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Assessing Water Shortage through a Balance Model among Transfers, Groundwater, Desalination, Wastewater Reuse, and Water Demands (SE Spain)

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Abstract: Currently, water demands are increasing notoriously, spreading the pressure on available water resources around the world in both quantity and quality. Similarly, the expected reduction of natural water inputs, due to climate change, depicts a new level of uncertainty. Specifically, Southeast Spain presents water scarcity due to its aridity—irregular and scarce precipitation and high evapotranspiration rates—combined with the competition between several water demands: environment, agricultural dynamics, urban-tourist activities, and industry. The study area of this work is the most relevant functional urban area of *Alicante* province (SE Spain), where the administration of water management is carried out by a range of authorities at different levels as the consequence of a complex historical development of water governance schemes: at the national, regional, and local levels. This study analyzes 21 municipalities and proposes a conceptual model which was developed by including different origins of water inputs—surface resources, groundwater, desalination, wastewater reuse, or interbasin transfers—and water demands with information obtained from 16 different sources. Our main results denote a relevant water deficit of 72.6 hm^3/year even when one of the greatest rates of desalinated water and reused wastewater in Europe are identified here. This negative balance entails restrictions in urban development and agricultural growth. Thus, presented results are noteworthy for the water policy makers and planning authorities, by balancing the demand for water among various end users and providing a way for understanding water distribution in a context of scarcity and increasing demand, which will become one of the most challenging tasks in the 21st century.

Keywords: integrated water management; water shortage; conceptual model; desalinated and reused waters; Southeast Spain

1. Introduction

Growing water demand and increasing physical water scarcity in arid environments are both encouraging changes in the way that water is understood and in the models developed to manage it [1–3]. In particular, the climate of *Alicante* province (southeast region of the Iberian Peninsula, where is located the case study of this paper) is characterized by its aridity—deficient and irregular precipitation, a high level of sunshine exposure which increases potential evapotranspiration, and repeated droughts [4–7]. Moreover, the impacts of extreme hydrologic events, due to intense precipitation, can lead to flash floods and vulnerable areas [8–10].

Structural water shortage is a key factor in constraining economic progress of this region [1,2,7] and social efforts are carried out continuously to ensure water availability. This requires complex planning and a holistic exploitation of hydraulic structures which involves considering, together, surface resources, groundwater bodies, desalination, reclaimed water, and interbasin transfers that include resources from outside the province [7,11].

For this paper, the aim was to develop an integrated perspective on the use of a wide variety of complementary water resources as a strategy to effectively achieve a water balance and to accomplish this by assessing 21 municipalities of *Alicante* province. This vision was transferred into a conceptual model considering all existing demands, such as agricultural, environmental, recreational, urban, and industrial, and the main hypothesis of the study suggests a negative effect on water balance shown by a water deficit. These municipalities represent the most relevant functional urban area of the *Alicante* region, made up of two metropolitan zones whose major cities are *Alicante* and *Elche*, respectively, with respect to population [12]; this is one of the few examples in Spain of a regional polycentric urban system. There are some case studies on the results of water balance for simulating specific flows or statistical hydrological modeling (e.g., [13–15]). However, few studies have dealt with holistic conceptual models, based on actual data, to allow an integral vision of water resource management for particular cities or regions [16–19].

With regard to hydrological basin planning authorities, the study area mainly covers the *Confederación Hidrográfica del Júcar*, which is the *Júcar* River Basin Authority, except for five municipalities—*San Fulgencio*, *Dolores*, *Catral*, *Crevillente*, and *Elche* (partially)—which are integrated into the *Confederación Hidrográfica del Segura*, the *Segura* River Basin Authority. Because decision centers are located outside the study area, in *Valencia* and in *Murcia*, respectively, a further difficulty could be expected in terms of obtaining disaggregated information, because there are two different river basins and two different administrative entities [4,6]. In addition, some zones are integrated into the *Júcar* Basin Authority but collect water from the *Segura* River or the *Tajo-Segura* transfer (e.g., entities such as *Mancomunidad de los Canales del Taibilla*, hereafter MCT, or *Sindicato Central de Regantes del Acueducto Tajo-Segura*, which will be defined below). In this regard, the administration of water management is carried out in the study area by many different authorities at different levels, as the consequence of a complex historical development of water governance schemes [2,16]:

- At the national level, the most important bodies are River Basin Authorities, which have responsibilities for hydrological planning, discharge authorizations, or concessions. Additionally, the MCT institution is an autonomous organization of the Ministry for the Ecological Transition (traditionally called Ministry of Environment), whose aim 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 the Alicante, Murcia, and *Albacete* regions. Another State institution is *Acuamed*, a public company with the objectives of hire, build, acquire, and operate hydraulic infrastructures, especially desalination plants, in the *Segura*, *Júcar*, *Ebro*, Andalusian Mediterranean, and Internal Catalonia water basins. With reference to agricultural institutions, the State Company of Agricultural Structures (*SEIASA*), attached to the Ministry of Finance and Civil Service, is responsible for the promotion, contracting, financing, exploitation, and technical support of the modernization and consolidation of the irrigations included in the National Irrigation Plan and defined as general interest. On the other hand, the *Tragsa* Group belongs to the group of companies of the State-owned holding entity *Sociedad Estatal de Participaciones Industriales* (*SEPI*) and works in different sectors such as the stock of agricultural, livestock, forestry, and rural growth services, or the protection and conservation of the environment [2,4,6,11,16].
- At the regional level, the *Generalitat Valenciana* is the government entity under which the Spanish autonomous community of *Valencia* is politically ordered and develops significant competences in environment and agriculture, through different agencies and departments. Particularly important is the *Entidad Pública de Saneamiento de Aguas Residuales* (EPSAR), the public wastewater sanitation

company, which manages the construction and operation of treatment plants in cooperation with town councils and association bodies [16,20].

- At the provincial level, the provincial government (*Diputación de Alicante*) focuses on legal, economic, and technical assistance to municipalities (generally, small municipalities) for the provision of municipal water service, through its area called *Ciclo Hídrico* or the public entity *Proaguas Costablanca* [21].
- At the municipal level, local companies control water management in the secondary phase (water supply) as a compulsory minimum local public service. Nevertheless, local entities can choose the type of management through a range of possibilities: direct concentrated or direct decentralized, as well as indirect management (predominant in *Alicante* province), via concessions to private companies or by the creation of joint ventures [2,16,21].

Along with the aforementioned institutional and territorial administrations, other corporate administrations assume a key role in water management in *Alicante* province, in order to obtain irrigation water by grouping end users from numerous municipalities—user communities or general irrigation communities—such 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* [1,2,16,21].

2. Study Area

This study is located in *Alicante* province (Southeast Spain), where downpours are highly heterogeneous. In general, average precipitation amounts fluctuate between 230 and 900 mm/year, in the north of the region; but, eventually, some rainfall episodes involve 200–300 mm in just three or four hours [5,7,10]. Moreover, over the last four decades, the shoreline of *Alicante* province has undergone great urban development [9,22]. Currently, *Alicante* ranks fifth in terms of population in the provinces of Spain, with a total of 1,825,332 citizens. More than half of this registered population (59.3%) is located in coastal municipalities. Similarly, the province is considerably affected by the temporary population increase as a consequence of tourist activity, which involves more than 3.4 million tourists and 14.5 million overnight stays per year, mainly in the summer [23,24]. As a result of the identified climatic features, and due to the agricultural, industrial, and urban growth experienced since the sixties of the 20th century, *Alicante* has uncovered various structural problems such as water shortage and aquifers with intensive exploitation—for instance, the *Serral-Salinas* aquifer, located in the southern part of this region, was defined as the fifth formation with the highest overexploitation rates in the world [25–29]—or political disputes related to interbasin transfers from other regions [1,11,16] and great levels of desalinated water and reused wastewaters [2,4,16]. *Alicante* province has therefore been identified as a province with one of the highest desalinated and wastewater reused rates in the world, in terms of production (in this region, between 49 and 50% of the total wastewater is reused), considering as well the developed technology and the energy consumption (kW-h/m^3), information for which can be found in [17,30,31].

The analyzed 21 municipalities of *Alicante* province denote a great potential for improving their industrial, urban, agricultural, territorial, or hydric requirements and connections (Figure 1). Accordingly, a territorial action plan was conducted by some entities, such as *UTE CERCLE & Jornet Llop Pastor*, local authorities from the *Valencia* Community and the University of *Alicante* to address this issue [12]. This study is framed in the action plan referred to and summarizes the key findings related to the water needs of the assessed municipalities.

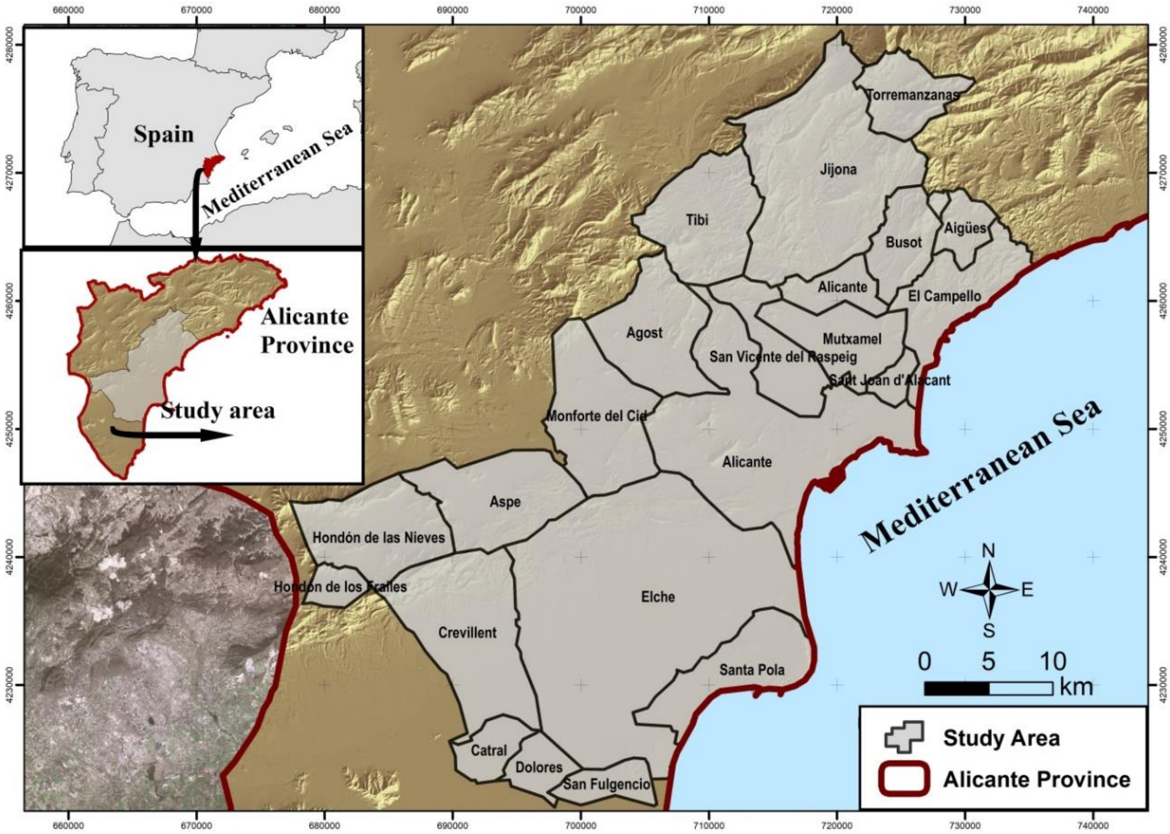

Figure 1. Study area with 21 municipalities (*Alicante* province, Southeast Spain).

3. Methodology

In order to assess water needs and scarcity within the studied municipalities, a conceptual model was developed by [32], including the possible sources of water, identified as inputs—surface resources, groundwater, desalination, reclaimed water, or interbasin transfers—as well as water demands such as agricultural, environmental, recreational, urban, or industrial. Data used to quantify water balance were extracted by screening techniques on information from 16 different sources or entities which will be described below, according to each data set referred to in the next sections: *Júcar* River Basin Authority, *Segura* River Basin Authority, municipality of *Elche*, municipality of *Alicante*, municipality of *San Vicente del Raspeig*, *Mancomunidad de los Canales del Taibilla*, *Sindicato Central de Regantes del Acueducto Tajo-Segura*, *Entidad Pública de Saneamiento de Aguas Residuales*, *Ciclo Hídrico* from *Diputación de Alicante*, *Proaguas Costablanca*, previous research studies present in the reference list [16–18], private information from desalination plants, and official statistics provided by the Ministry of Finance and Civil Service or by the Ministry for the Ecological Transition. Information was pretreated with GIS-based tools [33] in some cases.

The conceptual model (Figure 2) provides a heuristic framework for the analysis of water inputs and demands, illustrating cause–effect relationships in a complex system. It also helps to select the variables to be quantified thanks to the above-mentioned data processing software. The consequence of this conceptual process is an impact on water balance, which usually results in an unwelcome water deficit.

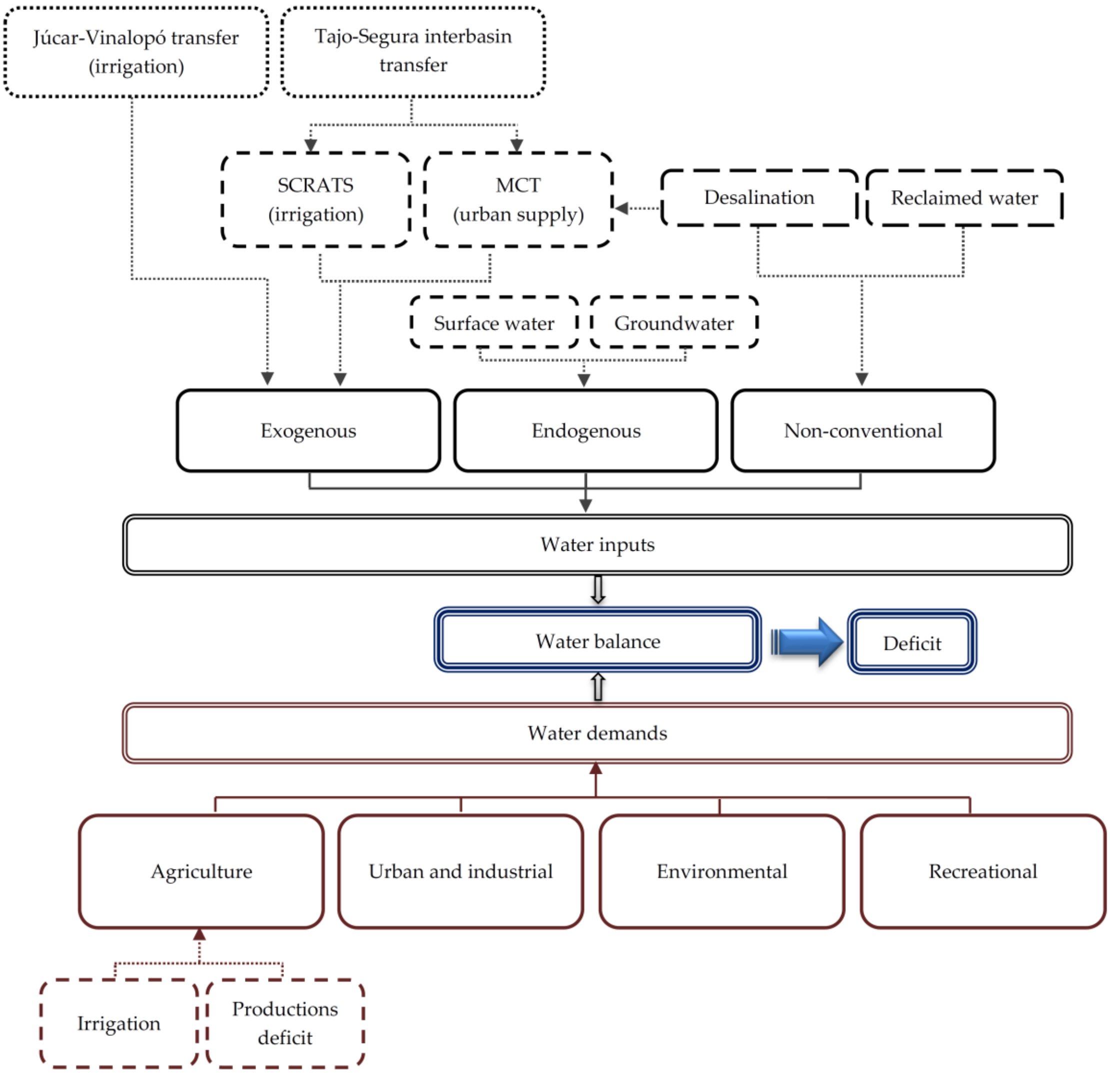

Figure 2. Conceptual model of water balance in the study area. Source: own elaboration.

4. Water Inputs

4.1. Surface and Groundwater Resources

Surface water resources of the study area were divided into endogenous or exogenous according to their origin: from Alicante province or other places, respectively. Endogenous resources mainly concern water bodies such as reservoirs, lakes, and lagoons, whereas exogenous ones include conductions, channels, and interbasin transfers from other locations geographically separated from the assessed area (Figure 3). Calculated annual volumes of both types of resources are integrated in the results section.

Regarding Figure 3, it also highlights some additional considerations that have been addressed in identifying specific infrastructures:

- The drainage network is made up of small riverbeds and ravines, which are dry the greater part of the hydrological year (ephemeral channels [21,38]).
- The *Pedrera* reservoir, despite being outside the borders of the study area, could be encompassed in the global management system illustrated in Figure 3 as its resources are used to supply municipalities located in the southern part of the study area. These resources are conducted to these municipalities through the following hydraulic constructions: *Tajo-Segura* interbasin water transfer and channels from MCT [16,35,37].

- The *Rabasa-Amadorio* conduction, despite being in the study area, was not included in Figure 3 because it is carrying flows from municipalities outside the study area, to others outside the study area as well [2,16].

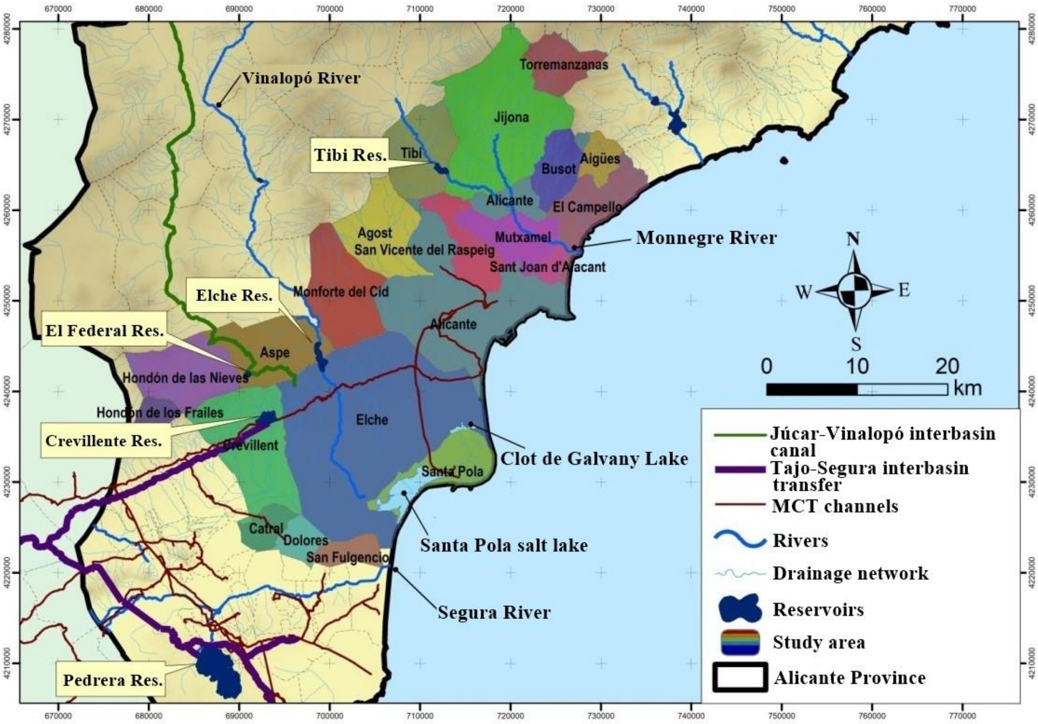

Figure 3. Endogenous and exogenous surface water resources. Source: elaborated with information from [34–37].

Similarly, some municipalities of the assessed area obtain their water supply from the following hydraulic conductions: *Cid*, *Huerta*, and *Villena-Elche* [16,21]. These channels are not reflected on the map (Figure 3) due to the lack of cartographic information, but are described below:

- The *Cid* canal. *Aguas Municipalizadas de Alicante Empresa Mixta* (AMAEM) is a joint venture which manages the resources of this canal and supplies the following municipalities in the study area: *San Juan* and *El Campello*, which do not depend on the MCT, together with *San Vicente del Raspeig* and *Alicante*, which are supplied by the MCT as well [2,16]. In particular, the *Cid* canal, built in the 19th century [39], has an important infrastructure for collecting and transporting water from the *Jumilla-Villena*, *Yecla-Villena-Benejama*, and *Peñarrubia* aquifers. However, this system is subjected to the availability of groundwater in these aquifers, often with overexploitation problems [18,21,26,27,40].
- The *Huerta* canal. This canal supplies four municipalities of *Alicante* province. Two of them are involved in the study area: *Agost* and *Mutxamel* [16,18]. However, it should be noted that, currently, this canal does not provide a relevant water supply, since the transferred resources to these four municipalities represent only 3.10% of the total annual volume of water used in *Alicante* province [2,18,21].
- The *Villena-Elche* canal. The supply to the *Elche* municipality shows two origins: water received through the MCT entity and water coming from wells in smallholder crops, called *Finca los Frutales*. This smallholding supplies *Elche* through the *Villena-Elche* canal, which is 49.6 km long [18,41].

More details and information on these infrastructures and their supplied municipalities can be found in [2,16,18].

As regards groundwater resources, or groundwater bodies following the European [42] terminology, formations in the study area are components of two different river basin districts: the *Segura* River basin district [4,35], located in the south, and the *Júcar* River basin district [6,34], in the north (Table 1). Furthermore, it should be noted that several groundwater bodies are located under the same municipality, and, in some cases, multiple groundwater bodies go beyond the administrative boundaries of the municipalities due to their large size. Hence, to estimate groundwater volumes in this surface, data gathered from pumping wells [21,34,35] was weighted according to the area of each municipality using GIS-based tools.

Table 1. Groundwater bodies and descriptive features (available resource, extraction, and exploitation index), weighted according to municipal areas. Source: elaborated with data from [21,34,35].

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	-

Intensive aquifer exploitation is illustrated by the exploitation index (IE, Table 1). Currently, under the Spanish water resource management scheme, it is estimated that a groundwater body (or a cluster of groundwater bodies) is overexploited (significant pressure) when the IE is higher than 0.8 and, moreover, there is a clear trend of declining piezometric levels in an important area of the groundwater body [43–45]. This index is shown in Equation (1):

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

where *IE* is the exploitation index; *Extractions* are the total registered pumping in the groundwater body (hm^3/year); and *Available resources* are the total reserves available in the groundwater body (hm^3/year).

In light of the exploitation indexes registered, geological formations that suffer from overexploitation are as follows (see Table 1): *Argüeña-Maigmó* (IE: 0.88), *Sierra de Argallet* (IE: 1.63), and *Sierra de Crevillente* (IE: 3.38). In the last two cases (*Argallet* and *Crevillente*), extractions exceed available groundwater resources. This is owing to extractions by pumping collect the volume of water estimated as "available resource" to supply water demands and, furthermore, part of the volume that involves the "reservoirs" of these groundwater bodies. Obviously, the use of these reservoirs generates overexploitation problems. Although the differentiation between "available resources" and "reserves" in groundwater bodies is complex, "resource" has traditionally been considered as the volume of water stored in an aquifer that exceeds the height which is located above the piezometric level of the natural spring, whereas "reserve" is considered as the volume of water located under the piezometric level [25–28,46].

With regard to the presented conceptual model, total extractions registered (24.14 hm^3/year) are the volume estimated as groundwater inputs.

4.2. Non-Conventional Resources: Wastewater Reuse and Desalinated Water

As a result of the above-mentioned water scarcity and the urban, agricultural, and industrial development achieved in the province of *Alicante*, this region presents one of the highest rates of reclaimed and desalinated in Europe [17,31,47]. Specifically, the study area of this work is a good example, with 25 wastewater plants and 9 desalination plants, treating 46.05 hm^3/year and 32.66 hm^3/year, respectively. Tables 2 and 3 present both types of treatment plants, which are often named according to the municipality where the plants are located.

Table 2. Wastewater plants located in the study area and treated volumes (hm^3/year). Source: elaborated with data from [20] and private information.

Wastewater Plant (Number in Figure 3)	Treated Annual Flow (hm^3/year)	Reused Annual Flow (hm^3/year)	Reused Flow with Respect to Treated Flow (%)
San Fulgencio-Daya Nueva-Daya Vieja (0)	0.83	0.83	100
Dolores-Catral (1)	0.77	0.77	100
Elx Carrizales (2)	0.31	0.31	100
Alacant Isla de Tabarca (3)	0.02	0.00	0.00
Crevillente Realengo (4)	0.03	0.03	100
Santa Pola (5)	2.78	2.78	100
Crevillente-Derramador Urbana (6)	0.87	0.87	100
Crevillente-Derramador Industrial (7)	0.34	0.00	0.00
Elx Algoros (8)	7.98	7.98	100
Elx Arenales (9)	1.19	1.19	100
Hondón de los Frailes (10)	0.03	0.03	100
Hondón de las Nieves La Canalosa (11)	0.01	0.00	0.00
Hondón de las Nieves (12)	0.04	0.04	100
Alacant Rincón de León (13)	18.42	6.19	34
Aspe (14)	0.71	0.00	0.00
Novelda-Monforte del Cid (15)	1.34	0.00	0.00
Alacant Monte Orgegia (16)	7.57	3.37	45
Agost (17)	0.17	0.17	100
Alacanti Norte (18)	1.96	0.00	0.00
El Campello Cala D'or (19)	0.05	0.00	0.00
El Campello La Merced (20)	0.05	0.002	4.00
El Campello Venta Lanuza (21)	0.05	0.00	4.00
Aigües (22)	0.02	0.00	0.00
Xixona (23)	0.44	0.00	0.00
Tibi (24)	0.04	0.04	100
Torre de les Macanes (25)	0.03	0.00	0.00
$\sum =$	46.05	24.61	-

Table 3. Desalination installations identified in the study area and produced flows (hm^3/year). Source: elaborated with private information.

Desalination Plant (Number in Figure 3)	Produced Flow (hm^3/Year)	Use (Supply)
Alicante I (0)	10.00	Urban
Alicante II (1)	3.00	Urban
Club de Golf Plantío (2)	0.55	Recreational
Terciario Rincón de León (3)	12.41	Agricultural
Alicante Golf Hesperia (4)	0.91	Recreational
El Campello/Mutxamel (5)	3.30	Urban
Tomatera Bonny Muchamiel (6)	1.58	Agricultural
Club de Golf de Bonalba (7)	0.55	Recreational
Aigües (8)	0.37	Urban
$\sum =$	32.66	-

Regarding wastewater installations, there are three possible uses for treated wastewater: reuse it for irrigation, or discharge it into riverbeds or into the Mediterranean Sea (depending on the location of the plant, with discharge points close to riverbeds or the sea). In Table 2, plants without wastewater flow reused (*Alacant Isla de Tabarca*, *Crevillente-Derramador Industrial*, and *Hondón de las Nieves La Canalosa,* for instance) decide in favor of discharging flows due to a lack of suitable reuse infrastructures or price control mechanisms. For example, wastewater treatment plants located in the municipality of *Alicante* (*Rincón de León* and *Monte Orgegia*) provide water to the dual urban water network, whose main objective is to supply water to irrigate private lands of owners' communities, as well as to irrigate public parks and gardens, in parallel with the consolidated drinking water network. This ideal approach has been made possible thanks to large infrastructure investments and cross-subsidization between drinking water and reclaimed water. Hence, in the proposed conceptual model, total reused flows (24.61 hm^3/year) were the volume estimated as reclaimed water inputs.

Figure 4 shows the location of desalination and wastewater plants within the studied municipalities. Regarding wastewater treatment plants with discharge of flows into riverbeds, these are usually located inside the province, whereas plants with discharge of flows into the Mediterranean Sea are located near the shoreline. In particular, from the total flow (46.05 hm^3/year) treated by the 25 identified wastewater plants, 53.4% (24.61 hm^3/year) is reused, 10.8% (4.99 hm^3/year) is discharged into riverbeds, and, finally, 35.7% (16.46 hm^3/year) is discharged into the Mediterranean Sea.

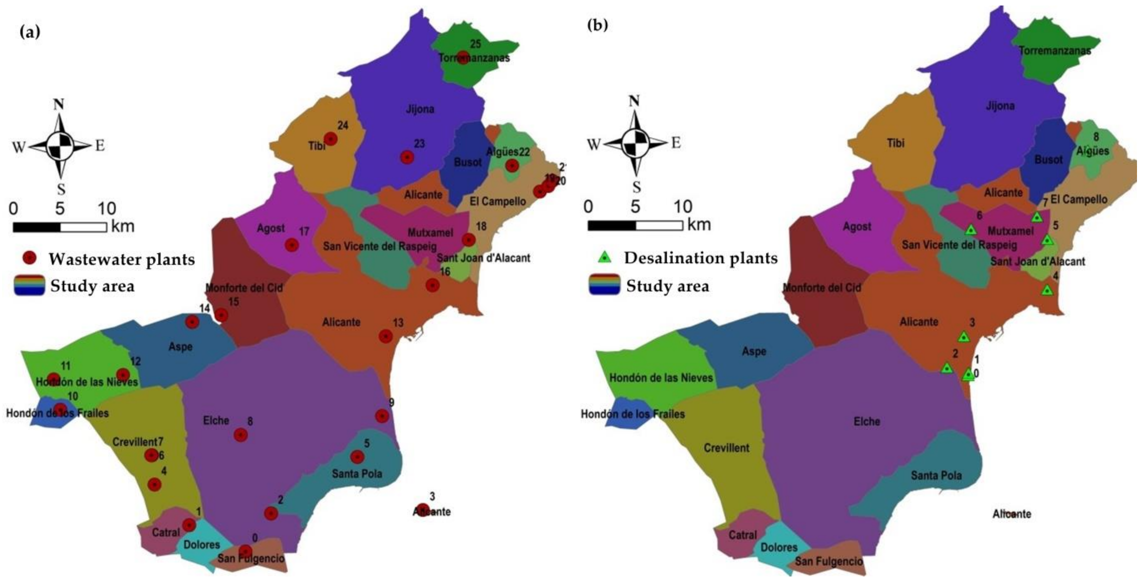

Figure 4. Location of non-conventional treatment plants in the study area: (**a**) Wastewater plants; (**b**) Desalination plants. Source: elaborated with information from [20].

5. Water Demands

In this work, water demands are identified as agricultural, environmental, recreational, urban, and industrial, in line with the official nomenclature established by the Spanish River Basin Authorities (watershed hydrologic plans).

5.1. Agricultural, Environmental, and Recreational Demands

The study area presents the following agricultural water demands, according to the same codes that identify these zones in planning documents of the River Basin Authorities: Riegos del Amadorio (082069A), Riegos de la cabecera del Monnegre (082070A), Riegos del Jijona (082071A), Riegos de Levante M.I.: Huerta de Alicante y Bacarot (082072A), Riegos del Alacantí (082073A), Riegos del Medio Vinalopó (082076A), Riegos del Bajo Vinalopó (082077A), Riegos de Levante M.I.: Camp d'Elx (092001A), Riegos del Pinós y Albatera (092002A), Regadíos superficiales del Chícamo y acuífero de Quíbas (UDA06), Tradicional Vega Alta, Ojós-Contraparada (UDA20), Tradicional Vega Baja (UDA46), Regadíos redotados del TTS de RLMI-Segura (UDA53), Regadíos redotados del TTS de RLMI-Vinalopó-L'Alacantí (UDA54), Acuífero de Crevillente (UDA55), and Regadíos redotados del TTS de la Vega Baja, margen izquierda (UDA72). These water demands (Figure 5), for which complete descriptions can be found in [48], acquire their resources from diverse water inputs, with one of the most important being groundwater [21,25,26,29].

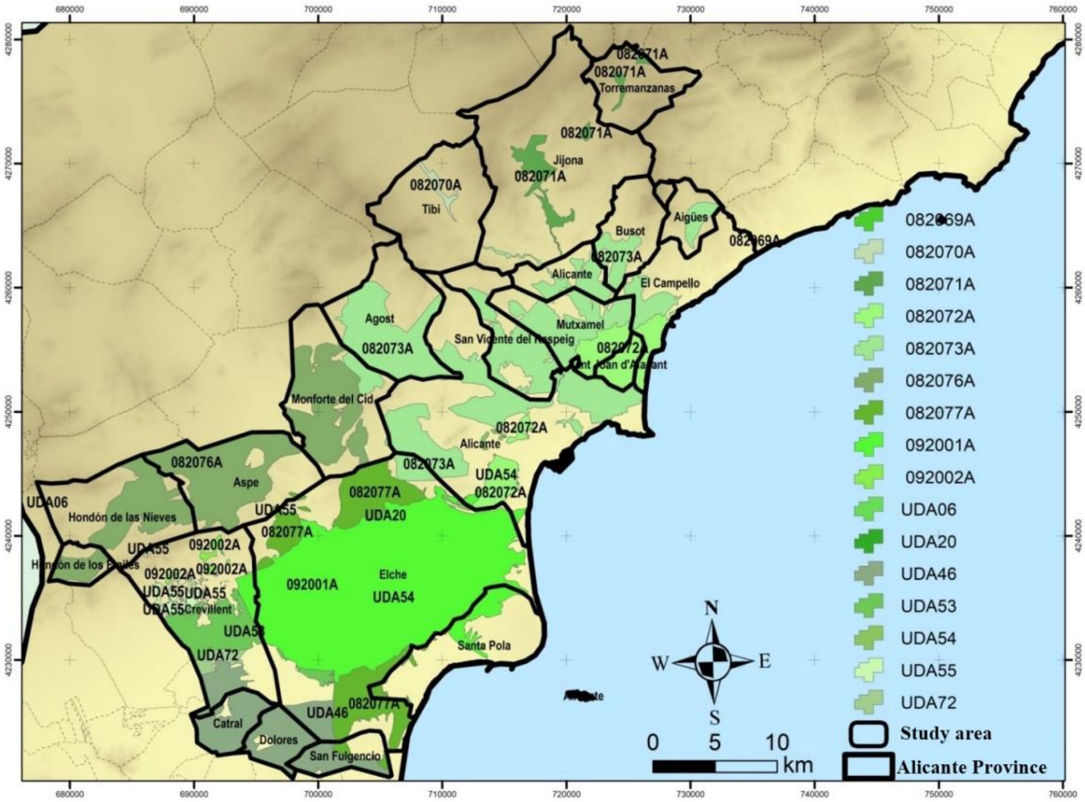

Figure 5. Agricultural water demands (in Spanish UDAs) located in the study area. Source: elaborated with information from [34,35].

Water-intensive crops, such as gardening products, vegetables, or orange and lemon trees, account for half of the irrigated area, whereas almond, pomegranate, and olive trees, less demanding in quantity and quality of water, account for the other half of the surface [49].

Concerning environmental water demand, and bearing in mind its difficult calculation and disaggregation, it has been obtained as an average percentage of the estimated amount for natural areas by the *Segura* and *Júcar* River basin districts, in accordance with hydrological planning [4,6,34,35]. Therefore, 2% of the total water demands calculated in this study was considered as the environmental water demand from ecosystems of the assessed area [12,16].

Similarly, recreational water demands (operational golf courses of the evaluated area) were calculated according to [4,6,50], by estimating an average annual consumption of 8000 m^3/hectare. This theoretical estimation, which prior studies have shown, was widely confirmed on field visits. The studied golf courses are as follows: *Alenda Golf* (in the municipality of *Monforte del Cid*), *Font del Llop* Golf Resort (*Monforte del Cid* as well), *El Plantío* Golf Resort (*Elche*), *Alicante* Golf (*Alicante*), *Club de* Golf *de Bonalba* (*Mutxamel*), and the golf school of *Elche*. The analyzed golf courses cover 18 holes, except for *Elche* (the golf school) with 9 holes, according to information gathered from field visits mentioned above.

5.2. Urban and Industrial Demands: Municipal Supply and Efficiency

Urban and industrial demands are presented in this section, and the type of management is indicated in Table 4, by specifying both phases (primary and secondary) of urban supply for each municipality. In the case of municipalities supplied in the primary phase by the MCT, volumes distributed in 2015 are shown, with urban and industrial uses considered.

Table 4. Types of urban and industrial water management in the study area. Source: own elaboration from [16,51].

Name of the Municipality	Water Distribution Entity in the Primary Phase (Distributed Volume in 2015)	Management System in the 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 a local entity
Busot	-	Direct management by a 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 a 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 a local entity
La Torre de les Maçanes	-	Direct management by a local entity
Monforte del Cid	-	Indirect management

According to the available information, which was provided by certain provincial entities such as *Ciclo Hídrico* (*Diputación de Alicante*) and *Proaguas Costablanca*, supplied volumes to municipalities in 2012 and 2016 (comprising urban and industrial uses, where tourism is considered, together with served and invoiced water) are presented in Figure 6. This urban and industrial consumption reflects residential, tourist, and urban-industrial uses. Similarly, the difference between served and invoiced water is recognized as uncontrolled consumption, such as leaks, municipal consumption without a water meter, or even fraudulent connections. Fortunately, over the last few years, a great reduction from these uncontrolled consumptions has been identified [16,52,53]. In particular, in the case of *Alicante* city, data from 2017 provided by the above-mentioned entities showed a total supplied volume of 22.6 hm^3, of which 17.6 hm^3 were supplied by the MCT (Figure 6).

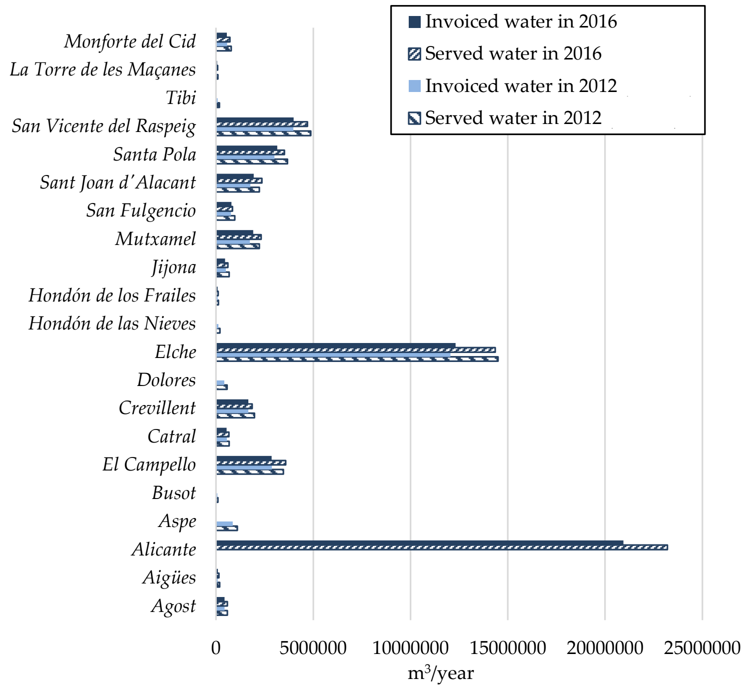

Figure 6. Urban and industrial water demand for the municipalities of the study area. Source: own elaboration from [40,54].

6. Results and Discussion

After gathering information on water inputs and water demands from the study area, the main results are presented in this section, considering the integration of these data as a holistic model of water management (Figures 7 and 8). However, it should be noted that the presented data are subject to uncertainty due to the lack of information, especially in the small municipalities located inside the province. Similarly, some municipalities use small supply sources that are not collected by local authorities and administrations, such as illegal wells, underground connections, or desalination plants with low capacity [4,6,18,29,52].

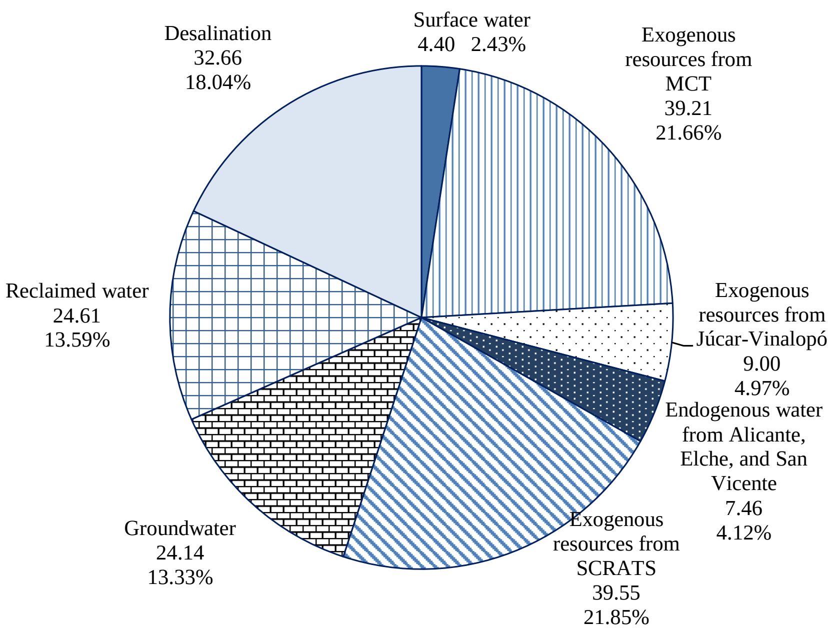

Figure 7. Water inputs in the study area, shown in hm^3/year and percentage. Source: own elaboration relying on previous sections.

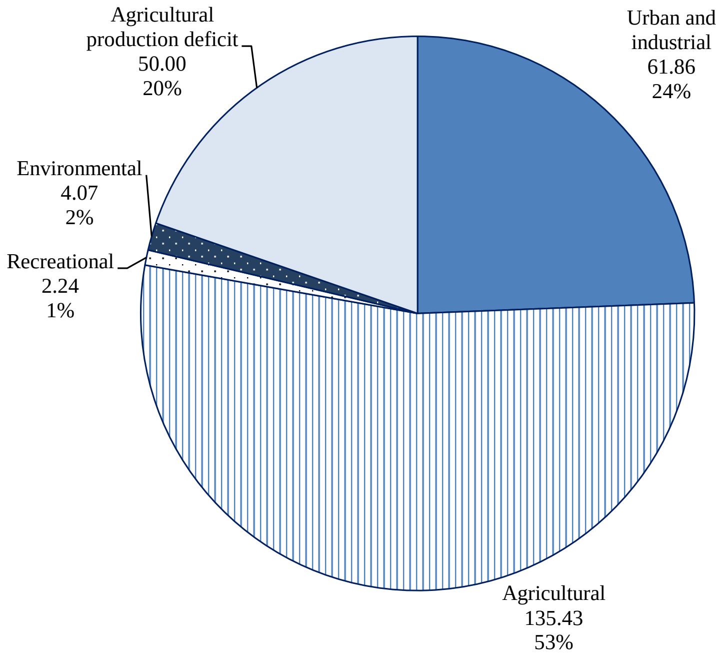

Figure 8. Water demands in the study area, shown in hm^3/year and percentage. Source: own elaboration relying on previous sections.

As regards the described water inputs in the study area (Figure 7), they were classified into endogenous and exogenous resources. Endogenous sources comprised surface resources (4.4 hm^3/year); own resources from the municipalities of *Alicante*, *Elche*, and *San Vicente del Raspeig* (7.46 hm^3/year); and groundwater (24.14 hm^3/year). Exogenous resources were composed of 39.21 hm^3/year supplied by the MCT entity; the *Júcar-Vinalopó* contributions (around 9.0 hm^3/year); and resources from SCRATS (39.55 hm^3/year). Thus, endogenous resources represent 19.9% (36 hm^3/year) of the total water inputs in this system, whereas exogenous resources represent 48.5% (87.8 hm^3/year) of the total water inputs. Therefore, great differences between the amount of endogenous and exogenous sources can be observed. These relevant differences, in particular 51.8 hm^3/year, denote the importance of exogenous resources in a vulnerable area such as Southeast Spain [2,16]. In addition, it should be noted that groundwater reserves are the most vulnerable sources, as several aquifers of the study area suffer from overexploitation problems, according to the exploitation index (IE) previously mentioned. Hence, if this trend continues, these formations will experience total depletion in the years to come. Similar results and predictions can be found in [26,28,29,46] about the Spanish case, and in [27,55] about comparable Mediterranean and semi-arid cases. Because of this future groundwater depletion in the study area, the established differences between endogenous and exogenous resources could increase.

With reference to non-conventional resources, 24.61 hm^3/year were obtained from wastewater treatment plants to reuse and 32.66 hm^3/year were collected from desalination plants (Figure 7). These volumes represent, respectively, 13.6% and 18.05% of the total water inputs. According to [17,30,31,47] and considering the possible reuse of discharged flows (16.46 hm^3/year) into the Mediterranean Sea, this treated flow could replace the supply from some groundwater resources in the study area and, consequently, remedy overexploitation situations of numerous aquifers.

Water demands in the study area were classified into two groups. The first cluster, related to agriculture and environmental services, implies the following requirements: 4.07 hm^3/year for environmental demands; 2.24 hm^3/year for recreational needs; and approximately 135.4 hm^3/year required by agriculture, which is aggravated by several water restrictions in SE Spain [11,21,29,55]. Therefore, an additional deficit of 50 hm^3/year, created by accounting for the lack of resources in water-stressed agricultural productions (about to wither), was considered in the presented balance (Figure 8). This deficit is particularly relevant in extensive areas of irrigated crops from Southeast Spain (provinces of *Almería*, *Murcia*, *Alicante*, etc.) which are close to the wither status [2,4,6,16,18], the same as the situation occurring in some Mediterranean countries with a semi-arid climate and a high water demand. Thus, problems arising from high water-stress of irrigated crops pose a risk for producers, who obtain lower-quality agri-food goods, with a lower volume and caliber. As a result, this situation causes significant economic losses in the study area's agricultural sector [18,21,55]. To sum up, the first cluster of water demand, including agricultural, environmental, and recreational, presents a total requirement of 191.74 hm^3/year, which represents 75.6% of the total.

Regarding the second group of water demands, 61.86 hm^3/year were quantified as municipal supply. This urban and industrial requirement entails 24.4% of the total water demands of the study area (Figure 8). Therefore, great differences among clusters of water demands are evident. In particular, agricultural, environmental and recreational demands surpass the second group by 129.9 hm^3/year, with agricultural demand being the highest. In contrast, municipal supply appears to be in a favorable position with regard to the priority of the subjected water supply [4,6,21,52,53].

Thus, the difference between total water inputs and total water demands reached 72.6 hm^3, included as water deficit per year in the conceptual model of the study area. This result, together with previous data, could provide water planning authorities with useful information in order to face the scarcity of water resources in a context of increasing demand.

The present deficit estimated between water demands and water inputs could rise if certain environmental inputs, such as groundwater, continue decreasing their reserves [2,26,28,29]. Similarly, other circumstances which could increase these differences come from the obligation to carry out several normative measures, such as the Water Framework Directive [42]. In brief, this directive put several rules into place, such as environmental objectives, the polluter pays principle, or the full cost recovery principle of water services, that European Member States must respect throughout the 2009–2015, 2015–2021, and 2021–2027 periods. According to [2,16,18,31], in order to ensure the good status of surface resources and groundwater within the study area, the following solutions are proposed: (i) increase the rates of reclaimed water considering that, currently, a volume of 16.46 hm^3/year is discharged into the Mediterranean Sea; (ii) activate the *Júcar-Vinalopó* water transfer (illustrated in Figure 3) taking into account that, during the last few years, this conduction has been gradually transporting minor flows (e.g., 9 hm^3/year and 4 hm^3/year), essentially due to political disputes and water governance discrepancies [1,2,47]. It should be noted that this canal was approved in 1998, under the environmental premise of replacing the supply from wells with the equivalent transferred volume from the *Vinalopó* River system [6,18].

7. Conclusions

Endogenous reserves from *Alicante* province are visibly scarce in order to manage the production system and satisfy the total water demand. Hence, in the study area, there is a great consumption of its own resources for which the stress has reached a critical level. Therefore, endogenous and exogenous sources (channels, interbasin transfers, etc.) must be combined, together with unconventional resources coming from wastewater treatment and desalination. The main result of this work shows a water deficit of 72.6 hm^3/year, established as the difference between total water inputs and total water demands in the study area. This result could provide water planning authorities with useful information in order to face an increasing water demand, in conjunction with the phenomenon of droughts, which have progressively aggravated the chronic situation of water deficit in Alicante province.

This case study may serve as an example of the need to be integrative when planning water resource management in similar areas, because holistic views, which consider all available water alternatives and accurate projections of water demand, should be implemented, as well as the integration between water and urban-territorial planning [56].

To sum up, this complex management model in a situation of shortage needs an integrated solution to ensure the sustainability of stakeholders, users, and territory, as defined in the *Pacto Provincial del Agua* (Provincial Water Pact), an agreement signed in the provincial government of *Alicante* [57] by different political parties, along with communities of irrigators, the water supply sector, the Chamber of Commerce and universities. This agreement seeks to respond to the major water challenges in the province of *Alicante* as a benchmark. In summary, the following guidelines are proposed:

- In the study area, 25 wastewater plants have been identified, treating a total water flow of 46.05 hm^3/year. Of this volume, 53.4% (24.61 hm^3/year) is reused, 10.8% (4.99 hm^3/year) is discharged into riverbeds and, finally, 35.7% (16.46 hm^3/year) is discharged into the Mediterranean Sea. Therefore, if a significant share of these discharged flows could be recovered as reclaimed water, the intensive exploitation of coastal aquifers would be reduced. In addition, this could be an opportunity to satisfy mandatory principles, related to wastewater treatment, put in place by European Directives.
- Regarding water transfers in the study area, they must be preserved, as the contributions of the *Tajo-Segura* interbasin transfer are the guarantee for urban and agrarian supply and as a strategic element for socioeconomic growth. Concerning the planned irrigation program and the continuity of existing crops, they represent another strategic objective whose inadequate supply must be corrected by means of the necessary inputs, modernization, and high efficiency systems. Similarly, the *Júcar-Vinalopó* water transfer should be reactivated, taking into account that this conduction has gradually been transporting minor flows (e.g., 9 hm^3/year and 4 hm^3/year) over the last few years, essentially due to several political disagreements and water governance issues, for which new participatory exploitation rules should be established.
- Finally, from the perspective of urban and industrial demands, the integration of municipalities into supra-municipal networks should be promoted, since efficiency increases when it occurs in certain municipalities, with guaranteed development thanks to good water governance schemes implemented by entities such as MCT or AMAEM [2].

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