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Water-resource stress on the Spanish Costa del Sol: policy requirements to improve supply security

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Abstract

The Costa del Sol, in common with many Mediterranean (and similar) coastal areas, is having to face increasing water-resource stress as a result of global warming and land-use change, coupled with extremely high peak water demand resulting from large tourist numbers and summer climatic factors. An assessment is presented of current water-supply provision, possible measures to enhance the resilience of the water-supply system (focusing on improved use of groundwater storage), and the institutional challenges confronting their implementation.

Keywords: Conjunctive water management; Non-conventional water resources; Water-demand variability; Water governance; Water-supply security

Highlights

- Assessment of water-supply security.
- Complex institutional arrangements with water-utility fragmentation.
- Role of groundwater in climate change adaptation.
- Overcoming institutional impediments.

Objective and methodology of paper

The principal objective is to assess how increased utilisation of groundwater storage can contribute to climate change adaptation, and thus improve water-supply security and constrain water-supply costs for an important section of the western Costa del Sol of Malaga, Spain (Figure 1), and to inform water-resource planning in comparable coastal areas.

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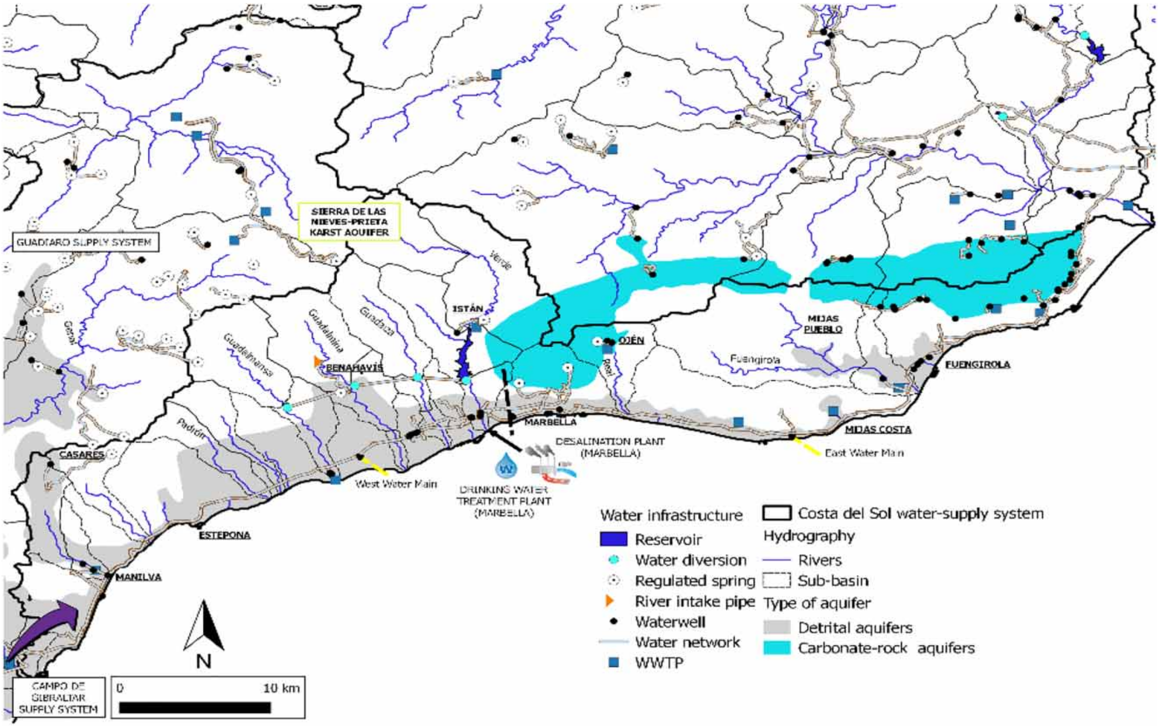

Fig. 1. Situation map of the Costa del Sol water-supply system. WWTP, wastewater treatment plant; dashed line is referred to the hydrogeologic section of Figure 5.

The Costa del Sol (in common with various water-scarce coastal regions with a major tourist industry) faces a significant challenge to its water-supply security, with the need to maximise use of its available storage, in the coming decades as a result of the interaction of:

- an extremely variable seasonal water demand arising from the major tourist industry;
- a drought-prone climate with global warming potentially impacting the area preferentially, and resulting in increasing summer water demand, an increased incidence of surface-water drought and higher intensity rainfall events;
- a natural topography which provides few sites suitable for storage reservoirs;
- the need to continue reducing dependence on its desalination plant in view of its high operational cost and larger carbon footprint; and
- rapid land-use change on the coastal plain which forms the recharge area of local aquifers, with variable impacts from the urbanisation of previously arable land and the large number of golf courses irrigated partly with treated wastewater.

The scientific approach taken in the paper involves:

- the in-depth analysis of all local meteorological data;
- an appraisal of the existing water sources and their supply characteristics;
- an evaluation of the groundwater resource potential of local aquifers;

- an assessment of the present institutional framework and its constraints; and
- an assessment of the available supply-side and demand-side measures to bring about improved water-supply security and climatic resilience.

A special focus of the paper is to review how far ‘conjunctive use policy’ can be implemented within the currently complex institutional framework governing the use of water resources and provision of water supply in the area concerned.

There are no known closely comparable studies in the published literature, but useful insights into certain facets of the problem addressed can be obtained from Swaney *et al.* (2011), CPUC (2014), and Morote & Hernández (2016).

Findings of research

Characteristics of study area

The study area comprises nine municipalities (Estepona, Marbella, Mijas, Fuengirola, Manilva, Casares, Benahavis, Istan and Ojen) on the Spanish Mediterranean coast in Malaga Province, termed here the ‘Costa del Sol’, although Benalmadena and Torremolinos municipalities (in the extreme east of the area) have been excluded. This area is one of the primary tourist destinations in Europe and expected to be the one most impacted by global warming. These municipalities have a combined permanent population of 0.39 million (2017), with the largest urban centres (Marbella, Fuengirola, Estepona and Mijas) accounting for 92% of the total. In common with many other Mediterranean coastal areas, the permanent population is more than doubled in summer months by tourism. This, together with seasonal climatic factors, results in a widely varying water demand from 79,000 m^3/d in winter (December–February) to 173,000 m^3/d in summer (June–August), with the peak summer figure probably reaching a significantly higher value on some days.

The study area has a typical Mediterranean climate with warm summers and mild winters, and a markedly orographic rainfall distribution, varying from about 600 mm/a along the coast to over 1,200 mm/a in the neighbouring hills (of up to 1,450 m altitude). Rainfall is often of high intensity and short duration, and the area has experienced severe droughts in recent years (Figure 2) – a tendency which is becoming more pronounced with global warming. The Costa del Sol coastal strip has also

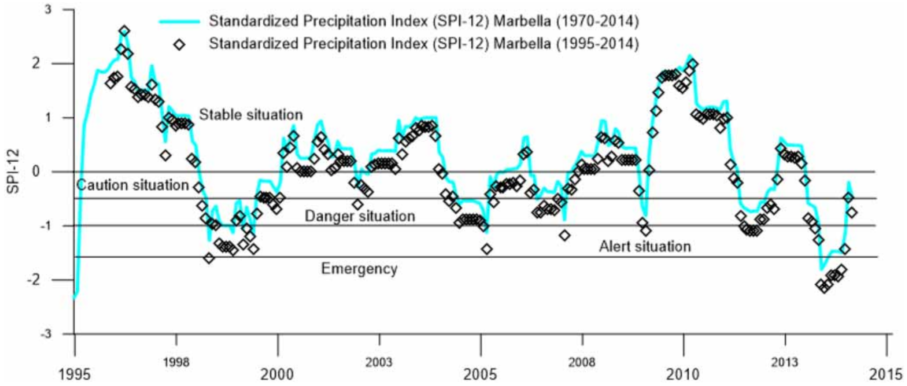

Fig. 2. Temporal evolution of Standardized Precipitation Index (SPI) during 1995–2015 to illustrate climate variability on the Costa del Sol.

experienced major land-use change between the 1960s and 2000s – with the urbanised area reaching over 50%, a major reduction in cultivated agricultural land (from over 70% to less than 20%) and development of many golf courses (to occupy some 5% of the total land area).

Current water-resource situation

The freshwater supply system of the Costa del Sol draws principally on three separate sources:

- La Concepcion Reservoir of the Costa del Sol Public Water-Services Company (ACOSOL) constructed in 1970 on the Rio Verde, which has the lowest operational water cost but a limited usable storage of only 57 hm^3, and receives a variable surface-water transfer from adjacent catchments.
- The Marbella Desalination Plant of ACOSOL (operating since 2005), which has a potential capacity of 20 hm^3/a but high operational water cost and thus intermittent use.
- Numerous waterwells of private water companies tapping the Marbella-Estepona Quaternary and Pliocene aquifers (of 20 and 120 m average thickness, respectively), which underlie about 70 km^2 of the coastal plain and have a current yield of 14 hm^3/a and a larger potential of perhaps 30 hm^3/a, and the Fuengirola Quaternary aquifer with a mean annual pumping rate of about 3 hm^3/a.

A summary of the main water-source characteristics (including minor surface-water transfers) is given in Table 1. There are established operational rules which relate the actual stored volume in La Concepcion Reservoir with external transfers and use of the other sources – when the stored reservoir volume is high, the lower the waterwell abstraction, the production of the Marbella Desalination Plant and the transfer from the Campo de Gibraltar System.

Two important management measures that have already been taken since 2005 are:

- promoting re-use of treated wastewater to exceed 5 hm^3/a principally for golf-course irrigation, with Estepona Municipality alone having used 37 hm^3 during 2000–2015, which has reduced pressure on groundwater resource use for recreational purposes; and
- a significant reduction of annual water-supply demand from 65 hm^3/a in 2005 to 55 hm^3/a in 2014 (Figure 3) – through widespread implementation of household water-saving measures (flow reducers), general increases in water network distribution efficiency (Swaney *et al.*, 2011) and increased user awareness of the need to save water (Morote & Hernández, 2016).

Present institutional framework and constraints

The main roles of the principal institutions involved in water-resource administration and water-supply provision are summarised in Table 2. The ‘Agencia del Medio Ambiente y Agua’ (AMAyA) is responsible for objective setting, water monitoring and resource management to conserve or improve the quantity and quality status of water bodies in accordance with the EU Water Framework Directive. One such measure concerns the implementation of conjunctive water-resource management to improve drought water security.

ACOSOL is the public water-service company providing water and sanitation services for several municipalities. Its main water sources are La Concepcion reservoir, the Marbella Desalination Plant and waterwells in the Fuengirola alluvial aquifer (Tables 1 and 2). The Costa del Sol supply system

Table 1. Water-supply sources of the Costa del Sol.

Type	Storage and capacity	Temporal security	Water cost	Water quality	Water uses
La Concepcion Reservoir (including transfers from Guadalmansa, Guadalmina and Guadaiza rivers)	57 hm^3 (plus transfers averaging 8 hm^3/a)	Drought-vulnerable, inter-annual storage – transfers dependent on the reservoir state	€0.02/m^3	Good	Drinking water supply
Marbella Desalination Plant	20 hm^3/a (but averaging 5 hm^3/a)	Production mainly during drought	€0.50/m^3[b]	Good	Drinking water supply
Waterwells in Quaternary Aquifers	up to 8 hm^3/a[a]	Higher production during drought, especially from Pliocene Aquifers	€0.09/m^3[b]	Moderate to good, but susceptible to saline intrusion	Drinking water supply
Waterwells in Pliocene Aquifers	up to 6 hm^3/a[a]				Drinking water supply, private-garden and golf-course irrigation
Inter-Basin Transfers from Campo de Gibraltar System	7 hm^3/a (maximum)	From neighbouring rivers, but dependent on the reservoir state	€0.17/m^3	Good, but locally high manganese	Drinking water supply
Reclaimed Wastewater	54 hm^3/a (golf-course irrigation 5 hm^3/a)	Constant potential production	€0.14/m^3	Moderate to highly mineralised	Golf-course and public garden irrigation; street cleaning

[a] Average value based on water utilities databases (water use = drinking water supply).

[b] Average value based on the economic assessment carried out by MIMAM (2003).

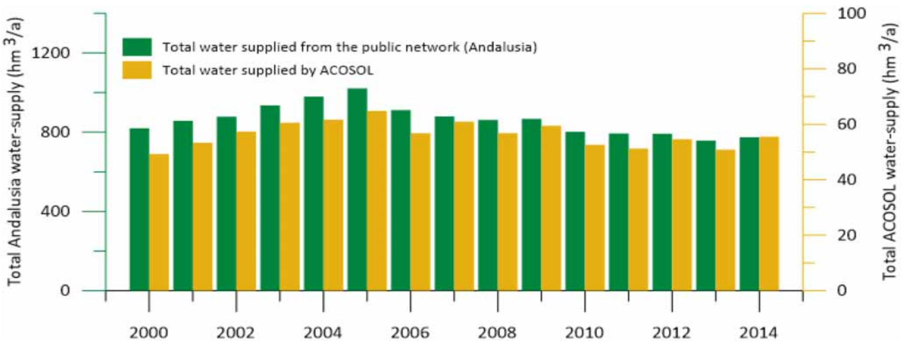

Fig. 3. Temporal evolution of public water supply in Andalusia (green bars) and Costa del Sol (yellow bars) (INE (2016) and ACOSOL database).

also receives a highly variable external surface-water transfer from the Campo de Gibraltar system (Figure 1) of up to 7 hm^3/a. Private water companies also have localised responsibility for domestic water provision and sanitation services (Table 2), with HIDRALIA using groundwater sources for Marbella, Estepona and Manilva and surface-water sources for Benahavis to complement water supplied from the ACOSOL east-west trunk water main and GESTAGUA extracting groundwater for non-

Table 2. Institutional responsibilities of main water-sector stakeholders on the Costa del Sol.

Name	Type of institution	Main responsibilities	Water sources or infrastructure
AMAyA	Regional environment and water-resource authority	Public administration of water resources	La Concepcion Dam & Reservoir; monitoring network
ACOSOL	Public water company	Principal provider of water supply and wastewater services for coastal urban areas	Marbella DW & WW treatment plants, principal water mains (in western and eastern sectors), Fuengirola waterwells
HIDRALIA	Private water companies	Water-supply and sanitation services (Manilva, Estepona, Marbella and Benahavis)	Manilva Quaternary Aquifer, Marbella-Estepona Coastal Aquifers and surface water intake from Guadalmina River
GESTAGUA		Water supply, sanitation services, street cleaning and garden irrigation (Fuengirola)	Fuengirola Pliocene Aquifer waterwells
Municipal Councils	Local public administration	Water supply for Casares, Istan and Ojen	Waterwells and springs in local karstic aquifers, managed by ACOSOL
Irrigation Water Districts and Golf Course Companies	Independent entities	Irrigation of remaining agricultural land and golf courses	Waterwells and various surface water diversions from local rivers, and reclaimed water in the case of golf courses

potable uses (such as street cleaning and public garden irrigation). The water supply of Casares, Istan and Ojen municipalities is beyond the reach of the ACOSOL water infrastructure (east and west water mains) and provided from springhead and waterwells in local limestone aquifers.

None of the municipalities relying on ACOSOL's water sources would be able to be supplied solely from 'alternative sources' (waterwells and/or desalination plant) in extreme drought and loss of surface water from the La Concepcion Reservoir. Marbella's current average annual demand (of 20 hm^3/a) corresponds to the maximum capacity of the Marbella Desalination Plant (which has not yet been reached) and is a measure of the importance of achieving effective coordination between ACOSOL and all stakeholders involved in the Costa del Sol's water supply.

Review of water management policy

Challenges to getting the balance right

The key to further improving water-supply security, and adapting to the challenges arising from global warming, will be in the successful implementation of a balanced combination of demand-side and supply-side management measures. This needs to include detailed consideration of making more intensive medium-term use of natural groundwater storage (Foster & Ait-Kadi, 2012) and supplementing its overall sustainable yield through managed artificial recharge of urban stormwater drainage to offset the drought vulnerability of the La Concepcion Reservoir.

As regards the use of non-conventional water resources, the ACOSOL Marbella Desalination Plant has been operative since 2005 with a maximum capacity of 20 hm^3/a. The historical evolution of actual production (which has not exceeded 12 hm^3/a) reflects both technical factors and plant breakdowns (such as membrane problems caused by the high seawater turbidity) and economic factors (especially high energy and maintenance costs), although it remains an important facility in terms of ensuring water-supply availability in severe drought.

Demand-side measures

Reducing peak demand by further reduction of distribution-system leakage and increased tariffs for luxury use remains a high priority. Since 2005 considerable progress has already been made in this respect, as the historic evolution of water-source deployment and water-supply provision reveals (Figures 3 and 4). For the Costa del Sol, the scope for elimination of water-mains leakage to achieve further economies is likely to reach a threshold related to the age and design of the network. However, a further incentive for water-supply utilities to act in this regard is required, such as that proposed by AMAyA to levy a fee of €0.25/m^3 for water lost in the distribution network. ACOSOL has estimated that it would need an investment of €0.45 million for an economy of 1.8 hm^3/a.

The water-supply tariff structure has a fixed potential-supply component and a variable water-use charge, which allows excessive consumption to be penalised. However, as yet, there is no provision for varying charges according to water-resource status and dependence on more expensive sources – as is practised in San Francisco for example (CPUC, 2014). In Marbella and Mijas, a 'desalination charge' (of €0.16/m^3) is levied, but this is irrespective of whether water from the desalination plant is actually incorporated in supply.

It is recommended that consideration is given to modifying the tariff structure such that charges reflect the actual temporal variation of different water sources to the overall supply, so as to act as a further incentive to constrain peak summer demand. One possibility would be to relate this to the water stored in the La Concepcion Reservoir, which is readily conceived and publically available on the ASOSOL website. The information could easily be incorporated in the corresponding water bills, and the procedure would much better reflect water scarcity and the cost of production.

Supply-side measures – (A) urban drainage and groundwater recharge

Given the occurrence on the Costa del Sol of Pliocene and Quaternary aquifers (Figure 5), there is considerable scope for the mobilisation of water-supply utilities to expand the use of aquifer storage

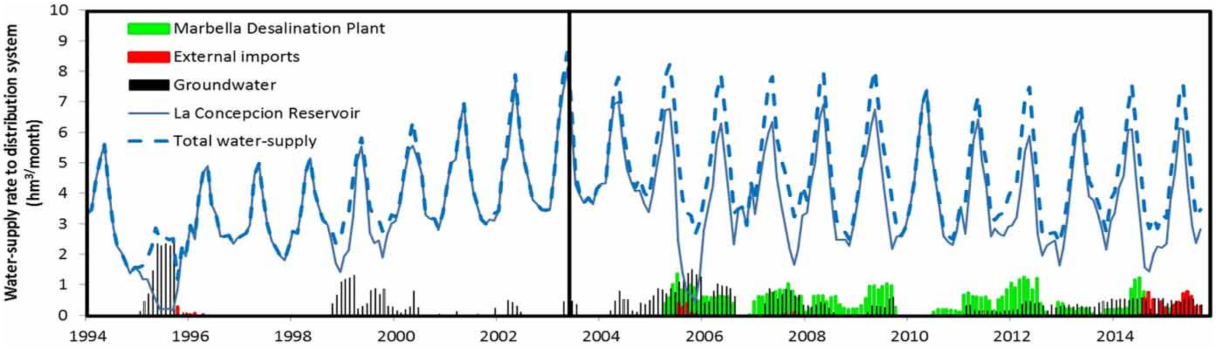

Fig. 4. Historical evolution during 1994–2015 of water-source use to meet the demand of the Costa del Sol (ACOSOL database).

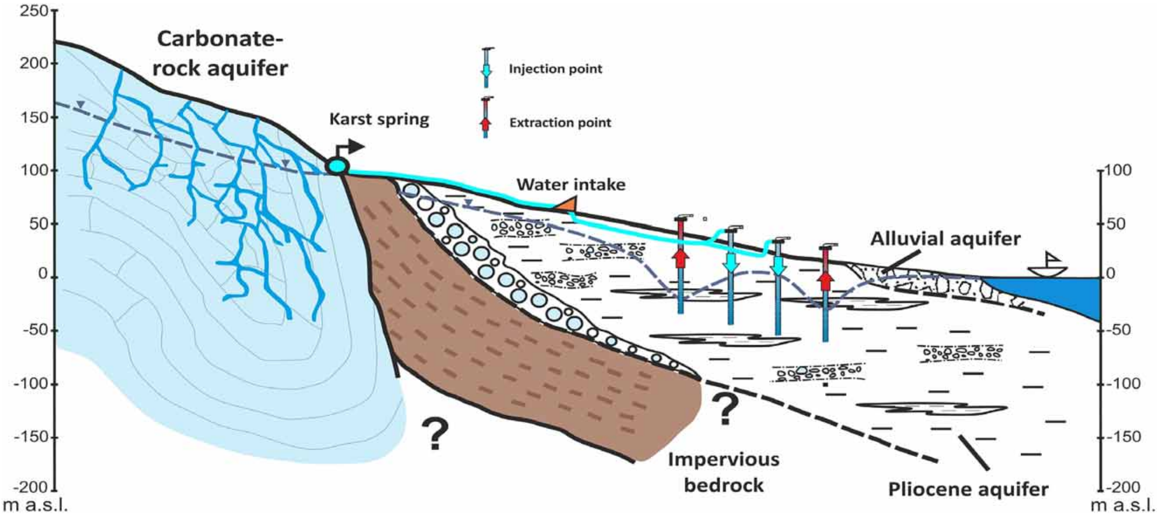

Fig. 5. Hydrogeological cross-section of the Costa de Sol coastal plain illustrating a simplified scheme of MAR (modified from Argamasilla *et al.* (2017)).

to improve drought water-supply security. Operating in such a 'conjunctive use mode' would involve more intensive medium-term use of waterwells during periods of surface-water deficit, while resting them at other times. Present estimates of average groundwater recharge rate to the Quaternary and Pliocene aquifers suggest that more than 90% of the total derives, respectively, from streambed infiltration and rainfall recharge (Table 3), with irrigation returns from recreational use and water-mains leakage losses probably being of decreasing significance but difficult to quantify reliably.

The overall sustainable groundwater offtake could be enhanced through a managed aquifer recharge (MAR) operation, and AMAyA urgently needs to commission:

- a detailed technical and institutional evaluation of stormwater drainage arrangements in urban areas to establish where and how these could be modified to enhance aquifer recharge without compromising groundwater quality;

Table 3. Groundwater budget for the Marbella-Estepona Quaternary and Pliocene Aquifers.

Groundwater component		Quaternary aquifer	Pliocene Aquifer	Total
Recharge (hm^3/a)	Excess recharge	1.6 (6%)	10.6 (91%)	12.2 (33%)
	Riverbed seepage	23.1 (93%)	–	23.1 (63%)
	Water-mains leakage	–	(? 9.4[a])	?
	Agricultural irrigation returns	0.3 (1%)	1.1 (9%)	1.4 (4%)
	Total recharge			**36.7**
Discharge (hm^3/a)	Urban waterwell pumping	4.5	7.2	11.7
	Irrigation pumping[b]	0.8	13.9	14.7
	Submarine discharge	–	–	10.3
	Total discharge	**–**	**–**	**36.7**

[a] Unaccounted water lost in the distribution system, some of which is likely to result in aquifer recharge.
[b] Mainly for private-garden and golf-course irrigation.

- a systematic technical and institutional assessment of the possibility of using excess water production for MAR for recovery during drought periods, and the current role of water-mains leakage in providing aquifer recharge;
- further investigation of streambed seepage to groundwater and how this might be further enhanced through simple engineering and maintenance measures; and
- improved monitoring of groundwater levels and quality to establish an aquifer response to intensive groundwater abstraction and groundwater quality trends in urbanised areas and beneath golf courses.

An optimised MAR operation would require AMAyA to gather all the information generated by the water utilities (notably HIDRALIA), including groundwater levels (0–0.5 m ASL) and electrical conductivity (1,000–1,500 μS/cm) at their abstraction points to monitor groundwater status and any advance of saltwater intrusion.

In particular, urban stormwater drainage is currently the direct responsibility of municipal governments, who have little incentive to maximise the use of soakaways for roof and paved area drainage, so as to maximise groundwater recharge while avoiding groundwater contamination by the same route, and indeed in most cases may not be aware of the need and possible approaches. It is strongly recommended that AMAyA should become proactive in the promotion this type of water-conservation measure, both in plans for new urbanisation and in modifying existing urban drainage arrangements in critical aquifer recharge zones.

Supply-side measures – (B) controlled re-use of treated wastewater

Golf-course irrigation is governed by local statutes of 2008 which prescribed that ‘golf courses ought to be irrigated by regenerated water, according to the requirements of existing norms for the reutilisation of treated wastewaters (Real Decreto 1620/2007), but if the available supply of treated wastewater is not sufficient, the water-resource agency can authorise the use of other water resources for this purpose within the constraints of the National Hydrological Plan’.

Considerable progress has been made on wastewater re-use for golf-course irrigation since 2004 (Figure 6). However, surveys of the use of reclaimed water for golf-course irrigation revealed that practically all courses have their own water-supply source (surface water and/or groundwater) to

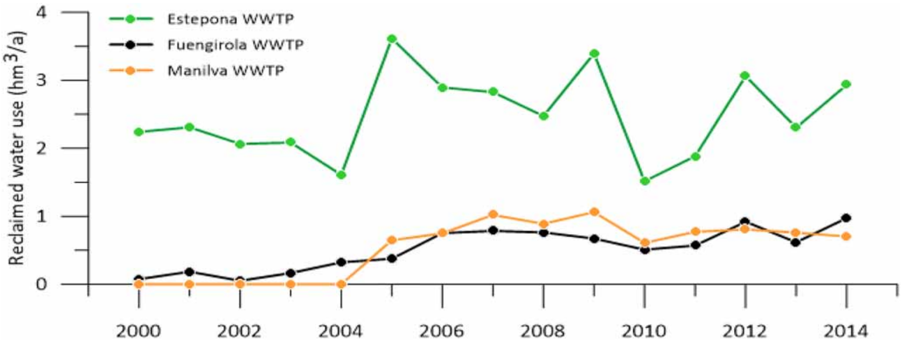

Fig. 6. Temporal evolution of reclaimed water use (mainly for golf course irrigation) during 2000–2014 (wastewater treatment capacity on Costa del Sol is 50 hm^3/a and current golf-course water demand is 15 hm^3/a).

complement wastewater re-use, and many prefer for economic and cosmetic reasons to make use of their own waterwells. While some groundwater use may be justified to achieve an acceptable quality both for the irrigated grass and the irrigation returns to underlying groundwater, there is an urgent need for both full enforcement of the existing decree and for greater financial incentives from ACOSOL in this regard, given its potential to free-up fresh groundwater reserves for drinking water supply. There is also a need to conduct more careful monitoring, supplemented by field research, to establish the quality of groundwater recharge derived from golf-course infiltration.

Concluding discussion

Practical implications of research

The research results clearly reveal the vulnerability of the area to extended drought and need to strengthen its water-supply security. Since considerable progress has already been made on conventional demand-side management measures and further options in this respect are few, efforts now need to be concentrated on supply-side management measures such as improved exploitation of available groundwater resources, the judicial use of urban drainage for groundwater recharge and the controlled re-use of treated wastewater.

Climatic resilience of water-supply system

In the case of the Costa del Sol, a relatively stable reducing trend in water demand has already been achieved, but it has to be recognised that peak demand could escalate under some global warming scenarios. Thus, the main concern as regards climatic resilience of water supply is related to the impact of increased drought frequency on the sources of surface water supply. However, the existence of a range of different water resources which exhibit differing characteristics offers the possibility of improving the climate resilience of public water supply, if an adequate level of institutional cooperation and investment can be achieved to deliver the required management measures.

Confronting institutional fragmentation

Water managers have to make decisions on water-resource and water-supply planning which are subject to significant uncertainty associated with growth in the population served and their water demand, and the impact of climate change on a diverse range of water-supply sources. Worst-case scenarios occur where demand is rising rapidly and water-supply sources are of limited climatic resilience, and where there is a lack of effective mechanisms for cooperation between different stakeholders.

In common with many parts of the Mediterranean Coast and beyond, the Costa del Sol water sector includes a substantial number of independent stakeholders and decision-makers with different and potentially conflicting interests. Too often those in water-resource agencies, charged with the function of ‘water-resource management’, restrict their decision-making to catchment level, and in practice delegate important details of conjunctive water-resource use to water-supply operators, whose perspective is inevitably more short term.

For the available range of water resources to be deployed on an integrated basis will unquestionably require a more effective arrangement to facilitate cooperation between the principal stakeholders, and this will need to be under the general direction of AmAyA and the operational guidance of

ACOSOL. There will be many benefits from including all the stakeholders long term in a more proactive dialogue on water-supply infrastructure and water-resource management, and in mobilising their knowledge and capacity to confront the many challenges associated with achieving water security under climate change. This should lead to definition of a *win-win* policy that is acceptable to, and owned by, all parties. The practical implementation of such a policy will, however, not always be straightforward given that, for example, various water companies are responsible for the management of different water-supply zones with inter-related water-supply sources. Thus, a transparent procedure for conflict resolution will need to be defined and agreed between AMAya and ACOSOL.

The Spanish National Pact for Water Management (2017–2018) could act as a useful catalyst to focus regional government, water utilities and other stakeholders on an integrated water-resource plan for the Costa del Sol to deliver increased water-supply security to the area, while reducing undesirable environmental footprints. The issues and approach detailed in this paper are highly relevant to the mobilisation of stakeholders in constructive action.

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Data availability statement

All relevant data are included in the paper or its Supplementary Information.

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