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A hybrid multi-step approach for urban area mapping in the Province of Milan, Italy

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Abstract

Remote sensing products have proven an effective tool for the study of urban areas, from city management to environmental monitoring. This work focuses on the mapping of urban areas in the Province of Milan, Northern Italy, using mid-resolution remote sensing data covering the last 20 years. The methodology consists of three main steps: (i) a pixel-based classification tree, (ii) object-based filtering of agricultural terrain, and (iii) joining of land cover classes into two (urbanized and non-urbanized) ,adding post-classification editing. The final derived urban maps were validated and demonstrated to reach very good accuracy (error: 7-13%), thus providing reliable thematic information for urban planning of local and regional authorities.

Keywords: Remote Sensing, GMES Land Services, Soil Sealing, Urban areas, Multi-temporal analysis.

Introduction

Urban management needs reliable and updated knowledge about urban area structure and evolution, because of its influences on and relations with runoff control, urban vegetation planning, public transport and other services, infrastructure development, air quality monitoring and improvement, and also with mitigation and adaptation studies of climate change effects. Therefore, an accurate mapping of urban, land-cover features can provide critical information that helps scientists and decision-makers to better understand urban area ecosystems and consequently take decisions, with the aim of improving environmental and human life quality in urbanized areas [Jensen, 1981; Small and Balstad Miller, 2000; Fichera et al., 2012].

The impact of human activity on an area may be assessed using cartographic products that describe land-use and land-cover in different time phases; such data may be the basis for the assessment of soil sealing and imperviousness, which are considered to be effective

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indicators of urbanization-related processes. Urban area maps can be produced using different data (direct survey, aerial photography, satellite images, etc.) and methodologies (photo-interpretation, supervised methods, unsupervised clustering, etc.), which are usually chosen based on the objectives the final product is expected to fulfill, as well as on the mapping scale [Ridd and Liu, 1998]. In this context, mapping products resulting from satellite data exploitation represent a useful source of information for the evaluation of the status and changes of urban areas, especially within the medium spatial scale (1:25000 to 1:50,000), and in conjunction with other cartographic sources such as land-use thematic maps or planning and cadastral maps [Mas, 1999; Ji et al., 2001].

Multi-spectral data, ranging from 20 meter to 100 meter ground pixel size, have proven to be very effective in environmental analysis at a local to regional scale. This is particularly true in areas where human influence on the natural environment is heavy, as in the case of urban and sub-urban areas, due to the good compromise between the spatial and spectral details provided. The Province of Milan area, in northern Italy was taken as a test area because of its environmental and socio-economic characteristics that produced fast urban sprawl in the last decades. The land use change of this area was previously analyzed for the period 1900-1990 using cartographic and satellite (Landsat TM) data [Gomarasca et al., 1993]. For these reasons, this work focused on the exploitation of SPOT High Resolution Visible InfraRed (HRVIR, 20 m ground resolution) and Landsat Thematic Mapper/Enhanced Thematic Mapper+ (TM/ETM+, 30 m ground resolution) data for urban area analysis, even if the spectral response mixture, at this level of resolution, of sparsely urbanized areas constitutes one of the major challenges to deal with.

The most significant effort in this work was dedicated towards the development of an effective and straightforward methodology for urban status and change mapping, performed through a hybrid and semi-automatic approach. The aim of such a methodological framework was to distinguish between impervious and non-impervious surfaces, that is between man-made (urban) and natural (non-urban) features, using remote sensing data. The final result of this kind of methodological approach is therefore a mapping product that is capable of separating Terrain Occupied by artificial surfaces from Non-Occupied terrain.

Within the context of this work, the terminology relating to “occupied terrain”, “urbanization” and “urban” phenomena refer to built-up areas and are merely a definition of surface materials and properties, rather than one relating to actual land-use. Therefore, the term “urbanization” refers here to the detected artificial surfaces, and acts as a synonym for the term “built-up terrain”, rather than the classical meaning of “urbanization” in urban planning studies, that refers to a broad category of land uses where a mixture of different surfaces can be categorized as “urban”.

The main outcome of this work, therefore, was the production of urban area maps covering the Province of Milan in Italy, for the years 2008, 1998 and 1989. The methodology applied consisted of three main parts and is based on decision tree classification and post-classification refinement.

The structure of this paper consists of: (1) an overview of soil sealing issues and related geo-information monitoring services in the Province of Milan, Northern Italy; (2) the description of the remote sensing dataset used and the pre-processing activities; (3) the main section devoted to the presentation of the methodological framework used to obtain urban area multi-temporal mapping products from remote sensing data; (4) the presentation of these mapping results and a discussion about their usefulness and synergistic use together with other tools that are suitable for Public Authority urban planning purposes.

Soil sealing in the Province of Milan and related Geoservices

The issue of urban sprawl and soil sealing monitoring is nowadays one of the hottest topics in the context of human environment management. The current model of urban development has significantly increased the amount of terrain that is used for anthropogenic activities and whose surfaces have been made impervious for both residential and non-residential purposes. This is a phenomenon which occurs in many parts of the globe, and especially in densely populated areas, in Europe.

The Milan metropolitan area is one of the most urbanised areas in Europe. The studies conducted by PIM (*Centro Studi per la Programmazione Intercomunale dell'area Metropolitana*, which translates as Study Center for Inter-municipal Planning for the Milan metropolitan area), based on cartographic information regarding the historical dynamics of soil sealing and socio-economic indicators, have demonstrated that the Province of Milan has been suffering since the 1960s from progressive urban saturation within the central area (now over 90%) and from a subsequent increase in urban expansion away from the city of Milan.

This urban expansion has taken place along transport routes and communication lines, thus occupying the open spaces surrounding the city and leading to fragmentation of the urban centres further out [Centro Studi PIM, 2009].

When this process is analysed in detail, it is possible to highlight that the growth, in urban areas has seen a significant slowdown over the last decade in those areas of the province that were already populated. On the contrary, the urbanisation dynamics show a tendency towards increased pressure on the rural areas located in the southern part of the Province of Milan, that are still unoccupied. The information on these dynamics leads us reasonably to expect that the metropolitan area will have to deal, with this persistent phenomenon of urban growth for a certain period in the near future, in particular as regards the conversion of agricultural land into built-up land. Therefore, the environmental issues associated with these phenomena will continue to affect the Milan provincial area at least in the short-medium term.

The study of soil sealing dynamics saw the advent of a range of new analysis tools during the 1980s, thanks to the availability of digital information and the spreading of GIS software that made spatial analysis easier. GIS and geospatial tools still remain the major tools for urban studies in general and in particular for urbanisation growth monitoring and management.

An example of this approach is provided by the MISURC (*Mosaicatura Informatizzata degli Strumenti Urbanistici Comunali*), realised by PIM [Centro Studi PIM, 2008]. MISURC integrates and mosaics the City Master Plan tools of each municipality in the Province of Milan using a particular set of methods and procedures. The adopted method has became a regional standard for the entire Lombardy Region. Nevertheless, cartographic products such as MISURC usually require a certain time to receive updates, because of the costly production of new master plans. Moreover, this cartography represents the potential, planned destination of the urban area, identifying urban polygons in relation to their actual or intended use, that do not necessarily correspond to the effective occupation by artificial and built-up surfaces.

During the last decade, therefore, new geospatial tools and techniques, including multi-temporal and mid-high resolution Remote Sensing, have increasingly pushed local administrations to experiment with novel methodologies and approaches that integrate with traditional urban study approaches so as to provide more frequent mapping product updates as well as a more cost-efficient framework for urban-area studies at a local and regional level.

One of the core applications of the European GMES (Global Monitoring for Environment and Security) initiative focuses on land-based geo-information services. Earth Observation (EO) capability development is one of the multi-aspect prospects of the GMES operational phase, with the aim of providing operational services for land-cover mapping and monitoring. Such thematic services are of particular interest to Public Authorities who have the responsibility to manage the territory and its environmental issues. In fact, remote sensing data and techniques cover a range of environmental application fields where the innovative solutions from science and technology, integrated with the existing tools such as cartography and GIS, can be beneficial for the development of plans and services in the Public Administration context.

GMES Land Services have already contributed new geo-information contents which are available to citizens and authorities, including some notable features, such as CORINE, land cover/use mapping on a continental scale (1:100000), the Imperviousness and Soil Sealing maps and layers on a 1:25000 scale, and the Urban Atlas, a system of detailed land cover mapping for a number of important urban areas at high scale resolution (1:5000).

In particular, the Imperviousness and Soil Sealing maps provided by GMES Land services offer an adequate solution for monitoring urban growth and soil sealing, because they provide spatially-referenced and consistent information in support of National and European reporting obligations. Available Products (maps, statistics, indicators and scenarios) describe the pressures, state and impacts of expansion in urban area. Mapping services and downstream products provide views of soil sealing trends and their impact on representative European areas on the sub-national (regional and sub-regional) levels, [GSE Land Information Service, 2010].

This work presents a remote sensing exploitation test conducted in the Province of Milan in order to investigate its capabilities for monitoring the dynamics of urban occupied territories, using satellite data. This study evaluated the contribution of satellite data towards providing a framework for faster updates of urbanized area maps and soil sealing information, especially in conjunction with the traditional analysis performed on thematic layers such as MISURC. Moreover, the adopted approach could provide mapping products that go beyond traditional urban studies, and extend the range of tools available to the Public Authorities in urban planning, also in the context of establishing GMES-promoted, local downstream services.

Remote sensing dataset and pre-processing

Within the scope of evaluating urbanization in the Province of Milan over the last 20 years, the dataset was composed of one Landsat 5 TM scene for 1989, acquired in August, two SPOT 4 HRVIR scenes for 1998, acquired in May, and four SPOT 4 HRVIR scenes for 2008, acquired in April and August, as shown in Table 1. Additional and supporting data used in this study consisted of three different sources: a) the DUSAF2000 [ERSAF, 2000], a vector land cover/use database derived from aerial orthophotos, using photo-interpretation techniques, which covered the entire Lombardy Region, including the Province of Milan at a maximum equivalent scale of 1:10000 - this was employed to test the classification approach; b) the MISURC08 (thematic database for urban planning), a vector layer consisting of the mosaic of city master plans of all the municipalities in the Province of Milan derived from raster maps on a scale of 1:5000 to 1:10000 scale, which was used for validating the automatic classification results; c) a supplementary Landsat 5 TM scene for 1990 was used for cloud covered areas in the 1989 data.

Table 1 - Satellite dataset utilized in the study.

Satellite-Sensor (level)	Year 1989-90 (scene – date)	Year 1998 (scene – date)	Year 2008 (scene – date)
Landsat5 TM (level 1A)	SCENE 1: 194-28 – 31/08/1989 SCENE 2: 194-28 – 12/04/1990 (*)		
SPOT4 HRVIR (level 2A)		SCENE 3: 056-258 – 10/05/1998 SCENE 4: 057-259 – 10/05/1998	SCENE 5: 056-259 – 01/04/2008 SCENE 6: 057-258 – 24/08/2008 SCENE 7: 056-258/2 - 01/04/2008 SCENE 8: 057-259 – 19/08/2008

(*) 1990 data utilized only for covering clouded areas in 1989 data.

Pre-processing of satellite data has included geocoding, radiometric calibration and atmospheric effect correction, radiometric normalization and mosaicking of the scenes covering only part of the Province of Milan territory. The data was geo-referenced in the Gauss-Boaga zone 1 reference system using DUSAF2000 as the cartographic base. The resulting planimetric Residual Mean Square Error (RMSE) was around 8 meters for geo-referenced data (below 0.5 pixels for SPOT data), consistent with an intended mapping scale of 1:50000.

Radiometric calibration and atmospheric correction were performed, using the MODTRAN-4 atmospheric model, to retrieve ground reflectance values [Berk et al., 1999]. In order to boost the radiometric comparability of multi-temporal data, a final step of radiometric normalization was carried out using SPOT SCENE 7: 056-258/2 (April 2008) as the point of reference. Manual Pseudo Invariant Features collection (minimum consistence of 10 invariant targets over each image) and linear regression transform were performed [Villa and Boschetti, 2009], reaching a good level of matching at $R^2>0.95$, which ensures a better matching of mapping results throughout the period of analysis (1989-2008).

Lastly, for the SPOT data covering 1998 (2 scenes) and 2008 (4 scenes), both mosaicking and edge matching were performed, as shown in Figure 1.

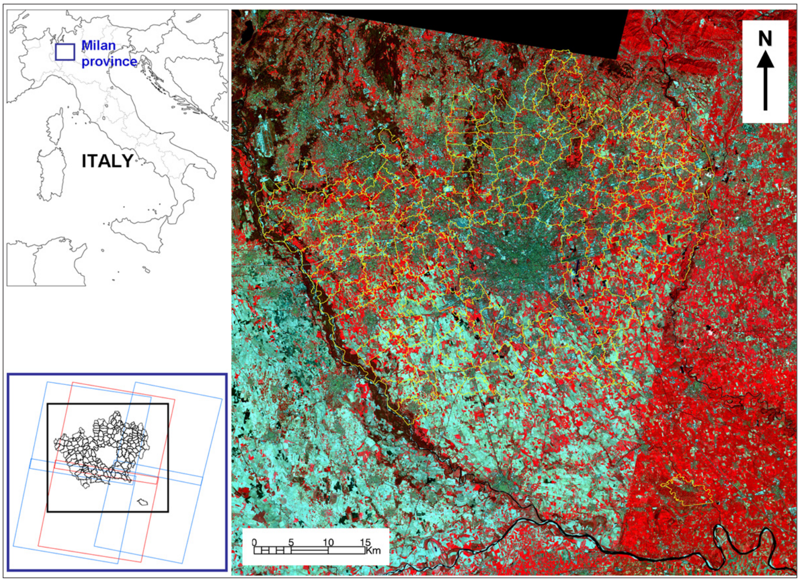


Figure 1 - Study area investigated: The Province of Milan, located in Northern Italy. CIR visualization of the mosaic of 4 SPOT4 HRVIR scenes covering study area (municipality borders highlighted in yellow) in 2008. Bottom left panel provides an overview of the SPOT scenes coverage (blue and red color represent respectively data extension for 2008 and 1998).

Urban area mapping

The methodological framework used to obtain and validate urban area maps from mid-resolution satellite data consists of a multi-step scheme composed of 3 processing steps followed by a validation phase, as shown in Figure 2.

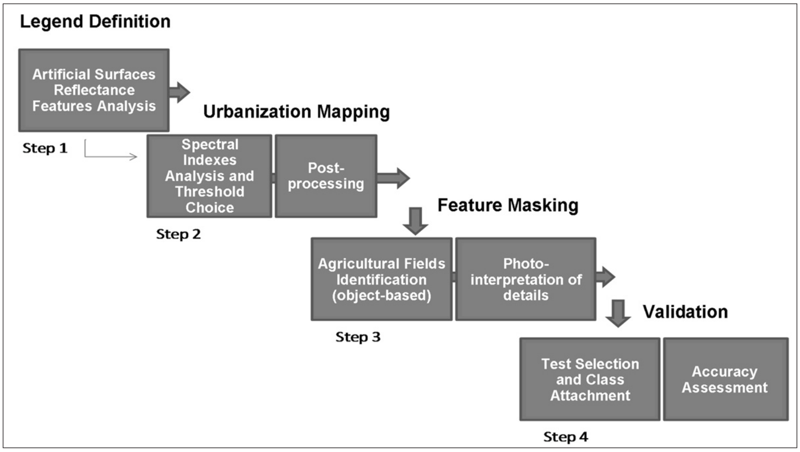


Figure 2 - Processing steps diagram for urban mapping methodology utilized within the study.

Separation thresholds were defined for the 10 land cover classes, starting from the analysis of spectral response features, calculated over selected sample areas. These steps allowed us to define the criteria and threshold values to be applied when using automatic detection in the urban area of the Province of Milan.

Table 2 - Classification Legend.

Macro-classes	Class number and description		
Non-Occupied terrain	1 Bright Vegetation 2 Dark Vegetation 3 Bare Soil - Bright 4 Bare Soil - Dark 5 Paddy Fields		
Water		6 Water	
Occupied terrain			7 Bright Industrial 8 Dark Industrial 9 Dense Urban 10 Residential Urban

The classes were then grouped into three main interest macro-classes: Non-Occupied terrain (classes 1 to 5), Water (class 6) and Occupied terrain (classes 7 to 10). The approach for this first step in urban area mapping exploited pixel-based, binary cascade thresholding with a decision tree classifier (Fig. 3). The spectral features utilized in decision tree design and processing were derived from spectral band response and from spectral indices as already proposed and adopted in literature [Villa and Boschetti, 2009]. In detail the spectral features adopted for the classification tree are:

- SWIR – Reflectivity of a surface in shortwave infrared wavelength domain (1.55-1.75 µm, HRVIR band 4/TM band 5), useful in discriminating water and water-related features;
- NDVI – Normalized Difference Vegetation Index, a vegetation index which exploits spectral characteristics of vegetation in visible red and near-infrared wavelengths [Rouse et al., 1973];
- ALB – Pseudo-albedo derived from HRVIR and TM homologous bands by averaging the reflectance response in Visible-Near Infrared and Shortwave infrared bands (HRVIR bands 1, 2, 3, 4/TM bands 2, 3, 4, 5), useful for separating high from low reflectance surfaces;
- SVI – Soil and Vegetation Index, a perviousness index which exploits visible short wavelengths and shortwave infrared response (HRVIR bands 1 and 4/TM bands 1 and 5), in order to separate impervious from non-impervious cover classes [Villa, 2007];
- RGRI – Red Green Ratio Index, spectral gradient response of visible red wavelength band (0.63-0.69 µm, HRVIR band 2/TM band 3) and visible green wavelength band (0.52-0.60 µm, HRVIR band 1/TM band 2), used in identification of mixed response pixels containing partial vegetative features (sparsely vegetated agricultural fields, residential areas, etc.) [Gamon and Surfus, 1999].

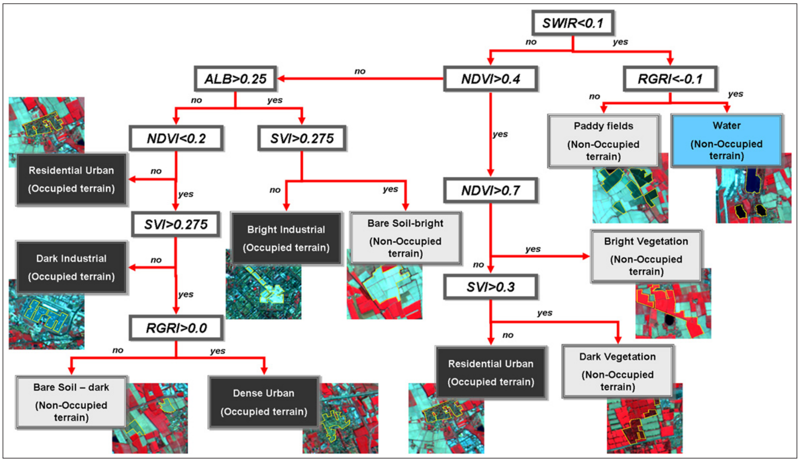


Figure 3 - Classification tree utilized for land cover mapping in the urban area of the Province of Milan, exploiting spectral bands and indices for mapping Occupied/Non Occupied terrain.

An example of the binary tree classification approach can be described using the "Bright Industrial" class as a reference. A pixel in the satellite data is detected as occupied by the "Bright Industrial" class when its spectral response is high in the shortwave infrared domain (SWIR), and shows low values in the vegetation index (NDVI), as well as a high average overall reflectivity (ALB) and low perviousness (or high imperviousness) features(SVI). The cascade fashion decision-making in the classification tree described above finally leads to labelling a pixel showing these particular spectral features in class 3.1 (Bright Industrial). In the 1989 case of urban area mapping, "Bright Industrial" areas are characterized by values of SWIR > 0.1, NDVI <0.4, ALB <0.25 and SVI <0.275.

The classified maps of Occupied/Non-Occupied terrain coming from this first processing step were refined by using majority analysis filtering so as to clean up small groups of incorrectly-labelled pixels and produce the "FILTERED Urban Map".

The filtered data were then post-processed with a cascade application of refinement masks, in order to improve the accuracy of the final product, through steps 2 and 3 described in Figure 2. Therefore, a first improvement was made with the adoption of a mask covering (vegetated and non-vegetated) agricultural fields as a result of image segmentation and object-based classification of agricultural features [Willauck, 2000]. Agricultural areas, and especially non-vegetated fields, are in fact sometimes confused by the high albedo response from artificial surfaces, when using mid resolution data with insufficient spectral richness at a pixel based level. An object-based approach on the other hand, can exploit shape and size features and, in this way, better identify patches of agricultural land cover. Therefore, the remote sensing data were first segmented into objects characterized by homogeneous spectral response and contextual consistency, and these objects were then classified as agricultural fields on the basis of their NDVI (vegetated fields) and SVI (non-vegetated fields) response. The application of this object-oriented derived mask, covering agricultural features, to the "FILTERED Urban Map" produces a final automatic mapping product of Occupied/Non-Occupied terrain in area of the Province of Milan, which is called the

"AGRI_MASKED Urban Map".

The final phase of mapping refinement was carried out through photo-interpretation of satellite data with hybrid utilization of a vector land-use database (DUSAF2000) drawn from aerial orthophotos acquired in 1998-99 and expert knowledge. In this way the "FINAL Urban Map" was obtained using a semi-automatic approach as a consequence of the aforementioned automatic mapping and including a final expert refinement.

The results of these post-processing operations are the final Soil sealing maps ("FINAL Urban Map" products) for the years 1989, 1998 and 2008, as shown in Figure 4.

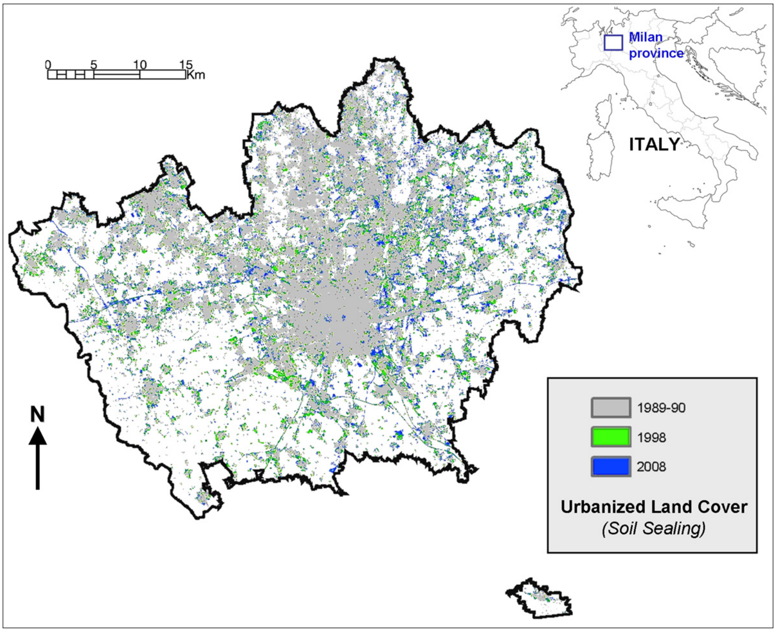


Figure 4 - Multitemporal overlay of Occupied/Non-Occupied terrain map for the Province of Milan: urbanized land cover for 1989-90 (grey), for 1998 (green) and for 2008 (blue). The detached municipality south-east of the main provincial area is San Colombano al Lambro village, part of the Province of Milan.

Results and discussion

The main outcome of the mapping methodology illustrated in the previous section was the production of "Urban Maps" showing Occupied/Non-Occupied terrain status for the area of the Province of Milan referring to the years of 1989, 1998 and 2008. These results can also be used to map the evolution of urbanization across the last 20 years, as is shown in Figure 4. From these results, the measured extension of urban and built-up areas in the Province of Milan grew from 563.03 km2 (28.4% of the whole province) in 1989, to 610.95 km^2 (30.8% of the whole province) in 1998, and reached 761.34 km^2 (38.4% of the whole province) in 2008. As a consequence, the built up areas showed a relative growth of +8.5% from 1989 to 1998 and a notable +24.6% from 1998 to 2008, thus confirming the huge pressure exerted on the Province of Milan by urban sprawl over the last 20 years.

Each single final map was validated through photo-interpretation of the original, full-resolution satellite data [Congalton, 1991]. Starting from a stratified random sample of 352 pixels, the accuracy was calculated for the binary Occupied/Non-Occupied terrain maps as regards the products which were derived using solely automatic means (FILTERED and AGRI_MASKED Urban Maps) as well as for the semi-automatic photo-interpretation refined maps (FINAL Urban Maps). The accuracy evaluation results are described in Table 3.

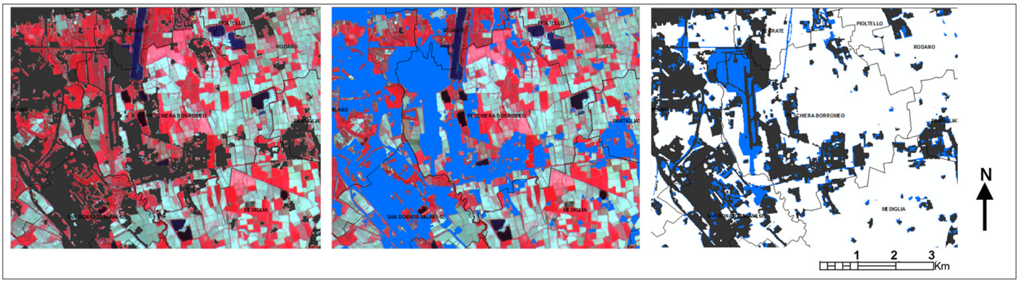
Overall accuracy ranges from 87.78% (2008) to 94.60% (1989) for maps obtained by using solely automatic techniques, whereas accuracy of final maps, with expert photo-interpretation refining, peaks at between 93.18% (2008) and 94.89% (1989). The discrepancy between the levels of accuracy for the 1989 maps and the 1998 and 2008 maps is mainly due to the seasonal differences in satellite data acquisition (summer for 1989, spring for 1998 and 2008), which strongly affect agricultural and vegetated land covers distribution and separability between its features and artificial surfaces ones. These effects are also present in the SPOT maps whereas the 1998 urban area map seems to slightly underestimate the extent of Occupied terrain and the 2008 map seems to slightly overestimate it; this fact is associated with greater vegetation vigour found in the 1998 data, that were acquired in mid-May, as opposed to the 2008 data, that were acquired in early April. However, the validation results show that the method can provide correct and reliable maps with a very satisfactory level of accuracy.

Table 3 - Accuracy statistics for urban area maps, both automatically derived (FILTERED, AGRI_MASKED product) and expert refined (FINAL product).

	Product Map	Overall Accuracy	Kappa Coefficient	User's Accuracy (Occupied)	User's Accuracy (Non-Occupied)
1989	*Urban Map 1989_FILTERED (automatic)*	94.60%	0.874	91.28%	96.08%
	Urban Map 1989_FINAL (semi-automatic)	94.89%	0.879	94.17%	95.18%
1998	*Urban Map 1998_AGRI_MASKED (automatic)*	88.49%	0.734	76.95%	95.09%
	Urban Map 1998_FINAL (semi-automatic)	93.89%	0.858	89.29%	96.04%
2008	*Urban Map 2008_AGRI_MASKED (automatic)*	87.78%	0.743	82.14%	91.51%
	Urban Map 2008_FINAL (semi-automatic)	93.18%	0.855	90.67%	94.72%

In order to better analyze and understand why some results match and why others differ, the Occupied terrain derived from the 1998 SPOT data and from the DUSAF2000 were also compared with regard to their spatial accordance. The DUSAF2000 vector data were rasterized with a cell size of 20m and all the land cover/land use classes related to built-up features and soil sealing were grouped together as Occupied terrain, which was eventually compared to satellite-derived urban area maps for the year 1998. The tested agreement over the entire Province of Milan was verified at 82%.

The satellite derived map presents an omission error of 18% and a commission error of 9% with respect to urbanized areas identified on DUSAF2000. The omission errors are concentrated over some specific land use classes, such as the areas covered by the airports of Linate (Fig. 5) and Bresso, where the differences in thematic concept between occupied terrain as seen by satellite and urbanized areas considered by land use cartographic products (such as DUSAF2000) are more evident. These differences are the result of the intrinsic differences between the two products: DUSAF2000 in fact is a land use map, while urban maps derived from satellite data describe land cover only.



a) b) c)

Figure 5 - Comaprison between SPOT satellite data processing for the year 1998 and thematic map derived from DUSAF2000 product: overlay of urban mapped,black (a), overlay of DUSAF2000 urban area, blue, (b) on CIR composition of SPOT and overlay of the two products (c).

Finally, a comparison was made between the remote sensing derived Urban Maps and the existing vector land use and planning cartography data, by calculating Occupied terrain areas at a local level in every municipality in the Province of Milan. In particular, the 1998 results were compared with the DUSAF2000 data land use polygons, and the 2008 results were compared to MISURC08 data. In order to interpret the Occupied Terrain depicted by DUSAF2000 and MISURC08, it was necessary to take appropriate decisions regarding the interpretation of the original legends. Moreover, in order to better understand the results in areas which are not highly and densely populated, the data relating to the two largest cities of Milan (about 12000 ha) and Monza (around 2000 ha) were excluded from the comparison. These two municipalities could bias the evaluation of results adopting a regression analysis approach.

The results (Fig. 6) show the good accordance of the remotely-sensed derived maps with the cartographic products available (R^2>0.96), thus confirming the positive nature of the proposed methodology and the results emerging from this study. Despite the satisfactory level of accuracy obtained, the maps produced contain residual and intrinsic errors due to spatial resolution and seasonal variability within the dataset. The strong heterogeneity of the urban texture in the Province of Milan area raises various issues related to mixed pixel interpretation when using automatic approaches [Hsieh et al., 2001], and the fragmentation and variety of agricultural areas cause some confusion and overlapping with certain artificial surface features, preventing higher accuracy success rates in the maps that are produced.

The study shows that results are influenced by the period in which the satellite data are acquired. Data from the height of summer minimizes the confusion between bare soil and certain artificial targets. From this point of view, these results provide information layers that are more suitable for provincial scale studies rather than for application at a local and municipal level.

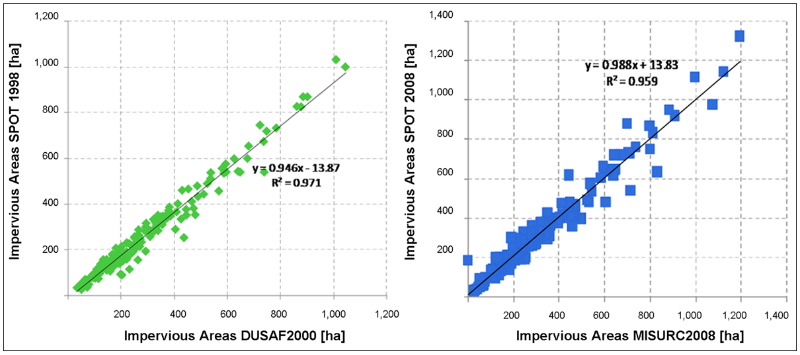


Figure 6 - Urban area mapping comparison between remotely sensed results of this study and land use and planning thematic databases at municipality level (urbanized area covering municipality total area): accordance between 1998 satellite derived results and DUSAF2000 (left graph, green color) and accordance between 2008 satellite derived results and MISURC08 (right graph, blue color).

The method as described above allows urbanisation map (occupied/non occupied) to be produced in a cost-efficient and reliable way. This approach could be used for making rapid updates of the artificial surface layer that is suitable for monitoring soil sealing at frequent time intervals. These maps can be used appropriately to derive synoptic urbanisation change and evolution maps (see Fig. 7), that can assist users in Public Administration when conducting planning studies.

As an example of this, it is possible to simply highlight the degree of increment in occupied terrain at a provincial level by re-sampling urban area differences over 1 km cell scales, in Figure 7 a view of the 1989-2008 analysis is provided. This higher level of information provided by analysing the multi-temporal results can provide the Public Administration with a tool for analysing the dynamics of land occupation, thus highlighting critical situations on which the Authorities can focus its future actions. These results show an overview of the remote sensing monitoring capabilities, when integrated with traditional cartographic tools, to support urban planning.

Conclusions

This work has presented an application of mid-resolution, remote sensing data and techniques for urban area evolution study, producing a multi-temporal set of Occupied/Non-Occupied terrain maps derived from multi-source data (SPOT4 HRVIR and Landsat5 TM), for the years 1989, 1998 and 2008.

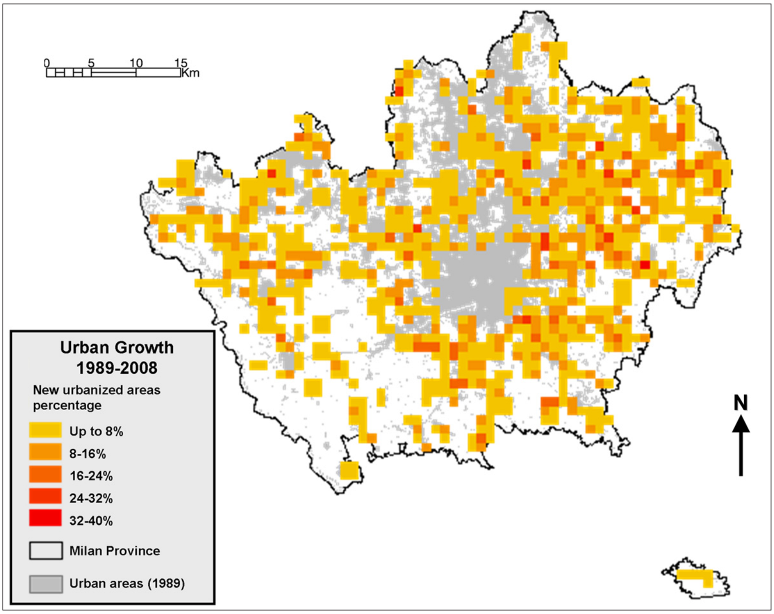


Figure 7 - Map of urban area percentage increment over 1km resolution cells in the area covered by the Province of Milan, derived from occupied terrain differences between 1989 and 2008 satellite derived maps.

The aims of such a discussion are twofold: firstly, to demonstrate the usefulness of satellite, remotely-sensed data when mapping soil-sealing dynamics at a local to regional scale, and secondly, to describe the role and capabilities of the methodology as a provider of integrated land services for Public Administrations within the framework of the GMES initiative.

The semi-automatic methodology used for mapping as described above, achieved an accuracy which is in line with the best practices highlighted in literature on urban remote sensing techniques which use mid-resolution data. The overall, average mapping errors were assessed to be lower than 13% for the automatically produced maps and lower than 7% for the expert interpretation refined products.

The results show that periodical use of mid-resolution satellite data can be an effective approach for fast and cost-efficient urban area, soil sealing monitoring on a provincial scale, which can be used in conjunction with traditional monitoring and mapping tools such as digital thematic cartography and GIS systems. For the development of an integrated monitoring system, it is important, however, to consider some of the difficulties encountered in this study, mainly concerning the type and characteristics of the satellite data used: the season of the satellite data (non-agricultural vegetated land, acquisition times), the type of data (spatial resolution, spectral type) and the processing time. Some further investigation and extension of the study should be possible with the utilization of different satellite data. Multi-date annual images acquired in different vegetation seasons (one in winter, one in summer and one in spring) for every year, could be used with the aim of reducing confusion between artificial features and non-vegetated agricultural fields, while integration of higher resolution images should guarantee a more detailed analysis of urban texture.

It is important to remember that the new GMES Sentinel 2 mission [ESA, 2011] will, in the coming years, provide Europe with free of charge optical data at 10-20 m resolution with a revisiting cycle, of about one week. This new opportunity will reinforce the usability of EO data for updating urban land cover, allowing more frequent multi-temporal analysis capabilities. By using future Sentinel 2 data, both the methodological framework as described and the accuracy of the final urban mapping products could be enhanced. In this perspective, an EO data acquisition system of this kind may be seen as a fundamental tool for regional to local scale application, both in Europe and beyond.

In conclusion, this work has given a detailed and reliable overview of mid-resolution mapping capabilities in urban areas, as well as its perspective in terms of future utilization of a remote sensing synoptic approach, exploiting multi-spectral and multi-temporal data to map urban environmental issues.

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