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The Western Mancha aquifer: data mapping to provide transparency to aid stakeholder participation and decision making

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Abstract

The paper presents a series of maps on the Western Mancha aquifer, an aquifer of 5,500 km^2, extending over an area of 41 villages in the region of La Mancha, in the central Spanish plateau. Maps were produced using cartograms, which highlight the differential groundwater use at the local level of the municipality, looking at equity and efficiency issues related to groundwater. The main purpose of the paper is to provide comprehensive, transparent and easily understandable mapping of groundwater use in a region where data is abundant but not necessarily consistent, clear or presented in an easily accessible or understandable format. The paper provides a meta-analysis in the form of maps of available data as a result of a large number of European research projects, national and European policy initiatives, but where a general multi-disciplinary and summative overview is still lacking. This mapping can contribute to decision making in public policy, as support for compliance with the European Union Water Framework Directive on good ecological status, in an area where there are competing, and in many ways incompatible, water demands between irrigation and wetlands. This analysis highlights that a spatially differentiated approach could provide win-win scenarios, i.e. intensive groundwater use and wetland protection.

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1. Introduction

The Western Mancha aquifer is one of the largest aquifers in Western Europe, extending over 5,500 km^2 (Figure 1), and one of the most studied aquifers because of conflict over water use between farmers and wetlands. Despite the large number of scientific studies and public policy initiatives, there is a high level of uncertainty on key issues like the number of irrigated hectares (Llamas, 1988; Cruces de Abia et al., 1996; Martínez Santos et al., 2008). One of the main problems of this intensive aquifer use is that it is exploited by thousands of farmers over a large area, where - in a classic example of the 'tragedy of the commons' - the rational actions of farmers have led to a drop in aquifer levels of between 20 to 30 meters and the emptying of 3,000 M m^3 from 1980 to 2004 (Martínez Cortina, 2001; Confederación Hidrográfica del Guadiana, 2008). Additionally, and in line with many areas of the world, much of the water abstracted is outside the formal regulatory framework (i.e. abstracted illegally).

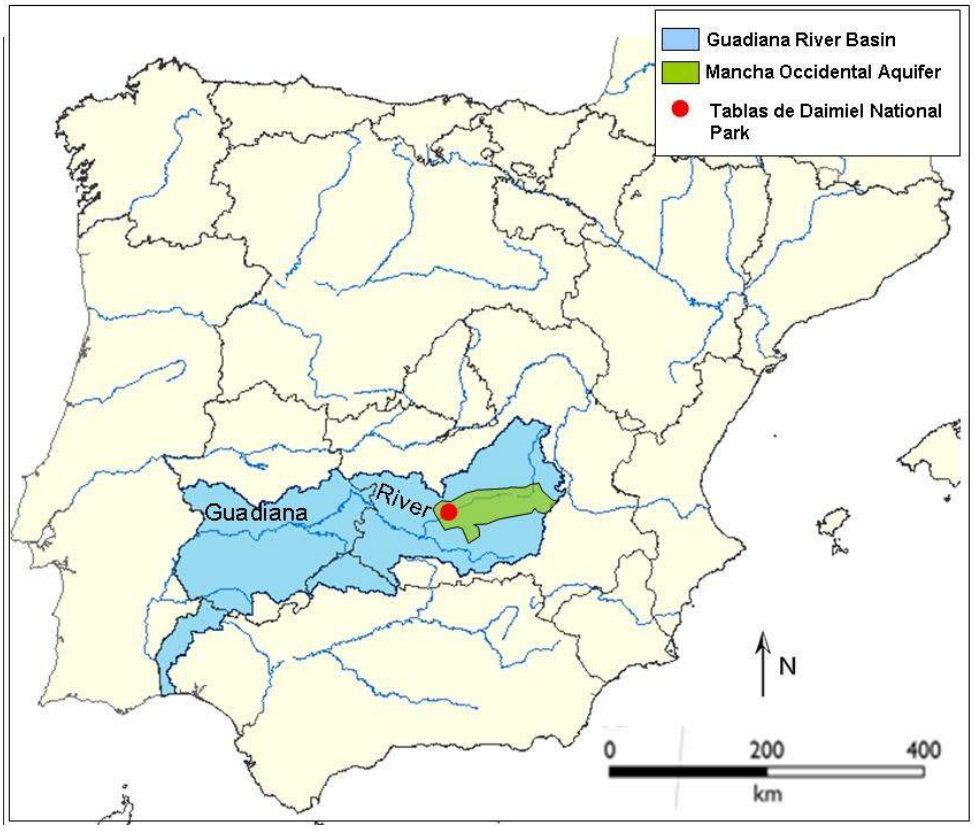

Figure 1. Location of the Western Mancha aquifer (Guadiana basin- Spanish part).

This intensive groundwater use has translated into clear environmental externalities, as impacts on protected wetlands dependent on the aquifer outflow. The recovery of the Western Mancha aquifer is essential for the restoration of the Mancha Húmeda Man

and the Biosphere reserve, a series of wetlands that has reduced its area from 25,000 ha to 7,000 ha over the past 30 years (De la Hera, 1998; Aragon and Crespo Zamorano, 2007). A key element is the Tablas de Daimiel National Park, a wetland of international environmental value protected under international, European and national law, and currently a red listed Ramsar Site. Compliance with changes introduced under the European Water Framework Directive (WFD) require that good ecological status is achieved by 2015 (or 2027 if an extension is granted). As a result this area is currently undergoing a comprehensive plan, the Special Upper Guadiana Plan, with a budget of €5,000 Million to comply with the directive's requirements (Confederación Hidrográfica del Guadiana, 2006). In addition as highlighted in Map 1 (blue line), the Western Mancha aquifer will be managed for the purposes of the WFD as three separate water bodies.

Despite advances in science and technology during the last 10 years, the level of uncertainty in key variables has increased rather than decreased (López Gunn, 2003; Zorrilla, 2009). For example, in the case of estimated irrigated area (the main determinant for the amount of water abstracted), data ranges between 130,000 ha to 254,000 ha for similar years (Confederación Hidrográfica del Guadiana, 2008; Zorrilla, 2009). In this context, adaptive management is based on flexible decision making that can be adjusted to uncertainties, as outcomes from management become better understood and can be fed back into the system. Large aquifers classify as systems with inherently high levels of uncertainty, where multiple and changing objectives are required (National Research Council, 2004). In addition, one of the key policy principles in water governance is transparency. Transparency is a core component of second generation institutional reform, and it is increasingly associated with better socio-economic development, as well as with higher competitiveness and lower corruption, which ultimately can improve policy outcomes (Bellver and Kaufmann, 2005). This is the purpose of the maps presented here: to provide transparency on the existing data.

2. Methods

Comprehensive data was collected on the factors influencing groundwater management in the area. A series of primary and secondary data sources were utilized (detailed in Table 1), largely based on data from the *Confederacion Hidrografica del Guadiana* (Guadiana Water Authority; Figure 1), and Official Statistics of the agricultural and population census. Maps have been produced stating the origin and year of the data.

The main data handling involved the collection of data into a single file and its presentation as a uniform set of cartograms. Cartograms represent map feature surfaces in such a way as to make them proportional to a given statistical variable. A cartogram is a map in which some thematic mapping variable - like population or agricultural added

value - is substituted for land area. The geometry and space of the map is distorted in order to convey the information of this variable. An area cartogram is sometimes referred to as a value-by-area map which, as stated earlier, illustrates the relative size of the variable represented by scaling the area, in this case of each municipality in proportion to the variable represented; the shape and relative location of each municipality is kept. For example the area size of each municipality in the case of Cartogram 2, shows the proportion of all population that live in each municipality from the total number of population living within the aquifer perimeter. It highlights that a relatively small village like La Solana has a relatively large number of people proportionate to its small size. It should be noted however that this cartographic distortion does not allow for a detailed technical and scientific comparison among different thematic maps in terms of quantification, where instead the original data used to generate the cartograms should be used. An additional limitation is the fact that these cartograms only show a snapshot in time, and therefore lack a dynamic view of the groundwater system responses to development. This is a deficiency that is partly due to the data available. In the future this could be addressed with other dynamic forms of data representation, such as 'gapminder' (http://www.gapminder.org).

Here we present 1 map and 15 cartograms that were produced characterizing agricultural groundwater use in the area, which account for 95% of the total water use. The cartograms are presented in three sheets; in each sheet, the first map shows the real surface area of each municipality (Map 1). The first sheet of cartograms characterize the agricultural sector in the aquifer: maps were produced on population (Cartogram 2), water abstraction (Cartogram 3), value added in agriculture (Cartogram 4 and Cartogram 5) and water productivity (Cartogram 6). The second sheet of cartograms highlight water use for agriculture, in particular cartograms have been produced for rainfed farming (Cartogram 7), total irrigated area (Cartogram 8), irrigated cereal (Cartogram 9), irrigated vineyards (Cartogram 10) and horticultural irrigated area (Cartogram 11). The third sheet of cartograms represent water allocation by indicating the number of farmers (Cartogram 12), the legally irrigated area (i.e. with recognized water rights) (Cartogram 13), the illegally irrigated area (Cartogram 14), the number of wells (Cartogram 15) and the number of complaints. This refers to official lodging of complaints by officers from the river basin authority under different categories such as a new illegal well, or abstracting more water than the allocated water rights (Cartogram 16). In terms of map design, the color of each village is always the same to facilitate interpretation and comparison between maps.

	Carto-gram	Theme	Unit	Data source (Secondary & Primary)	Year	Data reliability, accuracy and confidence
General	1.	Area	Km^2	Confederación Hidrográfica del Guadiana (2006)	2006	High
	2.	Population	inhabitants	Confederación Hidrográfica del Guadiana (2006) based on Censo de Población y Vivienda (Instituto Nacional de Estadística (INE) 2001)	2004	High
Correlations with potential policy implications	3.	Water abstractions from agriculture	m^3/ha	"Hojas 1T" (MARM)	2007	Medium
	4.	Agricultural Added Value		Confederación Hidrográfica del Guadiana (2006) based on Contabilidad Regional de España (INE), 2001	2001	Low
	5.	Agricultural Added Value from irrigated crops	Million euros	"Hojas1T" Ministerio de Medio Ambiente, Rural y Marino (MARM)	2007	Medium
	6.	Water productivity	Euro/ m^3	"Hojas1T" (MARM)	2007	Medium
Agricultural water use	7.	Rainfed farming	Hectares (ha)	"Hojas1T" (MARM)	2007	Medium
	8.	Irrigated area	Hectares (ha)	"Hojas1T" (MARM)	2007	Medium
	9.	Irrigated area of cereals (a)	Hectares (ha)	"Hojas1T" (MARM)	2007	Medium
	10.	Irrigated area of vineyards (b)	Hectares (ha)	"Hojas1T" (MARM)	2007	Medium
	11.	Irrigated area of horticultural products (c)	Hectares (ha)	"Hojas1T" (MARM)	2007	Medium
Farming population and water allocation	12.	No farmers (total)	No farmers	Instituto de Estadística de Castilla la Mancha (2007) based on Ministerio de Trabajo y Asuntos Sociales. Secretaría de Estado de la Seguridad Social. Afiliaciones Seguridad Social.	2007	High
	13.	Legally irrigated area	Hectares (ha)	Confederación Hidrográfica del Guadiana (2008)	2006	Medium
	14.	Illegally irrigated area	Hectares (ha)	Confederación Hidrográfica del Guadiana (2008)	2006	Medium
	15.	No of wells (incl. legal and illegal)	No. wells (000)	Confederación Hidrográfica del Guadiana (2008)	2006	Medium
	16.	Complaints	Number complaints	Confederación Hidrográfica del Guadiana (2008)	2006	Medium

Table 1. List of cartograms generated, with data sources and dates. These data include both legally and illegally irrigated areas, i.e. total crop area

3. Discussion

The main goal of this mapping exercise is to provide transparency in groundwater use in order to aid decision making and, in line with the Special Upper Guadiana Plan, a strategic approach to the re-allocation of groundwater rights. This study shows that the strategic purchase or re-allocation of water rights could prioritise areas and sectors since current water use is highly spatially variable. In addition, as shown below, some areas in the aquifer could have added value in terms of wetland conservation and achievement of good ecological status.

A number of issues become relevant from the spatial analysis presented: first, it indicates potential interesting associations and correlations between variables, and consequently the generation of a map (Cartogram 6), which, for example, shows the spatially

Map	Title	Unit	Unit	Year
1	Undistorted municipalities	8,355	Squared km	2006
2	Population	304,374	Inhabitants	2004
3	Water abstractions from agriculture	372	Mm^3	2007
4	Agricultural value added	342	Million euros	2001
5	Agricultural value added from irrigated crops	336.2	Million euros	2007
6	Water productivity	0.9 as average	Euros/mm^3	2007
7	Rainfed area	265,347	Hectares	2007
8	Irrigated area	135,251	Hectares	2007
9	Irrigated area of cereals	67,535	Hectares	2007
10	Irrigated area of vineyards	49,812	Hectares	2007
11	Irrigated area of horticualtural products	17,904	Hectares	2007
12	Number of farmers	12,999	Farmers	2007
13	Legally irrigated areas	207.865	Hectares	2006
14	Illegally irrigated area	52,368	Hectares	2006
15	No of wells (incl. legal and illegal)	42,811	No wells	2006
16	Complaints	6,885	No complaints	2006

Table 2. Cartograms and Units

distributed water productivity in terms of euros per m^3. This can be useful for the development of public policy in land/water use planning, by making the range of options visually available in an easily accessible format. For example, in terms of efficient water use, cereals represent 55% of the water abstracted and of this 55%, almost half is abstracted in only three villages. Yet, in terms of productivity, cereals only account for 19% of the value generated. Meanwhile, vineyards, which account for only 21% of the water abstracted, generate 46% of the economic value. Figure 2 highlights water withdrawals, which is not consumption, but rather the amount of water lost from the system (by ET, incorporation in crops, etc.).

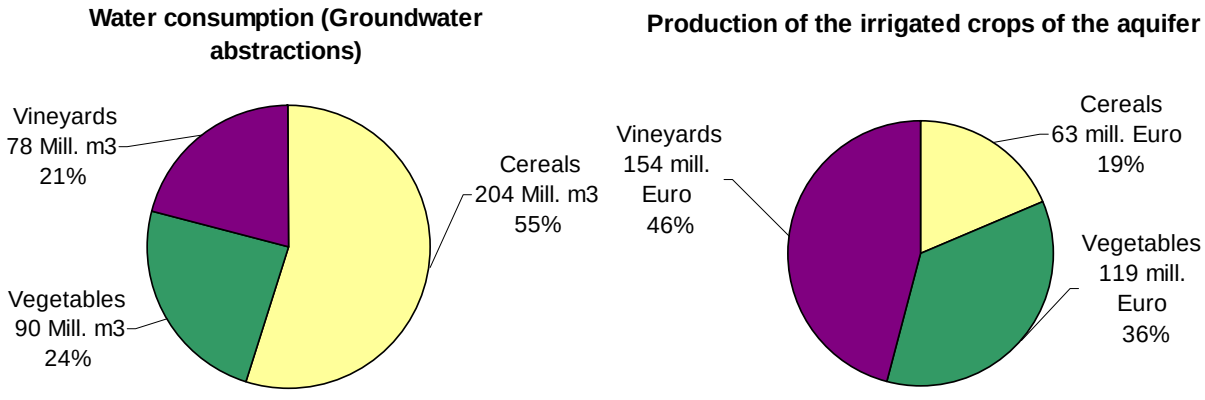

Figure 2. Water consumption and irrigated crops in the Western Mancha aquifer.

In terms of irrigated area, the maps enable visualization of spatial distribution patterns of legally and illegally irrigated land. In terms of equitable allocation, three villages

hold 44% of the legal water rights, yet these villages only represent 7% of the farmers in the aquifer.

One of the main objectives of this paper is to highlight the spatial distribution of water use and allocation. A preliminary conclusion is that a priority could be the purchase of cereal water rights for re-allocation to vineyards, horticultural crops and wetlands, for two reasons: (i) it would be more efficient in terms of water productivity (see Cartogram 6); (ii) it would be more equitable in terms of the number of farmers benefitting (see Cartogram 12) and a more equitable allocation of water rights between uses, including wetlands.

4. Conclusion

Through the production of a series of comprehensive cartograms at a relatively small scale, we aim to contribute to strategic Cartogram mapping, which can prove effective at showing how water is used. Furthermore, strategic Cartogram mapping can facilitate the participation of stakeholders and the general public in associated debates about water rights. Cartograms have been chosen because they are a graphic and easily understandable format for presenting complex data to the wider public and to stakeholders. This also contributes to opening up decision making processes in a topic that is difficult to comprehend, due to its technical nature and high level of uncertainty.

Transparency in groundwater use and allocation is a key step in the process of stakeholder participation. The paper is based on two working hypothesis that will be developed in separate papers: first, transparency as a key element in the development of social capital, which often underpins collective action, e.g. in common pool resources. Second, a more spatially differentiated management approach to groundwater bodies is needed, in line with recent experiences undertaken by the US Geological Survey (Alley, 2006; Leake et al., 2008)

In the context of a public policy programme to invest €5000 million over a twenty year period, this paper has two main conclusions: the need to adopt a more spatially nuanced approach to decision making for large groundwater bodies under the Water Framework Directive and second, the need to integrate different types of information, e.g. on the productivity of water, or the allocation and re-allocation of water rights amongst competing users in a transparent manner.

Software

The map layout was performed using ArcGIS v9.2. The data and different variables were processed in Microsoft Excel. The meta-data were checked for reliability, accuracy, and confidence in the data presented. Then, using digital maps provided by the Guadiana water authority, these were converted into cartograms using ScapeToad-v11. ScapeToad uses the Gastner and Newman (2004) diffusion-based algorithm to adapt map surfaces to user-defined variables without altering their topological relations.

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