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The Horizontal Covered Well (Draining Gallery) Technique as a Model for Sustainable Water Use

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Abstract: Among the techniques for capturing nearby groundwater, the covered horizontal well (draining gallery) stands out in its different types of water mine, qanat, and cimbre. The water collected by these means is used to supply people and livestock, in irrigation, in the movement of hydraulic devices, etc. Because they are carried to the surface by gravity (without the need for energy) and because only the recharging of the groundwater table that takes place after the rains are captured, they serve as models for sustainable water use. The measured flow is variable depending on the rainfall and infiltration, but the quality of the water makes it its own water resources of great interest at the local level. The study area is the territory of the Southeast of Spain (more than 22,000 km^2), with a rich hydraulic heritage. The research is a regional analysis (diachronic and compared) of several socio-hydric systems, with extensive fieldwork.

Keywords: groundwater; nearby water tables; draining galleries; sustainability; southeast of Spain

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1. Introduction

The study area is located in the southeastern quadrant of the Iberian Peninsula, a geographical space of coastal fields delimited by the Mediterranean coastline to the South of Cabo de La Nao (Alicante) and to the North of Cabo de Gata (Almería). This area extends towards the interior of the peninsula to the isolines with an average annual temperature of 16 °C and 400 mm of precipitation. It is a territory of more than 22,000 km^2 in which almost three million people live, known as the Iberian Southeast or the Southeast of Spain. (Figure 1). Spanish hydrological planning includes the central part of the Iberian Southeast in the Segura Hydrographic Demarcation (hereinafter DHS).

The Southeast of Spain is one of the driest areas in Europe, with a high structural deficit in the relationship between water resources and water demands. Climate change scenarios can aggravate this situation [1]. In order to attend to the settlement of the population and the development of their socioeconomic activities, they resort to optimizing their own water resources and water transfers from other basins and regions. Among our own resources, groundwater stands out. For the collection of nearby groundwater, covered horizontal wells or draining galleries are built. Sometimes they are combined with vertical wells (popularly known as "lumbreras" or "espejuelos"), which are useful both in the construction and in the maintenance of the filtering or draining system.

The "lumbrera" is a vertical well/shaft (from the surface to the interior of the draining gallery), which allows aeration and lighting and facilitates cleaning tasks. Gil and Gómez coined this terminology in 1993 when describing these systems in the coastal fields of Águilas (Murcia Region, Spain) [2]. Palerm, in his work in Mexico in 2004, attributes to these authors the term "gallery with shaft-wells" as a synonym for filtering galleries or qanats [3]. The word "espejuelo" also refers to the vertical shaft of the draining gallery. When there is water circulating, sunlight is reflected in it as in a mirror; hence "mined with small mirrors," as they are called in the Jumilla-Yecla Altiplano (Murcia Region, Spain).

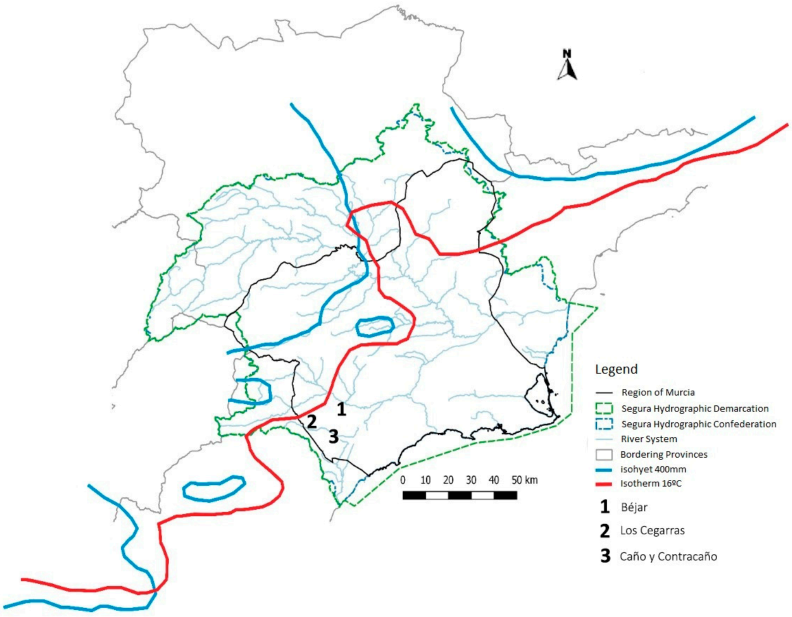

Figure 1. The study area, with functional covered horizontal well systems (draining gallery) and associated with the subalvea dam. Source: Authors.

In order to obtain nearly all of the sub-surface circulation present in the sediments that fill the rambla riverbed, it is important to emphasize those hydraulic complexes in which the gallery with shafts is connected to a subalvea dam (Figure 2) [4].

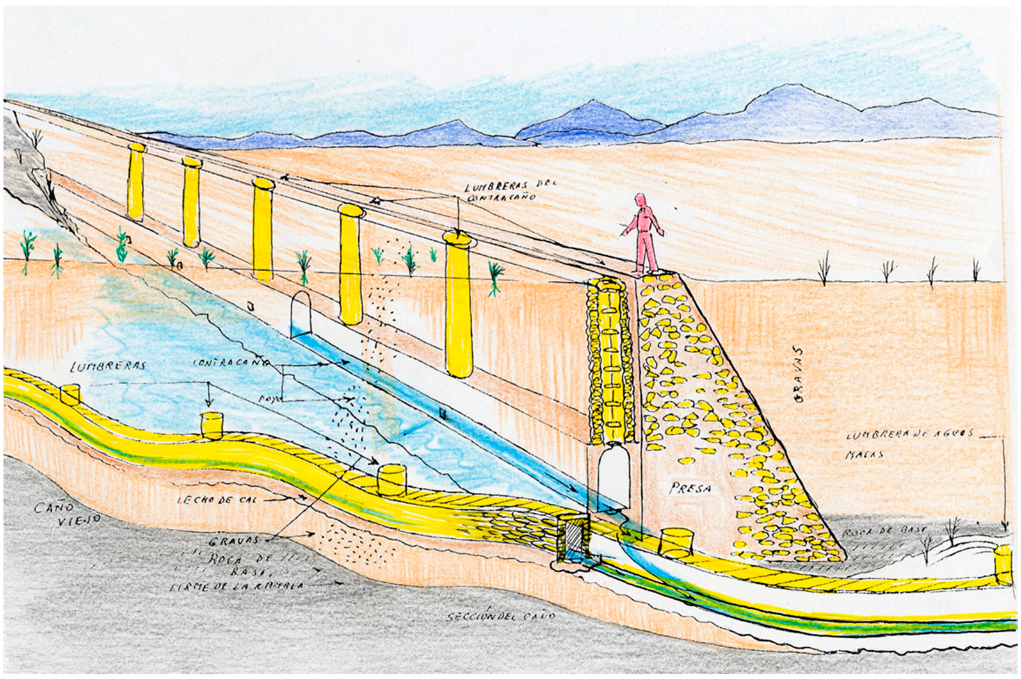

Figure 2. Diagram of the draining gallery associated with the subalvea dam. Source: Reprinted/adapted with permission from Ref. [5].

In terms of the typology of horizontal draining wells, it is interesting the one presented by Hermosilla et al. on galleries in the province of Almería [6], complemented by the later work of Antequera et al. on draining galleries in Spain [7]. As well as the one developed by Martinez et al. in the Iberian Southeast, distinguishing between water mines, qanats, and cimbras [8]. Moghadam et al. define drainage galleries as hydraulic structures for the extraction of groundwater using only the force of gravity without the need to apply external force by pumping [9].

The water mine is a horizontal well dug to collect groundwater, which does not usually have vertical wells to the draining gallery, and in most of these systems, the volume measured is small.

The qanat is a covered horizontal well, a gallery or mined, generally dug into slopes. The groundwater drains by gravity from a mother well to the surface (headwaters). In its construction and operation, it has vertical wells (louvers or mirrors) that allow aeration, cleaning, and even access to the horizontal well. Khaneiki studied the climatic and geogeraphical conditions that promoted the technology of the qanat, the base of agricultural production in the central plateau of Iran. He defines the qanat as an underground tunnel on the side of a hill that drains groundwater and transports it to the surface [10].

The cimbre is a covered horizontal well that is located in a ditch or open wall in the sediments that fill the bed of a stream to capture the interstitial circulation that exists between those materials of the deposit or alveo, actually captures the subsurface circulation that exists in the bed of a fluvial course.

The main problem faced by draining galleries is the overexploitation of aquifers by other technologies, such as the vertical well with the extraction of groundwater by motorized pumps. An example of this is what is happening in central and eastern Iran, where there is a high rate of groundwater depletion due to excessive extractions that cause drops in piezometric levels and poor water quality [11].

All these hydraulic systems provide water resources, which due to their quality (in most cases, they are drinkable), make their ownership and exploitation disputed by different groups and uses (supply, irrigation, etc.). Sometimes, they are the only source of their own resources at the local level, especially in arid and semi-arid environments, where water is scarce but necessary for the settlement of the population and the diversification of activities. In addition, they have a rich hydraulic heritage, which can contribute to local development as an endogenous resource [12]. Environmental, social, and economic sustainability is practiced in most of these socio-hydraulic complexes. This adaptation to environmental conditions means that some of them are being rehabilitated as models of sustainability [13].

The analysis of ancient water supply systems by qanats (structure, characteristics, and operation) indicates that they should not only be protected as a World Heritage Site (UNESCO) but should also be considered a sustainable form of groundwater management in arid and semi-arid regions [14].

The research focuses on the hydraulic systems to capture nearby groundwater, among which the covered horizontal well or draining gallery stands out. The object of the study is to present historical adaptation solutions to the lack of water in dry environments. In the context of water scarcity, it is necessary to correctly manage both the offers and the demands. In the demands, action will be taken on the main consumer of water in the Southeast of Spain with modernization of irrigation, supply irrigation (localized pressure), innovation in the application of water to deal with evapotranspiration (buried irrigation tape), and measures to avoid water stress (deficit irrigation), etc. The supply of water with unconventional resources (desalination and reuse) will also be increased [15,16]. The purpose of the research is the study of sustainability models in the collection and exploitation of groundwater in arid and semi-arid environments.

2. Materials and Methods

The bibliography on qanats has been one of the basic materials in this study of regional geographical analysis. It has allowed us to learn about the development of these hydraulic systems in Spain and to compare it with the development in other areas of the world [8,17–23]. Among the groups of researchers in Spain, the Research Unit of Territory, Landscape and Heritage Studies (ESTEPA) of the University of Valencia stands out, which has maintained several projects with Tunisian researchers, two Doctoral Theses, and several publications on galleries in Spain and Tunisia [24–26].

The Research Group on Environmental Change, Landscape Transformation and Territorial Planning (GAPT) of the University of Murcia has highlighted these models of sustainability, their interest at a local level, and the role of subalvea dams associated with filtering galleries [4,8], should also be highlighted. Both groups are a benchmark for hydraulic heritage in the use of draining galleries.

Simultaneously, a search for documentation has been carried out in archives such as that of the Segura Hydrographic Confederation (CHS) in Santomera and the Espín Fund of the former Mediterranean Savings Bank (CAM) in Lorca. In the Municipal Historical Archive of Murcia and the Municipal Historical Archive of Lorca. The files have also been consulted in the Registry and Catalog of Waters that exist on water uses by the Water Commissioner of the CHS.

The fieldwork, the analysis of the cartography and the aerial photo of the 1956 American flight, and the interviews with the users of the illuminated waters have allowed us to locate them in the territory, evaluate their state (abandoned or functional), the hydraulic heritage generated (galleries, wells, manholes, spouts, spouts, ponds, etc.), as well as the cultural landscape associated with these hydro-social spaces.

In the description of the qanat as an ancient underground structure to extract water from the groundwater without the need for external energy, some researchers use remote sensing to find out the changes in land use and the state of the qanat in spaces such as the Mashhad plain in Iran [27].

It is a regional geographical analysis research with a dynamic (evolutionary) and comparative study (with those of other places). The data from rounds and capacity are collected to approach a quantitative investigation and the qualitative aspects with the experiences and perceptions of the system that users manifest.

3. Results

In the 19,025 km^2 of the territory of the DHS, more than 160 hydraulic systems have been counted in which horizontal wells are used to capture and distribute phreatic water in order to bring it to the surface. These hydraulic systems have water collection, conduction, and distribution areas. In some cases, because of the reduced capacity, an accumulation element is also required (pond, pool, pond, etc.), visible in the landscape, with a great variety of shapes, capacity, and materials used in its construction.

3.1. The Draining Gallery Systems and Subalvea Dams in the South-Western Quadrant of the DHS: Terms of Lorca and Puerto Lumbreras

In this geographical area, there is a group of draining galleries that capture water from the groundwater and whose exploitation systems are still functional. Thus, in Alto Lorca, there are the galleries of Ojos de Luchena and those of Venta Ossete, Casa Robles, Loma del Cuartel, and La Mina in the district of La Paca (Table 1). In the hamlet of Avilés, there is one in Los Pozos de la Fuente and another in Zarzadilla de Totana [28].

Table 1. Some functional draining systems located in Alto Lorca.

System	Water Flow m^3/Year *	Aquifer and Place That Drains.	Constructive Elements	Type	Uses
Ojos de Luchena.	10,060,000	Pericay-Luchena.	260 m of gallery and 6 shafts.	Water mine and falsework (cimbra)	Supply and irrigation
Fuente La Mina (La Paca).	346,896	Don Gonzalo-La Umbría (Mingrano-Rincón).	80 m of gallery and 2 shafts.	Qanat	Irrigation

Table 1. *Cont.*

System	Water Flow m^3/Year *	Aquifer and Place That Drains.	Constructive Elements	Type	Uses
Pozos de la Fuente (Avilés).	315,360	Bed of rambla of Avilés. (El Cargador).	414 m of gallery, 15 shafts.	Falsework	Domestic and irrigation
Venta de Ossete	126,144	Bed of rambla.	300 m of gallery, 12 shafts, and pond.	Qanat	Irrigation
Zarzadilla de Totana	94,698	Cambron (Zarzadilla).	187 m of gallery, 9 shafts, pipes, trough, and sink.	Qanat	Supply, domestic, and irrigation.
Casa Robles	63,072	Bed of rambla of Turrilla	130 m of gallery, 10 shafts, pond.	Qanat	Irrigation

Source: Authors. (*) Data from 2019, according to Segura Hydrographic Confederation (SHC).

In the Upper Lorca, the Ojos de Luchena System stands out in terms of capacity, with an average of more than 10 hm^3/year. It has been and continues to be the traditional source of irrigation in Lorca. This gallery begins as a water mine and continues as a cimbre with wells until it flows into the bed of the Luchena River, a tributary of the Guadalentín river-rambla. The system is located downstream of the Valdeinfierno reservoir and drains the Pericay aquifer. The main gallery has six openings along its route, and its mouth is 2.30 m high and 1.50 m wide. It has maintained a capacity of more than 260 L/s, even during periods of intense drought, which means that despite the variations in the volume of water supplied, it has been a continuous resource (Table 1).

Between Lorca and Puerto Lumbreras, there are three of the galleries and subalvea dam systems that are still functional and make use of the subsurface circulation in the course of the Béjar and Nogalte wadis. These are the Caño y Balsa de Béjar, Caño y Balsa de Los Cegarras, and Caño-Contracaño hydraulic complexes in Puerto Lumbreras (Table 2).

Table 2. Features of hydraulic gallery systems associated with a subalvea dam to light subsurface waters in the riverbed of boulevards in the southwestern sector of the DHS (terminals of Lorca and Puerto Lumbreras).

System	Channel	Gallery	Groundwater Dam	Pond (m^3)	Other Elements	Shift	Uses
Caño y Balsa de Béjar	Rambla de Béjar	900 m and 17 shafts	60 m dam and gallery with 3 shafts	1852	Pipes, trough, sink	14 days, 336 h of water	Supply, domestic, and irrigation
Los Cotes-Los Cegarras	Rambla de Nogalte	700 m y 16 shafts	Gallery registered in the dam at the 3 rambla crossroads	617	Pipes, drinking trough, sinks, 3 hydraulic mills-oil mills	15 days, 360 h of water	Supply, domestic, industrial, and irrigation
Caño y Contracaño	Rambla de Nogalte	Cimbre of 312 m and 13 shafts. The gallery of the joint section of more than 200 m and with several luminaries.	112 m dam and gallery in front with 7 shafts	Before 1280 m, now a 952 m cistern	Pipes, trough, sink, 4 hydraulic mills	14 days, 336 h of water	Supply, domestic, industrial, and irrigation

Source: Authors.

In the case of galleries associated with groundwater dams, the one that makes up the Caño-Contracaño hydraulic complex is particularly noteworthy (Figure 3). First, there was the Caño Viejo, which is a shoring system with more than 300 m of gallery length and several openings. It is built in the sediments that fill the bed of the Nogalte wadi as it passes through Puerto Lumbreras, and in 1890, it was joined by the new Contracaño system [5]. This was built with a sub-surface dam measuring 4 m in base by 8 m in height, cutting off practically the entire subsurface flow, and to which a gallery was added to collect the flow of sub-surface water. The new gallery is more than 60 m long and has seven shafts. The entire system has maintained a variable but continuous flow, which has only been interrupted due to obstruction following a flood in which the cover of one of the galleries was broken and filled with mud, stones, etc. This happened after the floods of 28 September 2012 and 12–13 September 2019, interrupting the time necessary for cleaning (Figure 3).

Figure 3. Interior of the Contracaño gallery (Puerto Lumbreras). Source: Authors (2 April 2004).

At the head of Nogalte, there is also a set of galleries, since 1926, that form the Los Cotes-Los Cegarras system. The system consists of a main gallery, whose first section is a gallery dam, which acts as a gallery inscribed in a subalvea dam, a situation that is repeated in the three crossings it makes in the bed of the Nogalte Rambla (from one bank to another) and two secondary galleries. The first one enters the left bank and goes up the Barranco de Los Cotes (about 60 m long); The second gallery (known as Tía Beatriz) is located on the right bank of the rambla and connects with the main one at light 4. The main gallery has a total length of more than 700 m, and it has 16 lights open. The illuminated water is deposited in a trapezoidal-shaped pool with a capacity of about 1600 m^3. From it, the distribution of water for irrigation is organized, and the irrigable perimeter is rather discontinuous, formed by sectors of terraced terraces according to the slope of the river course. Along its route, the illuminated waters moved three hydraulic bucket mills, now converted into oil mills for grinding olives [29].

The rambla of Béjar (with a catchment area of about 88.6 km^2) starts from the Estancias and La Torrecilla mountains, draining in an NW-SE direction in the Viznaga rambla, a tributary of the Guadalentín-Segura. In the bed of the Béjar rambla, downstream of the Cortado de las Peñas de Béjar, the subsurface circulation is captured by means of a hydraulic complex formed by a subalvea dam and a drainage gallery placed before it. The illuminated water is conducted (buried on the right bank) through a gallery of more than 900 m in length, which presents 17 lights along its route. At the exit of the mine entrance, there is a drinking trough, a washing place, and the channeling that leads the water to the 1400 m^3 capacity pond, from which the irrigation batch is organized.

To the west of Nogalte is the rambla of Vilerda and other riverbeds such as Los Carrascos, La Ramblilla, del Fraile, Goñar, etc. In the Los Carrascos reservoir, a small subalvea dam (about 18 m long) is still functional, which has a gallery that conducts the illuminated water along the left bank to the Los Porceles reservoir (from Above and Below), with several luminaries on their tour.

3.2. The "Minados Con Espejuelos" Sistem of the Altiplano de Jumilla-Yecla, in the North-Western Quadrant of the Segura Hydrographic Demarcation (DHS)

In Yecla, the systems of Las Tobarrillas, El Pulpillo¸ Fuente Negra, and Fuente del Álamo stand out. In the municipality of Jumilla, the mines with mirrors of La Alquería and Fuente del Pino, as well as the rehabilitated mines of Casa Herrera, Partido de Los Álamos and several of the Compañía del Prado, and La Pinosa.

In the Altiplano of Jumilla-Yecla, the two longest gallery systems are the Tobarrillas in Yecla and those of the former Compañía del Prado and La Pinosa. The Tobarrillas System is a qanat with a mined area of more than 2000 m in length (2098 m) and 33 mirrors (29 in the main gallery and 4 in the secondary gallery). The set of galleries of the Compañía del Prado and La Pinilla, currently the Cañada del Judío Irrigation Community, is being rehabilitated with the aim of establishing a water route in Jumilla, which can be visited to appreciate the hydraulic heritage (Figure 4).

Figure 4. Restoration of the fountain, spouts, pond, and trough of the Compañía de Aguas del Prado y La Pinosa, supplied by the water collected by several mines with mirrors in Jumilla (Region of Murcia). Source: Authors (2 December 2022).

The galleries of Partido de Los Álamos and Casa Herrera in Jumilla have also been rehabilitated. In both cases, it has been an individual (the owner of the farms) that completes the irrigation of olive groves of old assisted dry land with the lighted water.

At the SW end of the Sierra de Santa Ana, at the foothills of the sunny area of Los Alacranes and La Buitrera, there is the mine with mirrors from the Los Álamos District, which has a gallery or mine of 250 m and eight shafts or mound. The illuminated water was deposited in a 1200 m^3 capacity raft. In 2008, the entire structure of the pool was reinforced, expanding its capacity to 2000 m^3.

On the northern slope of the Sierra del Buey, in the foothills, in the area of Doña Jimena, there is a mine over 430 m long and various spectacles. In 2008, the first 200 m of mining and its corresponding wells were rehabilitated. The lighted water is deposited in a 160 m^3 pool. The rehabilitation has consisted of plastering the walls of the mine with stone and mortar, and at the base, the illuminated water is channeled through one of the sides; in this way, the dry passage of visitors is allowed, and cleaning tasks are facilitated.

In the neighboring province of Almería, in municipalities such as Pulpí, Cuevas de Almanzora, Huercal-Overa, etc., close to the Region of Murcia, there are more than 110 groundwater collection systems through galleries. The horizontal filtering wells built in the sediments of streambeds and river streambeds, known as cimbres, trenches, or tajeas, predominate. Like the Sufli Ditch, the Chaulema Ditch, the Padules Ditch, and the Beneficiario Fountain Ditch. The latter, the Beneficiario Fountain Ditch, has more than 300 m of gallery on the left bank of the Almanzora River; it captures the flows of the hypodermic circulation that exists between the gravel and sand of the riverbed. The light flow varies from 35 L per second (after the snowmelt in the Sierra de Bacares) to only 5 L per second in dry periods. It was also lighting by cimbre, the one developed on the left bank of the rambla of Guazamara, known as El Rincón or the Atenores, with more than 300 m of covered horizontal well and several shafts.

The simplest systems for capturing groundwater on slopes and foothills are the water mines, such as the Fuentes de las Perdices in Nieva (Huércal-Overa district), whose sources of lighted water are part of the resources owned by the Irrigation Community of Huércal-Overa Norte.

The most complex system is the qanat, part of a mother well whose water table is captured, and an excavated gallery that drains the groundwater that cuts on its way to the mine entrance (sometimes located several hundred meters from the origin of the qanat, the mother well) or meirat). Among these systems, the qanat of Fuente del Cabezo stands out, owned by the former "La Asunción" Water Collective Society, later integrated into the own resources of the Irrigation Community of Huércal-Overa Norte. It is an excavated gallery 814 m long, which has a mother well near the "Zurrío del Agua" in Cabezo de La Jara. The ten main luminaries are of great dimensions, more than 2 m in diameter and 12 m deep. The lighted water accumulates in a pool with an almost square floor plan, 28.30 m wide by 20.80 m long and about 2 m deep, giving it a capacity of 1600 m^3. In the past, the water was listed according to the times that corresponded to each irrigator in the 14-day batch (it was auctioned by faithful of the water "El Relojero"). In 2012, the pond and the 8882 m of common channel channeling were rehabilitated by those of the three distribution branches (del Polo, Las labores, and Los Pedregales). As a more complex qanat that becomes a gallery inscribed in a subalvea dam every time it crosses the sediments of the riverbed of the Albox rambla, it is the qanat of the Fuente del Marqués.

In the Almanzora Valley, the set of flows illuminated by water mines, cimbre, and qanats accounted for more than 10 percent of consumption in irrigation (11.10%) in the hydrological year 2014/2015. A hydraulic heritage (the draining galleries) that is completed and expanded with the use of these waters in supply and domestic uses (pipes, laundries, etc.) or in energy (hydraulic bucket mills, waterfalls for light factories, etc.).

4. Discussion

Qanat researchers disagree about the origin of these draining horizontal well hydraulic systems, perhaps only in their antiquity of more than 3000 years of them [30]. As for the technique used to excavate the horizontal well, Goblot, H. attributes a mining origin to it [22]; but other researchers such as Carbonero, M. A. (1992) indicate that they do not have a single origin [31]. As for the place of origin, most authors such as in Refs. [22,23] prefer Mesopotamia (Armenia and Persia), but others, such as Lightfoot, D. R. in [32], place them in the Arabian Peninsula and the Near East. In reality, the origin varies locally. In terms of location, there are other areas far from the Mediterranean where they also have extraordinary development, as is the case of Turpan in Xinjiang-China [33]. This technique has also been extended in Mexico [3]. The horizontally covered well technique (draining gallery) can also be observed in regions with higher rainfall, such as Antalya-Turkey [34].

There is hardly any discussion of environmental sustainability in the exploitation of the systems studied in the southeast of Spain and in other regions of the world. In Iran, Bouzarjomhri and Khatami have studied environmental sustainability in 16 qanats in Yard province, showing that these water resources make it possible to face crises due to water scarcity and plan sustainable development [35]. Depending on rainfall and infiltration processes, the groundwater (sub-surface and aquifers) is recharged, which is the feeding reservoir, without generating overexploitation. The waters are brought to the surface depending on the slope, by gravity, without energy consumption. These systems are adapted to the conditions of the environment (topography, nature of the materials they pass through, rainfall, etc.).

The usable flow depends on the rainfall, infiltration, and the state of the system. The variability of rainfall in arid or semi-arid environments, as is the case in the Southeast Iberian Peninsula, is transferred to the use and is marked. Table 3 shows the flows produced by the Caño-Contracaño system in the period 2007–2022.

Table 3. Water volumes supplied by the Caño-Contracaño System in the period 2007–2022.

Year	Volume (m^3)
2007	369,600
2008	333,600
2009	277,200
2010	710,400
2011	589,200
2012	248,400
2013	808,800
2014	296,400
2015	100,800
2016	70,800
2017	759,600
2018	237,600
2019	240,000
2020	487,872
2021	85,536
2022	2,555,712
Total 2007–2022	8,171,520
Average 2007–2022	510,720

Source: Authors, with data from the Irrigation Community of “Caño y Balsa” of Puerto Lumbreras.

If the average is 510,720 m^3/year, there are years in which it does not reach 120,000 m^3 (2015, 2016, 2021) and others in which it exceeds 500,000 m^3 (2010, 2011, 2013, 2017, 2022). In addition, the extracted volume varies from one batch to another in the same year; it can be observed in the months of the last three years (Table 3).

Due to the rains in the months of March and April 2022 (Table 4), a volume of 7776 m^3 was exceeded in January and February; to 51,840 m^3 in March and 77,760 m^3 in April. With volumes removed by the system of 155,520 m^3 in the month of May and 207,360 m^3 in June. All this after the cultural practices carried out in the bed of the boulevard to favor the infiltration of the superficial runoff that emerged in the area of Peñas Blancas, a few kilometers upstream from the location of the Caño-Contracaño; practices that were maintained until the first months of 2023 (Figure 5).

Table 4. Monthly rainfall at Finca Sol y Luna, in the alluvial fan of the Rambla de Nogalte in the Murcian Pre-coastal Depression.

Hydrological Year/Months	2019/2020 (mm)	2020/2021 (mm)	2021/2022 (mm)	2022/2023 (mm) (*)
October	35.0	11.5	2.0	6.0
November	16.0	7.5	45.0	28.5
December	36.0	0.0	1.5	20.0

Table 4. *Cont.*

Hydrological Year/Months	2019/2020 (mm)	2020/2021 (mm)	2021/2022 (mm)	2022/2023 (mm) (*)
January	65.0	45.0	7.0	6.6
February	2.0	0.0	6.6	0.0
March	86.0	66.0	296.0	2.1
April	76.5	59.0	61.5	0.0
May	23.0	48.0	28.0	120.9
June	18.0	10.0	6.0	(*) 34.2
July	0.0	0.0	0.0	(*)
August	0.0	0.0	0.0	(*)
September	10.0	6.0	9.5	(*)
Total	361.5	307.0	462.5	318.3

(*) The data is up to 15 June 2023. Source: Authors, with data from the Finca Sol y Luna of the Díaz Family.

Figure 5. Cultural practices with the construction of ponds in the Rambla of Nogalte favor infiltration and increase the sub-surface flow extracted by the Caño-Contracaño System. Source: Authors (3 November 2022).

The year 2022 has been recorded in extracted volumes, more than 2.5 million cubic meters (2,555,712 m^3/year). Undoubtedly due to the precipitation that fell in the months of March, April, and May (385.5 mm of a total of 458.5 mm/year, 82.29% of the annual precipitation) and also the rain that fell on several days (18 days on March 6 in April and 4 in May); a way that favors the infiltration and recharge of the groundwater. (Table 4). In the second half of 2022, it registered 2,047,600 m^3 (80.12 of the total for that year).

Perhaps it is more difficult to explain social and economic sustainability due to changes over time and the context of each place:

- Systems that have been abandoned due to flow competition with vertical wells, which have overexploited the aquifer;
- Lack of interest in the social group that used it, and even exodus from rural areas.
- Shortage of experts for its maintenance and rehabilitation;
- Competition of newly irrigated lands for the greater availability of water resources.

These threats are not exclusive to the southeast of Spain. They are also observed in other areas, such as Iran, where the abandonment of the qanats is attributed to sharp drops in the water table in the last thirty years and the little interest of the new generations in maintaining these ancient structures [9,27].

Table 5 shows the structure of water ownership, in three of these hydrosocial systems, of still functional subsurface water use. Initially organized as Civil Societies, as Communities of Water Owners, they aspire to become Irrigation Communities when the use continues, and there is interest in its users. Thus, on 28 July 1926, the Deed of Constitution of the Community of Owners of the Aguas del Caño and Balsa de Lumbreras was carried out in Lorca, and on 21 August 2014, it was constituted as an Irrigation Community. Article 1 of its Ordinances indicates that the owners of the assets attached to the use of groundwater from the subsurface of the Rambla de Nogalte as it passes through the municipality of Puerto Lumbreras constitute an ordinary or first-degree Community of Users with the denomination of Community of Irrigators Aguas Caño y Balsa de Puerto Lumbreras, in accordance with the provisions of articles 81 and 88 of the Consolidated Text of the Water Law.

Table 5. Water ownership structure in Nogalte and Béjar (2020).

Scale	Béjar (Owners)	Béjar (Total Water Hours)	Los Cegarras (Owners)	Los Cegarras (Total Water Hours)	Puerto Lumbreras (Owners)	Puerto Lumbreras (Total Water Hours)
<10 h	6	26.0	25	162.5	106	202.4
10–20 h	5	75.0	4	46.0	4	58.8
>20 h	6	235.0	4	151.5	2	74.8
TOTAL	17	336	33	360	112	336.0

Source: Prepared by the authors with information from Caño y Balsa de Béjar, Aguas de Los Cegarras, and C.R. del Caño y Balsa de Puerto Lumbreras.

Most of these owners barely have less than 10 h of water from the batch, but its value has increased due to the quality of these volumes of water, which makes them suitable for use on farms in high-quality productions that demand a lot of workforces. This environmental, social, and economic assessment can be observed in the Caño and Contracaño System in Puerto Lumbreras Region of Murcia). The quality of the water entails its use by companies dedicated to the production of ornamental plants, such as Barberet & Blanc, which employs more than 400 workers. The extracted water is a resource for employment and local development, which allows for avoiding the depopulation of rural areas (Figure 6).

Figure 6. Interior of the state-of-the-art greenhouses of the Barberet & Blanc company in Puerto Lumbreras (Region of Murcia). Source: Authors (4 October 2014).

Some of these owner-irrigators are in other irrigation communities, where the price of water resources is ten times the price per cubic meter generated by systems such as the Caño-Contracaño. In this case, the economic valuation is clear when it is known that the Irrigation Community of Puerto Lumbreras, which has an irrigable perimeter of more than 4000 hectares and almost 1000 community members, acquires part of the extracted water.

Although the origin of the water used in the Irrigation Community of Puerto Lumbreras in the period 2017–2021 is mostly water from desalination (72.07%) (Table 6), especially from the Instalación Desaladora de Agua de Mar (IDAM) (Seawater Desalination Plant) of Águilas-Guadalentín, of which it has a concession of 5 hm^3/year. Los Caños water is important to mix and improve the quality of irrigation water. Almost two million cubic meters in the 2017–2021 period, more than five percent (5.56%) of the total volume consumed by the C.R. of Puerto Lumbreras in that period of 2017–2021. In 2022, a humid year with several rainy days in March and April, there were more than two million cubic meters of water obtained by draining galleries. The hydraulic complex is economically viable as a water resource for the Irrigation Community of Puerto Lumbreras, since the volume acquired from the Caño-Contracaño (at less than 0.10 euros per cubic meter, including the distribution in the irrigable perimeter) balances that of desalinated water from the IDAM Águilas-Guadalentín, which since 2016 has been purchased at 0.36 euros per cubic meter at the plant outlet, but to which must be added the cost of delivery and channeling up to the irrigable perimeter of the C.R. of Puerto Lumbreras.

Table 6. Origin of the water used by the C.R. of Puerto Lumbreras (2017–2021).

Designation	Volume (m^3)	Volume (%)
Rainwater (sweeping streets, roads, etc.)	78,000	0.23
Aquifer wells	5,039,078	15.00
Gallery pipes	1,904,669	5.56
EDAR (treatment and regeneration)	1,603,238	4.68
Desalination	24,699,008	72.07
Assignments of rights and drought wells	947,596	2.76
Totals	34,271,589	100.00

Source: Prepared by the authors with information provided by the Irrigation Community of Puerto Lumbreras.

The technique of the covered horizontal well, drains of water mines, qanats, and cimbres, etc., which sustainably exploit groundwater, has been revitalized in recent years, with numerous examples of its functionality. Thus, in the streets between greenhouses, trenches are opened in which a drain is installed that collects the water that drains from the waterproof covers without preventing the street from continuing with its output function for the productions inside the greenhouse, and at the same time, the supply of own water resources is expanded. What has led to the valuation of this entire underground hydraulic heritage, and after its rehabilitation, tourist routes have been planned, such as the Calle del Agua in Pliego, the Ruta del Agua in Puerto Lumbreras or the Minados Tour in Jumilla (Figure 7).

The technique of the covered horizontal well (draining gallery) is old (more than 3000 years). The cultural practices applied allow sustainable exploitation of water. The valorization of all this underground hydraulic heritage also becomes an endogenous resource of great interest locally [36,37] and even internationally (such as the inscription, in 2016, of the Persian qanat (1506 in Iran) on the List of World Heritage [38], and the proposals of qanats of Turfan-China and Yazd-Iran as World Heritage [14,38].

Figure 7. Rehabilitation of one of the mined mounds of the Irrigation Community of Cañada del Judío in Jumilla. Source: Authors (2 December 2022).

5. Conclusions

The construction of drainage gallery systems (qanats, trusses, mines, etc.), with which groundwater is exploited, which becomes its own high-quality water resources, has allowed the resilience of people who live in geographical spaces such as the Iberian Southeast. These own water resources allow them to cope with the lack of water, especially in periods of drought, which may be more frequent and pronounced in climate change scenarios in the coming years.

The reduction of old draining gallery structures is due to the overexploitation of aquifers (with a drop in piezometric levels and poor water quality), the rural exodus, and little interest of the new generations in maintaining these groundwater collection systems.

This research, with the data of the analyzed systems (Bejar, Los Cotes-Cegarras, and Caño-Contracaño), values the environmental, social, and economic sustainability of the application of the drainage gallery technology associated with the subalvea dam.

The environmental, social, and economic sustainability of the functional systems for the use of groundwater, through these techniques and cultural practices, is fully topical in dry regions, and there is an interest in the rehabilitation of this underground hydraulic heritage as an endogenous resource for local development.

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