the soil sealing map of 2010, an expert based visual interpretation was performed for all the changed objects.
As for the Veneto region, the quality of the classifications obtained were assessed by visual interpretation for both dates due to the lack of comparable high resolution land cover maps. For the reference soil sealing map of 2001 the training samples covered about 8% of the study area, whereas for the soil sealing map of 2010 the visual interpretation was performed for all the changed objects.

Results

Regarding the Campania region, from 2001 to 2010 the sealed areas increase of 1.6%, amounting to a total of about 1,230 ha (Tab. 7 and Fig. 3). As for the reference layer of 2001, an overall accuracy of 95.7% was achieved, by comparison with the existing land cover map of Regione Campania (CUAS). Satisfactory results were also obtained in respect to the changed polygons (overall accuracy of 89.5%) which, as mentioned, were assessed through visual interpretation. Regarding the Veneto region, from 2001 to 2011 the sealed areas increase of 1.8% equivalent to a total of about 1,036 ha (Tab. 7 and Fig. 4). For the reference layer of 2001 and the changed polygons of 2011, overall accuracies of 93.3% and 95.1% were attained, respectively.
Furthermore results show an improvement in terms of size of the MMU and of the changed object (1,44 ha in both cases) in respect to the CLC for both areas. Among the feature variables utilized, multi-temporal NDVI and Brightness were those contributing better to the identification of image objects without vegetation, while texture features (GLCM Contrast of panchromatic band) further helped in discriminating between non-vegetated arable land and "Sealed area" smaller than the MMU of the CLC.

Table 7 - Soil sealing variations.

	Soil sealing	Total (ha)	Variations (ha)
Campania region	2001	79,080.54	1,230.30
	2010	80,310.84	
Veneto region	2001	56,898.46	1,036.63
	2011	57,935.09	

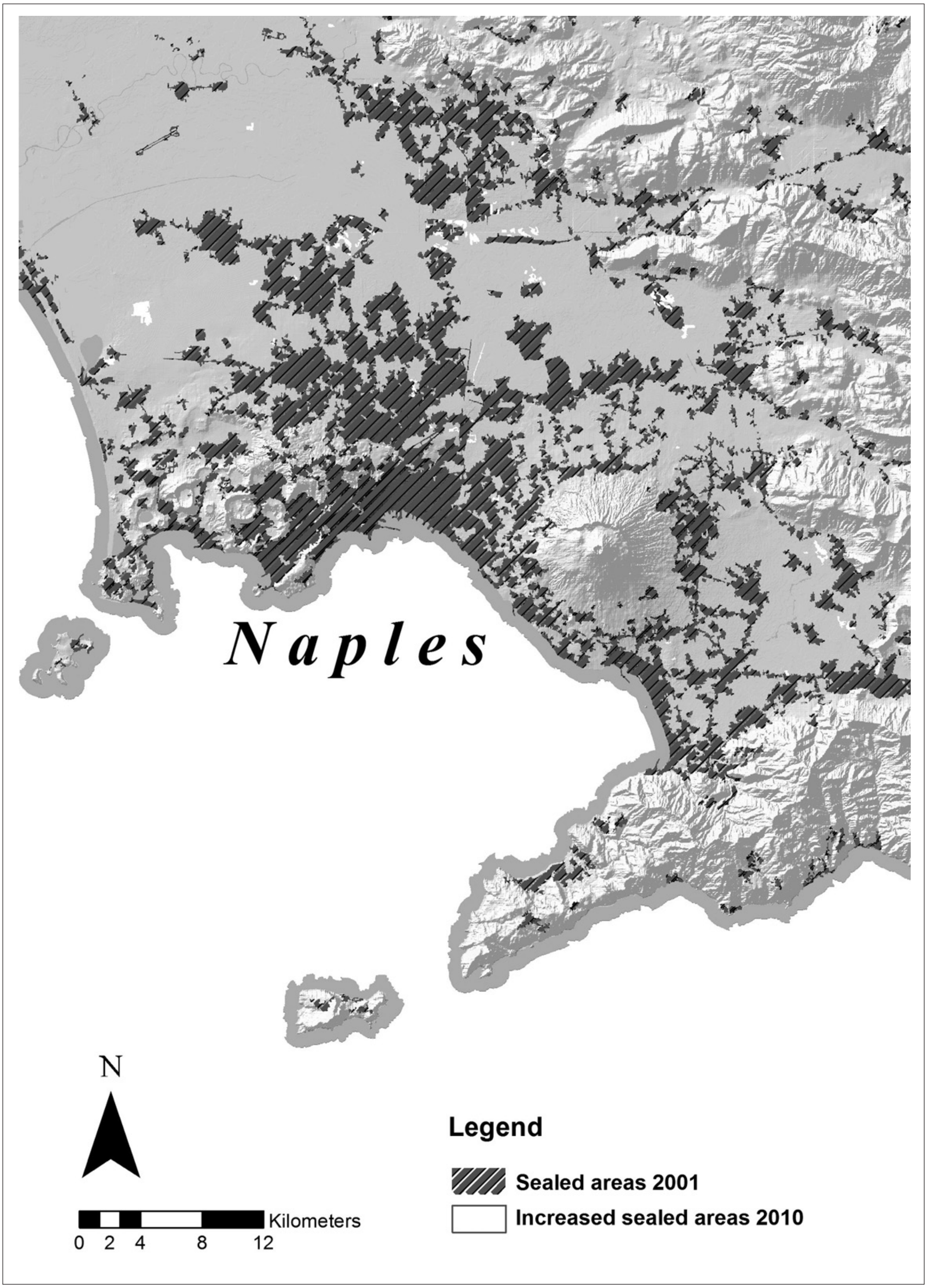

Figure 3 - A detail of the distribution of soil sealing variations (white polygons) in the Campania region.

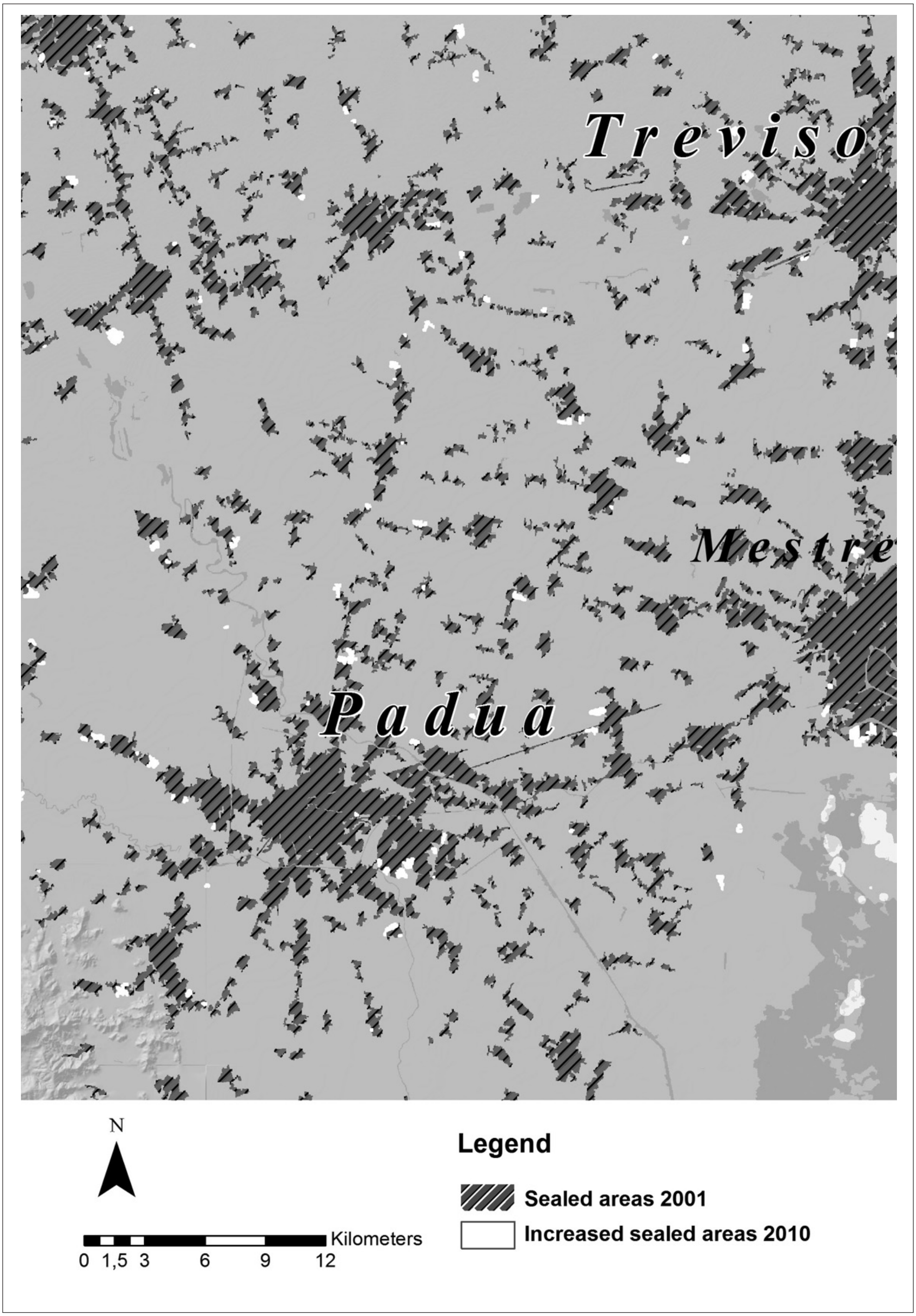

Figure 4 - A detail of the distribution of soil sealing variations (white polygons) in the Veneto region.

Conclusions

The results of the classifications showed high levels of accuracy for both the study areas and an improvement of the MMU of the soil sealing layers compared with available cartography based on Landsat (e.g. CLC). The employ of image and vector layers, integrating radiometric analysis, multi-resolution segmentation and OBIA proves to be effective in achieving good results in the classification performance of urbanized areas.

The results obtained for the Veneto region were achieved applying the feature variables and rule sets used in the classification of the Campania region, with only minor adaptations. This is encouraging and indicates the possibility to transfer the procedure in other geographic contexts, with different (natural, agricultural and artificial) landscapes and different underlying satellite imagery.

Furthermore, the proposed approach proves to be cost-effective given the fact that data are provided at low or no cost (free access to the Landsat archive) as well as the level of automation achievable. Hence the results highlight the potential of the proposed method in the perspective of a cost-efficient monitoring of the dynamics of soil sealing. Such monitoring could be extended to other satellite images sources, such as those provided through the Landsat continuity mission and especially through the Sentinel missions.

References

Ahl D.E., Gower S.T., Burrows S.N., Shabanov N.V., Myneni R.B., Knyazikhin Y. (2006) - *Monitoring spring canopy phenology of a deciduous broadleaf forest using MODIS*. Remote Sensing of Environment, 104 (1): 88-95. doi: http://dx.doi.org/10.1016/j.rse.2006.05.003.

Alberti M., Weeks R., Coe S. (2004) - *Urban Land Cover Change Analysis in Central Puget Sound*. Photogrammetric Engineering & Remote Sensing, 70 (9): 1043-1052.

Blaschke T., Lang S., Hay G.J. (2008) - *Object-Based Image Analysis. Spatial Concepts for Knowledge-Driven Remote Sensing Applications*. Springer Berlin Heidelberg, pp. 817. doi: http://dx.doi.org/10.1007/978-3-540-77058-9.

Beck P.S.A., Atzberger C., Hogda K.A., Johansen B., Skidmore A.K. (2006) - *Improved monitoring of vegetation dynamics at very high latitudes: A new method using MODIS NDVI*. Remote Sensing of Environment, 100 (3): 321-334. doi: http://dx.doi.org/10.1016/j.rse.2005.10.021.

Capotorti G., Del Vico E., Lattanzi E., Tilia A., Celesti-Grapow L. (2013) - *Exploring biodiversity in a metropolitan area in the Mediterranean region: The urban and suburban flora of Rome (Italy)*. Plant Biosystems, 147 (1): 174-185. doi: http://dx.doi.org/10.1080/11263504.2013.771715.

Ceccarelli T., Smiraglia D., Bajocco S., Rinaldo S., De Angelis A., Salvati L., Perini L. (2013) - *Land cover data from Landsat single-date imagery: an approach integrating pixel-based and object-based classifiers*. European Journal of Remote Sensing, 46: 699-717. doi: http://dx.doi.org/10.5721/EuJRS20134641.

Chander G., Markham B.L., Helder D.L. (2009) - *Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors*. Remote Sensing of Environment, 113 (5): 893-903. doi: http://dx.doi.org/10.1016/j.rse.2009.01.007.

Conchedda G., Durieux L., Mayaux P. (2008) - *An object-based method for mapping and change analysis in mangrove ecosystems*. ISPRS Journal of Photogrammetry and Remote

Sensing, 63 (5): 578-589. doi: http://dx.doi.org/10.1016/j.isprsjprs.2008.04.002.
Crist E.P., Cicone R.C. (1984) - *A physically-based transformation of Thematic Mapper data - the TM Tasseled Cap*. IEEE Transactions on Geosciences and Remote Sensing, 22 (3): 256-263. doi: http://dx.doi.org/10.1109/TGRS.1984.350619.
Duveiller G., Defourny P., Desclée B., Mayaux P. (2008) - *Deforestation in Central Africa: Estimates at regional, national and landscape levels by advanced processing of systematically-distributed Landsat extracts*. Remote Sensing of Environment, 112 (5): 1969-1981. doi: http://dx.doi.org/10.1016/j.rse.2007.07.026.
Eckelmann W., Baritz R., Bialousz S., Bielek P., Carre F., Houšková B., Jones R.J.A., Kibblewhite M.G., Kozak J., Le Bas C., Tóth G., Tóth T., Várallyay G., Yli Halla M., Zupan M. (2006) - *Common criteria for risk area identification according to soil threats. European Soil Bureau Research Report No. 20, EUR 22185 EN*. Office for Official Publications of the European Communities, Luxembourg, pp. 94.
Foody G.M. (2003) - *Remote sensing of tropical forest environments: towards the monitoring of environmental resources for sustainable development*. International Journal of Remote Sensing, 24 (20): 4035-4046. doi: http://dx.doi.org/10.1080/0143116031000103853.
Gargano D., Mingozzi A., Massolo A., Rinaldo S., Bernardo L. (2012) - *Patterns of vegetation cover/dynamics in a protected Mediterranean mountain area: Influence of the ecological context and protection policy*. Plant Biosystems, 146 (1): 9-18. doi: http://dx.doi.org/10.1080/11263504.2011.641689.
Hay G.J., Castilla G., Wulder M.A., Ruiz J.R. (2005) - *An automated object-based approach for the multiscale image segmentation of forest scenes.* International Journal of Applied Earth Observation and Geonformation, 7 (4): 339-359. doi: http://dx.doi.org/10.1016/j.jag.2005.06.005.
Huang C., Wylie B., Yang L., Homer C., Zylstra G. (2002) - *Derivation of a tasselled cap transformation based on Landsat 7 at satellite reflectance*. International Journal of Remote Sensing, 23 (8): 1741-1748. doi: http://dx.doi.org/10.1080/01431160110106113.
Jensen J.R. (2004) - *Introductory Digital Image Processing: A Remote Sensing Perspective*. 3rd Ed, Prentice Hall, Upper Saddle River, New Jersey, pp.526.
Johnson M.P. (2001) - *Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda*. Environment and Planning, 33 (4): 717-735. doi: http://dx.doi.org/10.1068/a3327.
Kumar D. (2011) - *Monitoring Forest Cover Changes Using Remote Sensing and GIS: A Global Prospective*. Research Journal of Environmental Science, 5 (2): 105-123. doi: http://dx.doi.org/10.3923/rjes.2011.124.133.
Lu D., Weng Q. (2004) - *Spectral mixture analysis of the urban landscape in Indianapolis with Landsat ETM+ imagery*. Photogrammetric Engineering & Remote Sensing, 70 (9): 1053-1062.
Myint S.W., Gober P., Brazel A., Grossman-Clarke S., Weng Q. (2011) - *Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery*. Remote Sensing of Environment, 115 (5): 1145-1161. doi: http://dx.doi.org/10.1016/j.rse.2010.12.017.
Pettorelli N., Vik J., Mysterud A., Gaillard J., Tucker C., Stenseth N. (2005) - *Using the satellite-derived NDVI to assess ecological responses to environmental change*. Trends in Ecology and Evolution, 20 (9): 503-510. doi: http://dx.doi.org/10.1016/

j.tree.2005.05.011.
Salvati L., Sateriano A., Bajocco S. (2013) - *To grow or to sprawl? Land Cover Relationships in a Mediterranean City Region and implications for land use management*. Cities, 30: 113-121. doi: http://dx.doi.org/10.1016/j.cities.2012.01.007.
Salvati L., Zitti M. (2005) - *Land degradation in the Mediterranean basin: linking bio-physical and economic factors into an ecological perspective*. Biota - International Journal of Biology and Ecology, 5: 67-77.
Song C., Woodcock C., Seto K., Pax Lenney M., Macomber S. (2001) - *Classification and change detection using Landsat TM data: When and how to correct atmospheric effects?* Remote Sensing of Environment, 75 (2): 230-244. doi: http://dx.doi.org/10.1016/S0034-4257(00)00169-3.
Stathakis D., Perakis K., Savin I. (2012) - *Efficient segmentation of urban areas by the VIBI*. International Journal of Remote Sensing, 33 (20): 6361-6377. doi: http://dx.doi.org/10.1080/01431161.2012.687842.
Wylie B.K., Meyer D.J., Tieszen L.L., Mannel S. (2002) - *Satellite mapping of surface biophysical parameters at the biome scale over the North American grasslands: a case of study*. Remote Sensing of Environment, 79 (2-3): 266-278. doi: http://dx.doi.org/10.1016/S0034-4257(01)00278-4.
Zhang X., Friedl M.A., Schaaf C.B., Strahler A.H., Hodges J.C.F., Gao F., Reed B.C., Huete A. (2003) - *Monitoring vegetation phenology using MODIS*. Remote Sensing of Environment, 84 (3): 471-475. doi: http://dx.doi.org/10.1016/S0034-4257(02)00135-9.