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Satellite images and teaching of Geography

Javier Martínez-Vega[a], Marta Gallardo[b], Pilar Echavarría[a]

[a] Institute of Economics, Geography and Demography, Spanish National Research Council (IEGD-CSIC), Madrid, Spain

[b] Department of Geography, Concepción University, Concepción, Chile

Email: javier.martinez@cchs.csic.es

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Abstract

Satellite images can be very useful for teaching Geography at all levels. We describe their advantages over other traditional sources of information on observation of the Earth, and present the Remote Sensing and Environment teaching guide, a resource available on the Internet. This can be complemented by other resources – videos and image repositories – to facilitate the teaching of Geography. Two examples are given to illustrate how satellite images can be used in classrooms to explain urban processes. One is explained on a global scale. The other is a research study that uses a number of thematic maps based on satellite images to illustrate how land use has changed in the region of Madrid (Spain) over recent decades. Using a modeller based on neural networks, the land use scenario in the region of Madrid in 2025 is simulated. This graphic and cartographic material can be used by teachers to explain urban processes both globally and regionally. Processes that have already taken place can be discussed and related to environmental impacts. It is also possible to predict what might happen in the future if current trends continue. The aim is to involve students in order to increase their environmental awareness and encourage them to participate in the search for solutions to territorial problems.

Keywords: Satellite Images, Geography, Teaching Resources, Land Use and Land Cover Maps, Changes in Land Use, Future Scenarios

1. Introduction

Previous studies (Chicharro and Martínez-Vega, 1992; Martínez-Vega, 1997; Martínez-Vega et al., 2011) have discussed the usefulness of satellite images for teaching Geography, from the most basic levels to graduate and post-graduate levels.

These sources of geographical information offer a number of advantages over other more classic sources, including the following.

1. They give a global view so that phenomena affecting the whole planet can be appreciated (general circulation of the atmosphere, marine currents, ecosystem distribution), differentiating phenomena that are distributed latitudinally, following a pattern of zonality, from those that are influenced by factors that disrupt the zonality.

2. Multispectral and hyperspectral sensors provide information on regions that are not visible in the spectrum. It is thus possible to obtain global information on average ocean temperatures, helping to explain marine currents. It is also possible to map the burned areas because of the unequal spectral response in the wavelength near-infrared.
3. They allow for multi-scale observation of the territory, from local to global scale, because of different satellite orbits, observation heights, fields of vision and spatial resolution.
4. Data acquisition frequency allows multi-temporal observations. It is possible to monitor both dynamic processes that take place very fast on Earth, such as meteorological phenomena, and processes taking place over years such as deforestation and the shifting of the agricultural frontier.
5. Homogeneity of lighting conditions during the recording of images. Satellite images are recorded in a short time and, in the case of sun synchronous satellites, at a similar pass time, so that the acquisition conditions (time, height of the sun over the horizon, azimuth) are the same. This quality makes it easier to interpret satellite images than aerial photographs.
6. Other advantages include the digital format in which space information is usually recorded, making it easy to connect with other data in GIS (Geographical Information Systems). Also, this format makes it easier to receive images almost in real time, so that emergency managers can receive strategic information to mitigate the consequences of catastrophes caused by certain natural risks.

Many tutorials exist, but we shall stress only four.

The European Communities (1993) brought out a technical guide to the CORINE-Land Cover project. This produced, in a harmonised way, land use and land cover maps on a scale 1:100,000, with a common hierarchical legend based on the visual interpretation of Landsat or Spot images. The second part of the guide explains the 44 categories at level 3 of the legend. A satellite image is provided showing an example of each class and giving the result of the photointerpretation. The aim of this guide was that it should serve as a reference for all those working on the project, especially for the photo interpreters and for those responsible for national land cover cartographic series who could apply or replicate this methodology in their countries.

There is now a land use and land cover cartographic series for the whole of the European Union (EU), drawn up at different times (1990, 2000 and 2006). This is a very useful tool for explaining and illustrating the changes that have taken place, especially in the most dynamic parts of the European territory. As we shall see below, this series of satellite images is a valuable source of geographical information for researchers who are working on the simulation of future scenarios on different scales: regional, national and continental.

National Geographic (1998) published a very interesting world atlas based on images captured by different sensors and on mosaics built up from multiple satellite images. After the introduction explaining the technology used by Earth observation systems, the atlas covers the global phenomena (surface temperature of the sea and emerged land masses, sea level variability, differences between day and night-time temperatures, precipitation, depth of terrestrial and marine ice masses, distribution and primary productivity of ecosystems, wind speeds, topography and bathymetry of the Earth, plate tectonics, hurricanes and other atmospheric phenomena) that are so worrying for public opinion, in the context of studies on global change. There is then a thematic review showing geo-forms, forces of nature, human impacts and a catalogue of cities by continent.

One of the earliest and best-known tutorials, which included a broad repertoire of Landsat satellite images, was the work by Short (1982). An updated version of this tutorial can be consulted at Short (2010). In this recent digital publication, the author suggests how Landsat images can be used to support a variety of geographical practices at different academic levels by illustrating several themes. It contains notes for both teachers and students. Users can download a computer program for digitally handling satellite images.

The Canada Centre for Remote Sensing (CCRS, 2009) also offers an on-line tutorial that includes a large number of satellite images with examples and exercises to aid learning on subjects related to Geography and Earth Sciences.

The purpose of this study is to reflect on the usefulness of satellite images for teaching Geography and other related disciplines such as Earth Sciences and Environmental Sciences. It presents the Remote Sensing and Environment teaching guide, a tutorial designed for this purpose. Two examples will also be given to illustrate the process of urbanisation and the urban network on two scales – a global scale for the world as a whole and a regional scale focusing on the region of Madrid.

2. Remote Sensing and Environment Teaching Guide

This work (Martínez-Vega and Martín, 2010) is another recent tutorial on satellite images, sponsored by the Spanish Remote Sensing Association.

The aims of this guide are the following.

1. To make known the physical principles of Remote Sensing and its advantages over other systems for observing the Earth and, above all, to provide a selection of environmental applications of Remote Sensing.
2. To provide good-quality visual teaching materials for teachers at university and secondary levels to explain the geographical phenomena and environmental processes that are of concern to society.
3. To facilitate access to other teaching resources, especially other images and space photographs available on the image servers consulted.
4. To make students and readers of the guide aware of the need to preserve the Environment and to adopt practices to respect it.

This tutorial has been created as a product within the National Cartographic Plan[1]. It is offered as an audiovisual pack on Remote Sensing and the Environment, comprising this tutorial and an introductory video (UNED, 2011) which are complementary and freely accessible on the Internet. It is linked to subject g in Annex III of the LISIGE[2] and the INSPIRE Directive: Didactics, which covers physical and political aspects and any other information for teaching purposes.

As stated above, the guide is designed mainly for secondary school and university teachers on subjects related to Geography, Earth Sciences and Environmental Science. It also addresses the general public, that is, anyone interested in knowing more about techniques and tools for observing the Earth, the Environment, natural risks and the human footprint on the ecosystems of our planet.

This is a teaching resource containing extensive visual information:

- 241 vertical, oblique and three-dimensional images obtained from sun synchronous and geostationary satellites, manned platforms and the International Space Station;
- 42 field photos;
- 14 maps;
- 12 figures or sketches.

The latter support and complement the view obtained from space. The former illustrate various natural phenomena and risks and the various human impacts on natural resources. The images come from the websites of the most relevant space agencies (NASA, ESA, DLR, CNES, Agenzia Spaziale Italiana, NSPO), consortia of private satellite image distribution enterprises (Spot Image, Digital Globe, GeoEye, Deimos) and other environmental, cooperation and research agencies (UNEP, USGS, NOAA, NCGIA, ITOPF).

The use of computers, digital whiteboards and video projectors in classrooms makes it easier to transmit knowledge and provide access to teaching resources.

[1] The Spanish National Cartographic Plan (2013-2016), approved in December 2013 by the Government, aims to share infrastructure, resources and geographic and cartographic information (topographic and thematic).

[2] LISIGE is the acronym for Act 14/2010 on Spanish Infrastructure and Geographic Information Services (Official State Bulletin, nº 163, pp. 59628-59652).

The tutorial has 7 chapters. The first contains a brief introduction. The second summarises the history of Remote Sensing. The third gives basic notions of Remote Sensing so that readers can understand the content of the guide. The fourth presents the advantages of spatial Remote Sensing as opposed to other traditional systems for observing the Earth. These introductory chapters complement the above-mentioned video (UNED, 2011).

The fifth chapter covers various phenomena and natural risks as seen from space (hurricanes, volcanoes, floods, earthquakes, landslides, sandstorms, landforms, rivers and water masses, glaciers). The sixth chapter analyses human activities (land cover models, urbanisation processes, mining activities). It also covers the human imprint on the land and on the Environment (deforestation, forest fires, draining of wetlands, eutrophication of water masses, oil spills at sea). A number of very significant impacts are singled out and their environmental consequences are discussed.

The last section lists manuals and tutorials on Remote Sensing so that the readers, students and teachers using the guide can expand their knowledge on this technique for observing the Earth.

The contents of this teaching guide are useful for teaching Geography.

In secondary education in Spain, satellite images and geological photography are used to show singular geographical and geological elements (impact craters, volcanic craters), geomorphological phenomena (rivers, coasts), meteorological phenomena. Some images allow for comparative analysis of evolution over time of ecosystems (glaciers) and certain processes (desertification, fires).

Other Spanish-speaking countries (Mexico, Argentina) also use satellite images to teach Geography in secondary education. These are considered useful tools for giving a panoramic view of the Earth's surface. The aim is that students should learn to use satellite images together with other geographical information in order to understand territory on a local, regional, national and global scale.

In higher secondary education (Bachillerato), this tutorial could be useful for teachers of Earth and Environmental Science (2nd year). The examples that illustrate the guide can be used as teaching resources, at least for topics related to the main environmental problems – spatial remote sensing, radiometry, mineral deposits, impact of mining, volcanic risks, seismic risks, flooding risks, gravitational risks, general circulation of the atmosphere, risk situations caused by rainfall, atmospheric pollution, water contamination, water management, land and water ecosystems, impacts of agricultural and cattle-rearing, forest management, protected areas and the impact of erosion.

The tutorial might also be useful for teaching Geography (2nd year) to explain matters related to the relief of Spain, climate zones, biogeographic regions, hydrographic network and basins, the urbanisation process and urban networks, agricultural landscapes and the relation between Geography and the Environment.

University entrance tests usually include questions based on satellite images and aerial orthophotographs.

The contents of this tutorial are also related to several subjects covered in university degree courses on Geography.

For example, based on the syllabus for the Degree in Geography and Land Planning of the Universidad Complutense de Madrid, the images in this guide and in the repositories listed in it can be used to explain a wide range of subjects including Territory and the Environment, Climatology (1st year), Geomorphology and Hydrogeography, European Geography, Urban Geography, Rural Geography, Biogeography, Spanish Geography, Cartography and Representation Techniques (2nd year), Remote Sensing and Photointerpretation, Geographic Information Systems, Environmental Planning (3rd year) and Land Planning (4th year) or Regional Geography of Madrid (optional).

In the similar degree course offered by the University of Zaragoza (Spain), it would be useful to use multitemporal images illustrating the changes taking place in the world's large metropolitan areas and conurbations for the subject of Urban Processes and land organisation (2nd semester).

In the traditional subjects of Regional Geography and even in the descriptive subjects of European Geography and World Geography, the visual resources in this tutorial could be of use to the teacher when explaining topics of interest related to the main morphostructural units of relief, the atmospheric factors of climate (air masses, anticyclones and depressions), natural landscapes, the coastline and hydrographic network, urban networks, land use and land cover, agricultural landscapes and forests, etc.

Finally, satellite images are used regularly as a source of information to develop thematic mapping of land use and land cover in the compulsory subject of Visual Analysis in the Master courses on Geographic Information Technologies at the Spanish universities of Alcalá and Zaragoza and the Ecuadorian university of Azuay.

The teaching guide in Remote Sensing and the Environment is available in pdf format on various websites. Access is free. Originally, it was located on the website of the Spanish Remote Sensing Association and in the institutional repository of the Spanish National Research Council (Digital CSIC) but recently it has been placed on the Research Gate platform. The statistics on these repositories and data on distribution of two complementary editions in CD format produced by the CSIC and Ibercaja show that since 2010 it has been downloaded 4,705 times (Figure 1). Downloads from the Spanish Remote Sensing Association's website have not been taken into account because there is no access to such statistics.

75% of downloads of the tutorial took place in Spain and Latin America. It is significant that 8% of downloads were in the United States. This is perhaps because of the role of Spanish as a second language there.

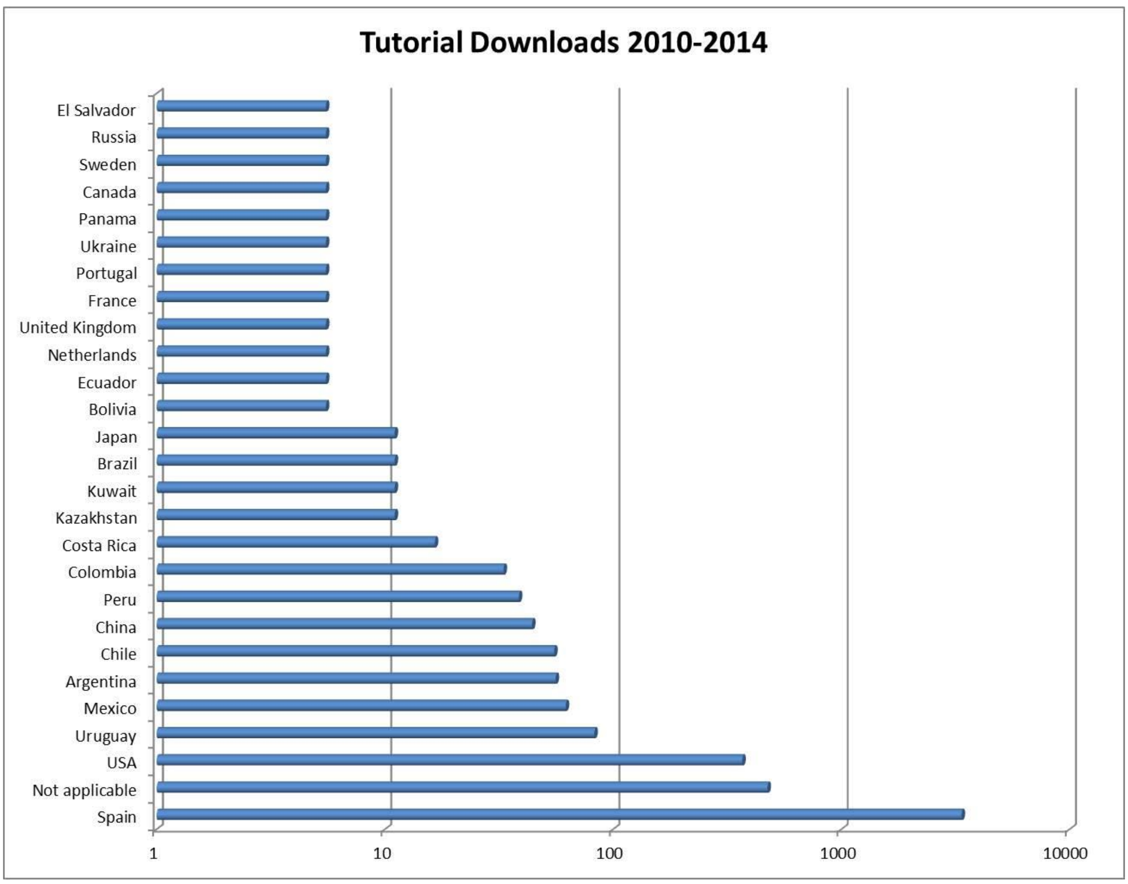

Figure 1. Downloads of the teaching guide on Remote Sensing and the Environment between 2010 and 2014. The abscissa axis is shown on a logarithmic scale.
Source: CSIC, Ibercaja and Research Gate.

3. First example of application

We would like to give an example for Geography teachers of how it can be used on a global scale. Figure 2 shows a striking mosaic of multitemporal images from the DMSP satellite (Defence Meteorological Satellite Program) obtained by the OLS sensor (Operational Linescan System). Because of its high radiometric sensitivity, even at night, scientists were quick to realise how useful it could be for generating a map to locate permanent lights on Earth. The lit-up areas correspond to the most urbanised areas although these are not necessarily the most highly-populated.

This mosaic shows not only the distribution of the human population in the world but also patterns of human occupation on the continents. It is very useful for explaining patterns of urbanisation in the world and imbalances in the urban network on a global scale.

Regarding human occupation of territories, there is a clear preference for coastal as opposed to inland areas of continents and for the strip between parallels 35º and 70º in each hemisphere. There also seems to be a relation between lighting and socio-economic development, because it is not only the developed countries of Europe and America that are very well-lit but also the highly-populated emerging countries in South-East Asia.

There is also a relation between the "light lines" and the main communication networks. The latter have sometimes determined or guided urban development along them. In other cases, they are the result of urbanisation. Examples can be seen in Africa, along the river Nile, and in the United States, where parallel light lines cross the Mid-West towards Denver and the Rocky Mountains. In Russia, light radii converge in Moscow, indicating centralised settlement. In Central Asia, the Trans-Siberian track creates a stream of light, another example of planned expansion. In the southern hemisphere, light corresponds to ports and the colonial past.

In comparison with urbanised areas, there are also vast uninhabited or weakly occupied spaces: deserts, polar areas and large tropical and boreal forests, all of which are dark. This is the *anecúmene*.

4. Second example of application

A study is presented below that can be used by Geography teachers to explain, on a regional scale, the intense changes taking place in land use and land cover in the functional regions organised by a large metropolis such as Madrid. Satellite images, GIS and simulators provide geographical information and tools for analysing, both visually and cartographically, the changes that have taken place and those that can be expected over coming decades. This information is very useful when decisions have to be taken by land planners and for designing a territorial strategy. This is a clear example of the connection between research and teaching.

The region of Madrid is located in the centre of Spain (Figure 3). It has a surface area of 8,026 km^2 and a population of 6,448,272 inhabitants. This is the highest population density in Spain (803 inhabitants/km^2). Since the early 1990s, there has been marked demographic growth (+21%) and intense expansion of urban, industrial and commercial areas and of infrastructure (Plata Rocha et al., 2010). Infrastructure has been key in structuring the territory. It has led to widespread improvement in accessibility throughout the region. The region's agricultural land, forests and Protected Areas are subject to great urban, industrial and recreational pressures which pose a threat to their extension and their value (Rodríguez-Rodríguez and Martínez-Vega, 2013). This process of urban sprawl is representative of the far-reaching changes that have taken place in Mediterranean metropolitan regions.

Gallardo (2013, pp. 141-260) has studied changing land use in the region of Madrid over four time periods that represent recent decades. She has drawn up and harmonised, using a common legend and scale, the 1982 regional map of vegetation and land use and the maps from the European CORINE-Land Cover Programme of 1990, 2000 and 2006 (López-Vizoso, 1989; Feranec et al., 2010). The latter were drawn up using visual analysis of images from the Landsat and Spot satellites. Figure 4 summarises the land use and land cover map for 2006. A legend at an intermediate level between levels 1 and 2 is given to make it easier to read.

Between 1990 and 2006 urban areas are seen to have grown by 72% and industrial and commercial areas doubled in size. Forests gained over 4% of the regional area. Agricultural land, however, lost 13%.

Subsequently, Gallardo (2013, pp. 261-351) drew up a future scenario for land use and land cover for 2025. This is a spatially explicit and dynamic model in raster format. It uses the Land Change Modeler (LCM) that is based on a neural network method and on the spatial and time trends for land use in the region recorded between 1990 and 2006. It relates the explanatory variables with changes in land use and land cover. The amount of change is modelled using a Markov chain analysis. The dependent variables are simplified land use and cover (urban, industrial and commercial, arable land, heterogeneous agriculture, forest, shrub and pastures, others).

Two independent groups of variables were considered: biophysical (altitude, slope, lithology and distance from rivers and reservoirs), and socio-economic (mainly accessibility measured in terms of distance and time to travel to towns, airports, motorways and main roads and the railway network). Verburg et al. (2004) considered that accessibility is the most explanatory and determinant factor for changes in land use and land cover. Between 1990 and 2006 urban areas are seen to have grown by 72% and industrial and commercial areas doubled in size. Forests gained over 4% of the regional area. Agricultural land, however, lost 13%. Subsequently, Gallardo (2013, pp. 261-351) drew up a future scenario for land use and land cover for 2025. This is a spatially explicit and dynamic model in raster format. It uses the Land Change Modeler (LCM) that is based on a neural network method and on the spatial and time trends for land use in the region recorded between 1990 and 2006. It relates the explanatory variables with changes in land use and land cover.

Figure 2. Mosaic of multitemporal images of the Earth, registered by the Operational Linescan System (OLS) of the Defense Meteorological Satellite Program (DMSP) satellite.
Source: www.visibleearth.nasa.gov.

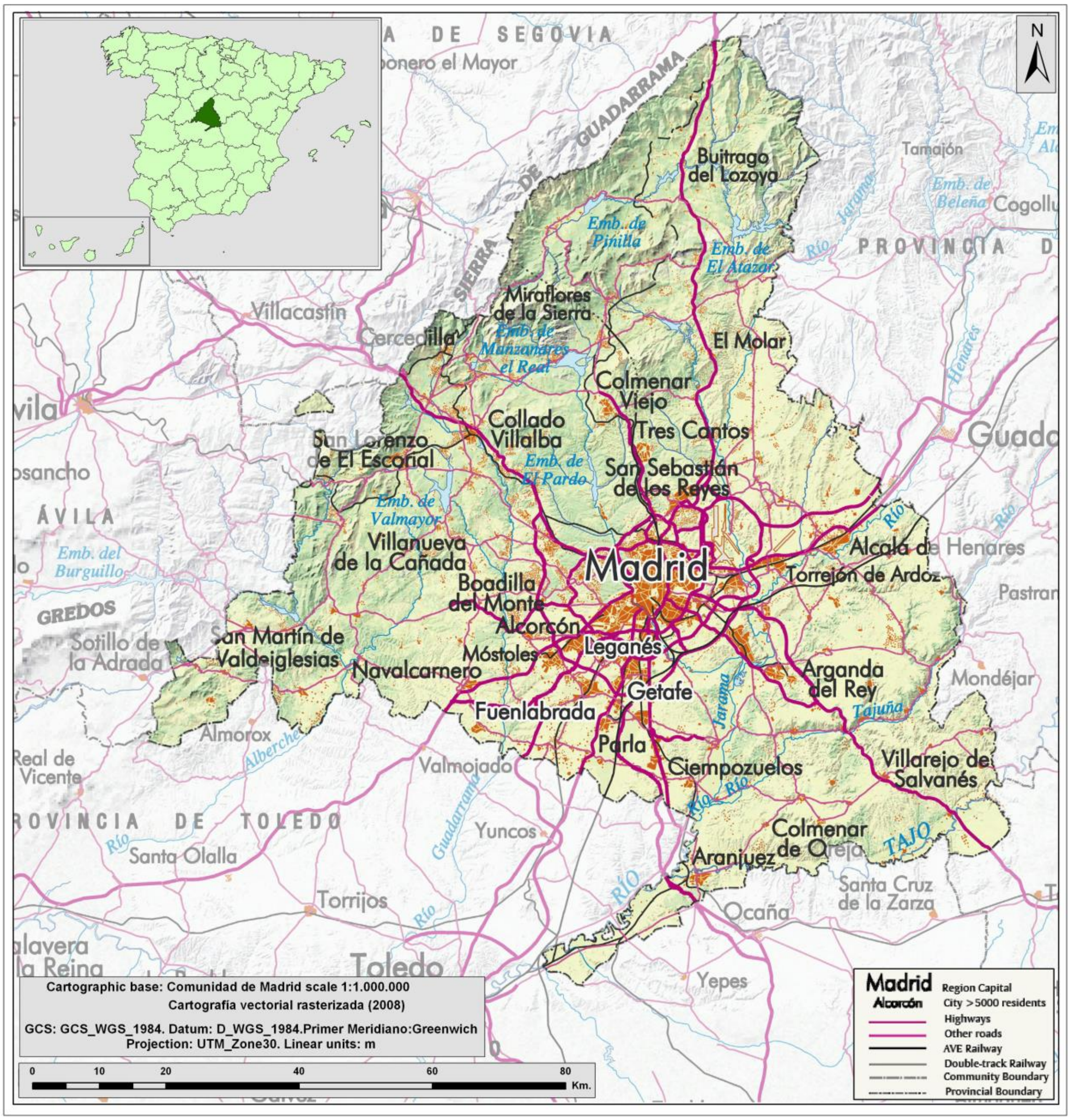

Figure 3. Location map of the region of Madrid.
Source: elaboration of P. Echavarría.

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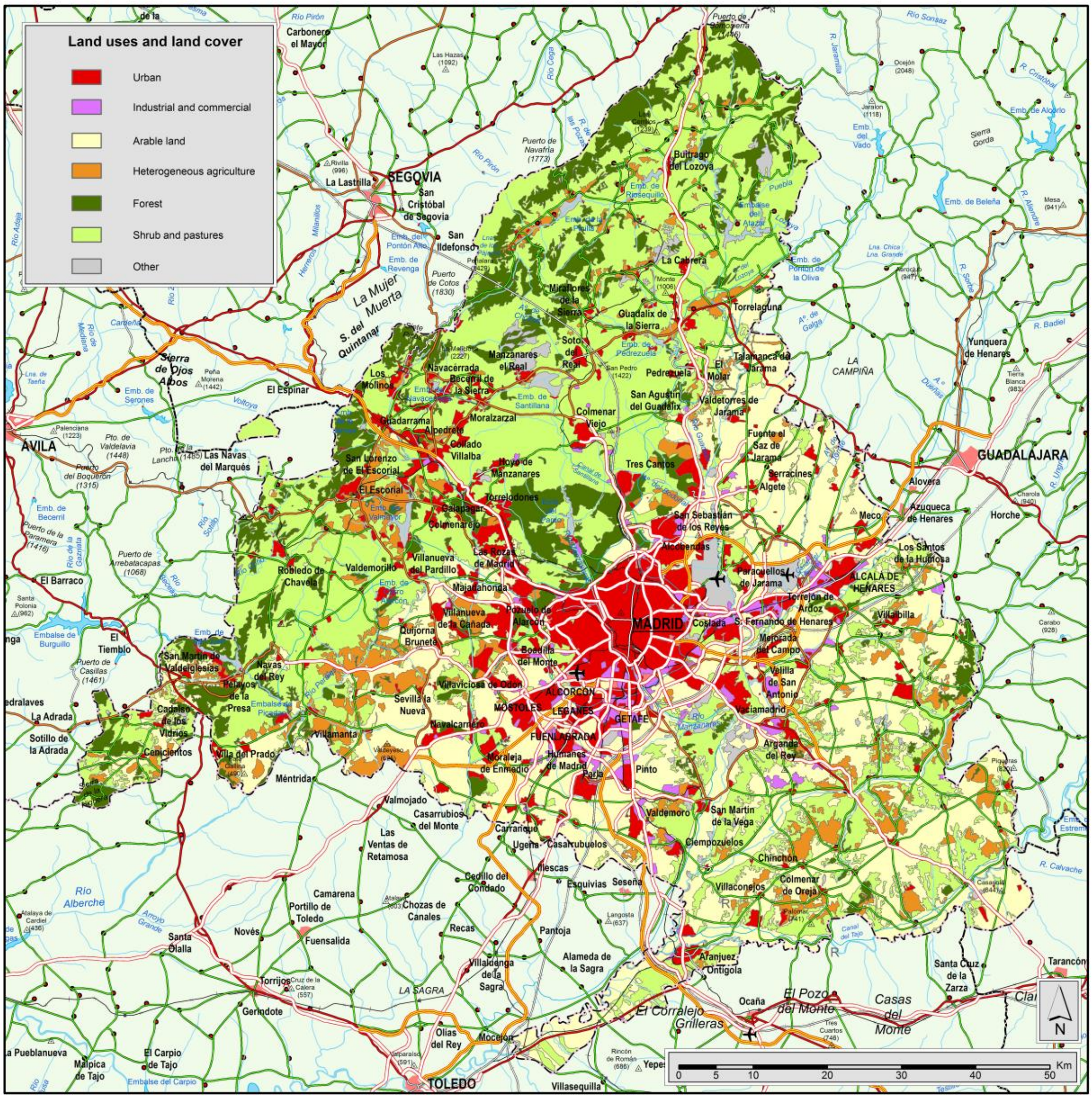

Figure 4. Land use and land cover map for the region of Madrid in 2006.
Source: elaboration of M. Gallardo and P. Echavarría.

In addition, a number of restrictions that limit the implementation of certain land uses were taken into account, such as environmental legislation (protected areas, water police zones, infrastructure protection zones, burned areas that cannot be reclassified for a period of 30 years).

Certain factors (neighbouring areas) that may encourage the location of certain land uses were also taken into account.

Demand for each land use and land cover is determined by a transition matrix indicating the probability of change from one use to another.

Statistically, between 2006 and 2025, urban and industrial and commercial areas are each expected to increase their surface area by 33%, and forests by just +0.72%. However, arable land is expected to decrease by -9.35% and general agricultural land by -0.87%.

Geographically, figure 5 shows a simulation of trends and spatial distribution of land uses in the region of Madrid.

This shows the extensive artificialisation of the region if recent trends continue.

Urban areas will spread around the metropolitan area, towards the south and south-east, following the main transport lines. They are expected to fill the current non-urban interstices. There is also likely to be scattered growth in the mountainous areas to the north-west of the region as a result of increasing numbers of second homes.

The traditional urban network of the region of Madrid, which is of a concentric-radial type, is likely to be reinforced, even though the main central area is growing and becoming more compact, with the main radii being located along the radial motorways.

Industrial and commercial uses will mostly spread towards the south, south-east and east of the metropolis following the axes of the A4, A3, A2 motorways and towards the airport. Both categories will gain ground from arable land. In the south-west of the region, agricultural land will also lose surface area as a result of the abandonment of marginal lands, which will be invaded by grasslands and scrub.

In summary, far-reaching changes can be expected in land use in the form of gains, losses and interchanges. These processes will have important implications for the region's geography. Land planners must be prepared and must plan to avoid possible environmental impacts.

5. Discussion

Satellite images are undoubtedly a useful tool for teaching Geography at every stage of education. As sources, they provide very visual, up-to-date information that is easy to understand. The fact that they are dynamic means that they provide sequences and set of images that illustrate very variable multitemporal geographic processes, from those occurring in just a few hours (meteorology) to those occurring over decades (deforestation, urban growth). Their spatial coverage gives multi-scale information. Geography teachers can investigate or explain processes occurring on a local scale as well as other more global phenomena.

In addition, the satellite images available in the repositories referred to in the guide are freely accessible.

This is a great advantage for Geography teachers anywhere in the world. For use in the classroom, all that is required is a device for visualising the images and a connection to the Internet.

The teaching guide on Remote Sensing and the Environment can serve as the basis for enjoyable, visual teaching of Geography, in a similar way to other teaching initiatives (Sevilla, 2004). It can be used in combination with other complementary materials, as proposed in the Spanish National Cartographic Plan: on-line videos (UNED, 2011), DVD and VHS (Chuvieco, 1995), repositories of space images and cartographic repertoires.

In this way it is possible to meet the objectives laid down in the new European Higher Education Area (EHEA) regarding more active teaching methodologies, based on the use of computer resources in classrooms (Marrón, 2011). Active teaching is necessary to replace the traditional, deep-rooted, memory-based teaching of Geography.

The teaching guide presented in this study may help students and future teachers to achieve the following basic targets: skills of perception, orientation, systematization and understanding of space, the values of environmental and social commitment and skills in using Information and Communication Technologies.

For this to be possible, certain impediments that still exist in some schools need to be corrected.

- Little interest on the part of teachers in didactic innovation.
- Incomplete teacher training and lack of information on new resources and training possibilities.
- Incomplete provision of digital equipment to support teachers in their work.
- Poor Internet connections preventing such on-line resources from being used in an agile way.
- Paper continues to be the dominant support in classrooms. Paper maps are still used more than digital maps, aerial orthophotographs, satellite images or the teaching guides, tutorials and videos that are available on the Internet.

6. Conclusions

Today's teachers and students have at their disposal a wide range of resources for teaching and learning Geography. We are convinced that greater use of such resources in classrooms will make it easier to achieve the objectives and skills laid down in syllabuses.

It will also change the way in which Geography is learnt. Learning by rote should be abandoned and replaced by a more modern method that takes up the advantages of the teaching resources available on the Internet, especially satellite images. The new generations of students will have better skills and will be trained to take an active part in solving environmental problems in the places where they live.

In this way, students can be useful collaborators for managers and planners of the territory.

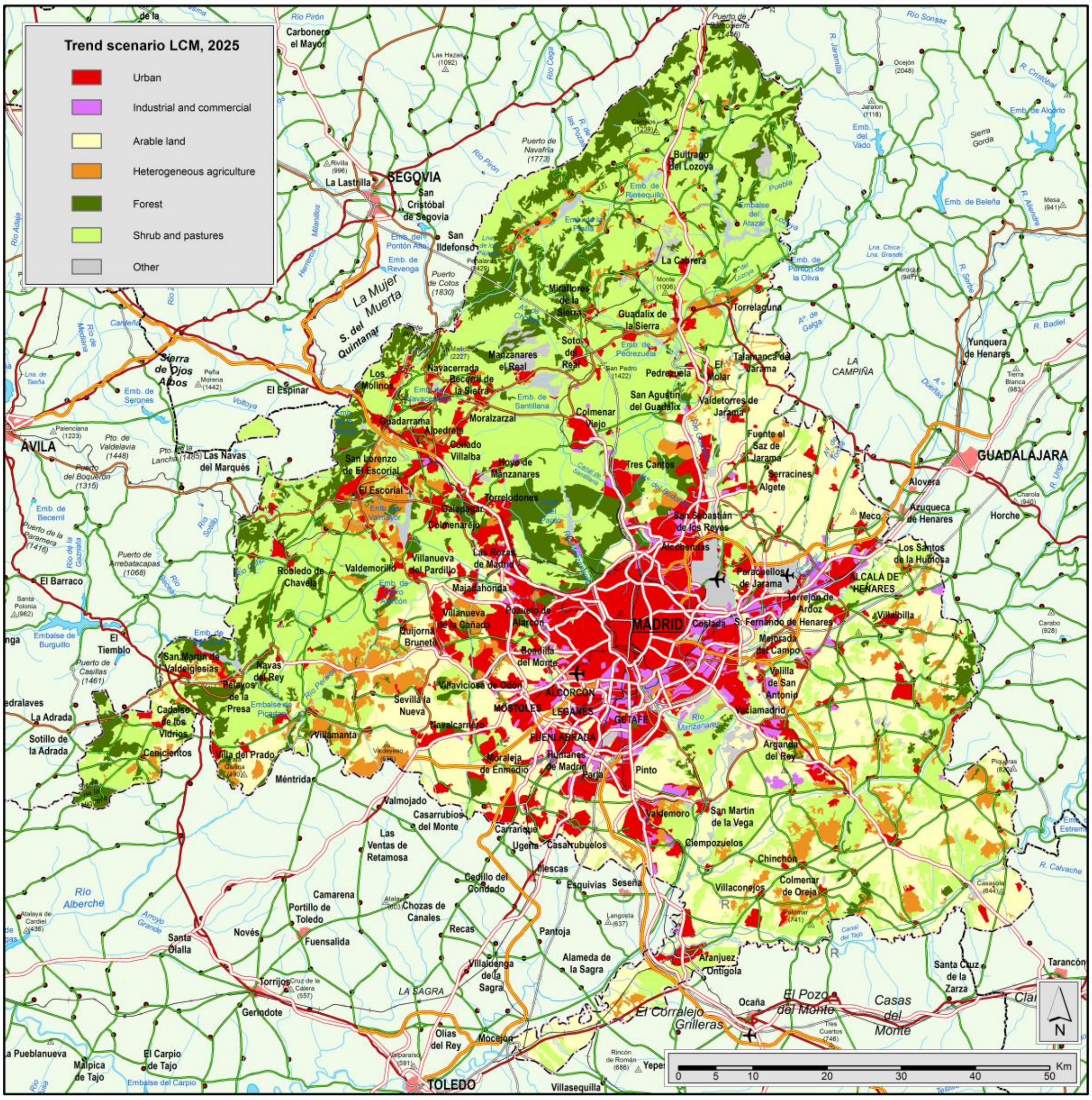

Figure 5. Land use forecast for 2025 in the region of Madrid.
Source: elaboration of M. Gallardo and P. Echavarría.

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