Monitoring urban development consolidation for regional management on water supply using remote sensing techniques

Lourdes Albizua¹, Uxue Donezar¹ and Juan Carlos Ibáñez²

¹Department Territorial Information System, Cabárceno 6, 31621-Sarriguren-Navarra-Spain
²Subdirección de I+D+I, Canal Isabel II, Santa Engracia 125, 28003-Madrid
*Corresponding author, e-mail address: lalbizua@tracasa.es

Abstract
This work’s frame is the assurance of water availability/demand balance in the Community of Madrid linked to the urban growth. The paper presents the development of an operative methodology to define and create a cartographic database in the Community of Madrid, based on SPOT5 satellite imagery and its periodical updates with a further usage of QuickBird images for its validation. This database reflects the evolution of urbanized areas as a result of the Urban Development Plannings’ consolidation in all municipalities, as well as the state and evolution of green urban areas. The resultant cartographic database has been integrated in the Canal de Isabel II’s Geographical Information System and is intended to be the reference information for the development and updating of the strategic infrastructure plans that should anticipate to future water demands caused by urban expansion in the Community of Madrid.

Keywords: Water supply demands, Urban planning, Urban changes, Remote sensing.

Introduction
Development and land planning in cities involve an increase and a geographical redistribution of water demand. Canal de Isabel II (CYII) is the company responsible for supplying drinking water to the Community of Madrid, which has a population of over six million people. It operates in all phases of the water cycle, from acquisition to its return to the environment with adequate quality conditions. Therefore, CYII should schedule the necessary investments to ensure service conditions to all new properties that enter the system. In this framework, this project tries to develop a feasible methodology for monitoring the urban growth and its location.

Growth expectations on municipal urban planning development are the main reference for predicting future water demands. Construction and commissioning of new water supply infrastructures depend mainly on the speed on which urban soil consolidation is done [Cubillo, 2005].
Project overview
Earth observation satellites and advanced remote sensing techniques have been proposed as tools to narrow the uncertainty concerning the expectations of urban consolidation, set out in municipal urban plans. They have also been found useful for the detection and quantification of urban green areas, which are considered as major elements of water demand. [Beamonte et al., 2010].

The aim of this project is the development of an operational methodology, using remote sensing techniques, (1) to enable the definition and upgrade of a cartographic database for the Community of Madrid reflecting the temporal evolution of urban consolidated areas, as a result of the consolidation of the different municipalities’ urban development plans, and (2) detecting and monitoring urban green areas and estimating their water demand. The resultant cartographic database must be periodically updated.

High resolution satellite SPOT5 images throughout the Community of Madrid, and very high resolution QuickBird images for a pilot area, are the basic information for the project. The resultant cartographic database has been integrated in the Canal de Isabel II’s Geographical Information System (GIS) and is intended to be the reference information for the development and updating of the strategic infrastructure development plans, which are related to the urban expansion process in the Community of Madrid.

Study Area and Data
The study area covers the entire Community of Madrid (Spain, 8,021.80 km²), focusing mainly on the most dynamic areas concerning Urban Development Plans in the community, likely located in town surroundings.

Satellite images
Satellite SPOT5 4 full coverages over the entire Community of Madrid, with a spatial resolution of 10 m in multispectral and 2.5 m in panchromatic, have been acquired for the following periods: summer 2008, summer 2009, spring 2010 and summer 2010.
In order to validate the methodology, QuickBird images have been acquired in 2.4 m multispectral mode and 0.6 m panchromatic, over a 50 km² pilot area on similar dates to those of SPOT5 (Tab. 1).

| Satellite | Path/Row | Summer 2008 | Summer 2009 | Spring 2010 | Summer 2010 |
|-----------|----------|-------------|-------------|-------------|-------------|
| SPOT5     | 32/268   | 2008-08-09  | 2009-07-18  | 2010-04-09  | 2010-08-23  |
|           | 32/269   | 2008-11-06  |             |             |             |
|           | 33/267   | 2008-06-18  | 2009-07-13  | 2010-05-21  | 2010-08-12  |
|           | 33/268   | 2008-06-18  | 2009-07-13  | 2010-05-21  | 2010-08-12  |
|           | 33/269   | 2008-06-26  |             |             |             |
|           | 34/268   | 2008-10-05  |             |             |             |
|           | 35/268   |              | 2009-07-24  | 2010-03-15  | 2010-08-28  |
|           | 35/269   | 2008-07-19  | 2009-07-24  | 2010-03-15  | 2010-08-28  |
|           | 35/270   | 2008-07-19  |             |             |             |
| QuickBird |          | 2008-08-10  | 2009-07-13  | 2010-03-28  | 2010-08-21  |
Ancillary information

Relevant geographic information collected for this project is:
- Reference information mandatory for georeferentiation: 1) 1:5,000 digital orthophotography from 2006 flight, 2) 25m Digital Terrain Model from the IGN.
- Ancillary data: 1) Digital urban cadastral map updated in 2009, 2) Urban planning 2009, 3) SIOSE 2005 map at 1:25,000. SIOSE is a Spanish Land-Use Map (reference year 2005) with more than 50 categories, 4) Orthoimage SPOT5 2005 PNT [Villa et al., 2005], 5) Green areas and outdoor water uses’ cartographic database, updated with 2006 photogrammetric flight.

Methodology

Step 1: Cartographic database design

The cartographic database design is based on the change monitoring legend, associated to the SPOT5 images’ discrimination capacity in the categories of interest. The designed cartographic database has the following 6 layers:
- Strata: areas with an homogeneous behavior, that includes the following categories: consolidated urban soil, urban soil in consolidation process, rainfed and irrigated agricultural land, forestry and others.
- Urban settings: areas with a uniform degree of consolidation, (being urbanized, urbanized, being built and built) within the urban soil in consolidation process stratum (Fig. 1).
- Urban settings: significant elements within urban settings (building, soil, paved lanes and unpaved lanes).
- Green substratum, vegetation growing within the urban strata, this is, growing in “consolidated urban soil” and in “urban soil in consolidation process”.
- Green settings: golf courses and gardens.
- Green parcels: trees and grass.

Figure 1 - Urban setting.
**Step 2: Image processing**

1. Basic image processing: It integrates quality control, orthorectification, atmospheric and radiometric corrections, pansharpening and mosaic. The advanced pansharpening method used is the Spectral Response Function (SRF) [González-Audicana et al., 2006], based on SPOT5 sensors’ spectral response curves.

2. Urban monitoring processing: It includes specific processes for identification, classification and monitoring urban areas:

   - Stratification: delimiting areas with homogeneous land cover and urban behavior based on SIOSE Map (2005). Legend has been defined according to the frame of this project. Furthermore updating yearly stratification is required [Fichera et al., 2012].
   - Image segmentation: identification of urban objects for further classification, with two different approaches: 1) image is segmentated with objects from cadastre when available and 2) spectral and textural analysis is carried out for object extraction otherwise.
   - Object oriented classification [Miller et al., 2009]: within the identified urban parcels of the previous stage, this advanced classification technique takes into account the shape, textural and spectral properties of the objects in the image (Fig. 2).
   - Change detection: it has been used for 1) strata delimitation and updating, 2) location of new urban settings and 3) updating urban parcels’ classification in urban settings [Albizua et al., 2005]. Used change detection techniques were Image difference and Principal Component analysis (PCA).

3. Delimitation of vegetated areas: green areas were delimited in urban, agricultural and natural environments based on NDVI index (normalized difference vegetation index). In addition, vegetation activity thresholds were estimated for each stratum. Within the green substratum, image segmentation, and tree and grass discrimination has also been carried out [Leránoz et al., 2008] due to their different behavior towards water demands.

4. Methodology verification. For each updating period, a QuickBird image has been acquired and processed with the same methodology as that used with SPOT5 over a pilot area (Fig. 3 and 4). Qualitative and quantitative comparisons between the results obtained with both types of images validate the developed methodology. Numerical differences found are consequence of the different spatial resolution. The main conclusion was that lower resolution images, SPOT5, tend to overestimate both green areas and buildings’ parcels. Even so, compared results support the methodology developed for SPOT5 [Théau et al., 2010].
Step 3: Estimation of water demands

The hypothesis for the estimation of water demand in urban areas, as a derived product of the urban development monitoring within areas of urban soil consolidation process, is based both on the knowledge of the intended water use as well as the intended construction area of different urban settings from urban planning. CYII could estimate the final water demand value combining forecasted urban consolidated surfaces (based on urban planning) with current urban consolidated surfaces (provided in this project using remote sensing). The water demand in green areas is estimated in terms of monthly based irrigation water requirements (NR$_{\text{month}}$) from the equation:

$$NR_{\text{month}} = \frac{ET_{\text{C(month)}} - P_{\text{month}}}{\text{Irrigation Efficiency}} \quad [1]$$

Where $P_{\text{month}}$ stands for monthly accumulated precipitation and $ET_{\text{C(month)}}$ for monthly evapotranspiration of green covers. $ET_{\text{C(month)}}$ is estimated from reference evapotranspiration $ET_o$, calculated with Hargreaves [Hargreaves and Samani, 1982] method and corrected by a $K_c$ factor provided by FAO and Muncharaz Pou depending on the type of crop. Irrigation Efficiency is a parameter dependant on the irrigation method [Mucharaz Pou, 2006]. In this study, sprinkler irrigation was considered, with an efficiency coefficient of 0,75 [FAO, 2004]. Annual water requirements for green urban areas are then estimated from monthly irrigation requirements for grass and tree areas.

Results

The results of the project include: the design, generation, updating and exploitation of the cartographic database (Geodatabase) and the estimation of the water demand. The results and project information have been integrated into the CYII corporate GIS, which
allows the generation of reports, thematic maps, etc. Results are expressed graphically due to the confidentiality of data. Results are expressed in terms of urban parcels’ classification in developing areas, according to the legend (building, soil, paved lanes and unpaved lanes), and for the different urban settings according to the degree of consolidation achieved for each of the dates tested. The following figure (Fig. 5) shows the area classified in the different studied periods.

![Figure 5 - Results of classified area for each data studied.](image)

The vast majority of urban settings have achieved the “being built” degree of consolidation; this degree of consolidation increases its surface over the years of study (Fig. 6).

![Figure 6 - Evolution of consolidation degree.](image)
Thematic maps prepared for municipalities collect cartographic and numerical changes detected through the studied period (Fig. 7). Crossing the Geodatabase of all dates with the current urban planning can track the status of implementation of urban development. The result of crossing is provided in a database that summarizes, for each municipality and each sector planning, the historical evolution of the classified area. Urban green areas (Fig. 8), rainfed and irrigated land, and forestry have been identified based on the vegetation status using NDVI. Water demand estimation is given in two ways: 1) the overall result for all the Community of Madrid and 2) its spatial distribution (m3/year) for 1ha (100x100m) grids (Fig. 9).
Conclusions
- The intended goals have been achieved, strengthening an operational methodology, based on SPOT 5 images, to track urban consolidation in the Community of Madrid. It has also been established a methodology for estimating water demand in green urban areas.
- High-resolution SPOT5 satellite images provide suitable information for assessing the current urban development situation at a reasonable cost, due to their availability, viability, characteristics and continuous territorial coverage by purchasing annual summer coverage. However, their spatial resolution is too low in areas with little structure or with highly fragmented urban subdivision when further identification of buildings is required.
- SIOSE is a strong support in the delimitation and identification of urban soil consolidation process strata. It should also be highlighted the importance of the availability of an updated cadastre, which is essential as a basis in segmentation and classification processes of urban parcels.
- Results are provided in a geodatabase, which presents a huge potential from both a graphical and numerical exploitation approach. The use of this geodatabase allows the manager to exploit it according to their needs.
- Results show that green areas identified in summer correspond to irrigated areas, while those identified in spring also include rainfed areas.
- The client (CYII) has validated the results of this project, and considers that the developed methodology is a very important tool in future development plans.

Discussion
- The cost of the project is divided in 50% images’ acquisition and 50% processing information. The work can also be divided in 50% remote sensing processes and 50% GIS processes. Annual updating of the whole Community of Madrid requires two full-time expertise technicians on remote sensing and GIS, considering two months of execution.
- Feasibility studies for image acquisition give lower temporal window collection in summer.
Furthermore, summer acquisition makes it possible to consider that all green vigorous areas are irrigated areas. Therefore, in order to estimate reliable water demand, summer images are mandatory.

- In order to continually improve the valuation of urban monitoring and sort out existing disadvantages, the following alternatives are proposed for future updates:
  - Combine high and very high resolution images adjusting acquisition timing according to the degree of urban consolidation of the different areas of the Community of Madrid. A yearly SPOT5 coverage acquisition in summer is considered adequate to get an assessment of the degree of consolidation of the urban monitoring. However, in areas with an advanced degree of consolidation or which require further detail, the use of specific acquisitions of very high resolution satellites is advisable, in order to achieve a greater precision in identifying small buildings
  - Use of LiDAR information (Light Detection and Ranging): The development of monitoring techniques with LiDAR images would provide vertical information. Combining these data with currently available ancillary information, the built area in both dimensions (ground and height) could be obtained. Consequently a better estimation of urban water demand could be achieved

These techniques and data, especially the LIDAR, are more expensive and a feasibility assessment is required.

References
Albizua L., Leránoz A., Zalba M. (2005) - Seguimiento detallado de los cambios urbanísticos que se producen en el término municipal de Madrid, publicado XI Congreso Nacional de Teledetección, pp. 241-244.
FAO Irrigation and Drainage Papers (2004) - Crop evapotranspiration. Guidelines for computing crop water requirements.
Beamonte Garcia, Pimentel Conde, Gómez Cristóbal, Herrero de Andrés, Fernández Antón, (2010) - Técnicas de teledetección y sistemas de información geográfica para la evaluación de la demanda de agua para usos de exterior en la Comunidad de Madrid. Canal de Isabel II, Cuadernos de I+D+i Nº 11.
Cubillo González F. (2005) - Desarrollo urbano y planificación de infraestructuras y demandas. http://grupo.us.es/ciberico/archivos_acrobat/sevilla1cubillo.pdf.
Fichera C.R., Modica G., Pollino M. (2012) - Land Cover classification and change-detection analysis using multi-temporal remote sensed imagery and landscape metrics. European Journal of Remote Sensing, 45: 1-18. doi: http://dx.doi.org/10.5721/EuJRS20124501.
Gonzalez-Audicana, Otazu, Fors, Alvarez-Mozos (2006) - A low computational-cost method to fuse IKONOS images using the spectral response function of its sensors. IEEE Transactions on Geoscience and Remote Sensing, 44 (6): 1683-1691. doi: http://dx.doi.org/10.1109/TGRS.2005.863299.
Hargreaves G.H., Samani Z.A. (1982) - Estimating potential evapotranspiration. J. Irrig. And Drain Engr., ASCE, 108(IR3): 223-230.
Leránoz A., Albizua L., Zalba M. (2008) - Seguimiento de las medidas de ahorro de agua mediante técnicas de Teledetección y Gis en la provincia de Málaga. XII Congreso Nacional de Tecnologías de la Información Geográfica.
Miller J.E., Nelson S., Hess G. (2009) - An Object Extraction Approach for Impervious
Surface Classification with Very-High-Resolution Imagery. The Professional Geographer, 61 (2): 250-264. doi: http://dx.doi.org/10.1080/00330120902742920.
Mucharaz Pou M. (2006) - Las necesidades de agua en jardinería. Cálculo por el método del coeficiente de jardín. Arquitectura del paisaje, 14 (8): 16-25.
Théau J., Sankey T., Weber K. (2010) - Multi-sensor Analyses of Vegetation Indices in a Semi-arid Environment. GIScience & Remote Sensing, 47 (8): 1-16.
Villa G., Arozarena A., del Bosque I., Valcarcel N. Garcia C., Solis M.J. (2005) - El Plan Nacional de Observación del Territorio en España. Proc. XI Congreso Nacional de Teledetección, Tomo I, 249-254.

Received 14/10/2011, accepted 05/05/2012

© 2012 by the authors; licensee Italian Society of Remote Sensing (AIT). This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/4.0/).