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Application of reverse osmosis to the regeneration of wastewater in the Southeast of the Island of Gran Canaria (Spain)

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ABSTRACT

Water is a necessary resource for human activity and especially for agriculture. In regions with a lack of water resources to obtain the water needed for crops is a handicap which solution should be establishing adequate management and treatment of the available water. This work details the quality of the water obtained by applying reverse osmosis treatment to wastewater which comes from a secondary treatment by a plant located in the Southeast Zone on the Island of Gran Canaria is detailed. The Southeast of Gran Canaria is a region with a large area intended for agricultural use, so water needs are high. Another aspect to take into account is that the main crops in the area are salinity sensitive crops, so water quality is a fundamental parameter for the choice of using regenerated water in agriculture, so this work is valued if the quality of the water obtained meets the limit values established by Royal Decree 1620/2007 for the reuse of regenerated water and for what uses it is appropriate.

Keywords: Wastewater; Reuse; Water treatment; Reverse osmosis; Regenerated water

1. Introduction

Water is a necessary resource for human activities, for economic development and social welfare [1].

It is estimated that 50% of the world's population will live in regions with a lack of water in 2025, hence the importance of proper water management and treatment [2].

According to the World Health Organization (WHO), irrigation is the activity that consumes the most freshwater in the world, which represents about 70% of all global water withdrawals [3].

When water resources are scarce, its use in agriculture is limited, so it is necessary to look for alternatives to obtain such water [4].

Agricultural activity demands wastewater due to the need for a regular supply that compensates for the scarcity of the resource, due to the seasonality or irregular distribution of the supply of other water sources throughout the year [5].

On the other hand, agriculture requires more water than other uses, such as domestic or industrial; however, for the use of wastewater, quality aspects must be considered in order to avoid risks to public health, mainly in terms of their microbiological characteristics [6].

In December 2007, Royal Decree 1620/2007 was approved in Spain, establishing the legal regime for the reuse of water, including the name of regenerated water in the

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mentioned law. Regenerated water is considered as the purified wastewater that, where appropriate, has been subjected to an additional or complementary treatment process that allows its quality to be adapted to the intended use. In the Royal Decree, the following uses are distinguished: urban, agricultural, industrial, recreational and environmental and in its annex I the quality criteria are differentiated according to the uses providing mandatory limits [7].

The reuse of treated water in Spain has been carried out for decades, being one of the countries in which it is practiced is more widespread, however, in the first decade of the 21st century, it was not possible to reuse more than 5% of the total collected wastewater [8], increasing in recent years up to 10.74%, treated water in the more than 2,000 Spanish wastewater treatment plants (WWTP) [9].

In the Canary Islands, due to being a region with a scarcity of water resources, the treated water is reused in several sectors since the end of the 60 s, in Fig. 1 we can observe the evolution of the volume of treated and reused water in the period from the year 2000 until 2016 [10].

As can be seen, although a greater amount of treated water has been generated in the last decade, only approximately 20% of the treated water is reused, the majority use of water is being the agricultural use and irrigation of gardens and sports areas as reflected in Table 1 [11]:

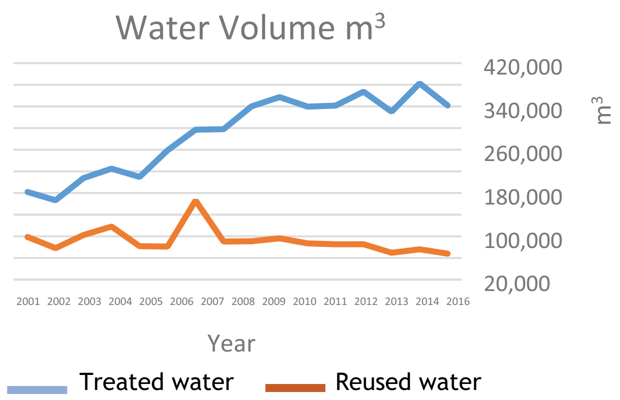

Fig. 1. Evolution of the volume of treated and reused water in the Canary Islands (own elaboration based on data provided by the Canary Islands Government).

It must be taken into account that the water used in the agricultural sector has specific quality requirements to obtain optimum production rate. One of the problems of using low-quality water in irrigation is the possible accumulation of salts in the soil that can have a negative effect on crops [12].

Since the late 1990s, tertiary treatments with reverse osmosis (RO) desalination have been implemented in Gran Canaria, as well as an important infrastructure for the distribution of water regenerated by the island [13].

RO has worldwide acceptance in both water treatment and desalination applications. It is a pressure-driven process whereby a semipermeable membrane rejects the dissolved components present in the feedwater. This rejection is due to size exclusion, charge exclusion and physicochemical interactions between solute, solvent and membrane [14]. The efficiency of the process depends on the operational parameters and the properties of the membrane and the feedwater [15].

Salinity and the reduction of water infiltration, toxicity or effects related to a group of various hazards of water components are minimized or completely eliminated through this management strategy for inappropriate effluents in agricultural irrigation [16].

The following sections indicate the characteristics of the regenerated water obtained in the WWTP in the Southeast of the island of Gran Canaria, treatment consisting of the application of RO to produce water suitable for crop irrigation.

2. Background

2.1. Location

The Comarca del Sureste is located on the Southeast slope of Gran Canaria, which has an area of 178.99 km^2, equivalent to 11% of the total area of the island of Gran Canaria, is formed by the municipalities of Agüimes, Ingenio and Santa Lucia de Tirajana (Fig. 2).

Table 1
Statistical data on wastewater volume and reuse in the Canary Islands (Source: Statistical data of the Canary Islands Government)

	2016	2014	2013
Volume of treated wastewater (m^3/d)	341,769	382,674	330,186
Percentage of treated wastewater that final destination by sea	77.9	79.3	78.4
Percentage of treated wastewater that final destination by fluvial channel	2.1	0.6	0.5
Percentage of treated wastewater that final destination by regenerated water	19.8	19.9	21.1
Percentage of treated wastewater that final destination by the sea soil	0.2	0.2	0.0
Volume of reused water (m^3/d)	67,962	75,968	69,611
Percentage of reused water by agricultural uses	70.8	53.1	57.3
Percentage of reused water by industrial uses	0.0	1.8	0.0
Percentage of reused water by gardens and recreative zones	27.2	36.3	42.6
Percentage of reused water by street cleaning	2.0	5.6	0.1
Percentage of reused water by another uses	0.0	3.2	0.0

Statistical dates are not available for 2015

Fig. 2. Location of the study area.

It occupies a territory of great landscape variety that extends from the interior to the coast and from the Gran Canaria Airport to the outskirts of the tourist area in the south of the Island.

The Comarca del Sureste supports a population of approximately 133,846 people, who about 110,000 live in flat areas near the coast. It is the geographical space of the island with the highest population growth in the last 17 y [17].

Of the area occupied by the region, 68 km^2 is classified as agricultural land [18], but only 20% of the area is currently in agricultural exploitation, with the rest of the abandoned land being one of the factors that cause this fact, the lack of water resources. The distribution of crops that occur in the region can be seen in Fig. 3, where the main crops are tomato and banana as well as several vegetables that correspond to crops highly sensitive to salinity [19].

In order to solve its water supply problems, the region has provided a reliable seawater desalination and distribution system and another one for collecting, purifying and reusing wastewater.

A large part of these treated waters is subjected to tertiary treatment, in order to obtain water suitable for use in agriculture in the area.

2.2. Characteristics of WWTP

The WWTP of the Southeast of Gran Canaria (Southeast WWTP, Fig. 4) is located about 10 km south from the Gran Canaria airport, within the Industrial Zone and near the town of Arinaga, within the municipality of Agüimes.

The WWTP was designed in its construction to treat a flow of 6,000 m^3/d, by means of two twin lines of 3,000 m^3/d of treatment capacity each one. Due to the increase of the population of the municipal that pour into it and the growth of the polygon itself, the plant was becoming small, executing two extensions of it, incorporating two more lines with a treatment capacity of 6,000 m^3/d. The treatment consists of grates and sieves, primary and secondary decantation with

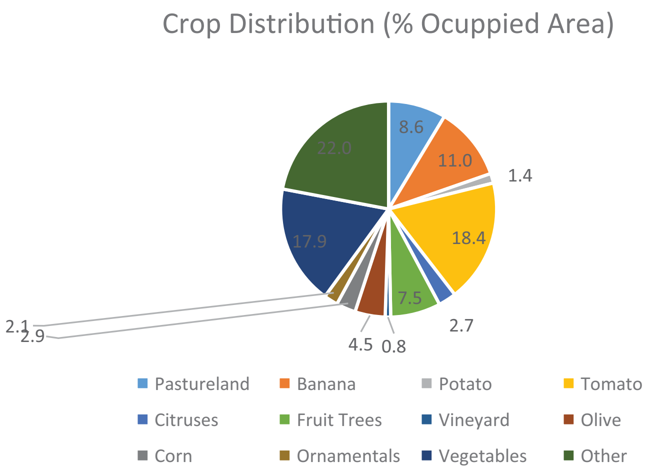

Fig. 3. Crops distribution (own elaboration based on data provided by the Canary Islands Government 2019 [20]).

capacity for 18,000 m^3/d (scheme of the treatment that can be seen in Fig. 5) and tertiary treatment with capacity for 6,000 m^3/d.

The tertiary treatment of the WWTP of the Southeast has a physical–chemical treatment of coagulation–flocculation, decantation and filtration prior to the treatment by RO, the scheme of the tertiary treatment is included in Fig. 6, a tertiary treatment that has been in operation since the year 2003.

3. Starting data

3.1. Plant characteristics

The Southeast WWTP has a capacity of 18,000 m^3/d, with two flow meters installed: one at the entrance to the plant and another at the tertiary treatment. The flow meters coupled to the pipe are electromagnetic flowmeters.

Fig. 4. View of the WWTP of the Southeast of Gran Canaria.

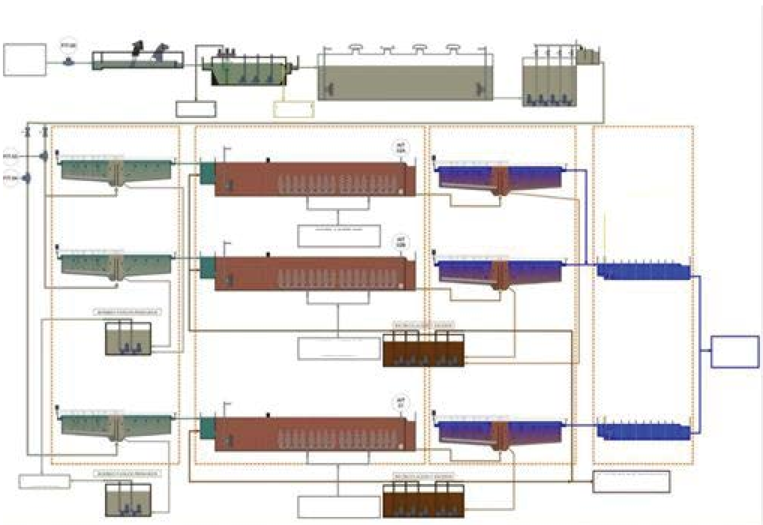

Fig. 5. Scheme of the WWTP (provided by Acciona Agua).

In the years 2013 to 2017, the flow of water treated in the Southeast WWTP can be seen in Table 2.

Part of the effluent obtained in the secondary treatment of the WWTP is discharged into the sea through an underwater emissary that is formed by 900 mm outside diameter polyethylene pipes joined by thermofusion, and has an approximate length of 981 m at a depth of 27 m.

A third of the secondary effluent goes into tertiary treatment. The water obtained in tertiary treatment is marketed for use in agriculture, so in the case of WWTP, the tertiary treatment works based on water demand.

The RO plant has a capacity of 6,000 m^3/d, its technical characteristics are being indicated in Table 3.

In Fig. 7 we can observe the variation of the annual volume of wastewater that enters the sewage plant and the annual volume that is regenerated.

In the years 2013 to 2017, the water flow obtained in the tertiary treatment can be observed in Table 4.

In the years of study, the RO plant has been producing regenerated water for agricultural use at more than 75% capacity throughout most of the year.

3.2. Characteristics of water

The parameters analyzed in the samples are electric conductivity (EC) 20°C, chemical oxygen demand (COD), turbidity, suspended solids (SS) and *Escherichia coli* (*E. coli*). The methods of analysis used are standard methods, being for the conductivity the method APHA 2510B, COD APHA 5220D, SS APHA 2540B, turbidity APHA 2130B, and *Escherichia coli* APHA 9222B [21]. In the case of permeate in addition to the parameters described above, the egg count

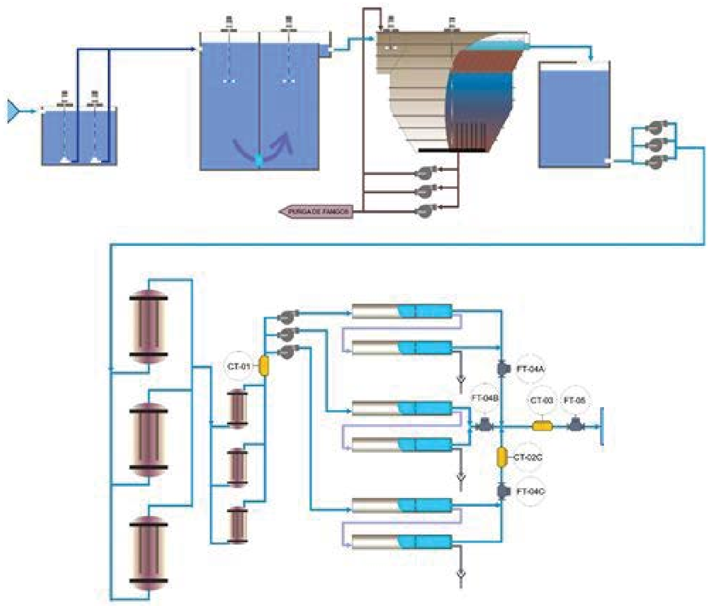

Fig. 6. Scheme of tertiary treatment of the Southeast WWTP.

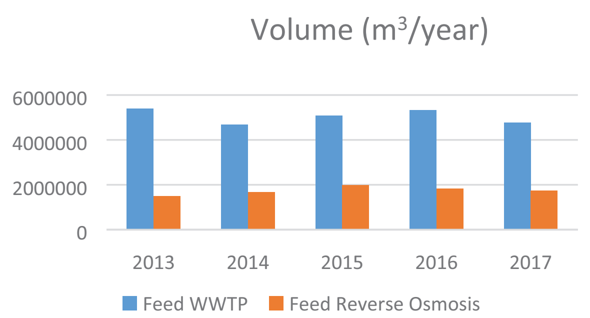

Fig. 7. The annual volume of treated wastewater and regenerated water.

Table 2
Water flows into the WWTP (m^3/d)

	Flows (m^3/d)		
Year	Minimum	Mean	Maximum
2013	12,100	14,793	20,038
2014	8,380	12,913	22,712
2015	9,767	13,934	23,557
2016	9,957	14,578	23,935
2017	10,019	13,080	18,972

of nematodes has been performed, using the Bailenger method.

The analysis of the wastewater has been carried out in Acciona's laboratories in the Southeast WWTP with the frequencies indicated in Table 5, the results obtained from 2013 to 2017 are indicated in Tables 5 and 6.

In addition, in 2013 a characterization was carried out whose analysis methods and results are included in Table 7.

Table 3
Technical characteristics of reverse osmosis plant – WWTP Sureste

Material	Polyamide spiral wound membrane
Number of racks	3
Number of step	2
Modules for rack	36–36–45
Membranes for module	6
Number of membranes	702
Operating Pressure	15–22 bar
Conversion	60%

Table 4
Water flows of the tertiary treatment (m^3/d)

Year	Mean	Maximun	No of days per year with 75% capacity
2013	4,085	6,718	221
2014	4,571	6,669	215
2015	5,420	7,007	290
2016	5,028	7,085	291
2017	4,782	6,590	247

3.3. Cost

The operation of the tertiary treatment involves the costs of chemical products necessary for the coagulation and flocculation treatments as well as energy costs due to the RO process.

For the flocculation coagulation process 40% ferric chloride is used, with a consumption of 1,125 m^3/d. Regarding energy consumption, the RO treatment plant has a consumption of 2,500 kWh/d, which represents 1 kWh/m^3.

Table 5
Characteristics of feedwater to tertiary treatment

Year	Description	EC 20°C (dS/m)	COD (mg O_2/L)	Turbidity (NTU)	SS (mg/L)	*E. coli* ufc/100 mL
	Minimum	1.06	13	1.28	2	0
2013	Mean	1.63	67	6.57	13	300
	Maximum	2.46	97	22.70	32	1,200
	Minimum	0.98	9	1.08	1	0
2014	Mean	1.69	62	6.60	15	320
	Maximum	3.00	100	28.20	27	1,100
	Minimum	1.16	37	1.47	1	0
2015	Mean	1.64	64	6.46	12	360
	Maximum	2.57	116	22.80	30	1,200
	Minimum	0.93	31.3	8	1	0
2016	Mean	1.66	63.2	21	9	346
	Maximum	2.71	123.0	31	27	940
	Minimum	1.18	32	9	1	0
2017	Mean	1.73	57	17	9	300
	Maximum	2.70	101	28	23	920
Frequency of analysis		Daily	2/week	2/week	2/week	2/week

Table 6
Water characteristics resulting from tertiary treatment

Year	Description	EC 20°C (dS/m)	COD (mg O_2/L)	Turbidity (NTU)	SS (mg/L)	*E. coli* ufc/100 mL	Nematode eggs
	Minimum	0.106	1	0.07	<L.D.	0	0
2013	Mean	0.243	4	0.17	<L.D.	1	0
	Maximum	0.376	9	0.71	<L.D.	9	0
	Minimum	0.104	0	0.1	<L.D.	0	0
2014	Mean	0.257	4	0.2	<L.D.	1	0
	Maximum	0.378	15	2.4	<L.D.	8	0
	Minimum	0.090	0.01	0.06	<L.D.	0	0
2015	Mean	0.257	3.05	0.21	<L.D.	1	0
	Maximum	0.388	11.30	3.46	<L.D.	9	0
	Minimum	0.085	1.3	0.1	<L.D.	0	0
2016	Mean	0.288	8.7	0.2	<L.D.	0	0
	Maximum	0.382	16.4	0.9	<L.D.	9	0
	Minimum	0.146	0.00	0.1	<L.D.	0	0
2017	Mean	0.250	5.68	0.2	<L.D.	1	0
	Maximum	0.344	14.00	1.1	<L.D.	9	0
Frequency of analysis		Daily	2/week	2/week	1/week	1/week	1/month

LD detection limit: 1 mg/L

4. Discussion

4.1. Characteristics of water

In Spain, Royal Decree 1620/2007 establishes the limit values for the reuse of wastewater, indicating the possible uses of regenerated water, these limit values are those indicated in Table 8.

From the results obtained, it is observed that the regenerated water obtained in the RO process in the WWTP of the Southeast of Gran Canaria complies with the specifications of the Royal Decree for agricultural, urban use in the services sector, industrial uses, recreational uses, and for environmental uses.

In the case of irrigation of crops, in addition to the parameters indicated in Table 8, the qualification of the water must include other parameters, including sodium adsorption ratio (SAR) and contents of boron and potentially toxic metallic elements.

4.2. Use for irrigation

Salinization is the consequence of several complex salt redistribution processes that depend on natural conditions, system characteristics, agricultural practices and irrigation and drainage management [22]. The excessive presence of salts prevents the growth of crops by decreasing the amount of water available to be absorbed by plants. The EC indicates the total salts dissolved in the water [23] and is the indicator used to determine the damage caused by salinity.

Table 7
Characterization of the water obtained in the tertiary treatment. Date: 2013

Parameters	Method	Results
Carbonates, mg/L	UNE EN ISO 9963	<3
Sodium, mg/L	APHA 3500	39
Calcium, mg/L	APHA 3500	0.5
Magnesium, mg/L	APHA 2340C	<0.1
Bicarbonates, mg/L	UNE EN ISO 9963	125
Chlorides, mg/L	APHA 4500 Cl-B	50
SAR	–	15
Borum, mg/L	APHA 3500	0.5
Total nitrogen, mg/L	APHA 3500	2.0
Sulfates, mg/L	APHA 4500	11
Nitrates, mg/L	APHA 4500	6.2
Arsenic, mg/L	APHA 3500	<0.01
Chrome, mg/L	APHA 3500	<1
Vanadium, mg/L	APHA 3500	<0.1
Manganese, mg/L	APHA 3500	<1
Selenium, mg/L	APHA 3500	<0.1
Molybdenum, mg/L	APHA 3500	<0.1
Nickel, mg/L	APHA 3500	<1
Copper, mg/L	APHA 3500	<1
Cobalt, mg/L	APHA 3500	<0.1
Cadmium, mg/L	APHA 3500	<0.5
Beryllium, mg/L	APHA 3500	<0.1

Taking into account salinity, in Table 5 it can be seen that secondary treatment is insufficient to obtain quality water for agricultural irrigation use since a high salinity water quality is obtained (conductivity values greater than 9.3 dS/m), so it is necessary to apply advanced treatments that reduce this salinity.

In this study, we can observe that the water obtained in the treatment of RO in the years from 2013 to 2017 has obtained values of EC between 0.085 and 0.388 dS/m, values between class C1 and class C2, so that the permeate obtained is suitable for crops with high sensitivity to salinity, as it can be seen in Table 9.

SAR is often utilized to check the suitability of irrigation water (Na^+, Ca^{2+} and Mg^{2+} in meq/L):

$$\mathrm{SAR} = \frac{\mathrm{Na}^+}{\sqrt{\frac{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}}{2}}}$$

In this study, we can observe that the water obtained in the treatment of RO in 2017 has obtained values of SAR about 15, values assigned class S2, as can be seen in Table 10 [25].

4.3. Costs

One of the problems of a RO process is energy consumption, in this case, the energy consumption is approximately 1 kWh/m^3, if we compare it with the electrical energy consumption for a seawater desalination plant by RO in the which is usually between 2,5–4 kWh/m^3 [26,27], the RO process for wastewater implies 50% less energy consumption than applied to seawater.

5. Conclusions

Despite the lack of water resources on the island, only one-third of the treated water is reused for agriculture or

Table 8
Maximum limits values by RD1620/2007

Intended water uses		Maximum permissible values			
		Nematode eggs/10 L	*Escherichia coli* ufc/100 mL	Suspended solids mg/L	Turbidity NTU
Urban	Residential	1	0	10	2
	Services	1	200	20	10
Agricultural	Quality 2.1	1	100	20	10
	Quality 2.2	1	1,000	35	Not fixed
	Quality 2.3	1	10,000	35	Not fixed
Industrial	Quality 3.1	1	1,000	35	15
	Quality 3.2	1	Absence	5	1
Recreational	Quality 4.1	1	200	20	10
	Quality 4.2	Not fixed	10,000	35	Not fixed
Environment	Quality 5.1	Not fixed	1,000	35	Not fixed
	Quality 5.2	1	0	10	2
	Quality 5.3	Not fixed	Not fixed	35	Not fixed

Table 9
Water classes according to salinity level [24]

Water classes	Conductivity (dS/m)
C1–Low salinity (can be used safely)	0–0.25
C2–Medium salinity (can be used for moderately salt-tolerant crops)	0.25–0.75
C3–High salinity (can be used for significantly salt-tolerant crops or on fields which have appropriate drainage)	0.75–2.25
C4–Very high salinity (cannot be used for irrigation of common crops)	2.25–5.00

Table 10
Water classes according to SAR [25]

Water classes	SAR
S1–Low sodium hazard (little or no hazard)	0–10
S2–Medium sodium hazard (considerable hazard but can be used with appropriate leaching, gypsum availability and cation exchange capacity)	10–18
S3–High sodium hazard (unsatisfactory for most crops but can be used at high leaching, good drainage and high cation exchange capacity)	18–26
S4–Very high sodium hazard (not suitable for irrigation)	>26

other uses in the Canary Islands, so it would be necessary to manage properly the resource by encouraging the reuse of treated water.

The quality of the water that is obtained after a tertiary treatment based on RO is suitable for the agricultural use of salinity sensitive crops but can be used with appropriate leaching, gypsum availability and cation exchange capacity.

RO is a technology that can be used to improve the environmental performance of treatment plants, having the effect of reducing discharges to the marine environment by reusing the regenerated water obtained in the process, since the regenerated water obtained has adequate characteristics, apart from agricultural use, to be used in different sectors such as irrigation of golf courses, irrigation of streets, cooling towers in the industry, as well as for aquifer recharge.

In the Canary Islands, due to the lack of resources, RO applied to wastewater constitutes a viable source of obtaining water for use in agriculture, taking into account that actually in the Canary Islands the water proceeds from RO plants of seawater whose energy costs are greater than those necessary for the use of RO with water from the secondary treatment of wastewater plants.

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