

Impact of three decades of urban growth on soil resources in Elche (Alicante, Spain)

Impacto en el suelo como recurso después de tres décadas de crecimiento urbano en Elche (Alicante, España)

Impacto sobre o recurso solo após três décadas de crescimento urbano em Elche (Alicante, Espanha)

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ABSTRACT

This article analyses the impact of soil sealing associated with three decades of urban growth in the Mediterranean coastal municipality of Elche (Alicante, Spain) on local soil resources. Geographical Information System (GIS) and remote sensing (RS) techniques were used to obtain and analyse different types of thematic information relating to urban growth and soil resources (soil class, land use capability, and physiographic classes). Map algebra techniques were employed to assess patterns of land occupation by urban growth and to compare maps of urban areas obtained from satellite imagery in 1978, 1992, 2001 and 2005 with thematic maps showing ancillary soil resources. Three different patterns of land occupation were identified in Elche: concentric growth outwards from the city of Elche (1978-1992), dispersed urban growth onto highly productive agricultural soils (1992-2001), and coastal urbanization (2001-2005). Soils with high land capacity for agricultural use were the ones most severely affected by soil sealing as a result of urban growth. Land use planning should therefore adopt measures to minimize the impact of soil sealing in agricultural areas in order to ensure the complete environmental functionality of the soil and guarantee food production.

RESUMEN

Este trabajo analiza el crecimiento urbano durante tres décadas del municipio costero mediterráneo de Elche (Alicante, España), con la finalidad de evaluar el impacto sobre el recurso suelo que ha tenido el sellado del suelo por el crecimiento urbano. Para llevar a cabo el estudio se emplearon métodos combinando un sistema de información geográfica y teledetección para obtener y analizar diferentes fuentes de información temática relativa al crecimiento urbano y al recurso suelo, tales como: clase de suelo, capacidad de usos y clases fisiográficas. Se emplearon técnicas de álgebra de mapas para detectar patrones de ocupación del territorio por el crecimiento urbano, comparando mapas de zonas urbanas obtenidos a partir de imágenes de satélite para 1978, 1992, 2001 y 2005, respecto a mapas temáticos del recurso suelo disponibles. Se identificaron tres patrones diferentes de ocupación del territorio en el municipio de Elche: crecimiento concéntrico desde el núcleo original de la ciudad de Elche (1978-1992), dispersión urbana ocupando áreas de suelo agrícola altamente productivas (1992-2001) y urbanización de la franja litoral (2001-2005). Los suelos con alta capacidad de uso agrícola fueron los más severamente afectados por el sellado del suelo en el crecimiento de las zonas urbanas. Resulta necesario considerar en la planificación territorial medidas para minimizar el impacto del sellado del suelo en las zonas agrícolas con la finalidad de garantizar la funcionalidad ambiental del suelo y la producción de alimentos.

RESUMO

Neste trabalho estudou-se o impacto sobre o solo, como recurso natural, do crescimento urbano ocorrido durante três décadas na cidade da costa Mediterrânica de Elche (Alicante, Espanha). Para levar a cabo este estudo recorreu-se a métodos que combinavam um SIG (Sistema de informação Geográfica) e um sistema detecção remota para obter e analisar diferentes fontes de informação temáticas sobre o crescimento urbano e o recurso solo tais como: tipos de solo, usos e classes fisiográficas. Utilizaram-se técnicas de cartografia para detectar padrões de ocupação do território devidos ao crescimento urbano, comparando mapas de áreas urbanas obtidos de imagens de satélite para 1978, 1992, 2001 e 2005, com mapas temáticos do recurso solo disponíveis. Foram identificados três padrões diferentes de ocupação do território no município de Elche: crescimento concêntrico do núcleo original da cidade de Elche (1978-1992), expansão urbana ocupando terrenos agrícolas altamente produtivos (1992-2001) e urbanização do litoral (2001-2005). Os solos com alta capacidade de uso agrícola foram os mais gravemente afectados pela impermeabilização do solo decorrente do crescimento das áreas urbanas. É, pois, necessário pensar em medidas de planeamento e ordenamento territorial que minimizem o impacto da impermeabilização do solo em áreas agrícolas com o objectivo de assegurar a funcionalidade ambiental do solo e produção de alimentos.

KEY WORDS

Soil resource, soil sealing, environmental impact assessment, land management

PALABRAS

CLAVE

Recurso suelo, sellado del suelo, evaluación de impacto ambiental, ordenación territorial

PALAVRAS-

CHAVE

O recurso solo, impermeabilização do solo, avaliação do impacto ambiental, ordenamento do território

1. Introduction

Soil is one of the most important natural resource and a key factor to understand the socioeconomic development in the Mediterranean basin. However, natural and human induced degradation processes are increasingly threatening Mediterranean soils. The importance of soil conservation is such that the land degradation has been identified as a primary cause that led to the decline of civilizations (e.g. Sumerians, Mayas, Rapanui, Anasazi) throughout the world (Good and Reuveny 2009).

Soil is a natural dynamic system ever-changing. Although these changes are slow and do not affect productivity in the short term, both the local effects of natural hazards and the general action of human activity generated more rapid changes denoted by high levels of land degradation (Sánchez 1993). Land degradation is a biophysical process driven by socioeconomic and political causes (Eswaran et al. 2001). Soil degradation implies a deterioration of the soil system to develop its functionality (Poch and Martínez-Casasnovas 2006). Complex physical, chemical and biological mechanisms are the responsible of soil degradation, which affects the soil capacity for self-regulation and productivity (Lal et al. 1989). In the context of land degradation studies, soil sealing is a current research topic.

Soil sealing is the destruction or covering of soils by buildings, constructions and layers of completely or partly impermeable artificial material (i.e. asphalt, concrete, etc.), being the most intense form of land-take and is essentially an irreversible process (Prokop et al. 2011). Soil sealing resulting from urban sprawl is fully recognized by the European Union among the main threats to European soils (Gardi et al. 2011). When land is sealed, the area for soil to carry out its functions is reduced and may have a great impact on surrounding soils by changing water flow patterns and increasing the fragmentation of biodiversity (European Commission 2002). The need to study soil sealing is due to the great efforts that are underway in the EU to assess changes in land use and environmental implications. CORINE Land Cover coordinated by European Environment Agency (EEA) and

Lucas coordinated by European Statistical Bureau (Eurostat) are two examples of projects aimed at monitoring changes in land cover/land use on European level (Gardi et al. 2011). All these efforts to understand the extent of soil sealing are due to the serious consequences involved. Soil sealing interrupts the exchange in between the soil system and other ecological compartments, including the biosphere, hydrosphere, and atmosphere, so all processes in the water cycle, biogeochemical cycles, and energy transfers are affected, leading to a number of negative effects on the soil system (Prokop et al. 2011): (1) less availability of fertile soils for future generations; (2) reduction of soil functions; (3) loss of water retention areas and increase in surface water runoff; (4) less soil carbon sequestration and carbon storage; (5) landscape fragmentation and loss of biodiversity through reduction of habitats and remaining systems too small or too isolated to support species; (6) unsustainable living patterns by urban sprawl; and (7) sealed surfaces have higher surface temperatures than green surfaces and alter the microclimate in particular in highly sealed urban areas. Thus, land managers and policymakers need information about soil changes and land degradation risks in order to be able to predict the effects of management on soil functions, compare alternatives and take appropriate decisions (Porta and Poch 2011).

Geographical information systems (GIS) and remote sensing (RS) techniques have introduced a new era for soil resources assessment and monitoring in terms of information quality (Mermut and Eswaran 2001). RS and GIS technologies are highly compatible, primarily because of the nature of RS as a source of spatial land use/land cover information to be merged with other datasets in GIS for environmental applications (Nizeyimana 2006). Both GIS and RS technologies have been frequently employed to map and model land degradation processes through the world (Lu et al. 2004; De Paz et al. 2006; Lavado et al. 2009; Meléndez-Pastor et al. 2010).

The objective of the study was the assessment of the environmental impact on the soil resource

after three decades of urban growth in a Spanish Mediterranean coastal municipality (Elche, Valencian Community). This work was based on several spatial analysis techniques and thematic information sources to quantify soil-sealing rate due to the development of new residential and industrial areas, and to evaluate the impact of urban growth in relation with the soil resource.

2. Materials and Methods

This study used geographical information systems and remote sensing techniques to map the temporal evolution of soil sealing as result of urban growth in the SE Spain (Elche, Alicante). Maps of dense urban areas (both residential and industrial areas) were obtained from satellite images from 1978 to 2005. Then, the evolution of urban expansion was related with the population of the municipality. Finally, the impact of urban growth was assessed in relation with the

soil resource information provided by maps of soil classes (De la Rosa et al. 2001), land capability (Antolín 1998), and physiographic classes.

Study area

The study area was the municipality of Elche on the southeast coast of Spain (Figure 1). The city is located around 38°16'N of latitude and 0°41'W of longitude. The municipality of Elche has an area of 326 km² and 230,822 inhabitants (the population in the city is 191,079), being the third city of the Valencian Community in 2010 (INE 2011). The climate is semiarid Mediterranean according to the aridity index of UNEP (1997), with a mean annual rainfall of less than 300 mm and mean annual temperature of 17 °C.

Major physiographical areas of the municipality are the following: (1) inner hills, located in the north boundary, with mountains up to 400 meter and where the *Pantano of Elche* was built in the XVII century (Ibarra 1895); (2) alluvial plains of Quaternary sediments carried away by the Vinalopó River and intermittent water courses

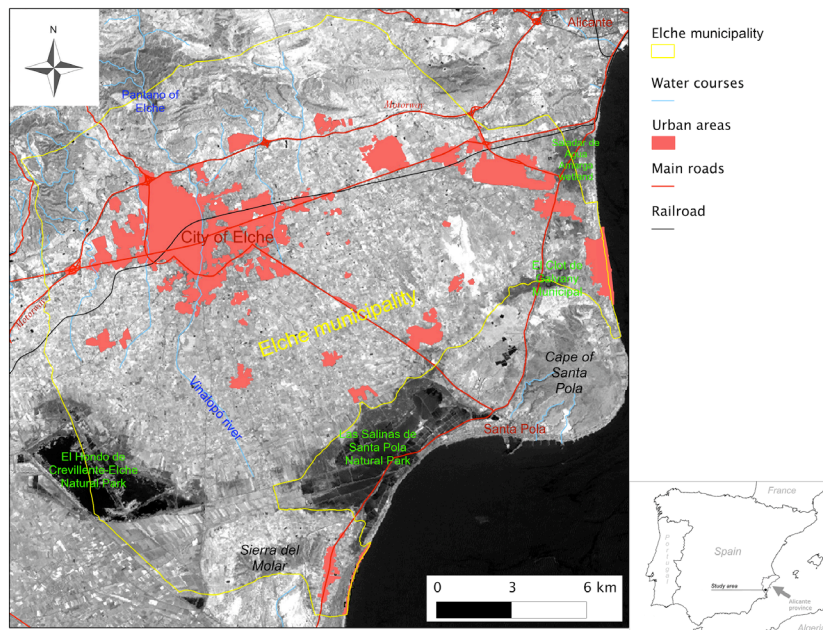


Figure 1. Map of the municipality of Elche. A background grey scale image of the Landsat ETM is shown.

(IGME 1973), nowadays occupied by dense and sparse urban areas and agriculture fields; (3) wetland areas, which centuries ago were part of a large lagoon (i.e. *Albufera of Elche*) and nowadays are protected areas but isolated by the drainage of the soil to expand agriculture; and (4) coastal areas constituted by the development of large dune systems that connected ancient islands (nowadays are coastal hills and cliffs) and separate the ancient lagoon from the sea (Box 2004).

Major economic activities are industry (shoe manufacture is the most important industry), irrigated agriculture, and tourism. The city of Elche is recognised by the *Palmeral*, a palm grove associated with the agricultural irrigation system built since the Islamic foundation of the city in the X century (Ibarra 1895). The *Palmeral of Elche* is included in the UNESCO-World Heritage List since 2000 (<http://whc.unesco.org/en/list/930>).

Satellite imagery

The urban growth of Elche began in the 1960's with the expansion of the shoe manufacture industry and the coastal tourism (Gozálvez et al. 1993). So, a historical repository of four Landsat scenes for 1978, 1992, 2001, and 2005 was employed for urban areas mapping. **Table 1** shows the main features of the satellite images used in the analyses. The scenes were acquired with the Landsat's MSS (Multispectral Scanner), TM (Thematic Mapper), and ETM+ (Enhanced Thematic Mapper Plus) sensors. This repository

was selected as the better information source to assess soil-sealing processes in the last decades.

Satellite images were properly pre-processed by the application of geometric corrections to ensure their multi-temporal comparability. Landsat scenes were georeferenced to guarantee their correct geographic location and the comparability of the images. Aerial orthophotos (scale 1:5,000) and digital cartography (scale 1:10,000) were used as spatial reference. The Landsat 7 ETM+ scene of 2001 was first geometrically corrected using Ground Control Points (GCP) identified on the orthophotos and cartography provided by the Valencian Institute of Cartography (ICV). This image was selected as the base image for the initial geometric correction for its better visual quality. The other Landsat scenes were co-registered to the base image. All images were resampled to 30 m of spatial resolution. In all geometric correction operations, a quadratic mapping function of polynomial fit and the nearest neighbour resampling method were used (using ENVI©, ITTVIS). The maximum allowable root mean square error (RMSE) of the geometric correction was less than half a pixel according to previous change detection studies (Townsend and Walsh 2001).

Urban areas mapping and temporal change

Urban areas are composed of a diverse assemblage of materials arranged by humans in a complex way, which greatly difficult the spectral recognition of urban landscapes (Jensen 2000).

Table 1. Overview of satellite images characteristics

Date (yyyy-mm-dd)	Satellite-Sensor	Path/Row/WRS	Spatial resolution (m)
1978-03-24	Landsat 2 – MSS	214/033/1	57
1992-04-20	Landsat 5 – TM	199/033/2	30
2001-06-08	Landsat 7 – ETM+	199/033/2	30
2005-05-10	Landsat 5 – TM	199/033/2	30

The delineation of urban/non-urban zones in the study area was particularly difficult by the presence of large palm groves within the city centre and the massive proliferation of sparse buildings along the entire municipality. One of the most suitable methods to delineate dense urban areas was the digitalization from satellite imagery with the aid of ancillary data. Historical topographical maps, aerial orthophotos, and land use maps aided in the delineation and validation of urban boundaries. Several false colour composites with the satellite images were employed as a tool to enhance the visualization of urban areas. The false colour composite RGB = Landsat TM/ETM+ bands 4, 3, 2 (MSS bands 7, 5, 4) and the false colour composite RGB = Landsat TM/ETM+ bands 7, 4, 2 were the most useful. During the early stages of industrial development in Elche, urban and residential areas were merged, precluding a proper separation of the two uses. The maps obtained only considered dense urban areas, both industrial and residential (using Geomedia Pro©, Intergraph).

Temporal change in soil sealing was quantified by pair-wise comparisons from consecutive urban area maps. Map algebra operators commonly implemented in raster-based GIS software were employed to extract and quantify new urban areas (using IDRISI©, Clark Labs). In addition, a derivative approach was used to assess the rate of urban growth (dS/dt) according to the following equation:

$$\frac{dS}{dt} = \frac{(S_2 - S_1)}{(t_2 - t_1)}$$

where S_i is the urban area mapped for a given year denoted by t_i . This expression relates the increase of urban surface with the lag of years lapsed between two maps. In order to assess the relationship between urban area growth and population, the number of inhabitants for the years of the satellite images were obtained from the census of Elche (INE 2011). Rates of urban and population increase were computed for all possible pair-wise combinations of urban maps and census data.

Soil resource maps

The impact of urban expansion on soil resource was evaluated considering three different environmental variables: (1) dominant soil class; (2) land use capability; and (3) physiographic class. The map of soil classes was obtained from the Spanish System of Soil Information (SEIS) (De la Rosa et al. 2001), freely available on the Internet. Soil classes were in accordance with the Soil Taxonomy classification system (Soil Survey Staff 1987). Land use capability expresses the host matrix for very general agricultural uses, evaluating what features are offered by the soil naturally and what are the limitations that restrict their use (Antolín and Año 1998). A map of land use capability of the Valencian Community was employed to assess the impact of urban sprawl on the most suitable for agriculture soils (Antolín 1998). That cartography has been developed according to the methodology proposed by Sánchez et al. (1984), derived from the land capability classification of Klingebiel and Montgomery (1961) with modifications introduced by McRae and Burnham (1981). A physiographical class map was developed to delineate the environmental units of the study area. The units were delineated according to the topography with the aid of a digital elevation model (DEM). A DEM is an ordered array of numbers that represents the spatial distribution of terrain characteristics such as surface elevation (Doyle 1978). A DEM for the study area was constructed by interpolating altitude contour lines of a topographic map (scale 1:10,000) with the aid of a triangulated irregular network (TIN). Resulting DEM was a raster image with the same spatial resolution than Landsat images. Slope and aspect parameters were derived from the DEM and also employed jointly with the elevation data and satellite imagery for the identification of physiographical classes.

3. Results

The soil sealing and urban growth were basically determined from the Landsat images and after that, they were compared with the population growth and soil resource variables to determine the impact of urban growth on soil resource.

Soil sealing by urban growth

Urban areas in the municipality of Elche notably increased from 1978 to 2005 (Figure 2). In the 1970s, major dense residential/industrial areas were located at the centre of the city of Elche, several urban areas spread in the *Campo de Elche*, and the airport infrastructure was created (located on the east of the municipality, halfway between the cities of Elche and Alicante). From 1978 to 1992, urban growth was notable at the right riverbank of the Vinalopó River for new industrial areas and at the north coast for tourism, and new residential states were developed towards the northeast of the city and the *Campo de Elche*.

In 2001 there were new urban areas at the left bank of the river with the construction of residential apartment blocks. Also, new residential areas were developed in the villages scattered throughout the municipality. In addition, the construction of a large industrial area located between the airport and the city of Elche began. This new industrial area grew significantly between 2001 and 2005. The new residential areas developed in the late twentieth and early twenty-first century continued growing.

The increase in sealed surface by the expansion of residential/industrial was on a par with a well-marked increase in the population of the municipality. In 1978 the population of Elche was 150,417 inhabitants with a sealed soil surface of 711.5 ha as determined by the map of dense urban areas (Figure 2). In 2005 the population of Elche increased up to 215,137 inhabitants and the sealed soil surface was 3292.2 ha. A strong positive correlation between population and urban areas was observed ($R^2 = 0.999$; p -value < 0.001) in this case.

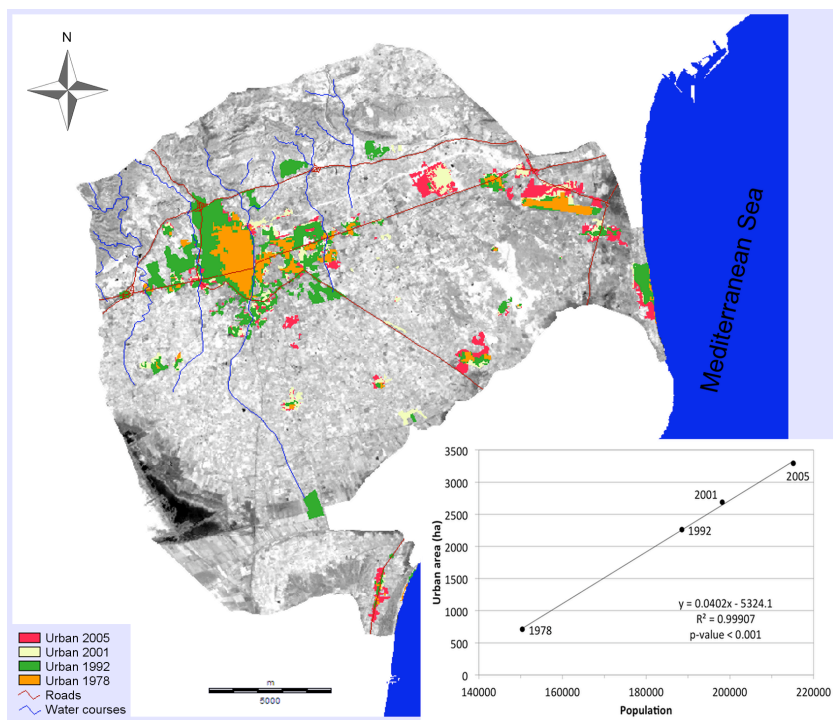


Figure 2. Map of urban areas expansion in the municipality of Elche from 1978 to 2005. A scatterplot relating population and urban area is included.

A derivative approach was used to assess the rate of urban growth (dS/dt) relating the increase of sealed surface (dS) with the time lag between satellite images (dt). The rate of population growth (dP/dt) was computed for the increase of population (dP) between satellite images (dt). All time intervals were in years. Data were available for four years (1978, 1992, 2001, and 2005), although six rates of popula-

tion growth and sealed surface were calculated. These six values of dS/dt and dP/dt are all possible combinations all four elements taken two at a time. It is expected that the consideration of all possible pairwise comparisons minimizes the effect of an exorbitant urban areas growth exceeding the demand generated by a smaller population increase (housing bubble).

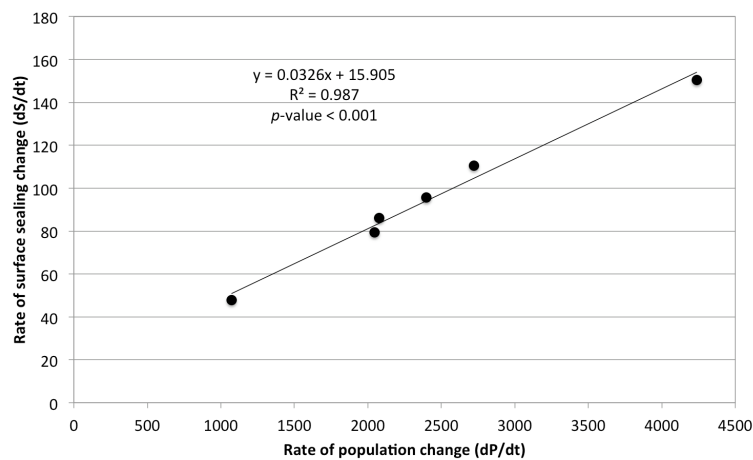


Figure 3. Scatterplot relating rates of population increase with urban growth.

A positive correlation ($R^2 = 0.987$; p -value < 0.001) between the rates of population change and soil sealing change was observed (Figure 3).

Soil resource variables

A digital elevation model (Figure 4.a) of Elche was computed and employed for further analyses. Altitude ranged from 0 m on the coast to 400 m in the hilly northern sector of the municipality. A cross tabulation among the DEM and each one of the soil resource variables maps was performed for a topographic characterization of individual categories (Table 2). The dominant soil class map obtained from De La Rosa et al. (2001), based on the Soil Survey Staff (1987), had established three categories (Figure 4.b) including three great groups of soils, namely Torrifluvents, Calciorthids, and Camborthids

(corresponding with Torrifluvents, Calcids, and Cambids, respectively, according to the Soil Survey Staff 2010). An association of Calciorthids and Camborthids was the dominant soils in the agricultural area of the Campo de Elche, whereas Torrifluvents dominated the lower and less stepped sector of the municipality. Dominant soil class in the northern and most mountainous area of the municipality was Calciorthid.

The land use capability map was obtained from Antolín (1998), including four categories from high capability to very low capability in the municipality of Elche (Figure 4.c). This system of land capability classification includes five different classes (from very high to very low and denoted by capital letters) and subclasses (lower case letters) to indicate limitations of use based on soil properties. The main characteristics of

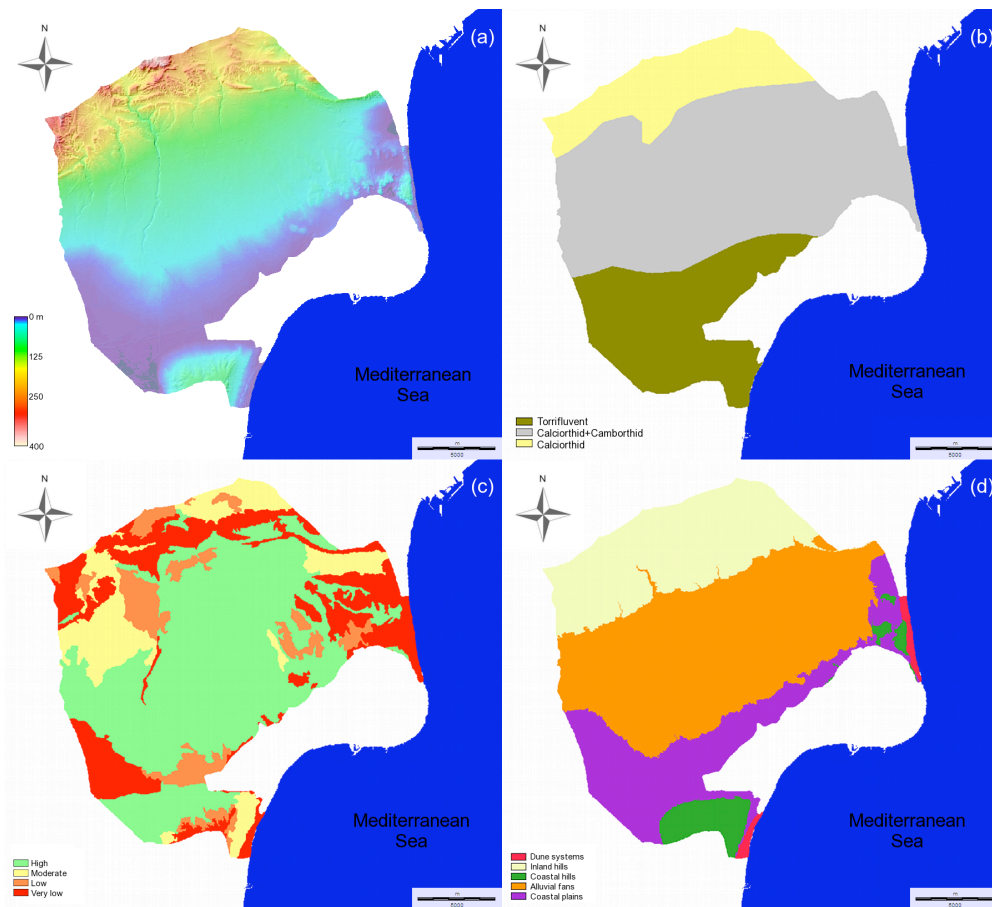


Figure 4. Maps of environmental variables considered in the study: 1) elevation; 2) major soil classes; 3) land use capability; and 4) physiographic classes.

land capability categories included in the study area are (Antolín and Año 1998):

- **High capability (B):** soils suitable for agriculture but with some physical (p) and chemical (q) limitations that require the implementation of more strict conservation practices. The categories Bpq and Bqp were present in the study area.
- **Moderate capability (C):** soil characteristics restrict agricultural usage and enhance degradation risk, especially erosion. The categories Cef, Cep, Cfq, Cgf, and Cxg were present in the study area. These soils are susceptible to erosion (e), high slope (p), stoniness (g), and may have a limited effective thickness (x).

- **Low capability (D):** soils with intense and severe limitations for agriculture and for many other uses. The categories Def, Dep, Dgf, Dsf, Dxg, and Dxr were present in the study area. Limitations by salinity (s) and rocky outcrops (r) were frequent for this category.

- **Very low capability (E):** These soils are unfavorable for almost any usage. The categories Eef, Eep, Eer, Efs, Epr, Esh, Exg, and Exr were present in the study area. Wetland soils were classified as Esh by their high salt content and water saturation (h) by their poor drainage and location at lower areas. On the opposite, the roughest sector of the municipality also had a very low agricultural land capability as is characterized by the highest slope and altitude of the study area, poor profile development, and high erosion risk (subclasses Eep, Eer or Exr).

Table 2. Summary statistics of altitude and slope for soil resource variables. Mean, standard deviation (St. Dv.), minimum (Min.), and maximum (Max.) values area included

Variable	Classes	Altitude		Slope	
		Mean ± St.Dv.	Min. Max.	Mean ± St.Dv.	Min. Max.
Soil class	Torrifluent	12.3 ± 14.2	-0.1 78.5	0.9 ± 1.4	0 17.5
	Calciorthid+Camborthid	59.4 ± 40.3	0.0 259.3	1.9 ± 2.9	0 43.4
	Calciorthid	191.8 ± 49.2	76.0 398.2	9.0 ± 7.3	0 50.4
Land use capability	High	46.5 ± 40.8	0.1 265.1	1.2 ± 1.7	0 35.1
	Moderate	100.5 ± 62.8	1.8 252.2	3.3 ± 3.3	0 44.6
	Low	95.2 ± 87.8	1.6 398.2	4.0 ± 5.4	0 50.4
	Very low	89.6 ± 91.6	-0.1 378.5	5.9 ± 7.2	0 49.4
Physiography	Dune systems	9.3 ± 9.8	-0.1 57.0	3.4 ± 3.1	0 23.0
	Inland hills	169.0 ± 51.3	100.0 398.2	7.4 ± 6.8	0 50.4
	Coastal hills	34.1 ± 19.3	12.0 78.5	3.1 ± 2.5	0 23.4
	Alluvial plains	47.5 ± 24.5	0.0 100.0	1.3 ± 1.6	0 35.3
	Coastal plains	5.7 ± 3.1	0.1 12.0	0.6 ± 0.9	0 23.3

The physiographical classes map (**Figure 4.d**) has the following five categories defined according to topographic and landscape criteria:

- **Dune systems:** coastal sand dunes that contributed to the formation of ancient wetlands by closing the outlet to the sea. Their heights exceed 10 m above sea level and are one of the largest and best-preserved dune systems in the south of the province of Alicante.
- **Inland hills:** the highest elevations and steeped slopes of the study area are located within this category. With a direction according to the NE-SW alignment of Subbética ridges to which they belong, they are a topographic barrier between the lower and middle Vinalopó.
- **Coastal hills:** they are low altitude littoral hills interconnected in between them by the dune system. The *Cape of Santa Pola* and the *Sierra del Molar* are Pliocene domes rich in marine fossils. These hills have gentle slopes except for a steep cliff in the *Cape of Santa Pola* coinciding with a fossil reef.

- **Alluvial plains:** this environmental unit corresponds with the land occupied by quaternary sediments carried by the Vinalopó River and many seasonal dry riverbeds. A large alluvial fan expands through the environmental unit with the vertex in the city of Elche. The boundary between the inland hills and the alluvial plains approximately coincides with the 100 m contour line.

- **Coastal plains:** this environmental unit is largely occupied with wetland areas and lies between the alluvial plains and the coastal reliefs. Their low altitude and slope induce a high susceptibility to flooding. Large and complex drainage systems have been developed for agriculture.

Very interesting features of the study area can be detected by overlaying the soil resource maps (**Table 3**). Torrifuents are generally soils of high land capability for agriculture more frequent on the coastal plains. The association Calciorthid + Camborthid occupies a large area of high land capability for agriculture and dominates the alluvial plains. The Calciorthid class is almost entirely restricted to the inland hills where the land

Table 3. Contingency matrix of soil resource variables. Values are in percentage of each cross-tabulation

		Land use capability				Soil class		
		High	Moderate	Low	Very low	Torrifluent	Calciorthid + Camborthid	Calciorthid
Soil class	Torrifluent	15.5	1.5	2.8	5.4			
	Calciorthid + Camborthid	36.2	8.3	5.0	9.6			
	Calciorthid	2.5	4.2	2.1	7.0			
Physiography	Dune systems	0.0	0.0	0.0	1.1	0.4	0.7	0.0
	Inland hills	6.4	6.0	4.0	8.7	0.0	9.5	15.6
	Coastal hills	1.4	1.1	0.9	1.5	4.0	0.9	0.0
	Alluvial plains	34.7	6.3	3.1	4.3	4.4	43.8	0.1
	Coastal plains	11.7	0.6	2.0	6.2	16.4	4.2	0.0

capability for agriculture is predominantly very low. Finally, dune systems have a very low land capability because they are sandy soils with very low water retention capacity.

Impact of urban growth on soil resource

The overlapping of urban growth maps with soil resource variables maps provides a simple and insightful method to assess the environmental impact of urban sprawl. The following combination of bar charts (Figure 5) shows the environmental patterns of soil sealing by urban growth for the time intervals 1978-1992, 1992-2001, and 2001-2005. For comparative purposes between time intervals, the proportion of new urban areas is the percentage of new sealed soil for each time interval independently of the absolute value of new urban areas.

From 1978 to 2005 new urban areas were predominately developed on the soil class association Calciorthid + Camborthid corresponding with the urban expansion through the *Campo de Elche*, with a progressive increase of soil sealing at Torrifluent areas by the development

of coastal residential areas. The pattern of soil sealing was more complex for the land capability and physiography variables. Both soil resource variables had more categories and a more complex spatial pattern than the soil class map. From 1978 to 1992, land consumption was almost equal for all the land use capability classes. Urban growth located at the alluvial plains and the lower and southern inland hills in the vicinity of Elche city (concentric growth). For the next time period (1992-2001), new urban areas sprawled through the municipality with a large impact on agricultural soils of the alluvial plains with high land capability. This could be considered a bad period of time for the conservation of highly productive agriculture soils. For the last time interval (2001-2005), there was a notable increase of soil sealing at very low and moderate land capability areas. The proportional increase of soil sealing at coastal hills and dune systems (which are characterized by moderate to very low land capability) suggests coastline urbanization for tourism or second residence. However, the coastal hill and dune systems are a relevant coastal ecosystem that should be conserved.

4. Discussion

Urban expansion often occurs on natural or agricultural land, and leads to a further deterioration of environmental quality in terms of air and water pollution and waste generation (De la Rosa 2008). Urban growth in Elche began in the 1960's with the expansion of the shoe manufacture industry and the coastal tourism (Gozálvez et al. 1993). Since then, the population growth has been steady and has been accompanied by growing urban areas (restricted in this case to residential and industrial areas). In fact, a linear regression analysis revealed a significant positive correlation between population and urban areas, observed through the time, with a Pearson coefficient of correlation $R^2 = 0.999$ between both variables (Figure 2).

Changes in the size of human population as well as changes in the activity of economic sectors may lead to urban expansion and infrastructure construction, thus built-up areas increase could be used as a proxy to quantify the land taken by urban expansion (Scalenghe and Marsan 2009). In this sense, a linear regression analysis revealed a significant positive correlation ($R^2 = 0.987$; p -value < 0.001) between the rates of population change and soil sealing change (Figure 3). This strong relationship suggests a correspondence between the urban expansion

and the demographic growth for the municipality of Elche. It is expected that an increase of 2 000 inhabitants will result in an increase of 81 hectares of new sealed soil (0.25% of the municipality area) by the expansion of urban areas.

An indicator of the intensity of land take is the proportion of the total built-up land area that is sealed (Prokop et al. 2011). The increase in sealed soil surface in Elche municipality was from 711.5 ha 1976 to 3292.2 ha in 2005, which is 4.5 times higher than at baseline. This increase pattern in urban areas of Elche is consistent with that observed in the CORINE Land Cover project for the whole Valencian Community, which found an increase in artificial surface above 50% between 1987 and 2000. This increment in urban areas has been largely at the expense of occupying agricultural land (OSE 2006).

Four mayor land transformation processes have taken place in Spain in the last decades (between 1987-2000) as were observed with the CORINE Land Cover project: (1) expansion of artificial land, especially sparse urban growth; (2) conversion from rain-feed agricultural fields to irrigated land; (3) alteration of forest ecosystems by forest fires and colonization of aban-

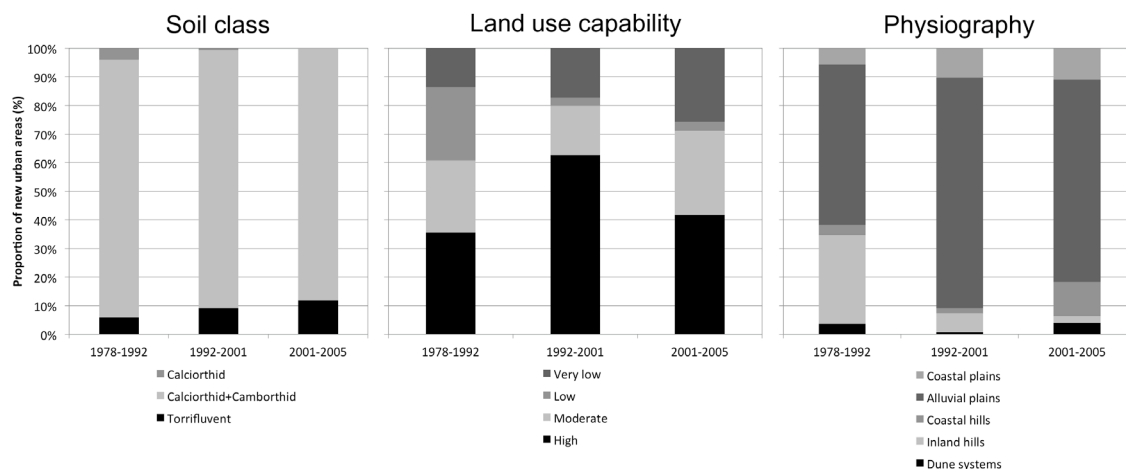


Figure 5. Impact of land use changes on environmental soil variables, land use capability, and physiographic classes.

doned rural areas; and (4) decline of natural wetlands, which can not be compensated by an increase in artificial reservoirs (OSE 2006). The more evident process of land transformation in the study area for the time period studied has been the growth of the original urban areas at the expense of consuming the surrounding agricultural land.

Although researchers have a growing knowledge about the processes and magnitude of land use/land cover changes and their environmental implications, there is no abundant information about the type of soil being sealed (European Commission 2002). Thus, spatial analysis may allow us to gain knowledge about the effects of urban growth in the soil resource by combining different layers of information on a GIS. The methodological approach of this study, analysing the spatial pattern of urban areas change on several soil resource information layers (soil class, land capability, and physiography), is an interesting and easy method to be implemented for quantifying the impact of soil sealing (Figure 5).

Spatial analysis revealed three different patterns of land occupation that occurred over time in Elche: (1) An initial phase of concentric growth of the city (1978-1992) due to the creation of outlying industrial zones and moving of ancient factories located inside urban areas to the new industrial areas. The impact of this first stage of urban growth on the soil resource was fairly equitable among the different land capability classes and physiographic categories. Most of the sealed soil corresponded with the soil class association Calciorthid + Camborthid (De la Rosa et al. 2001), the predominating soil class in the large agricultural area of the *Campo de Elche*. (2) The second phase was dominated by urban sprawl through highly productive agricultural soils between 1992 and 2001. A decrease in some soil availability is inevitable, but if the sealed soil plays a valuable role in food production, nature conservation, flood control or any other key function, then the consequences of sealing are damaging to sustainable development (European Commission 2002). (3) In the

last phase of coastal urbanization from 2001 to 2005, the soil sealing was remarkable along the coastline where soils are not very productive from the agricultural point of view (dune systems), but they have a great environmental value and need to be preserved.

Soil sealing is a major concern in land conservation. The sealing of soil can lead to decrease of water permeability, the loss of biodiversity, and in the reduction of the capacity for the soil to act as a carbon sink (Scalenghe and Marsan 2009). There is an urgent need to reduce the impact of soil sealing at the study area. Prokop et al. (2011) suggest three basic recommendations to combat soil sealing process: (1) prevent the soil sealing by implementing the prevention of soil loss as a key fact at the policy level; (2) limiting the soil sealing as far as possible; and (3) compensating soil losses by facilitating soil restoration measures somewhere else where they make sense. These logical recommendations should be seriously taken into consideration to guarantee the future availability of high quality soils suitable for agriculture.

Finally, the *Palmeral of Elche*, a traditional agro-system developed since the middle age has endured to our days thereby avoiding the total soil sealing in the centre of the city of Elche. This palm grove seated on the medieval irrigation system has enormous socio-cultural and environmental values and has been distinguished as World Heritage by UNESCO. Unsealed spaces play a crucial role in supporting urban ecosystems, a fact recognized in public policy commitments (Scalenghe and Marsan 2009). In addition, urban green infrastructure, depending on its quality in terms of naturalness and biodiversity, variability, size, form, and distribution, can provide an important variety of ecosystem services for quality of life in the city and makes cities resilient to climate and other changes (EEA 2010).

5. Conclusions

The combination of remote sensing and geographical information systems offers great possibilities for spatial analysis based on different sources of information and the methodology applied in this work can be easily adapted for quantifying the impact of soil sealing.

Based on these techniques, three different patterns of land occupation were detected when mapping urban areas in Elche (Alicante, Spain) with remote sensing imagery: concentric growth outwards from Elche city (1978-1992), dispersed urban growth onto highly productive agricultural soils (1992-2001), and coastal urbanization (2001-2005). Although different patterns of land occupation and soil sealing were observed during these periods, a significant correlation was found between population increase and soil sealing.

Soil sealing related to urban growth had a severe impact on the soil system and it was possible to gain important knowledge relating to this process by comparing maps of urban growth with soil resource maps using a GIS. Agricultural soils were those most affected by soil sealing in the study area. This type of agricultural soil consumption has had a severe environmental and economic impact due to the importance of agriculture in Elche. Land managers and politicians should therefore adopt policies to prevent, minimize and restore sealed soils, especially in areas with a high land capability for agriculture, in order to guarantee future food supplies and safeguard the environmental functions of soils.

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