AN AUTOMATED METHODOLOGY FOR CONVERTING OSM DATA INTO A LAND USE/COVER MAP

Cidália Fonte[(1,2)], Marco Minghini[(3)], Vyron Antoniou[(4)], Linda See[(5)], Joaquim Patriarca[(2)], Maria Antonia Brovelli[(3)], Grega Milcinski[(6)]

[(1)] Dep. of Mathematics, University of Coimbra, Apartado 3008, EC Santa Cruz, 3001 – 501 Coimbra, Portugal, Tel. +351 239791150

[(2)] INESC Coimbra, Rua Sílvio Lima, Pólo II, 3030-290 Coimbra, Portugal, Tel. +351 239796327

[(3)] Politecnico di Milano, Department of Civil and Environment Engineering, Como Campus, Via Valleggio 11, 22100 Como, Italy, Tel: +39 0313327336

[(4)] Hellenic Army Academy, Leof. Varis-Koropiou, 16673, Greece, Tel: +30 210 8206680

[(5)] Ecosystems Services and Management Program, International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, Laxenburg, A-2361 Austria, Tel: +43 2236 807 423

[(6)] Sinergise, Cvetkova ulica 29, SI-1000 Ljubljana, Slovenia, Tel: +386 1 320 6150

Abstract
Land Use/Land Cover Maps (LULCM), fundamental for many areas of application, are usually generated through the classification of satellite imagery. However, their creation is time consuming and therefore updated LULCM are seldom available. The OpenStreetMap (OSM) collaborative project collects a rich set of vector data provided by volunteers at a global scale. It has already been shown that OSM data may be converted into LULCM, but data quality issues in OSM raise some challenges for this conversion, such as overlapping features that should be assigned to different classes. Thus, the creation of LULCM using OSM requires a solution for handling these inconsistencies. In this article an automated methodology is proposed using rules of decision and spatial analysis in a GIS environment to convert OSM features into LULCM, which automatically solves the inconsistencies mentioned above. The methodology is applied to two areas in Europe and the results are compared to available LULCM.

INTRODUCTION

Land Use and Land Cover Maps (LULCM) are fundamental inputs to many areas of application, e.g. climate modelling and natural resource management among many others (Jones, 2008). These maps are usually generated through the classification of satellite imagery and their creation is time consuming. The update cycles of LULCM are also often long, e.g. CORINE Land Cover (CLC) is updated irregularly, with three years between the two most current products. This is insufficient for environments that are subject to rapid environmental change. More recently, researchers have been investigating the use of OpenStreetMap (OSM) as a source of LULC information, both to create and validate different products (Estima and Painho, 2015; Jokar Arsanjani et al., 2015a; Martinho and Fonte, 2015) particularly as the data are updated on a daily basis. OSM is one of the most well studied collaborative mapping projects and undoubtedly the most well-known Volunteered Geographical Information (VGI) initiative (Jokar Arsanjani et al., 2015b). The overall aim is to collect vector data provided by volunteers that enables the creation of a map at a global scale. The flexibility of use, data availability, free access to the latest information on a daily basis, the large number of contributions and users of the data, and the existence of data not traditionally available in other types of more authoritative map databases makes OSM a valuable source of information for several applications, e.g. navigation (Codescu et al., 2011) and disaster response (Zook et al., 2010; Soden and Palen, 2014).

It has already been shown that OSM data may be converted into Land Use/Land Cover classes (LUCC) such as those in the CLC and the Global Monitoring for Environment and Security Urban Atlas (UA), enabling the conversion of OSM into a LULCM with these nomenclatures (Jokar Arsanjani et al., 2013; Jokar Arsanjani and Vaz, 2015; Jokar Arsanjani et al., 2015a; Estima and Painho, 2015; Martinho and Fonte, 2015). For example, Jokar Arsanjani et al. (2013) converted OSM for Vienna into UA classes and then compared the OSM LULCM map with UA, resulting in 81% agreement. This work was extended to other cities in Germany (Jokar Arsanjani et al., 2015a) and across Europe (Jokar

Arsanjani and Vaz, 2015), with the resulting agreement for different cities varying between 53.6% and 86.2%. Good results were also found in validating the UA (Martinho and Fonte, 2015) and CLC (Estima and Painho, 2015) with OSM data. However, a common challenge was encountered in all of these studies, which was related to the conversion of OSM data into a LULCM. For example, there are frequently overlapping features providing information that should be assigned to different classes so there are issues related to the harmonization of LUCC from LULCM (e.g. CLC and UA) and the variety of features that are found in OSM. There are other issues related to positional accuracy, which results in partial overlapping of features that are inconsistent. Thus, the creation of a LULCM using OSM data requires a solution for dealing with these inconsistencies and class harmonization.

In this paper an automated methodology is presented for converting OSM features into a LULCM that solves some of the aforementioned types of inconsistencies using a hierarchical approach, a set of decision rules and spatial analysis operations in a GIS environment. The procedure is implemented in a fully open source environment using GRASS GIS, GDAL/OGR Python bindings and PostgreSQL/PostGIS database. The methodology is applied to two regions within parts of Milan and Paris, and the results are compared to available LULCM with different levels of detail.

MATERIALS AND METHODS

OSM data

The whole OSM database is licensed under the Open Database License (ODbL), which allows everyone to share, create and adapt the database for any purpose provided that attribution is made to OSM contributors. Currently there are many ways to download OSM data, e.g. using the "Export" button from the main OSM website (https://www.openstreetmap.org); using the Overpass API (http://wiki.openstreetmap.org/wiki/Overpass_API), for example through the Overpass Turbo frontend (http://overpass-turbo.eu); downloading the OSM Planet file (http://planet.openstreetmap.org), which is a complete, regularly-updated copy of the whole OSM database; using the data extracts for continents and countries provided by GeoFabrik (http://download.geofabrik.de) or for cities provided by Mapzen (https://mapzen.com/data/metro-extracts).

The OSM database is a collection of vector data objects that consist of point features (known as nodes), line and polygon features (both known as ways). Each object must have at least one attribute associated with it. OSM attributes are known as tags, where a tag is the combination of a key and a value: for example, a motorway is tagged in OSM as "highway=motorway", where "highway" is the key and "motorway" is its value. Additional (optional) tags can further characterize the motorway, e.g. detailing its width, number of lanes, maximum speed, etc. The contributers may use the tags listed in http://wiki.openstreetmap.org/wiki/Map_Features or add new values.

LULC nomenclature

In this study the nomenclature adopted by UA is used. This nomenclature is organized into three levels, shown in Table 1. Only LULCM corresponding to levels one and two were created, but as level two classes are formed by aggregating level three classes, these were also used during the process.

Methodology

The methodology used to convert OSM features into a LULCM consists of a sequence of steps that transform OSM features into the LUCC of levels one and two of the UA nomenclature. The transformation is done by considering any data in OSM that might be associated with classes in all three levels of the UA nomenclature. In this study only the linear features corresponding to the keys "highway", "railway" and "waterway" were used, as well as the polygon features with keys "building", "landuse" and "natural".

The linear features in OSM need to be converted into polygons to be included in the LULCM. This process requires the identification of their width. In most cases this must be estimated because the width of the features ("width" key) is not directly available in OSM, as providing a value for this key is optional.

The main steps of the methodology are:

1. Identification of the value of the keys available in the OSM data to be processed.

2. Conversion of the linear features into areas using spatial analysis and merging them with areas in the polygon features that have values of predefined keys that correspond to the themes of the linear features.

3. Conversion of the polygonal features to the LUCC using the value of the keys.

4. Convert the map into the appropriate Minimum Mapping Unit (MMU), merging small features with their neighboring features.

In the following subsections, additional details are provided about the conversion process.

Table 1. UA nomenclature

Level 1	Level 2	Level 3
1.Artificial Surfaces	1.1 Urban Fabric	1.1.1 Continuous urban fabric 1.1.2 Discontinuous urban fabric 1.1.3 Isolated Structures
	1.2 Industrial, commercial, public, military, private and transport units	1.2.1 Industrial, commercial, public, military and private units 1.2.2 Road and rail network and associated land 1.2.3 Port areas 1.2.4 Airports
	1.3 Mine, dump and construction sites	1.3.1 Mineral extraction and dump sites 1.3.3 Construction sites 1.3.4 Land without current use
	1.4 Artificial non-agricultural vegetated areas	1.4.1 Green urban areas 1.4.2 Sports and leisure facilities
2. Agricultural, semi-natural areas, wetlands		
3. Forests		
5. Water		

Roads (included in class 1.2)

Data about roads are available in OSM as linear features, with the key "highway". As the width of the roads is usually not provided by the volunteers, estimation may be done using information about their type, indicated as the value of the "highway" key (which is the only mandatory tag for a road), such as, for example, primary or secondary. However, even this does not provide a consistent way to estimate road widths for the entire OSM dataset, as this value may vary greatly for different roads. In urban areas, the roads are, in most cases, bounded by buildings, so the polygons with the building key will be used to estimate the road width. The processing steps to obtain the areas occupied by roads are:

1. From the values available for the "highway" key, choose the values to be considered for the conversion into LUCC (e.g. primary, secondary, residential).

2. Identify a maximum and a typical width for each road type in the region of interest (typically larger for primary roads and smaller for other less important roads). Predefined default values may also be considered.

3. The individual segments forming the linear features are identified. The distance between each segment and the buildings that are present within the maximum width of the roads defined in 2 is then computed, and the minimum value is stored.

4. An area feature will be generated for each road segment where the distance to buildings is larger than zero, using the width to generate a buffer. For those segments where the distance to buildings was not obtained, the typical width chosen in point 1 is applied.

5. The buffers created in the previous step are merged and dissolved.

6. If there is any overlap between the buildings and roads resulting from the buffering process (typically at the ends of the road segments), priority is given to the buildings, and the common regions are extracted from the road areas.

Railways (included in class 1.2)

The railways and associated land were obtained using the linear elements associated with the values of the "railway" key (such as "rail", "disused" or "platform") and the polygon features with the key "landuse" with values that correspond to "railway". The processing steps to obtain these regions are:

1. The typical width of the railways in the study is chosen.

2. Buffers around the linear features are created using the value chosen in the previous step.

3. The regions obtained in 2 are merged with the polygons with the value "railway" of the "landuse" key and dissolved, elimininating overlapping features that correspond to the same class.

Water (class 5.0)

The water regions are obtained from the linear features with key "waterways" that have values such as "river", "stream" or "ditch", and from the polygonal features with the key "landuse" with values that correspond to water regions, such as "riverbank" or "water". The preccessing steps are:

1. The typical width of the waterways in the region of interest is chosen according to the key value (typically dependent on the type of waterway, such as, for example, "stream" or "river").

2. Buffers around the linear features are created using the value chosen in the previous step.

3. The regions obtained in 2 are merged with the polygons of the "landuse" key that correspond to water regions and are then dissolved to eliminate overlapping features with the same LUCC.

Industrial, commercial, public, military, private and transport units (class 1.2)

This class (see Table 1) includes the roads and railways, as well as commercial, industrial, public and military areas. Therefore, it is obtained with the following steps:

1. Identification of the values of the "landuse" key that correspond to the features in this class, such as, for example, "industrial", "commercial", "retail" or "cemetery".

2. Merge the features obtained in the previous step with the roads and railway features created above, and dissolve the resulting features to eliminate overlapping regions corresponding ot the same LUCC.

Urban Fabric (class 1.1)

This class corresponds to urban areas that are mainly residential structures (see Table 1). Therefore, they are obtained considering polygons of the "landuse" key that have values corresponding to this type of region, merging them with the building polygons that do not have key values, assigning them specifically to other classes, such as industrial or commercial. The obtained regions are dissolved.

Mine, dump and construction sites (class 1.3)

This class is generated by extracting the OSM polygons with a "landuse" key that have values equal to, for example, "construction", "landfill" and "quarry".

Artificial non-agricultural vegetated areas (class 1.4)

This class is obtained from the data with the "landuse" and "natural" keys. The appropriate values found in the study areas should be identified. Examples of appropriate values for "landuse" are "flowers", "recreation ground" or "plants" and for "natural" are "park" or "forest", but these latter ones are typically only for small areas. The selected features are merged and dissolved.

Agricultural semi-natural areas, wetlands (class 2.0)

This class is generated by extracting the OSM polygons with a "landuse" key and values that can be assigned to agricultural semi-natural areas or wetlands, such as "farm", "allotments" or "orchard".

Forests (class 3.0)

The Forest areas correspond to the OSM polygons with the key "natural" with values equal to "forest". However, as there may be regions classified as forest by the volunteers that have very small areas and correspond just to small groups of trees, only polygons with a minimum area should be considered for addition to the class Forest.

Solving remaining inconsistencies

Even though some types of inconsistencies have already been removed in the process described in the previous subsections, overlapping features assigned to different classes may still exist. In the present work these inconsistencies were removed by considering a hierarchy of feature importance, which is shown in Table 2 for level 2 classes; in the case of overlap, priority is given to the classes occupying the highest level in the list. This list was created by analysing the types of commonly occurring overlaps and was then ordered by taking the elements of the landscape that are more important in the organization of space (such as roads and water lines) into account; the most frequent ordering of the overlapping elements in reality (for example, roads are usually found over water and not the inverse); the typical relative size of objects in the regions under analysis; the importance of the features; and the most common topological relations (for example, an agricultural region may contain buildings but buildings do not contain agricultural regions). For level 1 classes, class 1 (Artificial Surfaces) was considered a priority and the other classes were ordered as for level 2 classes. Once this hierarchy is applied, no overlapping classes exist in the output.

Table 2. Priority associated with classes when overlapping regions with different classes exist

Level of priority	UA Class (level 2)	Class Description
1	1.2	Industrial, commercial, public, military, private and transport units
2	5.0	Water
3	1.4	Artificial non-agricultural vegetated areas
4	1.3	Mine, dump and construction sites
5	1.1	Urban Fabric
6	2.0	Agricultural, semi-natural areas, wetlands
7	3.0	Forests

CASE STUDIES

Datasets

Two study areas were selected, each being a square of 10 km on one side for a total area of 100 km^2, in regions with different characteristics (Figure 1). One of the areas is located in France, approximately 60 km northwest of Paris, in a region with low density of urban areas and predominance of agriculture and forest regions. The other region is extracted very close to the center of Milan (Italy), in a highly heterogeneous region, which includes a very dense urban area (with a motorway and some large railway stations) together with small agricultural and rural areas, parks and a cemetery. The corresponding OSM datasets were downloaded from Geofabrik on the 19th of April 2016 in shapefile format. The OSM polygon features having the keys "buildings", "landuse" and "natural areas" were used, as well as the OSM linear features having keys equal to "railways", "higways" and "waterways". Table 3 shows the main values of keys used in both study areas and the UA level 2 classes to which they were associated. Level 1 classes where obtained by aggregating level 2 classes (see Table 1).
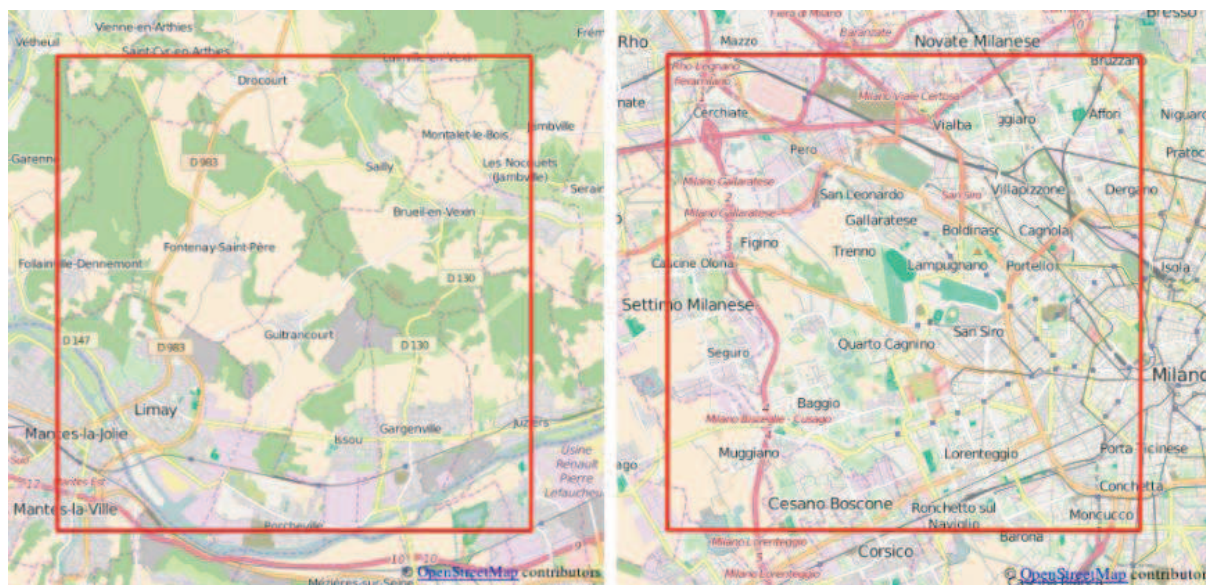
Figure 1. Left: Study area in the region of Paris (France); Right: Study area in the region of Milan (Italy)

Table 3. The main value of the keys used in the case studies and the UA class to which they were assigned

Key	Key values	UA class
highway (line)	primary, secondary, living_street, primary_link, residential, road, secondary_link, tertiary, tertiary_link, unclassified, service, pedestrian, motorway, motorway_link, trunk, trunk_link	1.2
railway (line)	rail	1.2
waterway (line)	river, stream	5.0
landuse (polygon)	residential	1.1
	cemetery, commercial, industrial, railway, retail	1.2
	brownfield, construction, depot, landfill, quarry, scrub	1.3
	beer-garden, flowers, grass, greenfield, meadow, plants, recreation_ground, recreational_area, recreational, village_green	1.4
	allotments, farm, farm land, greenhouse-horticulture, meadow, orchard, vineyard	2.0
	reservoir, pond	5.0
natural (polygon)	forest (if area <10 000m^2), park	1.4
	forest (if area >10 000m^2)	3.0
	riverbank, water	5.0
buildings (polygon)	apartments, house, garage, garages, residential, yes, "null"	1.1
	church, commercial, industrial, public, retail, school	1.2

Results

The results obtained with the conversion are shown in Figures 2 and 3, respectively for the Paris and Milan areas.
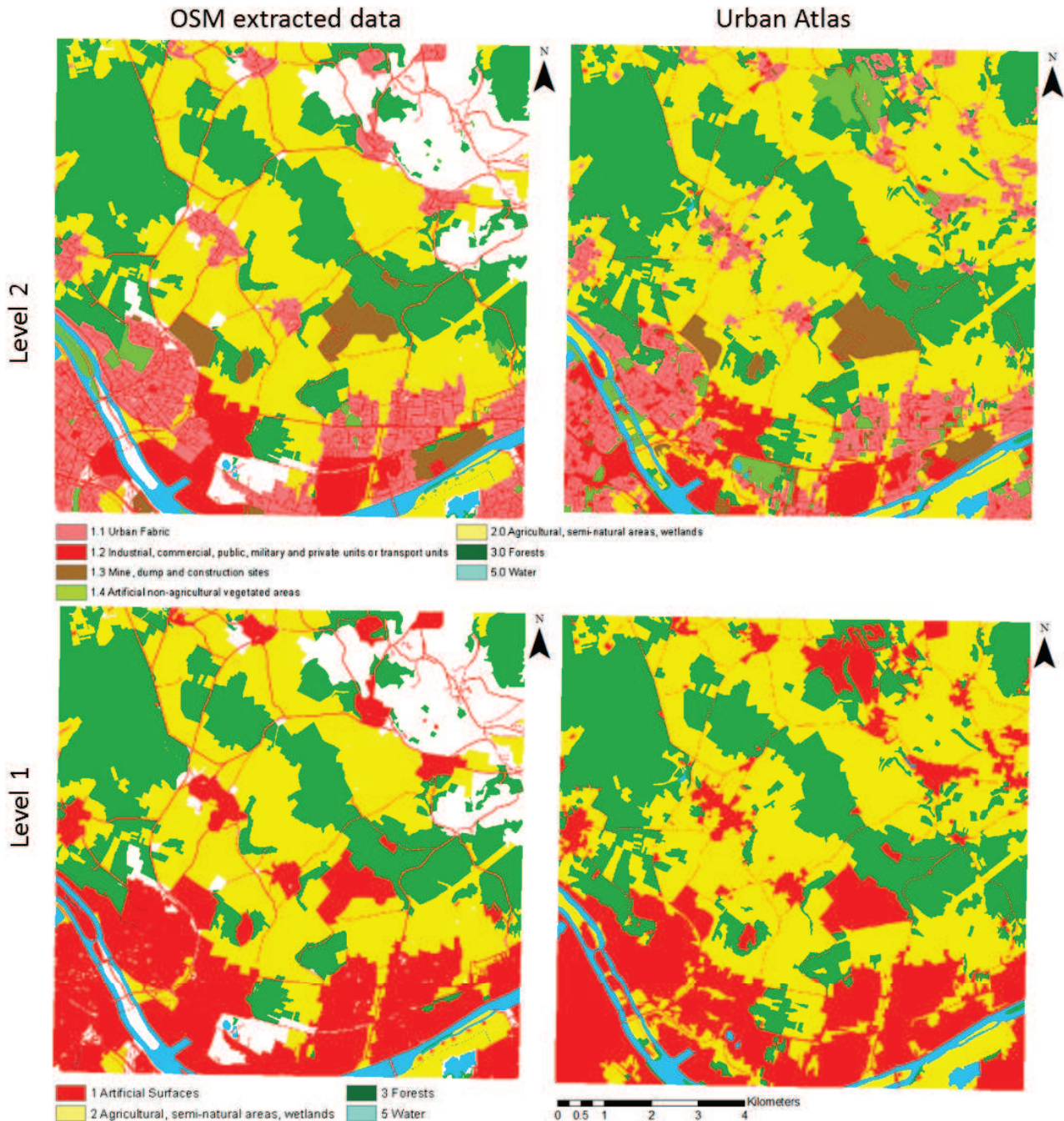

Figure 2. Results for the Paris study area. On the left results obtained from OSM for levels 1 and 2. On the right UA for levels 1 and 2 classes.

The results show that in both study areas there are regions with no data in OSM, but larger regions with no data were found in Milan. A more detailed analysis of the shapefiles downloaded from Geofabrik showed that, on one hand, they do not contain all of the data available in OSM, which are available when using, for example, the data downloaded from OSM Planet. On the other hand, some features are missing because they are assigned to tags not considered in this case. One example of this are some hippodromes located in the region of Milan, which are associated to the value "track" of the "leisure" key. The results obtained for level 1 classes is very good for the Paris region. For Milan, if the regions with no data are not considered, a good correspondence is also obtained.
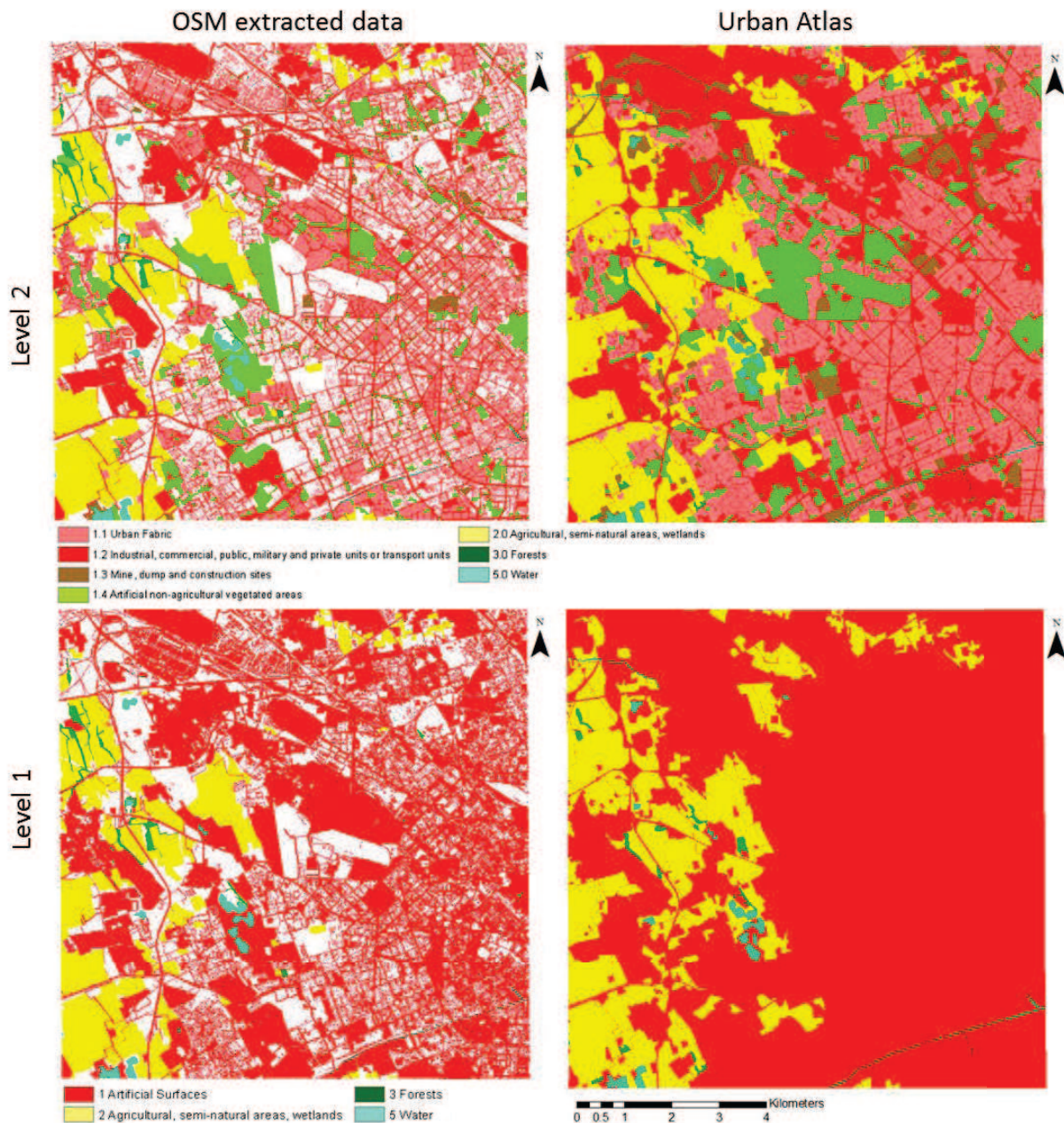
Figure 3. Results for the Milan study area. On the left results obtained from OSM for levels 1 and 2. On the right UA for levels 1 and 2 classes.

Discussion and Conclusions

Overall the results obtained through the automated processing can be considered satisfactory, even though they present a number of problems: 1) In some locations large regions with no data in OSM can exist, resulting in empty regions in the LULCM. In the presented case studies, shapefiles downloaded from Geofabrik were used, but as some of the data available in OSM were found to be missing in the shapefiles, the use of the original OSM files may reduce this problem. 2) As the volunteers can use values for the keys that are not listed in the OSM Map Features, all possible values used needs to be identified for each study area, as they may vary with location and over time. However, as the majority of values used by the volunteers belong to the predefined list, this limitation will not be a significant restriction in most regions. 3) The conversion of the linear features to areas requires the estimation of the width of these features, as this value is usually not available. The use of the distances to the buildings in the urban areas provided good results, but predefined values still need to be used for the cases where the roads are not bounded by buildings, and also for the railways and waterways.

Substantial work is still needed to further improve the procedure. For instance, additional rules are being created to decrease the importance of the predefined width values that are necessary for the conversion of the linear to area features. As the conversion process currently considers only a small subset of both the existing OSM objects (although the most important in terms of LULC classes are already used) and the existing tags. Only a small number of keys were taken into account as well as a small number of values for these keys. Future work will attempt to generalize the applicability of the procedure by including a larger number of tags that may be important for LULC classification. For example, the "surface" key identifies the physical surface of a road and can be important to ascertain if a road lies in an urban area (value equal e.g. to "asphalt" or "paved") or in a rural area (value equal e.g. to "ground" or "unpaved"); similarly, the tag "layer=-1" can be used to automatically discard a river or road that lies underground. Also tags such as "amenity", "emergency" or "leisure" will provide relevant information that may be usefull to, for example, differentiate commercial or public areas for residencial regions. Different languages also need to be considered in building a future rulebase so that LULCM can be created globally.

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BIOGRAPHY

Dr. Cidália C. Fonte has a PhD in Geomatic Engineering and is an Assistant Professor at the Department of Mathematics - Faculty of Sciences and Technology - University of Coimbra, Portugal, and a researcher and member of the board of directors of the Institute for Systems Engineering and Computers at Coimbra. Her main research interests are quality assessment of geographic information and uncertainty modelling, with applications in the areas of remote sensing, GIS and collection and use of Volunteered Geographic Information. She currently chairs Working Group 4 of the EU COST Action TD1202 "Mapping and the Citizen Sensor".
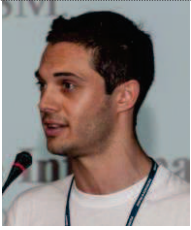
Dr. Marco Minghini has studied at Politecnico di Milano, where he obtained a BSc degree in Environmental and Land Planning Engineering with honors in 2008 and a MSc degree in Geomatics with honors in 2010. In 2014 he obtained his PhD with merit in Environmental and Infrastructures Engineering with a thesis on the use of open source software for VGI and citizen science applications. Since 2014, he is a postdoctoral research fellow at the GEOlab of Politecnico di Milano - Como Campus. Driven by the use of open source software, his current research focuses on geoWeb services and geoWeb applications, citizen science and VGI. He is member of EU COST Actions TD1202 "Mapping and the Citizen Sensor" and IC1203 "ENERGIC", a volunteer for the Humanitarian OpenStreetMap Team (HOT), a Charter Member of the Open Source Geospatial Foundation (OSGeo) and a member of the Italian Society of Photogrammetry and Topography (SIFET).

Dr Vyron Antoniou is an Army Officer serving in the Hellenic Military Geographical Service. He has served as head of the Remote Sensing & Photogrammetry Branch and as head of the Cartograph Branch. He has studied Surveying and Rural Engineering at NTUA (Greece) graduating first among his peers. He also holds an MSc in Geoinformation from NTUA. In 2011 he was awarded a PhD from UCL (UK) in Geomatics. His research focused on the analysis of the phenomenon of user generated spatial content and its challenges for mapping agencies. Research was made on the quality of VGI datasets, the behavior of the users and the spatial dimension of the phenomenon. His research interests are in GIS, spatial databases, spatial analysis, Web mapping applications, VGI, spatial data quality, OGC specifications, ISO standards, XML technologies and Web 2.0 technologies. He is also a Lecturer at the Hellenic Army Academy.
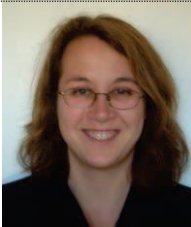
Dr. Linda See is a Research Scholar in the Ecosystems Services and Management Program at the International Institute for Applied Systems Analysis in Laxenburg Austria. She was awarded a PhD in spatial applications of fuzzy logic from University of Leeds in 1999, where she was a Senior Lecturer in Computational Geography and GIS for more than a decade. She spent one year at the Max Planck Institute for Atmospheric Sciences in Germany followed by four years at the Food and Agriculture Organization in Rome, working in agrometeorology and early warning for food security. She is an active member of the Geo-Wiki team and has worked on a number of crowdsourcing aspects including quality issues, community building, and a branch of Geo-Wiki concerned with validation of urban land cover. She currently chairs Working Group 1 of the EU COST Action TD1202 "Mapping and the Citizen Sensor".

Degree with honors in Physics, PhD in Geodesy. **Maria Brovelli** is currently Full Professor of GIS at Politecnico di Milano. From 2006 to 2011 she lectured GIS at the ETH – Zurich. From 2001 to 2011 she was the head of the Geomatics Laboratory of the Politecnico di Milano. Since 2011 she is Vice Rector for the Como Campus of Politecnico di Milano. Co-chair of ISPRS WG IV/5 "Web and Cloud Based Geospatial Services and Applications"; Charter Member of OSGeo; Member of the Advisory Board of the ICA-OSGeo- ISPRS Labs Network (GeoForAll) and the Italian SIFET, Co-Chair of GeoForAll Europe and Geocrowdsourcing/ Citizen Science, Co-organizer of the NASA WW Europe Challenge; Conference chair of FOSS4G Europe 2015. In 2015 she was honored with the 2015 Sol Katz Award for Geospatial Free and Open Source Software.

Joaquim Patriarca has a Master Degree in Geographic Information Technologies and is a Non-PhD Researcher at the Institute for Systems Engineering and Computers at Coimbra, Portugal. His main research interests are: construction and implementation of algorithms to solve spatial problems; GIS software testing; technology adoption at organizations; network analysis; risk assessment.

Grega Milčinski, a co-founder and CEO of Sinergise, has been leading software development teams for more than 15 years, out of these more than 12 years in the field of land use and agriculture. He held roles of consultant, project manager, business analyst and architect of several land use/land cover systems in Europe (Slovenia, Croatia, Macedonia, France) and Africa (Nigeria). BSc. in Physics and additional general management programme education proved to be a good combination of problem solving and managerial skills. He authored and co-authored several papers in the field of IT, agriculture and land administration policy. He was part of the group, which established Geopedia, the first crowd-sourcing GIS platform.