GROUNDWATER USE CHANGES IN SPAIN SINCE 1950: PAST AND PRESENT, CHALLENGES AND OPPORTUNITIES

Changements de l'usage de l'eau souterraine en Espagne depuis 1950: passé et présent, défis et opportunités

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ABSTRACT

Spain is the most arid member country of the EU. Its water management policy, as in most semiarid countries, has failed to prevent the loss of 60% of its wetlands, some aquifers are heavily exploited or in a situation of unfavorable ecological status, and surface waters have decreased flows and impaired chemical quality. The historical analysis of groundwater management since 1950 allows identifying its strengths and weaknesses, in an era of economic growth in Spain. The various water crises that have occurred in Spain since the beginning of the second half of the 20th century and the lessons learned from them are discussed. The state's water policy was based essentially on the regulation of surface waters and to a much lesser extent on the extraction of groundwater. In the 1960s, initiatives related to the investigation of groundwater in the Eastern Pyrenees basins, in north-easter Spain, pioneered what would later be the management of groundwater in the 21st century and the scientifically based hydro-geological studies throughout the country, thus fostering a significant increase in academic groundwater-related activity. Two milestones stand out since 1950: a) the Water Law of 1985, which in spite of successive modifications has failed to adapt to the reality of groundwater in Spain, favoring some legal and administrative confusion that significantly hinders its management and b) the implementation of the European Water Framework Directive (WFD) of 2000, which has fostered progress in the knowledge of the ecological, qualitative and quantitative state of groundwater and greatly improved transparency and accessibility. However, should the WFD provisions be strictly enforced, many groundwater intensive developments and productive activities in Spain may have to cease. The real challenge for the administration, technical staff, political forces, and social stakeholders in southern Europe countries will be to find the paths to the effective implementation of WFD principles in their specific hydro-climatic and socio-economical contexts and how to face water scarcity and droughts. To confront real issues, different practices of conjunctive use of surface and groundwater, such alternate use and karstic spring regulation are in use in Spain, as well as artificial recharge and modeling of complex water resources systems. Some attention is devoted to the impacts and uncertainties produced by climate and global change. Hydrological, economic and governance issues are considered as well as the associated uncertainty. Finally, both the role that aquifers can play and the role of virtual water concept in drought mitigation are considered.

KEY WORDS

Aquifer, Spain, water management, Water Framework Directive (WFD), water policy, wetlands.

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RESUMÉ

L'Espagne est le plus arid pays membre de l'Union européenne. Sa politique de gestion de l'eau, comme dans plusieurs pays semi-arides, n'a pas réussi à empêcher la perte de 60 % de ses zones humides, que certains aquifères soient très fortement exploités ou dans une situation d'état écologique défavorable et que les eaux de surface aient diminué le débit et la qualité chimique ait devenue pire. L'analyse historique de la gestion des eaux souterraines dupuit 1950, quand l'Espagne entra dans une ère de croissance économique, a permis d'identifier ses forces et faiblesses. Les diverses crises de l'eau qui ont eu lieu en Espagne depuis le début de la seconde moitié du XXème siècle et les enseignements tirées sont discutés. La politique de l'eau de l'Etat reposait essentiellement sur la régulation des eaux de surface et dans une moindre mesure sur l'extraction des eaux souterraines. Dans les années 1960, les initiatives liées à l'étude des eaux souterraines dans les bassins des Pyrénées-orientales a le norrdest de l'Espagne, lanca ce qui allait devenir la gestion des eaux souterraines au XXIème siècle. Les études hydrogéologiques scientifiquement établies dans tout le pays ont produit une augmentation significative de l'activité académique axée sur les eaux souterraines. Deux étapes se distinguent depuis 1950: a) la Loi sur l'eau de 1985, qui, en dépit de ses modifications successives, n'a pas réussi à s'adapter à la réalité des eaux souterraines en Espagne, en favorisant la confusion juridique et administrative qui entrave considérablement sa gestion et b) la mise en œuvre de la Directive Européenne Cadre eau (DCE) de 2000, qui a favorisé les progrès dans la connaissance de l'écologie, état qualitatif et quantitatif des eaux souterraines et a grandement amélioré la transparence et l'accessibilité. Toutefois, si les dispositions de la DCE sont strictement appliquées, nombreux développements intensifs des eaux souterraines et part des activités productives en Espagne pourrait cesser. Le véritable défi pour l'administration, les techniciens, les forces politiques et les intervenants sociaux dans les pays du sud de l'Europe sera de trouver les chemins d'accès à l'application effective des principes de la DCE dans leurs contextes spécifiques hydro-climatiques et socio-économiques et comment faire face à la pénurie d'eau et la sécheresse. Pour affronter les vraies questions, différentes pratiques d'utilisation conjointe, comme la utilisation alternée et le règlement karstique sont utilisées en Espagne, ainsi que la recharge artificielle et les modèles pour les systèmes complexes de ressources en l'eau. Une certaine attention est dédiée aux répercussions et incertitudes produites par le changement climatique et global. Les aspects hydrologiques et économiques et les questions de gouvernance sont également examines ainsi que leur incertitude. Et enfin, le rôle que peuvent jouer les aquifères et le concept d'eau virtuelle dans l'atténuation de la sécheresse sont considérés.

MOTS-CLEFS

Aquifère, Espagne, gestion de l'eau, Directive-Cadre sur l'Eau, politique de l'eau, zones humides.

1. INTRODUCTION

Spain extends over a large part of the Iberian Peninsula and includes two main archipelagos, the Balearic Islands in the Mediterranean Sea and the Canary Islands in the Atlantic Ocean, plus two cities in North Africa. It is a complex, varied territory in SW Europe, comprising from humid to semi-arid and near-arid areas. These last ones cover more than two-thirds of the land, mostly in the center, along the eastern and southern coastal areas and in the archipelagos, where a high percentage of the population, the corresponding industry and services, an important tourism industry and especially rich well-developed intensive agriculture based on irrigation are placed. As a Member State of the European Union, Spain has to adapt its own legislation to the general rules (Directives) of the Union. The fact that Spain is the most arid of the EU members, with a high water use, leads to unique situations that need special consideration. This paper focuses mainly on groundwater, whose abstraction is around 7 km^3/year and the effective recharge is around 30 km^3/year.

Water supply for urban and irrigation uses has been problematic in Spain since pre-Roman times, with different solutions adopted depending on the moment, technological capacity, social circumstances and political situation. To address the problems, the solutions consist in physical infraestructures and facilities but also in social and legal instruments, starting from an important Roman and Arab heritage.

This paper considers almost exclusively groundwater policy in Spain, considered in global framework. There are noticeable differences throughout the country. Several factors make the Spanish case relevant, including (1) the size, ca. 500,000 km^2 and population, about 47 million inhabitants, (2) the dramatic political and economic changes over the last 50 years, with the gross income increasing from US$ 300 to 30,000 per person per year, and (3) the background of water use and its socioeconomic implications.

This paper aims to provide an overview of the past and present strengths and weaknesses of Spanish groundwater policy, to enable a road map to be designed for future, more efficient water governance. It is important to take into account that considerations and figures at country level and even at regional level are poor and biased representations of local reality as circumstances vary dramatically from area to area.

2. GROUNDWATER DEVELOPMENT IN SPAIN

The history of hydrogeology and groundwater development in Spain has been the subject of several studies, such as Martínez Gil (1991) and Custodio (2013a) and the many relevant references cited in them. Altough early technological developments date from the late nineteenth century, intensive development started in the mid-twentieth century, first on the Canary Islands and wide areas of the Segura and Júcar basins, including the Guadalentín valley, for irrigation and urban and industrial supply, and the urban supply of the Barcelona Area. Since the 1950s intensive irrigation developments took place, most of them in south-eastern Spain.

2.1 Before 1950

Since Spain's first Water Law in 1866, most surface waters have been considered a public domain (Fornés et al., 2007). Until the mid-twentieth century, when Spain entered a new era of economic development, governmental water policy was based mainly on the artificial regulation of river flows and to a much lesser extent on groundwater extraction carried out mainly by private enterprises. Surface water was generally regulated on a statewide basis, except for hydroelectricity production. In contrast, groundwater was normally considered as a mineral resource to be used by whoever "tapped or discovered ir". There was little understanding of the underground part of the water cycle and the technology required for drilling water wells and for groundwater abstraction was underdeveloped, as recognized in the book edited by López-Geta and Fornés (2013).

2.2 After 1950

The considerable scientific and technological changes from the 1950s and 1960s onwards had a significant impact, although the construction of large dams to regulate water was still a predominant feature of government policy. In the late 1940s, the *Instituto Nacional de Colonización* (INC, National Institute for Settlement, later transformed into the IRYDA, Institute for Agrarian Reform and Development) started to sink a large number of drilled wells using modern machinery to boost agricultural development in new areas promoted by the government.

Studies of the hydrogeology and groundwater resources of the volcanic Canary Islands were also undertaken by the SGOP and UNESCO (Project SPA-15), which provided new advanced knowledge on these particular hydrogeological conditions (Cabrera et al. 2011).

In the period 1950-1970, ten years later than in south-western United States and at the same time as in Mexico, France and the French-administered territories in North Africa, a dramatic development took place in Spain, with groundwater becoming an important fresh water source for irrigation and water supply of many large towns in the Mediterranean area and in the archipelagos. Even so, Spain is one of the countries in Europe that uses the lowest percentage of groundwater for urban water supply (Llamas et al. 2001).

The year 1965 can be considered as the starting point for scientific hydrogeology in Spain. Evidence of this is that in 1967 the first international postgraduate courses specializing in hydrogeology were offered in Barcelona and Madrid. The *Curso Internacional de Hidrología Subterránea* (International Groundwater Hydrology Course) is still offered, and by 2016 will have been running continuously for fifty years; in fact it is the longest running Spanish university postgraduate course. The course materials were compiled, completed and published in the major work: *Hidrología Subterránea* (Custodio and Llamas 1976).

In 1975 the first Community of Groundwater Users to deal with groundwater issues, independently of the type of use and with a vision wider than the management of common infrastructures, was set up in Spain in the Lower Llobregat valley and delta. It has served as a model for some twenty other similar associations all over the country (Custodio 2010; Thuy et al. 2013). Today they are integrated into the *Asociación Española de Usuarios de Aguas Subterráneas* (Spain's Groundwater Users Association).

López-Geta (2000) considers that the period 1970-1985 made an outstanding major contribution to generating the infrastructure of hydrogeological science in the history of Spain, thanks to the work of the SGOP, the IGME and various University Departments in different cities, and the many hydrogeologists working in Spanish companies, organisations and universities.

In the second half of the 20th century, agriculture in arid and semi-arid countries pionereed a 'silent revolution' of intensive groundwater use, especially in Spain (Llamas and Martinez-Santos 2005; 2006; Fornés et al. 2007), challenging regulations. During that period, Spanish water authorities played a secondary role due to groundwater being under private ownership, as explained below. Therefore, groundwater abstraction escaped from governmental control and so also did its appropriate management, as is the case in many developing and developed arid and semi-arid countries worldwide.

Two important documents have been released recently, the white paper on Groundwater in Spain (MOPTMA-MINER 1994) and the white paper on Water in Spain (MIMAM 2000), as well as a preliminary evaluation of the costs and prices of groundwater in Spain (MIMAM 2003).

2.3 After 2000

The Directive 2000/60/CE of the European Parliament (WFD 2000) establishes a framework for community action in the field of water policy from an environmental viewpoint; the main aim is water protection through sustainable use, with ongoing reduction of contamination and pricing water use on a full cost recovery basis. This opened up a new panorama for water studies, widening the range of research possibilities and integrating groups of scientists from different areas, which undoubtedly have enriched water science overall and have provided a clear improvement in aquifer knowledge (López-Geta and Fornés 2013).

3. MAIN TENSIONS FROM THE LEGAL AND MANAGEMENT POINT OF VIEW

3.1 Water legislation in Spain and groundwater

Regulations for water acquisition and use have existed for centuries but at local level and with varied rules adapted to the different circumstances and historical heritage. This has proved a major handicap for countrywide development. These regulations rarely referred specifically to groundwater, a minor and poorly known resource at the time. In general terms, the water below the land surface was considered the property of the land owner, as in many countries. In 1866 the first national Water Act was drawn up, in which both surface and groundwater were considered public domains. This was too advanced at that time, when groundwater was hardly susceptible to regulation. It was soon replaced by the 1879 Water Act, which was in force until 1985. In the 1985 Water Act groundwater was declared a public domain. A main innovation is that the State, not the individual, is responsible for groundwater management. To avoid the Government having to expropriate and pay for groundwater rights, according to Spain's Constitution, the ruling was that the owners of private groundwater could retain their property for ever, but should they voluntarily handed over their rights to the government they would obtain official protection (a poorly defined concept), could continue with the current use for fifty years, and have priority for future concessions. The declaration of groundwater as a public domain was a change in groundwater rights. In fact, wells drilled from 1986 onwards need a concesion for using public domain water. A Register of Public Water and a Catalogue of Private Water were created as instruments for groundwater management. The inclusion of wells in either the Register or the Catalogue constituted a legal imposition on all owners. All well owners had to choose one of the two forms of groundwater ownership. A three-year period (deadline on 31 December 1988) for the adaptation of existing wells to the new legal framework was established and water authorities could impose coercive fines to enforce this rule. Well owners wishing to retain private ownership had to apply for inclusion in the Catalogue. However, the poorly defined advantages discouraged well owners from requesting inclusion as those who are not included are still in full possession of their rights, because inclusion in the Catalogue was not a prerequisite for ownership (Del Saz 2002), which was protected by the private property Register under civil law, which has a higher legal ranking than the Water Act.

In order to clarify the legal situation of groundwater, the Groundwater Register and Catalogue Update Program (ARYCA project) was initiated in 1995 by the Ministry concerned, as an ambitious attempt to solve the problematic legal situation of Spain's wells and groundwater use rights. The results were very poor and in 2001 the Ministry of the Environment launched a new Update Program for the Register and Catalogue Books Program, denominated ALBERCA. More than twenty years later, the situation of the Catalogue and the Register is still unsatisfactory and the ALBERCA program does not seem to address the situation of those wells whose owners never applied for inclusion in the Register or the Catalogue. In addition, it also seems to ignore the thousands of illegal wells drilled after 1986. On the other hand, after almost 30 years, in most river basins, data on registered wells are not available online, which is a legal requirement for all public water rights. The number of existing wells not considered in the ALBERCA program may total over one million. Thus, legal groundwater rights are only partially known, except for some exceptional cases as in the Vinalopó River Basin, in the Júcar Basin and in the Canary Islands, where registers started at an early time.

The current coexistence of public and private groundwater in a single aquifer has been a constant source of problems, as is also the current groundwater management chaos are the lack of funds and trained personnel in most water authorities' offices. This situation is further aggravated by illegal wells. "Hydrological insubordination" has become widespread in many of Spain's aquifers. In this context, a more proactive approach from the legislators and Basin Authorities is needed, especially since approximately half of Spain's irrigated agricultural production depends on groundwater (Llamas 2004; De Stephano and López-Gunn 2012). The existing legal and technical instruments seem unsuited to control such anarchy.

3.2 Groundwater role in droughts in Spain

Droughts are a naturally recurring phenomena in arid and semi-arid areas. Their effects are greater the more arid the area and the more intensive the use of water resources are. Significant droughts may last several years, with variable intensity. Spain is historically prone to serious droughts, with records going back to the Middle Ages. Their serious social and economic consequences often triggered important famines and human migrations. Currently, droughts can cause significant economic and social stress and may even become a serious political concern. At times, bizarre, costly and largely ineffective solutions have been adopted by politicians intended to placate the uninformed public and the biased and politically biased media, which often go contrary to what is recommended by the experts and by common sense. Two examples in Spain are the most recent serious droughts, affecting Cádiz in the south in the 1990s and the Barcelona area in the 2000s. In both cases, very costly but ineffective water supplies were imported by tanker ships to try to avoid urban water restrictions. The cost of these actions still is a serious economic burden after more than one decade.

The impact of dry spells on agriculture is usually less relevant today as it can be mitigated with surface water reservoirs and crop insurance, and especially by recurring to groundwater storage where this solution has been adopted and is administratively feasible. In fact, farmers using groundwater for irrigation benefit more during dry spells because they can continue to irrigate and send their products to poorly supplied markets. In some cases "drought wells" have been provided by the water authorities, operating only during droughts to complement water supply. This is well established in SE Spain (Senent and García-Aróstegui 2013). The Spanish cities that use aquifers for their urban water supply have had minor problems compared to those relying only on surface water. Seawater desalination is currently important to moderate drought effects but is costly, especially for the low annual use. Another relevant new method to mitigate supply problems during a drought is to import food and fiber (virtual water) from other countries (Garrido and Iglesias 2006) but this may mean financial loss for local farmers.

However, during normal and wet years, possible future drought is generally not a priority issue in the political agenda, although water authorities in Spain are gradually becoming more conscious of droughts and maintain some actions and emergency solutions active, included in their area water plans. These actions consist mostly of temporary groundwater aquifer over-pumping (Sahuquillo 2000) combined with optimized use of other natural water sources, such as surface water, options to import purchased waters from other areas, industrial water production such as seawater desalination, brackish groundwater salinity reduction, and reuse of tertiary treated wastewater. All these are commonly used in the most water-stressed areas of Spain, such as the Barcelona Metropolitan Area, the south-east of Spain, Mallorca in the Balearic Islands, and Gran Canaria and Tenerife in the Canary Islands.

How to use groundwater to mitigate the effects of climate variations varies from country to country and depends on existing regulations, capacity to implement plans, the severity of the economic and social effects, and the extent to which people understand the problems. In some areas of Spain, mostly but not only in the eastern Mediterranean agricultural areas, the drought wells already mentioned have been promoted and constructed by the water authorities or agreed with well proprietors to be used only under officially declared drought conditions. This requires appropriate maintenance of the wells and the associated facilities, which in some cases has proved difficult, although solutions have been or are still being implemented in the Spanish Mediterranean area.

3.3 Groundwater management in Spain

Current aquifer storage depletion in Spain is about 15 km^3 in the Iberian Peninsula, mainly in the south-eastern area, and about 2 to 3 km^3 in Gran Canaria and Tenerife Islands. Storage depletion is partly associated with dynamic effects and partly to abstraction exceeding recharge (groundwater mining). Groundwater level drawdown rates up to 15 m/year can be found in some aquifers, at least during a series of years. But important reserves still remain, although their abstraction is increasingly expensive, or they are brackish due to saline water in the ground, the effect of geological formations containing soluble salts (mainly Triassic rocks in SE Spain), or their sodium bicarbonate and fluoride content is too high as in deep Canary Islands volcanic rocks. On the islands of Gran Canaria and Tenerife, groundwater abstraction is less than recharge, but a large fraction of recharge is inevitably discharged into the sea as groundwater levels are well above the sea level, so groundwater storage depletion is the result of a long-lasting transient evolution.

In the arid and semi-arid areas of Spain there is a small but significant recharge, which means that groundwater storage will recover after abstraction ceases, except when the storage capacity has been artificially reduced, as in the case of Tenerife, where the storage volume is permanently drained by the long galleries (water tunnels) used to obtain groundwater at high and intermediate altitudes. The recovery time can be of many decades and even more than a century in some of the aquifers in SE Spain. In practice, this means permanent depletion for present and future generations. However, in spite of intensive development over the last fifty years, these aquifers continue to yield high-cost water, but due to their emplacement far from the coast and close to where it is used, it still costs less than water from other local sources, even when public water tariffs are lowered by direct and indirect subsidies. An important issue, much valued by water users in some areas, is the security provided by groundwater availability when other water sources fail due to natural and administrative-legal fluctuations.

The above considerations and circumstances are understood by water managers but policy makers and politicians find them difficult to understand and accept. This means that it is difficult to ensure that they will be considered in IWRM (Integrated Water Resources Management) and translated into appropriate regulations, which should incorporate flexibility and long-term vision to adapt to a changing world. This is something that is not in the current Spanish water regulations conception and underlying philosophy.

The European WFD does not help in addressing current problems. It forbids water mining, even when it is socially convenient and environmentally tolerable, although other elements in the Directive can be used to address these special problems should they properly analyzed and managed. Generally speaking, politicians and water managers in Spain prefer the easiest way to avoid confrontation and discussion (i.e. not to rock the boat) and accept the rules and constraints without discussion, even when derived obligations are almost impossible to comply with. They simply declare that the problems are known and will be solved in the coming planning periods, thus trying to avoid present responsibilities of action, knowledge, and monitoring. The reaction of the EU Commission is still not known, but it will surely insist on defining the action to be adopted. Asking about and agreeing on possible exceptions, according to the law, due to particular situations and disproportionate damage, happens only rarely since this demands in-depth knowledge and convincing explanations, in addition to well-prepared negotiators, and this is not politically rewarding.

In most semi-arid countries water is considered a scarce resource, although this is not necessarily true in the case of domestic water. Small savings in agricultural irrigation can ensure the water supply for many people, at least in quantity. A crucial problem may be food and fiber production, although this can be solved to a large extent through importation from other areas better endowed with water resources, provided fair trading conditions exist. This virtual water trade also helps to improve aquifer management and conservation,

to cope with droughts, and to mitigate the possible negative effects of climate and global change. Water quantity is the main current subject in water scarce areas, as mostly reflected in this paper, but water quality aspects are just as or even more important for many water uses and the environment, and will continue to be so in the future. Thus, water quality is an important aspect of water governance and this is also true for groundwater (Custodio 2013b). However, little attention is paid in Spain. Further groundwater degradation and environment impairing may be needed before the required reaction takes place and is duly reflected in laws, official attitudes, user behavior, and people's expectations, although the WFD helps a lot.

4. WATER IN THE FUTURE OF SPAIN

Intensive groundwater exploitation in Spain, partly by mining aquifers, mainly in the south-east and in Gran Canaria and Tenerife Islands, has bolstered impressive economic and social development based on specialized intensive agriculture and tourism, mostly since the 1960s (Llamas and Garrido 2007). Low income areas have become relatively rich, now complementing groundwater in the areas where it was the main water resource with imported water, desalinated seawater and brackish groundwater, and reclaimed wastewater. Nevertheless, all these important benefits have been achieved with chaotic groundwater management as a result of the 1985 Water Act defects, permitting public and private groundwater rights in the same aquifer, and mainly the lack of human and economic resources in most of the water authorities' offices. This situation has led to a significant deterioration of the Spanish natural capital in some regions, to the point where they has been considered examples of the 'tragedy of the commons' (Sevilla et al. 2010). To some extent this degradation is unavoidable and is needed to trigger the reaction of water authorities and users to halt it, attempt to restore it in part, and revert to a sustainable situation. The sooner this reaction occurs the more effective it will be, but an in-depth understanding of the problem is needed as well as the involvement of users and the general public. This is something new that needs experience, economic and social evaluation, and has important ethical implications, especially with reference to groundwater quality.

5. CONCLUSIONS

. A change in current Spanish groundwater policy is essential, so as economic and social development incentives will be not dominant factors, as currently happens. Water cost and its relative scarcity is not usually a key factor since urban supply and tourism can afford high water costs and expensive water is not a main deterrent to high-tech irrigation. Preserving and expanding markets for products, fertilizer and energy prices, and labor costs, are key factors for the feasibility of a new situation. However, the cost of water, even if small, is always a battleground for farming lobbies because it affects the net profits of the sector while the other assets are not under their direct control. The trend to official government subsidies for agriculture only delays the necessary paradigm shift and increases future stress. The EU agricultural subsidies (EU Common Agricultural Policy) have led to unscrupulous reactions and income expectations, but this is starting to change. This influences Spanish water policy but has little effect on the more intensively exploited aquifers since their economy is scarcely affected.

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