WP3. ACTIONS TO INCREASE THE QUALITY OF NON CONVENTIONAL WATER USED IN AGRICULTURE

Output 3.5. Report on the efficiency of the implemented pre and post treatments and MAR systems.

A 3.5.2 Evaluation of the efficiency of post treatment systems on non-conventional water. Carrión de los Céspedes Experimental Center, Spain

Responsible partner: AMAYA

30/10/2023

Menawara is a project funded by the EU unded the ENI CBC Med programme. Its total budget is €2.901.546,93 out of which €2.611.392,23 as EU funding (90% contribution).

This document has been produced with the financial assistance of the European Union under the ENI CBC Mediterranean Sea Basin Programme. The contents of this document are the sole responsibility of AMAYA and can under no circumstances be regarded as reflecting the position of the European Union or the Programme management structures.

The 2014-2020 ENI CBC Mediterranean Sea Basin Programme is a multilateral Cross-Border Cooperation (CBC) initiative funded by the European Neighbourhood Instrument (ENI). The Programme objective is to foster fair, equitable and sustainable economic, social and territorial development, which may advance cross-border integration and valorise participating countries' territories and values. The following 13 countries participate in the Programme: Cyprus, Egypt, France, Greece, Israel, Italy, Jordan, Lebanon, Malta, Palestine, Portugal, Spain, Tunisia. The Managing Authority (JMA) is the Autonomous Region of Sardinia (Italy). Official Programme languages are Arabic, English and French. For more information, please visit:

www.enicbcmed.eu.

The European Union is made up of 28 Member States who have decided to gradually link together their know-how, resources and destinies. Together, during a period of enlargement of 50 years, they have built a zone of stability, democracy and sustainable development whilst maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievements and its values with countries and peoples beyond its borders.

TABLE OF CONTENT

ABBREVIATIONS AND ACRONYMS

Acronym	Description
AMAYA	Agencia de Medio Ambiente y Agua de Andalucía (Environment and Water Agency of Andalusia)
BOD	Biological Oxygen Demand
CENTA	Centro de las Nuevas Technologias del Agua (Center of New Water Technologies)
CFU	Colony Forming Units
COD	Chemical Oxygen Demand
CW	Constructed Wetland
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
MAR	Managed Aquifer Recharge
NCW	Non-Conventional Water
N-NH4	Ammonium
N-NO3	Nitrate
NTU	Nephelometric Turbidity Units
O&M	Operation and Maintenance
P-PO4	Phosphate
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TWW	Treated Wastewater
WP	Work Package
WWTP	Wastewater treatment plant

1. BACKGROUND

This technical report has been written in the context of the third Work Package (WP3) of the MENAWARA project on *Non-conventional Water Re-use in Agriculture in Mediterranean countries* and more specifically for **Output 3. 5 "Reports on the efficiency of the implemented pre and post treatments and MAR systems"** and **Activity 3.5.2 "Evaluation of the efficiency of post treatments systems on non-conventional water"** as described in infographic below (Figure 1).

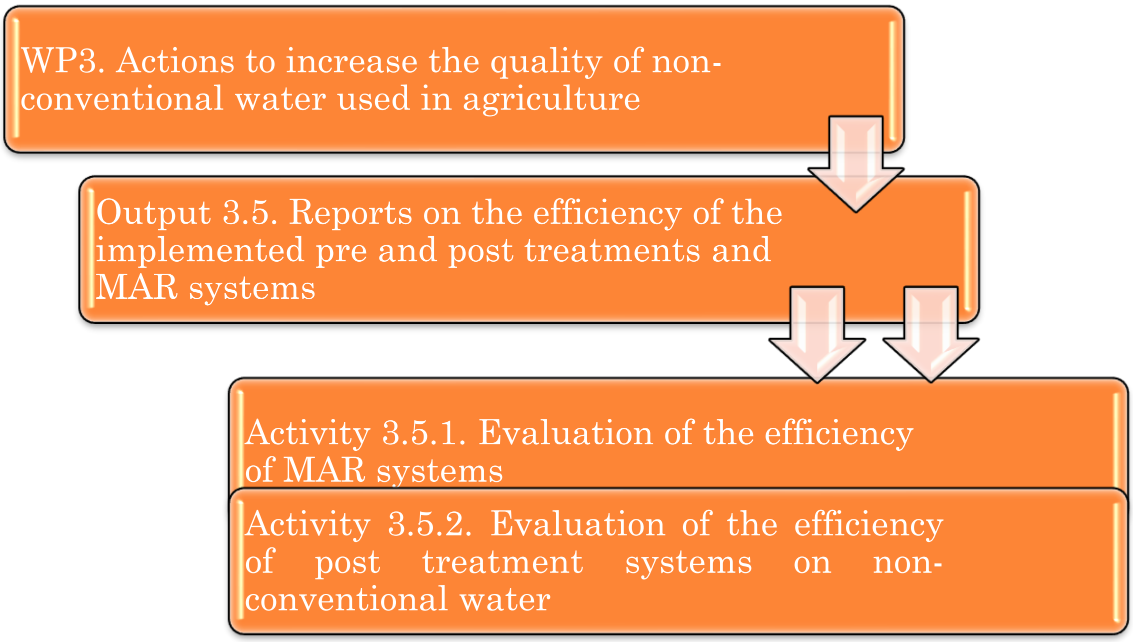

Figure 1. Infographic on the context of this technical report.

More specifically the Output 3.5 is described as follows: "Technical reports on the assessment of the efficiency of the implemented treatments and MAR systems will be produced by all involved partners supervised by CENTA. They will include all monitoring data related to the quality of the inlet water and TWW coming out from the post-treatment systems, the recharge water used for the FIA systems and groundwater of the sandy aquifer in Arborea as well as the Operation and Maintenance (O&M) activities carried out and the lessons learned".

This document details the quality of both the non-conventional water (NCW) and treated wastewater (TWW) coming out from the post-treatment systems implemented at the Carrión de los Céspedes Experimental Center, Seville, Spain; the monitoring and evaluation through bulk analytics, including the quality parameters (Physico-chemical and microbiological) established in the Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse, the O&M activities carried out and the lessons learned over the period from March 2021 to September 2023, covering 2 irrigation campaigns, as part of Activity 3.5.2 "Evaluation of the efficiency of post treatment systems on non-conventional water".

The results of this report are complementary to Activity 3.1.1 "Field assessment of the efficiency of the WWTP and the quality of non-conventional water" under output 3.1 "Non-conventional water quality indicators", and the technical aspects of outputs 3.2 "Efficient infrastructures and technical reports", output 3.3. "Pre and post-treatments and MAR systems designs and output 3.4 "No. of pre and post-treatment and MAR systems realized".

The document is structured as follows: i) an introduction and general overview of the treatment train after the post-treatment implementation (section 2); ii) the Regulation (EU) 2020/741 on minimum requirements for water reuse, and the physical-chemical and microbiological parameters followed for the assessment of the NCW and TWW coming out from the post-treatment systems implemented at the Carrión de los Céspedes Experimental Center (section 3); iii) the methodology including material and methods (section IV); the water quality including discussion of results obtained (section V); v) O&M activities carried out in the post-treatments implemented (section 6); vi) lessons learned and recommendations of possible improvements for up-scaling at the rural/local level (section 7) and vii) some concluding remarks (section 8).

2. Area of intervention

The area of intervention is located at the Carrión de los Céspedes Experimental Plant, in the small village of Carrión de los Céspedes, in Seville, Spain.

The Experimental Plant was created in 1990, in the context of the R+D Plan for Non-Conventional Technologies for the treatment of wastewater in small municipalities, launched in 1987 by the General Directorate of Hydraulic Works of the Junta de Andalucía.

After the first major expansion of the Experimental Center in 2003, research, dissemination and demonstration activities increased significantly: in the same physical space (currently 41,000 m^2) a wide variety of treatment technologies are available, allowing combinations between them under the identical technical and environmental conditions.

Currently, Carrión de los Céspedes Experimental Center is working as a Living-Lab for the co-creation, innovation and experimentation in the frame of wastewater treatment, reuse and circular economy; focused on the user, operating in a territorial context and involving stakeholders of the quintuple helix (Figure 2).

Figure 2. Location of the Spanish intervention site in MENAWARA project: Living lab, Experimental Center of Carrión de los Céspedes and olive trees plot

Carrión de los Céspedes village's population is around 3,000 people. The main economic activities are linked to agriculture (irrigated crops: sunflower, olive grove and almonds; and rain-fed crops: sunflower, olive grove, barley).

Experimental Plant is also working as the WWTP of Carrión de los Céspedes population and treats a daily wastewater flow of around 230-300 m^3/d.

The wastewater from Carrión de los Céspedes reaches the plant through a 300 mm collector.

Once inside the plant, the wastewater undergoes pre-treatment consisting of:

- Self-cleaning channel
- Thick screening: 3 cm straight screen with movable comb.
- Fine screening: 3 mm self-cleaning ladder screen.
- Manual cleaning channel
- Thick screening: 2 cm straight screen.
- Air desanding and degreasing, sand classifier and grease concentration.

The distribution of the influent flow to the different systems implemented in the Center is carried out from an accumulation tank elevated above the average level of the plant ("distribution tank"). It is 18 m^3 reservoir, with 11 outlets connected to different systems of the experimental plant.

From the distribution tank, a significant portion of the pre-treated water is sent to two Imhoff tanks located in the northern part of the plant. The tanks feed the subsurface vertical flow constructed wetlands and an aerated floating helophytic wetland developed in the framework of the EU Life INTEXT project (https://life-intext.eu/en/).

The following (7) Constructed Wetlands (CW), already implemented in Carrión de los Céspedes intervention site, have been included in the treatment train of the MENAWARA project:

1. Combination of subsurface vertical and horizontal flow CWS, (VSSF-1 and HSSF, respectively) to improve the performance of nitrification-denitrification processes.

2. Combination of vertical subsurface and free water surface CWs, (VSSF-3 and FWS, respectively). The free water surface CW is working as tertiary treatment, improving the final performance.

3. Subsurface vertical flow CW unplanted.

4. In synergy with the European project Life INTEXT, the following 2 innovative wetlands have been also included in the treatment train of MENAWARA project:

- Intermittent and aerated vertical-horizontal CW. The CW is innovative not only for its configuration and intensification of the process, but also because it works as a primary treatment, receiving pre-treated water;

- Previously mentioned Floating macrophytes, with the possibility of operating with aeration and recirculation, with several aerated and non-aerated zones.

Treated wastewater through the aforementioned (7) CWs are discharged to a reception chamber from where water is diverted to a storage lagoon for irrigation purposes.

The MENAWARA post-treatment starts in the storage lagoon, with the installation of an ultrasound treatment for microalgae and *E.coli* removal, followed by a filtration system consisting of a pressure sand filter followed by manual cleaning mesh filter. Finally, reclaimed water is conveyed from this post-treatment to the olive grove plot, by means of a pressure group, where irrigation is carried out by surface dripping. The complete working configuration is shown below:

Figure 3. Schematic representation of the working configuration, including Pre-treatment, Imhoff Tank, reception and pumping chamber, storage pond and post-treatment train implemented in the MENAWARA project and plot for irrigation of olive groves experiences.

Figure 4. Aerial view of treatment units at Carrión de los Céspedes Experimental Center, Seville, Spain: 1- Pre-treatment; 2-Homogenization tank; 3- Distribution channels; 4- Imhoff Tank; 5- Vertical Subsurface CW-1; 6- Vertical Subsurface CW-2; 7- Vertical Subsurface CW-3; 8- Fre Water Surface CW; 9- Horizontal Subsurface CW; 10- Aerated vertical-horizontal CW; 11- Floating helophytes; 12- reception and distribution chamber; 13-Storage pond; 14- Post-treatment: ultrasound unit + automatic pressure sand filter + manual cleaning mesh filter + pressure group; 15- Olive grove plot.

3. Standard for water reuse in agriculture in Spain

Although Spain had its own regulation on water reuse, contained in Royal Decree 1620/2007 establishing the legal regime for the reuse of treated water, MENAWARA was aware that the EU was working on the new Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0741), which finally came into force on June 26th, 2023, mandatory for all EU countries. In order to advance in the implementation of the Regulation (EU) 2020/741, the quality of reclaimed water in the Spanish intervention site has been evaluated according to the criteria established in the European Regulation.

The purpose of this Regulation is to guarantee that reclaimed water is safe for agricultural irrigation, thereby ensuring a high level of protection of the environment and of human and animal health, promoting the circular economy, supporting adaptation to climate change, and contributing to the objectives of Directive 2000/60/EC by addressing water scarcity and the resulting pressure on water resources, in a coordinated way throughout the Union, thus also contributing to the efficient functioning of the internal market.

Agricultural irrigation means irrigation of the following types of crops:

— food crops consumed raw, meaning crops which are intended for human consumption in a raw or unprocessed state;

— processed food crops, meaning crops which are intended for human consumption after a treatment process (i.e. cooked or industrially processed);

— non-food crops, meaning crops which are not intended for human consumption (e.g. pastures and forage, fibre, ornamental, seed, energy and turf crops).

The reclaimed water quality classes and the permitted uses and irrigation methods for each class are set out in Table 1.

Table 1. Classes of reclaimed water quality and permitted agricultural use and irrigation method

Minimum reclaimed water quality class	Crop category (*)	Irrigation method
A	All food crops consumed raw where the edible part is in direct contact with reclaimed water and root crops consumed raw	All irrigation methods
B	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	All irrigation methods
C	Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	Drip irrigation (**) or other irrigation method that avoids direct contact with the edible part of the crop
D	Industrial, energy and seeded crops	All irrigation methods (***)

(*) If the same type of irrigated crop falls under multiple categories of Table 1, the requirements of the most stringent category shall apply.

(**) Drip irrigation (also called trickle irrigation) is a micro-irrigation system capable of delivering water drops or tiny streams to the plants and involves dripping water onto the soil or directly under its surface at very low rates (2–20 litres/hour) from a system of small-diameter plastic pipes fitted with outlets called emitters or drippers.

(***) In the case of irrigation methods which imitate rain, special attention should be paid to the protection of the health of workers or bystander. For this purpose, appropriate preventive measures shall be applied.

The minimum requirements for water quality are set out in Table 2

Table 2. Reclaimed water quality requirements for agricultural irrigation

Reclaimed water quality class	Indicative technology target	Quality requirements				
		E. coli **(number/100 ml)**	**BOD$_5$ (mg/l)**	**TSS (mg/l)**	**Turbidity (NTU)**	**Other**
						Legionella spp.: < 1 000 cfu/l where there isa risk of aerosolisation Intestinal nematodes (helminth eggs): ≤ 1 egg/l for irrigation of pastures or forage
A	Secondary treatment, filtration, and disinfection	≤ 10	≤ 10	≤ 10	≤ 5	
B	Secondary treatment, and disinfection	≤ 100	In accordance with Directive 91/271/EEC	In accordance with Directive 91/271/EEC	-	
C	Secondary treatment, and disinfection	≤ 1 000			-	
D	Secondary treatment, and disinfection	≤ 10 000			-	

4. Methodology

This section details the location of water sampling points, sampling periods and periodicity, type of crop irrigated, irrigation method used and the analysed parameters and reference methods used.

Environment and Water Agency of Andalusia (AMAYA) has a proprietary laboratory at the Carrión de los Céspedes Experimental Center. In this sense, AMAYA staff carried out the water sampling at several locations in the treatment train of the Spanish intervention and at several times during the project implementation period to evaluate the treated wastewater before and after the post-treatment for water reclamation and reuse in olive groves irrigation. AMAYA staff also carried out the analysis of water samples taken. Water quality and sampling periodicity are recorded in Annex 1.

The sampling period has been from March 2021 to September 2023. The main sampling points have been:

- Imhoff Tank outlet
- Inlet to the storage lagoon (corresponding to the outlet of Constructed Wetlands)
- Outlet of the storage lagoon (after ultrasound treatment)
- Outlet of the filtration system (corresponding to reclaimed water for olive grove irrigation).
- Irrigation network

During the 2 olive grove irrigation campaigns, all the above-mentioned points have been sampled. During the non-irrigation campaigns, the monitoring programme has continued, to evaluate the effect of ultrasound, at the inlet to outlet from the storage lagoon (Figure 5).

Figure 5. Illustration of AMAYA´s staff sampling at the outlet of CWs, Filtration system and in the irrigation piping at the plot.

The main parameters analysed and reference methods are listed in the following table:

Table 3. Reference data of the parameters analysed for water quality in Carrión de los Céspedes intervention site.

PARAMETER	UNIT	REFERENCE METHOD
Temperature	º C	S.M*. 2550 B
pH	Ud pH	S.M. 4500 H+ B
Conductivity	µS/cm	S.M. 2510 B
Disolved oxygen	mg/l	S.M. 4500-O G
TDS	mg/l	S.M. 2510 B
TSS	mg/l	S.M. 2540 D
BOD_5	mg/l	S.M. 5210 D
COD	mg/l O	S.M. 5220 C
N-NH4	mg/l	ISO6060-1989 DIN38409-H41-H44 APC303, methods DR3900 ISO 7150-1, DIN 38406 E5-1
N-NO3	mg/l	APC339, methods DR3900 ISO 7890-1-2-1986, DIN 38405 D9-2
Total Nitrogen	mg/l	APC228/338, methods DR3900 EN ISO 11905-1
P-PO4	mg/l	APC350, methods DR3900 ISO 6878-1-1986, DIN 38405 D11-4
Total phosphorus	mg/l	APC350, methods DR3900 ISO 6878-1-1986, DIN 38405 D11-4
Chlorophyll a	µg/l	Talling & Driver, 1963

E.coli	CFU/100 ml	S.M. 9222 Order SCO/778/2009**

*SM: Standar Methods for the Examination of Water and Wastewater. APHA, AWWA, WPCF
** Order SCO/778/2009, 17th March, alternative methods for microbiological analysis of drinking water.

The plot, crop, area, number of trees, olive varieties and type of irrigation are visualized in Figure 6.

Figure 6. Visualisation of main characteristics of the irrigated olive groves plot.

5. Assessment of water quality

This section includes the results and discussion on monitoring data related to the quality of inlet water and reclaimed water coming out from the post-treatment system and use for irrigation in the Carrión de los Céspedes intervention site. Report data obtained from the AMAYA´s laboratory is shown in Annex 1.

Tables 4-8 show the average, maximum and minimum water quality analysis results from the outlet of treatments units: Constructed Wetlands (CW), storage pond, Filtration system and in 2 points at the irrigation network at the plot level.

Table 4. Average, maximun and mínimum values of parameters analysed at the outlet of Imhoff tank during the period of study

Parameter	Average	MAX	MIN
pH	7,3	7,5	7,1
Electricity conductivity (µS/cm)	1302,2	1366,0	1234,0
Temperature (ºC)	21,9	26,1	14,2
Dissolved oxygen (mg/l)	0,6	0,8	0,3
TSS (mg/l)	133,2	164,0	109,0
TDS (mg/l)	937,0	993,0	882,0
BOD_5 (mg/l)	268,3	360,0	220,0
COD (mg/l)	476,8	584,0	442,0
Total N (mg/l)	68,8	72,6	65,3
N-NH_4 (mg/l)	62,6	66,4	59,4
N-NO_3 (mg/l)	0,5	0,6	0,4
Total P (mg/l)	8,0	8,1	7,7
P-PO_4 (mg/l)	6,5	6,8	6,1
E.coli (CFU/100 ml)	4,E+06	8,E+06	2,E+06

Table 5. Average, maximun and mínimum values of parameters analysed at the outlet of Constructed Wetlands during the period of study

Parameter	Average	MAX	MIN
pH	7,4	8,8	6,0
Electricity conductivity (µS/cm)	1208,8	1537,0	790,0
Temperature (ºC)	21,2	30,1	12,1
Dissolved oxygen (mg/l)	2,4	4,7	0,5
TSS (mg/l)	20,7	89,0	1,0
TDS (mg/l)	870,7	1300,0	88,0
BOD_5 (mg/l)	19,1	90,0	1,0
COD (mg/l)	73,7	228,0	25,0
Total N (mg/l)	35,4	56,7	14,2
N-NH_4 (mg/l)	41,0	355,0	2,2

$N\text{-}NO_3$ (mg/l)	5,3	20,8	0,6
Total P (mg/l)	7,0	10,1	3,5
$P\text{-}PO_4$ (mg/l)	6,5	9,1	3,0
Chlorophyll a (µg/l)	21,8	234,6	0,0
E.coli (CFU/100 ml)	2,E+05	2,E+06	2,E+01

Table 6. Average, maximun and mínimum values of parameters analysed at the outlet of storage pond during the period of study

Parameter	Average	MAX	MIN
pH	8,9	10,5	6,6
Electricity conductivity (µS/cm)	1096,2	1389,0	846,0
Temperature (ºC)	21,5	28,2	10,5
Dissolved oxygen (mg/l)	6,3	22,5	0,2
TSS (mg/l)	36,6	101,0	3,0
TDS (mg/l)	801,8	1336,0	605,0
BOD_5 (mg/l)	26,7	170,0	2,0
COD (mg/l)	116,8	750,0	33,0
Total N (mg/l)	14,6	27,8	5,0
$N\text{-}NH_4$ (mg/l)	5,4	20,5	0,0
$N\text{-}NO_3$ (mg/l)	1,0	3,3	0,1
Total P (mg/l)	3,0	6,4	0,6
$P\text{-}PO_4$ (mg/l)	2,4	5,5	0,3
Chlorophyll a (µg/l)	326,5	1832,9	4,1
E.coli (CFU/100 ml)	2,E+02	1,E+03	2,E+00

Table 7. Average, maximun and mínimum values of parameters analysed at the outlet of Filtration system during the period of study

Parameter	Average	MAX	MIN
pH	8,9	10,0	7,7
Electricity conductivity (µS/cm)	1167,8	1364,0	1020,0
Temperature (ºC)	25,1	28,5	22,0
Dissolved oxygen (mg/l)	5,7	14,4	0,8
TSS (mg/l)	56,3	220,0	11,0
TDS (mg/l)	862,4	1126,0	728,0
BOD_5 (mg/l)	36,6	125,0	6,0
COD (mg/l)	156,4	339,0	62,0
Total N (mg/l)	15,7	31,0	4,7
$N\text{-}NH_4$ (mg/l)	6,2	20,8	0,0
$N\text{-}NO_3$ (mg/l)	1,3	3,0	0,4
Total P (mg/l)	3,0	6,5	0,7
$P\text{-}PO_4$ (mg/l)	2,1	5,6	0,5
Chlorophyll a (µg/l)	463,9	1337,6	33,1
E.coli (CFU/100 ml)	6,E+01	1,E+02	4,E+00

Table 8. Average, maximun and mínimum values of parameters analysed in the irrigation piping at plot during the period of study

Parameter	Average	MAX	MIN
pH	8,8	9,9	6,8
Electricity conductivity (µS/cm)	1200,2	1382,0	1024,0
Temperature (ºC)	25,3	31,6	20,0
Dissolved oxygen (mg/l)	4,9	14,0	1,9
TSS (mg/l)	48,1	100,0	9,0
TDS (mg/l)	856,9	988,0	733,0
BOD_5 (mg/l)	42,6	155,0	8,0
COD (mg/l)	159,8	303,0	61,0
Total N (mg/l)	16,3	30,7	6,0
$N\text{-}NH_4$ (mg/l)	6,9	20,2	0,0
$N\text{-}NO_3$ (mg/l)	1,1	3,1	0,4
Total P (mg/l)	3,0	6,5	0,6
$P\text{-}PO_4$ (mg/l)	2,3	5,6	0,5
Chlorophyll a (µg/l)	405,6	945,7	79,8
E.coli (CFU/100 ml)	7,E+01	1,E+02	4,E+00

The average pH values throughout the treatment train and during the study period vary from 7.3 at the outlet of the Imhoff tank to 8.9 at the outlet of the filtration system, a value that is practically maintained in the irrigation network at plot level. This rise is detected at the outlet of the storage lagoon, related to algal growth and increased photosynthesis.

The average electrical conductivity remains in the range of 1200-1300 µS/cm. Likewise, the mean TDS concentrations related to conductivity are in the order of 867 mg/l.

The average temperature is in the order of 21.6ºC, rising to 25ºC at the outlet of the filtration system.

The average TSS concentration shows a reduction of about 84% at the outlet of the CWs with respect to the Imhoff Tank. However, due to the massive growth of microalgae during the spring-summer months in the storage lagoon, there is an increase in the average concentrations of both TSS and Chlorophyll at the lagoon outlet, reducing the effectiveness of the filtration system and causing accumulation in the irrigation network.

Related to organic matter, the mean concentrations of COD and BOD_5 show a significant reduction (85% and 93%, respectively) at the outlet of the CWs. As with TSS, due to algal blooms in the storage lagoon, the average concentrations of organic matter are high at the outlet of the filtration system.

Total nitrogen and Total phosphorous, as well as their different forms, show a decrease in their mean concentrations from the storage pond.

The average concentrations of *E. coli* from the storage pond register values (200-70 CFU/100ml) below the criteria established in the new EU 741/2020 regulation for the irrigation of olive groves (1,000 CFU/100ml).

Figures 7-10 show in detail the evolution of water quality from the outlet of CWs to the irrigation pipes on the plot, for the control parameters at the level of water reuse in olive grove irrigation (TSS, BOD_5, *E. coli*).

During the spring and summer of 2021-2022 and 2023, BOD5 concentrations reach their maximum values in the storage lagoon. During the two olive grove irrigation seasons (July-October 2022, April-September 2023) the filtration system allows to reduce these concentrations (Figure 7).

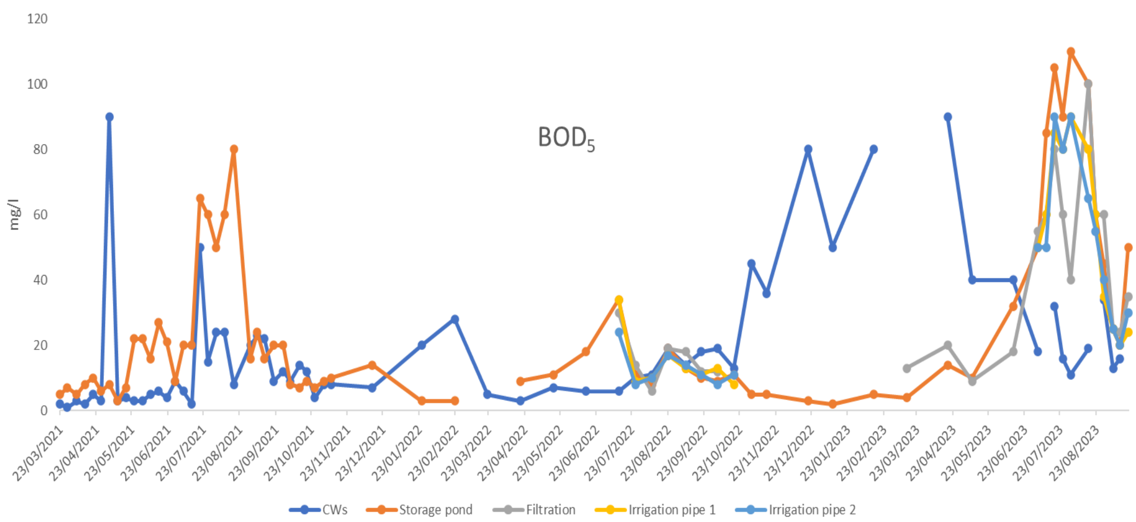

Figure 7. Evolution of BOD_5 concentration at the outlet of Constructed wetlands, storage pond, filtration system and irrigation pipes at plot during the period of study

As is the case for BOD_5, TSS reaches maximum concentrations in the storage lagoon. During the two irrigation campaigns, the filtration system allows these concentrations to be reduced with respect to the water coming from the storage lagoon (Figure 8).

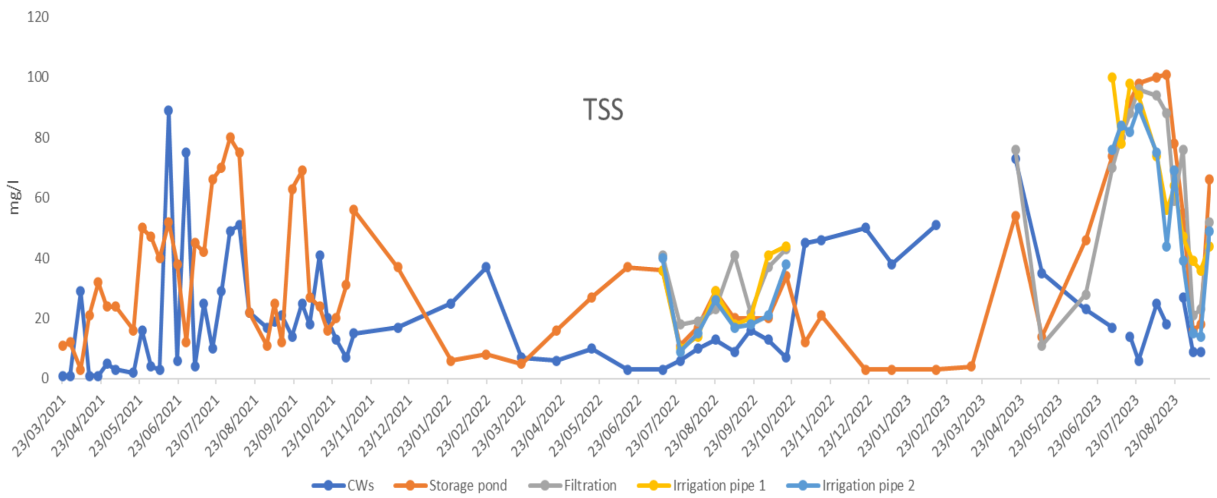

Figure 8. Evolution of TSS concentration at the outlet of Constructed wetlands, storage pond, filtration system and irrigation pipes at plot during the period of study

Related to *E. coli*, during the whole period of analytical assessment, the concentrations obtained in the storage lagoon have decreased in relation to that of the CWs. This decrease may have been due to the combined effect of UV radiation in the water column and the ultrasound equipment installed in the lagoon. It is also significant to note that the concentrations of *E. coli* during the irrigation campaigns, both in the reclaimed water (outlet of the Filtration system) and in the irrigation network at plot level remain below 100 CFU/100ml, meeting the quality requirement of ≤ 1 000 CFU/100ml established in the EU 741/2020 regulation for olive grove irrigation (Figure 9).

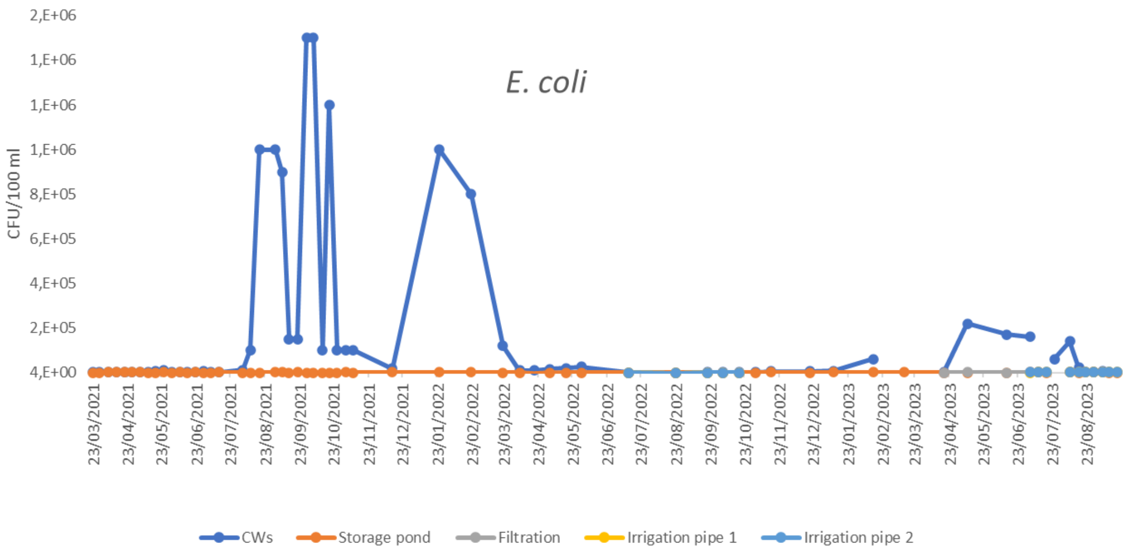

Figure 9. Evolution of *E.coli* concentration at the outlet of Constructed wetlands, storage pond, filtration system and irrigation pipes at plot during the period of study

Figure 10 shows the performance removals of *E. coli*, both in Log. units and % at the outlet of storage lagoon, compared to CWs. It is noteworthy that for most of the analysis period, the removal performance were high (3-5 u.log, 99.9-99.999%, respectively). These values were maintained at the outlet of Filtration system and in the irrigation network at the plot.

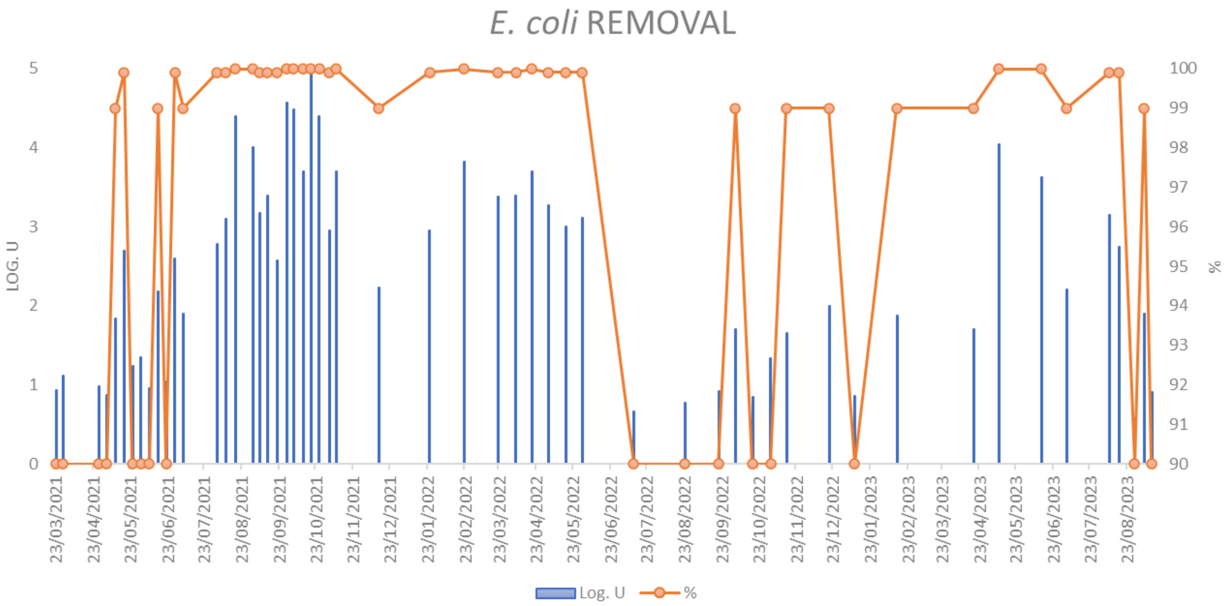

Figure 10. Performance removal of *E. coli* at the outlet of storage pond during the period of study

Analysing the evolution of the different forms of nutrients (nitrates, ammonium and phosphates), it is observed that the highest concentrations are recorded at the outlet of the CWs. Subsequently, they are reduced in the storage lagoon, remaining at the outlet of the Filtration system and in the irrigation network (Figures 11-13).

Reclaimed water provides macronutrients to the crops, making possible to reduce the use of conventional fertilisers and, therefore, the associated costs. During the two irrigation campaigns, the local farmers did not apply conventional fertilisers to the olive groves, providing only the nutrients contained in the reclaimed water used for irrigation.

Crop yields have been high. During the first season, 9,000 kg/ha were obtained. In the second season it has been reduced to 3,500 kg/ha, which is normal in olive groves, given that the varieties cultivated do not have the same productivity in two consecutive years (Figure 14).

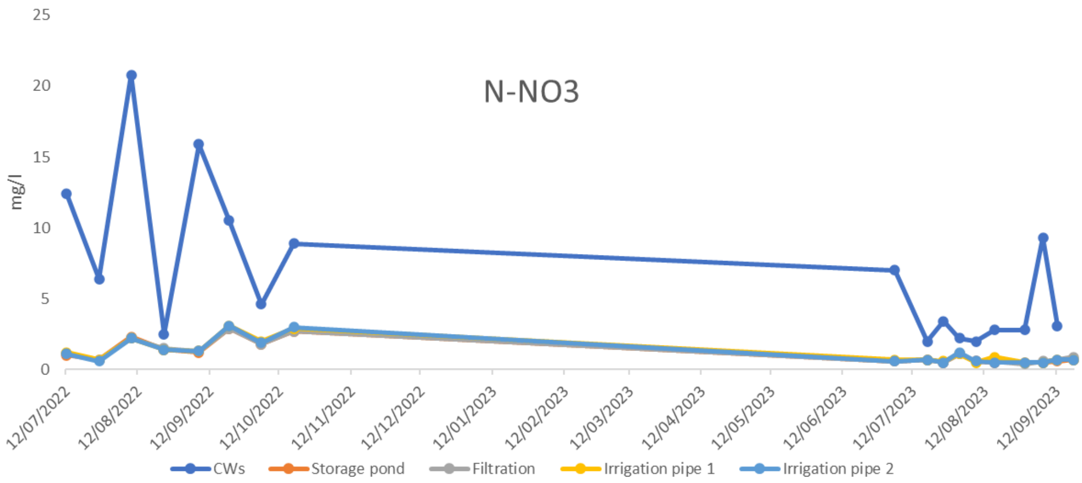

Figure 11. Evolution of N-NO3 concentration at the outlet of Constructed wetlands, storage pond, filtration system and irrigation pipes at plot during the period of study

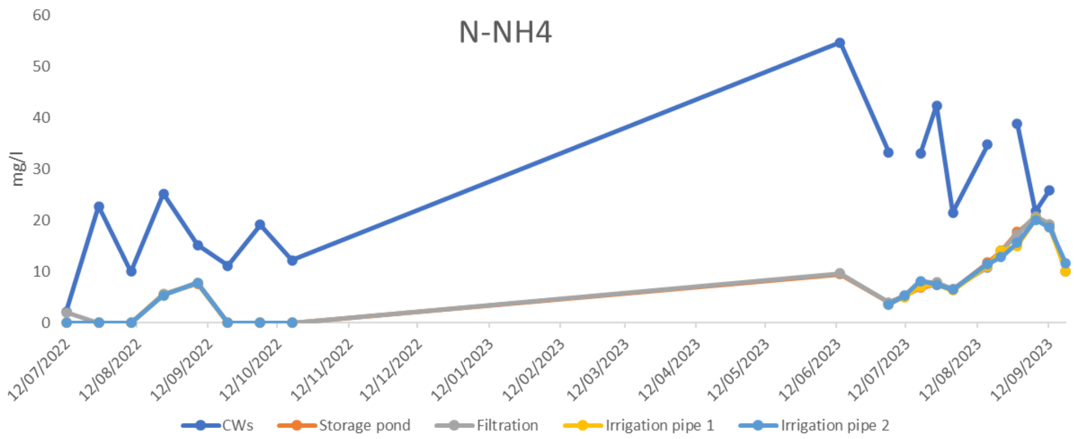

Figure 12. Evolution of N-NH4 concentration at the outlet of Constructed wetlands, storage pond, filtration system and irrigation pipes at plot during the period of study

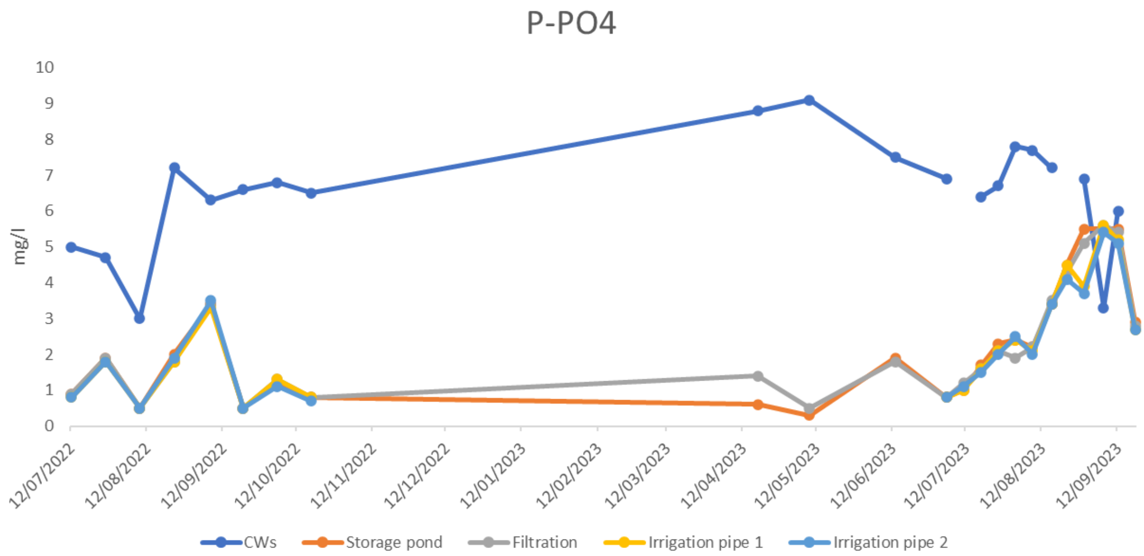

Figure 13. Evolution of P-PO4 concentration at the outlet of Constructed wetlands, storage pond, filtration system and irrigation pipes at plot during the period of study

Figure 14. Illustration of harvested olives of olive groves irrigated with reclaimed water at the Carrión de los Céspedes intervention site.

6. Operation and maintenance

This Section details the O&M activities carried out in the post-treatment implemented.

O&M have been carried out by AMAYA operators in the Experimental Centre, with the supervision of the Project's technicians and coordinator, who have been in permanent contact with the installation company. Also, the operators were trained on the operation and maintenance of all units implemented in the post-treatment.

The O&M has been carried out in different periods:

- Non-irrigation period.

  - The O&M were carried out on the Ultrasound equipment. It was checked daily to ensure that was switched on and correctly located in the storage lagoon.

- 2 irrigation campaigns.

  - The O&M have been carried out on the Ultrasound equipment as well as on the Filtration system and Pressure group.
  - Periodically, fouling (microalgae, other microorganisms and calcareous matter) was removed from the equipment, mainly during the microalgae blooms (Figure 15). When there is no algal bloom, the effect of the Ultrasound equipment on the water mass of the storage lagoon is observed to be more transparent (Figure 16)

Figure 15. Illustration of algal bloom in the accumulation pond and fouling of the ultrasound equipment.

Figure 16. Illustration of effect of Ultrasound equipment in the water of storage pond.

- It has been periodically checked that the pressure sand filter was automatically backwashing.
- Since the mesh filter is manually cleaned, cleaning was made every 2-3 days with pressure well water.
- Daily checks have been made to ensure that the pressure group has maintained the corresponding pressures.
- Daily checks of electrical panels and piping.
- Direct contact has been maintained with local farmers to request information on the distribution of water in the drip irrigation system.

To ensure the correct operation and maintenance of the installed post-treatment units, the operators have carried out daily O&M work on the pre-treatment system, the Imhoff tank and the Constructed Wetlands.

7. Lessons learned

Lessons learned and recommendations for scaling up post-treatment applied at rural/local level from the intervention site at the experimental centre in Carrión de los Céspedes are as follows:

- The reclamation treatment should be designed to achieve the irrigation water quality required for the target crop. In the case of rural areas, low-cost technologies in terms of implementation, operation and maintenance should be chosen.
- At rural/local level, sustainable and low-cost treatments have to be implemented to address both wastewater treatment and reclamation for reuse in agricultural irrigation.
- Starting from wastewater treated at secondary level is essential to guarantee the subsequent regeneration and reuse of the water.
- Nutrients in reclaimed water should be valorised in the fertigation system, contributing to the implementation of the circular economy, protecting the environment and reducing the costs associated with the use of conventional fertilisers.
- The correct operation and maintenance of the filtration system depends, among other factors, on the quality of the influent. In this regard, algal blooms in storage lagoons can reduce the performances obtained after filtration.
- Ultrasound treatment is efficient for the removal of microalgae and *E. coli* in water bodies. However, during episodes of massive microalgae growth, the power of the equipment must be increased or combined with conventional algaecides or other measures to reduce algal growth. A sustainable option is the implementation of photovoltaic panels on the surface of the pond, which in addition to reducing water evaporation, contribute by shading to reducing algal growth; also providing energy to be used in the treatment process.
- The implementation of renewable energy is recommended to reduce the energy costs of pumping systems.
- Engagement, training and cooperation of all stakeholders including local farmers and operators are crucial for the sustainability of the reclamation treatment.

8. Conclusion

In conclusion, the combination of NbS (Constructed Wetlands) and the post-treatment implemented significantly improved the performance of the reclaimed water for the irrigation of olive groves. Although during episodes of high algae growth in the storage pond the new EU Regulation 741/2020 regarding BOD5 and TSS has not been reached, the reductions in E. coli have been significant, with concentrations below those required in the European regulation throughout the period of execution.