Geoderma 214–215 (2014) 135–140

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Using TM images to detect soil sealing change in Madrid (Spain)

Pilar García *, María Eugenia Pérez, Antonio Guerra

Dpto. Regional Geographic Analysis and Physical Geography, University Complutense of Madrid, C/Profesor Aranguren s/n, 28040 Madrid, Spain

ARTICLE INFO

Article history:
Received 7 May 2012
Received in revised form 16 September 2013
Accepted 17 September 2013
Available online 11 October 2013

Keywords:
Soil sealing
Remote sensing
Land capability
Madrid

ABSTRACT

Landsat TM images are used to define soil sealing in the Madrid Autonomous Region (Spain) between 1989 and 2010. The comparison of images within this time frame obtains an estimated loss of 42,800 ha of agricultural land. Soil sealing mainly occurred in metropolitan areas as well as in the E, SW and NW of the capital. Landsat images overlaid on agrological classification maps and soil association maps show that the most significant losses correspond to agricultural classifications B and C and luvisols associated with cambisols, regosols, calcisols and fluvisols (WRBSR, 2007).

1. Introduction

One of the most serious problems of soil degradation is sealing. The simple observation of an evening satellite image shows the spread of urban conurbations in some areas of the world. In Europe, this mainly affects densely populated countries such as Holland or Germany, as well as the Mediterranean Basin; sealing is less often observed in Eastern Europe, although it has increased in recent years. The most important land use changes are due to increased building and public works (Blum et al., 2004; EEA, 2006; Lavalle et al., 2001; Montanarella, 2007; Van-Camp et al., 2004), which can be analysed through remote sensing.

Spain has the third largest population in the European Union, although the density is not particularly high, and is especially affected by the problem of sealing in coastal zones and near urban areas (Añó et al., 2005; Castillo et al., 2004; García and Pérez, 2007, 2011; Valera et al., 2006, 2011).

The expansion of residential zones up to 2008 resulted in increased soil sealing in urban areas. High land prices in inner cities also led to building on city outskirts or even in nearby towns, rather than in the city centre. The increase in second homes also increased soil sealing, as these were mainly semi-detached houses spread over large areas.

Soils removed for sealing are difficult to recuperate, due to the loss of constituent elements of the soil systems (microorganisms, mesofauna, flora, etc.). As a result, sealing is an important environmental problem.

Many authors are currently engaged in research into soil sealing in major city areas and how it affects and alters different ecosystem features with the related social costs (Biasioli et al., 2006; Blum, 1998; Bouma, 2006; Effland and Pouyat, 1997; Jones et al., 2012; Kampouraki et al., 2006; Nizeyimana et al., 2001; Scalenghe and Ajmone-Marsan, 2009; Tomas et al., 2010; Zhang et al., 2002).

The Madrid Autonomous Region was chosen to carry out a pilot project for soil sealing, as it is significantly affected by this problem due to its high population density and rapid population growth over the recent years (www.ine.es). The population density evolved from 618.4 persons/km^2 in 1989 to 781.2 persons/km^2 in 2008, higher than the mean values for Spain as a whole (76.8 and 91.4 persons/km^2). Although other researchers have analysed land use in the Madrid Autonomous Region with aerial photographs (Naredo and García, 2008) to determine the extent of urban sprawl (García Alvarado, 1997, 2000), so far research has not been carried out into the agricultural capacity and potential of degraded soils.

The aim of this paper is to produce a map showing soils which have been sealed in the Madrid Autonomous Region, to calculate the increase in soil sealing between 1989 and 2010 and to evaluate which agrological soil classifications are affected. Landsat images are overlaid on soil association maps to analyse soil losses.

2. Materials and methods

The ready availability of Landsat images allows us to analyse the changes in land use and soil sealing over the recent decades. Two dates twenty years apart were chosen, both of them in spring, which is considered to be the best season of the year to distinguish sealed soils. ERDAS Imagine 2010 software was used for image processing. The Landsat TM images correspond to path 201, row 32 from 25 March 1989 and 6 May 2010 (NASA, 2003 and IGN Plan Nacional de Teledetección, 2011). Both images have been georeferenced and atmospherically corrected.

* Corresponding author.
E-mail address: mpgarcia@ucm.es (P. García).

0016-7061/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geoderma.2013.09.017

Table 1
Capability classification.

Monturiol and Alcalá (1990a)	Klingebiel and Montgomery (1961)
A	I, II
B	II, III
C	IV
D	V, VI
E	VII, VIII

The visual and digital processing of the images carried out was as follows:

- Spectral channel combinations;
- spatial enhancements (statistical filters: summary 5 × 5 and 3 × 3);
- radiometric enhancements (histogram equalization);
- spectral enhancements (principal components, inverse principal components, Tasselled Cap, RGB to IHS, IHS to thyc=10?>RGB, natural colour and mineral and vegetation indices);
- 1989–2010 change detection (increased by <10% and increased by >10%); and
- unsupervised and supervised classifications.

Sealed soils, limited by polygons, have been mapped through digital processing of the images. Different band combinations were used to differentiate between different types of soil sealing (road infrastructure, factories, housing, etc.).

Images obtained by cutting polygons were processed to obtain new images showing only those surfaces with increased sealing between the selected dates.

The total area of soil sealing was calculated from the supervised classification of the 1989 and 2010 images, by setting up two categories (sealed and unsealed soils). This classification was used as the minimum distance criterion for assigning the pixel to the nearest class.

This new image overlaid on the agrological class and soil association maps (Monturiol and Alcalá, 1990a,b, adapted to WRBSR, 2007 and Soil Survey Staff, 2010 by the authors), produced two images which show agrological classes and soil associations removed in the twenty intervening years. Overlaying the maps and cutting the soil units required georeferencing to UTM coordinates. These 1:200,000 scale maps were chosen as this scale is the best for overlays on TM images with spatial resolution of 30 m. The agrological map shows five soil classes, A, B, C, D and E, corresponding to the eight agrological classes established by Klingebiel and Montgomery (1961): A corresponds to Class I and the best soils of II; B to the worst soils of II and to Class III; C to Class IV; D to Classes V and VI and E to Classes VII and VIII (Table 1).

The total and relative population data for 1989 and 2008 for the Madrid Autonomous Region was taken from figures provided by the National Statistics Institute (INE, www.ine.es).

3. Results

Digital processing of Landsat images was used to provide very detailed information on discrimination of sealed soils:

- Band combinations to identify and map road infrastructures and buildings (urban, periurban, industrial, sports, tourist areas, etc.).
- Changes detected between selected dates.
- Supervised classification of sealed soils.

Other digital image processing methods (principal components, Tasselled Cap, NDVI, etc.) do not give good results, as they do not differentiate sealed soils accurately from other groups (e.g. water, soils developed on gypsum or limestone, etc.).

The band combinations which best discriminate sealed soils are 5–4–1, 5–3–1, 5–3–2, 4–3–2 and 7–5–1, in red–green–blue spectra, respectively. The first combination (5–4–1) is shown in Fig. 1; here, the purple hues show urban and industrial areas and infrastructure. The increase of sealed soil in the last twenty years is also shown.

Using a combination of infrared and visible bands (1, 2, 3) allows accurate discrimination of any built-up area within the limits imposed by spatial resolution (30 m for Landsat satellites). Similarly, using thermal bands in red spectra (6–4–1) is useful for distinguishing built-up areas. Thermal bands also allow discrimination between types of soil sealing: roads, runways, housing, gardens, industrial areas, etc.

The geological layout over which soils have been generated influences their identification. It is easier to distinguish urban areas over Palaeozoic or tertiary arkose outcrops (N, W and central areas of the Madrid Region) than over the marls, gypsums, clays and carbonated materials of the E and S, as in the latter, geological outcrops can easily be mistaken for sealed soils. The use of different band combinations for mapping solves this problem to a considerable extent. On the contrary, the varied topography of this Region has not been a problem in detecting sealed soils, as they can also be differentiated by their spatial pattern.

Fig. 2 shows the sealed areas obtained from the 1989 and 2010 images, with different types of sealing in 4–3–2 band combination: in blue, the most compact buildings (continuous soil sealing); in red, housing with garden areas and urban parks; and in black, road infrastructure (discontinuous soil sealing). Comparison of the two images shows the growth of the capital city, and of the towns in the greater metropolitan area and on the E, SW and NW axes. In the Madrid Region the area of sealed soils has increased 38.6% (from 68,229 ha in 1989 to 111,094 ha in 2010). This sealed soil represents 8.5% of the Madrid Region in 1989 and 13.8% in 2010.

Comparing the two images and calculating the differences between them obtained a new image showing the increase in sealed areas over these years (Fig. 3), with growth over 10% (shown in black) and lower values (shown in white). This map neatly shows the soil lost: in the S and E areas, and along the A6 highway, in NW and N areas. In the rest of the Madrid Autonomous Region, sealing has occurred as a result of new roads and highways, especially where radial routes have been extended. Increased sealing can also be seen, although it is less important, where tourism has developed in the Central range and along the Tagus River.

Unsupervised and supervised classifications have been carried out to establish the accuracy of automatic classification and the results compared with those obtained by manual cartography through visual and digital analysis.

In unsupervised classification (independent of the number of classes assigned), the results are not completely reliable, as sealed and unsealed soils with natural vegetation cover and even bare soils developed over marls and gypsum are not differentiated. In addition, many sealed soils of this type are not included. Therefore it is essential to use supervised classifications working with TM images in this area. The most reliable classification is that not carried out with any parametric rule and with the minimum-distance algorithm (Fig. 4). Classifications made with maximum probability algorithms and Mahalonobis-distance are error prone, but even with fair reliability, they have some limitations. In the 1989 image, snow on the mountains is mistaken for urban areas, although it can be distinguished using a thermal band. In the 2010 May image, some urban soils are confused with gypsums and bare soils developed over neogenic materials from the SE of the Madrid Region. In these cases, the use of traditional cartography is better, as it avoids those mistakes. In fact, when using supervised classification, the difference in sealed area between the two dates is less (33,568 ha) than when drawn from original images (42,866 ha).

Analysing the set of images obtained by different digital methods, it can be concluded that the greatest soil sealing is shown in areas surrounding the city. Since 1989, soil sealing has mainly increased in three sectors:

- Large urban areas to the S, with mainly flat topography (population c. 100,000–200,000).
- Medium-sized urban areas to the N and NW of the capital (population c. 50,000–100,000), showing a rapid increase due to the development of the road network.