INTEGRATED MODEL TO MANAGE WATER SCARCITY IN HIGHLY COMPLEX SYSTEMS OF SOUTH-EAST SPAIN

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ABSTRACT

Nowadays, water demand is increasing continuously, which raises the pressure on available water resources around the world, in both quantity and quality. Moreover, the projected decrease of natural water inputs due to climate change denotes a new level of uncertainty. In particular, the south-east of Spain suffers from water deficit due to its aridity – irregular rainfall and high evapotranspiration rates – together with the competition between existing demands: environment, agricultural dynamics, urban-tourist activities and industrial sector. The study area is located in the Alicante province (SE Spain), where the administration of water management is carried out by several authorities at different scales as a result of a complex historical evolution of water governance schemes, at the national, regional, and local levels. This case study is focused on 21 municipalities and draws a conceptual model which is performed considering the different origins of the water inputs – surface resources, groundwater, desalination, wastewater reuse or interbasin transfers – and water demands with data from 16 different entities. The main results depict a general water scarcity of 72.6 hm^3/year generating restrictions in urban growth and agricultural development. These findings provide useful information on water planning policymaking in order to face the shortage of water resources in a context of growing demand.

Keywords: integrated water management, water scarcity, conceptual model, Alicante (SE Spain).

1 INTRODUCTION

The increasing demand for water and the scarcity of this resource are both forcing a change in the way water is understood and in the models to manage it [1]. Specifically, the climate of Alicante province (southeast region of the Iberian Peninsula, where this study is focused) is defined by its aridity, together with the scarce and irregular rainfall recorded, the high potential evapotranspiration due to the high level of sunshine exposure and the persistence and continuity of periods of drought [2], [3]. Moreover, some areas are subjected to the effects of flash floods caused by heavy and concentrated rainfalls.

The endemic water scarcity constitutes a limiting factor for the economic development of the province and constant efforts are made to increase water availability, based on the need to obtain resources from outside the territory or the gathering of alternative water supply sources which requires a complex process of planning and exploitation of hydraulic infrastructure, considering surface resources, groundwater, desalination, wastewater reuse and interbasin transfers [3].

Based on the above, the aim of the study is to analyse water resources in 21 municipalities of the Alicante province and the conceptual model that they characterise, taking into account all existing demands as agricultural, environmental, recreational, urban and industrial. These municipalities comprise the most important functional urban zone of Alicante province, integrated by two metropolitan areas whose main cities are Alicante and Elche, respectively, in terms of registered population.

With respect to hydrological planning basin authorities, the area of study is located mainly in Confederación Hidrográfica del Júcar, the Júcar River Basin Authority, apart from five municipalities – San Fulgencio, Dolores, Catral, Crevillente and Elche (partially) – which are located in Confederación Hidrográfica del Segura, the Segura River Basin Authority. This

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circumstance implies that the decision centers are situated outside the territorial area analysed, both in Valencia and in Murcia, respectively, entailing an additional difficulty in terms of access to disaggregated information due to two different river basins and two different administrative entities. Besides, increasing complexity of the system, there are areas that correspond geographically to the Júcar Basin Authority, but receive water from the Segura river or the Tajo-Segura transfer (for instance, thanks to entities such as Mancomunidad de los Canales del Taibilla or Sindicato Central de Regantes del Acueducto Tajo-Segura, which will be described in the following lines).

In the area of study, the administration of water management is carried out by several authorities at different scales as a result of a complex historical evolution of water governance schemes. At the national level, River Basin Authorities (hydrological planning, concessions or discharge authorisations), the entity called Mancomunidad de los Canales del Taibilla (MCT) which is an autonomous organisation, attached to the Ministry for the Ecological Transition (Ministry of Environment), whose purpose is the supply of urban and industrial water to the primary network (collection, purification, or desalination, piping, and storage in water reserve tanks) in 80 municipalities of Alicante, Murcia and Albacete provinces; Acuamed, which is a public company belonging to the Spanish state with the purpose to hire, build, acquire and operate all kinds of hydraulic structures (mainly desalination plants) in the area of the water basins of the Segura, Júcar, Ebro, Andalusian Mediterranean Basin and the Internal Basins of Catalonia; the State Company of Agricultural Infrastructures, SEIASA, belongs to the Ministry of Finance and Public Function and is an instrumental company for the modernisation and consolidation of the irrigations contemplated in the National Irrigation Plan and declared of general interest, by means of promotion, contracting, financing, exploitation or advice and technical assistance. Last, the Tragsa Group forms part of the group of companies of the state-owned holding company Sociedad Estatal de Participaciones Industriales (SEPI) and operates in different sectors such as the provision of agricultural, forestry, livestock, and rural development services, or the conservation and protection of the environment.

At regional level, the Generalitat Valenciana is the government institution under which the Spanish autonomous community of Valencia is politically organised and exercises important competences in agriculture and environment, through different agencies and departments. Particularly relevant is the Entidad Pública de Saneamiento de Aguas Residuales, the public wastewater sanitation entity, which controls the construction and operation of treatment plants in cooperation with town councils and association bodies on a territorial scale beyond its level. Wastewater treatment is mandatory from the European Directives and, in our context, is also an opportunity, because a significant share of the flows can be recovered as reclaimed water.

The provincial government (Diputación de Alicante) focuses on legal, economic and technical support or assistance to municipalities (mainly, small municipalities) for the provision of municipal water service, via its area called Ciclo Hídrico or the public company Proaguas Costablanca. Thus, at municipal level, local entities are responsible for water management in secondary phase (water supply) under a monopoly regime as a compulsory minimum local public service.

Together with the aforementioned territorial and institutional administrations, other corporate nature administrations constitute a key role in the management of water in Alicante province, in order to manage irrigation water by grouping end-users from many municipalities: user communities or general irrigation communities, as Sindicato Central de Regantes del Acueducto Tajo Segura (SCRATS), Riegos de Levante Izquierda del Segura, or Junta Central de Usuarios del Vinalopó, l´Alacantí y del Consorcio de Aguas de la Marina Baja [1], [3].

2 AREA OF STUDY

This work is focused in the Alicante province (SE Spain), where downpours are greatly heterogeneous. Generally, average rainfall amounts vary between 230 mm/year and 900 mm/year, in the north of the province, but eventually some precipitation episodes surpass 200–300 mm in just three or four hours [4], [5]. Likewise, on the last three or four decades the coastline of the Alicante province has experimented a large urban growth [6], [7]. Nowadays, Alicante is the fifth most populous province in Spain with 1,825,332 inhabitants, 59.3% of whom are located in coastal municipalities. In addition, it is considerably influenced by the growth in temporary population due to the tourist activity, that attracts more than 3.4 million tourists and 14.5 million overnight stays per year, especially in summer [8], [9]. As a consequence of the above-mentioned climatic particularities, and due to the high agricultural, industrial and urban development identified since the sixties of the last century, nowadays this province depicts several problems of water scarcity and overexploitation of aquifers, among others. For example, the Serral-Salinas aquifer, located in the south of the province, was classified as the fifth formation with the greatest overexploitation rates in the world [10]–[13].

The assessed 21 municipalities of the Alicante province compound a sensible area respect their industrial, urban, agricultural, territorial, hydric, etc. requirements and connexions (Fig. 1). As a proposal to resolve these issues, a territorial action plan was coordinated between some companies, as UTE CERCLE and Jornet Llop Pastor, local authorities from the Valencia Community and the University of Alicante [14]. This work belongs to this project and presents main findings regarding the water requirements of the analysed municipalities.

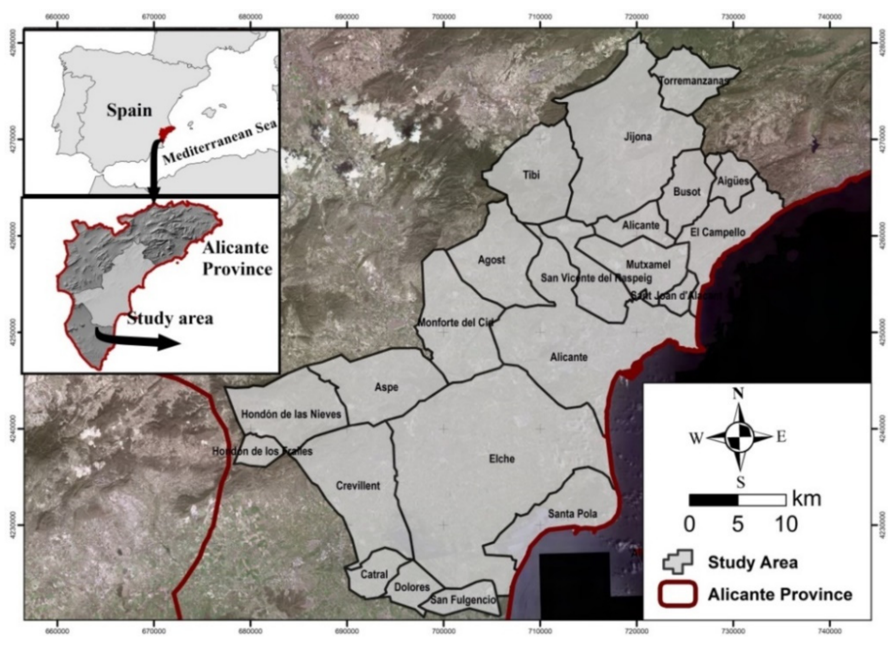

Figure 1: Study area with 21 municipalities of the Alicante province (SE Spain).

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3 METHODOLOGY

In order to quantify water requirements and shortage of the assessed municipalities, a conceptual model was built in [15] integrating the different origins of the water inputs – surface resources, groundwater, desalination, wastewater reuse or interbasin transfers – and water demands as agricultural, environmental, recreational, urban or industrial. Data belongs from private and public entities and, in some cases, were pre-treated through GIS-based tools. In the following sections, information added to this model is presented.

3.1 Water inputs

3.1.1 Endogenous and exogenous surface water resources

Surface water resources identified in the study area were classified as endogenous or exogenous based on their origin: from the Alicante province or other regions. Endogenous resources include mainly water bodies such as reservoirs, lakes and lagoons while exogenous involves conductions, channels and water transfers from other places do not totally covered in the study area (Fig. 2). The available annual volumes of both resources are shown in the four sections of this study.

Figure 2: Endogenous and exogenous surface water resources. *(Source: Elaborated with information from [16]–[19].)*

As regards the elements showed in Fig. 2, certain considerations are described below: (1) The drainage network essentially represents small riverbeds and ravines dry the most part of the hydrological years (ephemeral channels); (2) The Pedrera reservoir was included in the management scheme shown in Fig. 2 due to its resources are used to supply certain municipalities located in the southern portion of the study area. These resources are derived to these municipalities through the following hydraulic constructions: Tajo-Segura interbasin transfer and channels from MCT; (3) Certain municipalities of the study area receive water supply from the hydraulic channels called: Cid, Huerta and Villena-Elche [20]–[25]. These conductions were not included in Fig. 2 due to the absence of cartographic information.

3.1.2 Groundwater resources

Regarding groundwater resources, or groundwater bodies according with [26] nomenclature, the formations identified in this analysis belong to two different river basin districts: the Segura river basin district [17] in the south, and the Jucar river basin district [16] in the north (Table 1). In addition, it should be noted that numerous groundwater bodies are located under the same municipality, and, in some cases, certain groundwater bodies show dimensions that exceeds highly the administrative limits of the municipalities. Therefore, to calculate groundwater volumes in this area, the available data from extraction wells [16], [17] was weighted by the surface of each municipality using GIS-based tools.

Table 1: Groundwater bodies and their main information weighted with the surface of the study area. *(Source: Elaborated with information from [16], [17], [27].)*

Groundwater body	Available resource (hm^3/year)	Extraction (hm^3/year)	Exploitation index
Hoya de Castalla	1.02	0.43	0.42
Barrancones-Carrasqueta	4.50	2.78	0.62
Sierra Aitana	0.65	0.12	0.18
Argüeña-Maigmó	0.22	0.20	0.88
Orcheta	4.52	1.74	0.38
San Juan-Benidorm	2.99	1.58	0.53
Agost-Monnegre	6.80	0.90	0.13
Sierra del Cid	1.40	1.00	0.71
Sierra de Argallet	0.23	0.38	1.63
Sierra de Crevillente	2.39	8.05	3.38
Bajo Vinalopó	20.53	2.02	0.10
Impermeable 21	–	–	–
Impermeable 24	–	–	–
Impermeable 25	–	–	–
Vega Media y Baja del Segura	11.38	4.94	0.43
$\sum =$	56.62	24.14	–

Overexploitation problems in groundwater bodies from the study area can be depict with the exploitation index (IE, Table 1). Currently, in the Spanish water resource management system, it is considered that a groundwater body or a group of groundwater bodies show bad water status (significant pressure) when the IE is greater than 0.8 and, in addition, there is a clear trend of decreasing piezometric levels in a relevant area of the groundwater bodies [16], [17]. This index is presented in eqn (1):

$$IE = \frac{Extractions}{Available\ resources}, \qquad (1)$$

where *IE* is the exploitation index; Extractions are the total extractions achieved in the groundwater body (hm^3/year); and Available resources are the total available resources identified in the groundwater bodie (hm^3/year). According with the mentioned exploitation index, geological formations that present overexploitations conditions are: Argüeña-Maigmó (IE 0.88), Sierra de Argallet (IE 1.63) and Sierra de Crevillente (IE 3.38, Table 1). In the last two cases (Argallet and Crevillente), extractions exceed notoriously available resources from these groundwater bodies. This is due to extractions by pumping collect the volume of water considered as "available resource" to supply water demands and, in addition, part of the volume that integrates the "reservoirs" of these groundwater bodies generating overexploitation problems [10]–[12]. Finally, in the presented model, total extractions identified (24.14 hm^3/year) were the volume considered as groundwater inputs.

3.1.3 Non-conventional resources: wastewater reuse and desalinated water

The province of Alicante presents one of the greatest water reuse and desalination rates identified in Spain and in Europe [28]. Moreover, 25 wastewater plants and 9 desalination plants were identified treating a total water volume of 46.05 hm^3/year and 32.66 hm^3/year respectively. Tables 2 and 3 show both types of plants and, as can be observed, normally, these plants received the name of the municipality where they are located.

Table 2: Wastewater plants identified in the study area and treated flows (hm^3/year). *(Source: Elaborated with information from [29] and private data.)*

Wastewater plant	Treated annual flow (hm^3/year)	Reused annual flow (hm^3/year)	Reused flow respect treated flow (%)
San Fulgencio-Daya Nueva-Daya Vieja	0.83	0.83	100
Dolores-Catral	0.77	0.77	100
Elx (Carrizales)	0.31	0.31	100
Alacant (Isla de Tabarca)	0.02	0.00	0.00
Crevillente (Realengo)	0.03	0.03	100
Santa Pola	2.78	2.78	100
Crevillente-Derramador (Urbana)	0.87	0.87	100
Crevillente-Derramador (Industrial)	0.34	0.00	0.00
Elx (Algoros)	7.98	7.98	100
Elx (Arenales)	1.19	1.19	100
Hondón de los Frailes	0.03	0.03	100
Hondon de las Nieves (La Canalosa)	0.01	0.00	0.00
Hondón de las Nieves	0.04	0.04	100
Alacant (Rincón de León)	18.42	6.19	34
Aspe	0.71	0.00	0.00
Novelda-Monforte del Cid	1.34	0.00	0.00
Alacant (Monte Orgegia)	7.57	3.37	45
Agost	0.17	0.17	100
Alacanti Norte	1.96	0.00	0.00
El Campello (Cala D'or)	0.05	0.00	0.00
El Campello (La Merced)	0.05	0.002	4.00
El Campello (Venta Lanuza)	0.05	0.00	4.00
Aigües	0.02	0.00	0.00
Xixona	0.44	0.00	0.00
Tibi	0.04	0.04	100
Torre de les Macanes	0.03	0.00	0.00
$\sum$ =	46.05	24.61	–

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Table 3: Desalination plants identified in the study area and produced flows (hm^3/year). *(Source: Elaborated with private data.)*

Desalination plant	Produced flow (hm^3/year)	Use (supply)
Alicante I	10.00	Urban
Alicante II	3.00	Urban
Club de Golf Plantío	0.55	Recreational
Terciario Rincón de León	12.41	Agricultural
Alicante Golf (Hesperia)	0.91	Recreational
El Campello/Mutxamel	3.30	Urban
Tomatera Bonny Muchamiel	1.58	Agricultural
Club de Golf de Bonalba	0.55	Recreational
Aigües	0.37	Urban
$\sum =$	32.66	–

Wastewater plants show three uses to wastewater: discharge it into riverbeds, into the Mediterranean Sea or reuse. In Table 2, installations without wastewater reuse conduct the other uses. Thus, in the proposed conceptual model, total reused flows (24.61 hm^3/year) were the volume considered as wastewater inputs.

3.2 Water demands

In the present study water demands are divided in agricultural, environmental, recreational, urban and industrial demands according with the official classification fixed in the Spanish water resource management (watershed hydrologic plans).

3.2.1 Agricultural, environmental and recreational demands

Study area depicts numerous agricultural water demands which complete description can be found in [30]. These water demands obtain their resources from several water supplies being groundwater inputs highly relevant [24], [31].

Regarding environmental water demands, due to their difficult calculation and disaggregation, they were estimated as an average percentage among the considered for natural spaces by the Segura and Jucar river basin districts [16], [17]. Thus, a 2% of the total water demand obtained in this work was considered as the environmental water demand from ecosystems of the study area [14].

Finally, recreational water demands (mainly golf courses of the study area) were estimated, according with [32], considering an average annual consumption of 8,000 m^3/hectare, after golf courses in operation were counted. All of them have 18 holes, except from Elche (golf school) with 9 holes. The considered golf courses were: Alenda Golf (in the municipality of Monforte del Cid), Font del Llop Golf Resort (Monforte del Cid), El Plantío Golf Resort (Elche), Alicante Golf (Alicante), Club de Golf de Bonalba (Mutxamel) and golf school of Elche.

3.2.2 Urban and industrial demands: municipal supply and efficiency

Urban and industrial demands are gathered in this section, and the type of management is synthesised in Table 4.

Table 4: Type of local water management. *(Source: Own elaboration from [20], [33].)*

Name of the municipality	Water distribution entity in primary phase (distributed volume in 2015)	Management system in secondary phase (supply company)
Agost	Sociedad del Canal de la Huerta	Indirect management
Aigües	–	Indirect management
Alicante	MCT (17.20 hm^3) + Canal del Cid AMAEM (4.4 hm^3)	Indirect management by a public–private mixed company (Aguas de Alicante, AMAEM)
Aspe	MCT (1 hm^3)	Direct management by local entity
Busot	–	Direct management by local entity
El Campello	Canal del Cid AMAEM	Indirect management
Catral	MCT (0.64 hm^3)	Indirect management
Crevillent	MCT (1.85 hm^3)	Indirect management
Dolores	MCT (0.54 hm^3)	Indirect management
Elche	MCT (10 hm^3) + Sociedad Los Frutales (2.16 hm^3)	Indirect management by a public–private mixed company (Aigües i Sanejament d'Elx)
Hondón de las Nieves	MCT (0.15 hm^3)	Indirect and interested management
Hondón de los Frailes	MCT	Indirect management
Jijona	–	Indirect management (HIDRAQUA) together with direct management by local entity
Mutxamel	Sociedad del Canal de la Huerta	Indirect management
San Fulgencio	MCT (0.83 hm^3)	Indirect management
Sant Joan d'Alacant	Canal del Cid AMAEM	Indirect management
Santa Pola	MCT (3.3 hm^3)	Indirect management
San Vicente del Raspeig	MCT (3.7 hm^3) + Canal del Cid AMAEM (0.9 hm^3)	Indirect management
Tibi	–	Direct management by local entity
La Torre de les Maçanes	–	Direct management by local entity
Monforte del Cid	–	Indirect management

In Fig. 3, according to the available data on supply water to municipalities in 2012 and 2016 (comprising urban and industrial uses, where tourism is included), served and invoiced water are shown. The difference between served and invoiced water is identified as uncontrolled consumption, such as leaks, municipal consumption without a water meter or even fraudulent connections.

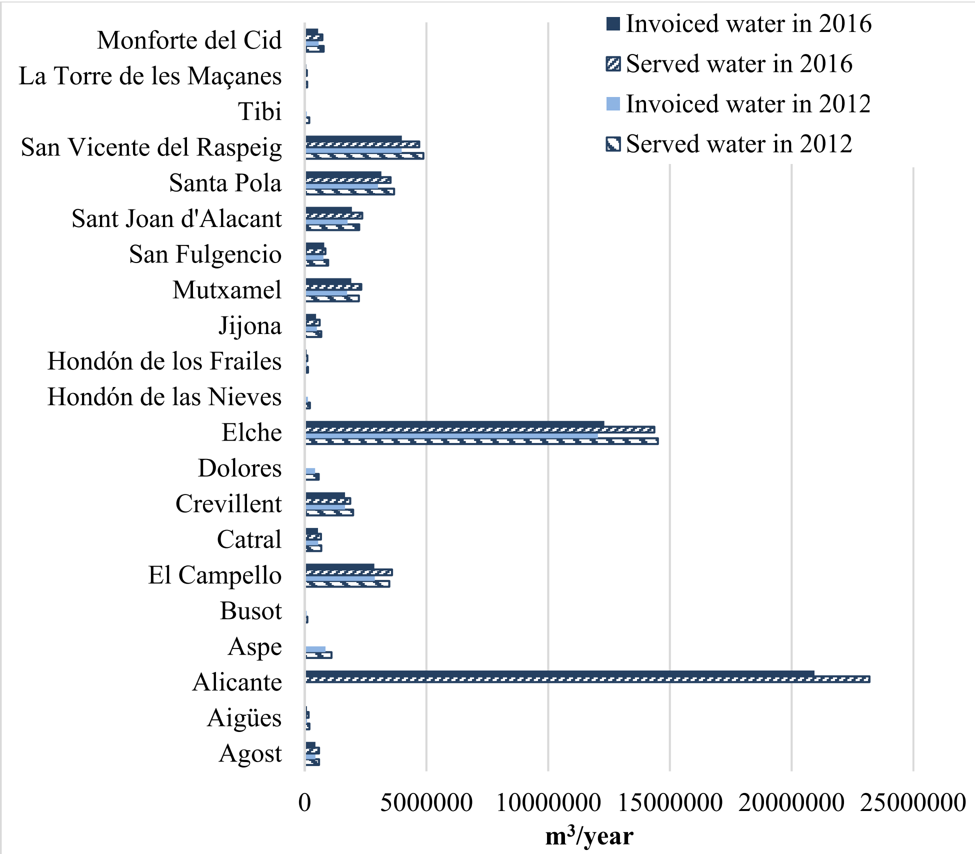

Figure 3: Urban and industrial water demand located in the municipalities of the area of study. *(Source: Own elaboration from [34].)*

4 DISCUSSION OF RESULTS

After gathering individual data on water inputs and water demands, in this section, general results are exposed considering the combination of this data as an integrated model of water management of an estimated cross section in 2016 (Fig. 4). Furthermore, an extra deficit of 50 hm^3/year, caused by accounting the lack of resources in water-stressed agricultural productions (about to wither), was added to the analysed balance [10], [22], [24].

The difference between total water inputs and total water demands is 72.6 hm^3 posted as water deficit per year in the area of study.

5 CONCLUSIONS

Endogenous resources from Alicante province are clearly insufficient to manage the production system and cover the total demand. Therefore, in the area of study, there is a consumptive use of own resources which stress has reached a peak. Consequently, it is necessary to combine endogenous with exogenous resources (channels, interbasin transfers, etc.) in addition to the unconventional resources coming from desalination and wastewater treatment. From the perspective of urban and industrial demand, integration of municipalities

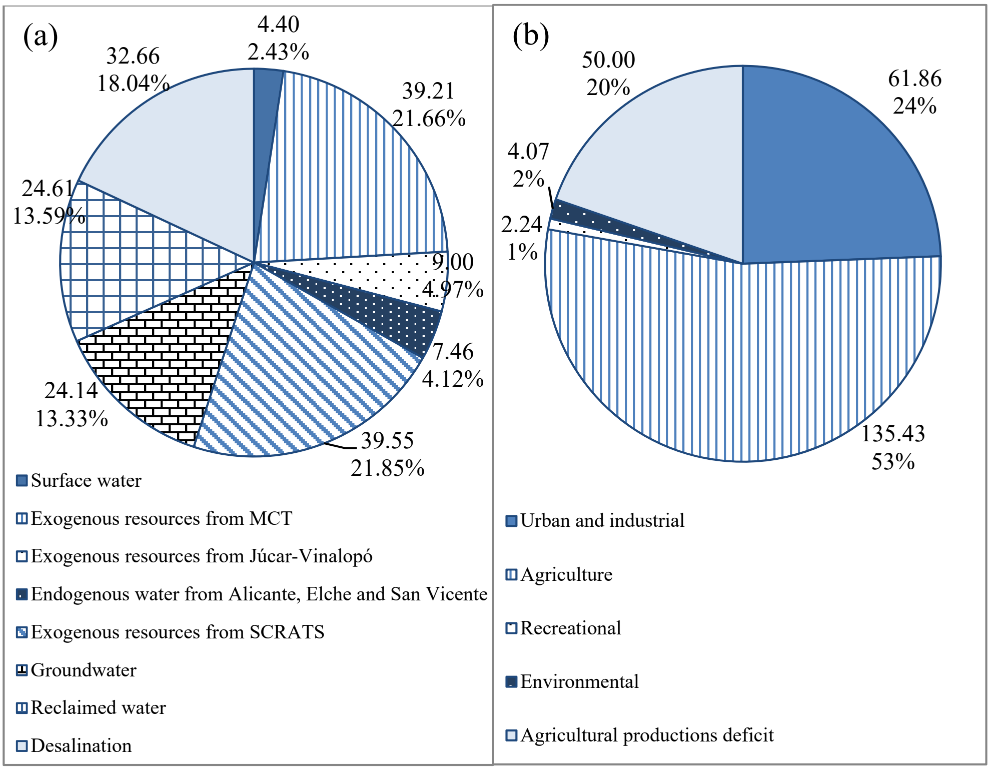

Figure 4: (a) Water inputs, and (b) water demands in the area of study (hm^3 and percentage). *(Source: Own elaboration based of previous sections.)*

into supra-municipal networks should be promoted since efficiency increases as occurs in some municipalities with guaranteed growth thanks to entities as MCT or AMAEM. In parallel, it is necessary to maintain the contributions of the Tajo-Segura transfer as an assurance for urban and agrarian supply and as a strategic element for socioeconomic development. With regard to the planned irrigation programme and existing crops, its continuity is other strategic objective whose inadequate supply must be corrected by means of the necessary inputs, modernisation and high efficiency systems.

In general, this complex management model in a context of scarcity needs an integrated solution to achieve the sustainability of stakeholders, users and territory, as described in the Pacto Provincial del Agua (Provincial Water Pact), an agreement signed in the provincial government of Alicante [35] by different political parties, as well as communities of irrigators, water supply sector, Chamber of Commerce and universities, which seeks to respond to the main water challenges in the province of Alicante as a benchmark.

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