Sustainable wastewater reuse for agriculture:

Addressing water scarcity, environmental risks and circular economy in agriculture

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Seeds of the Mediterranean II: Water Sustainability and Circular Solutions for Mediterranean Agriculture
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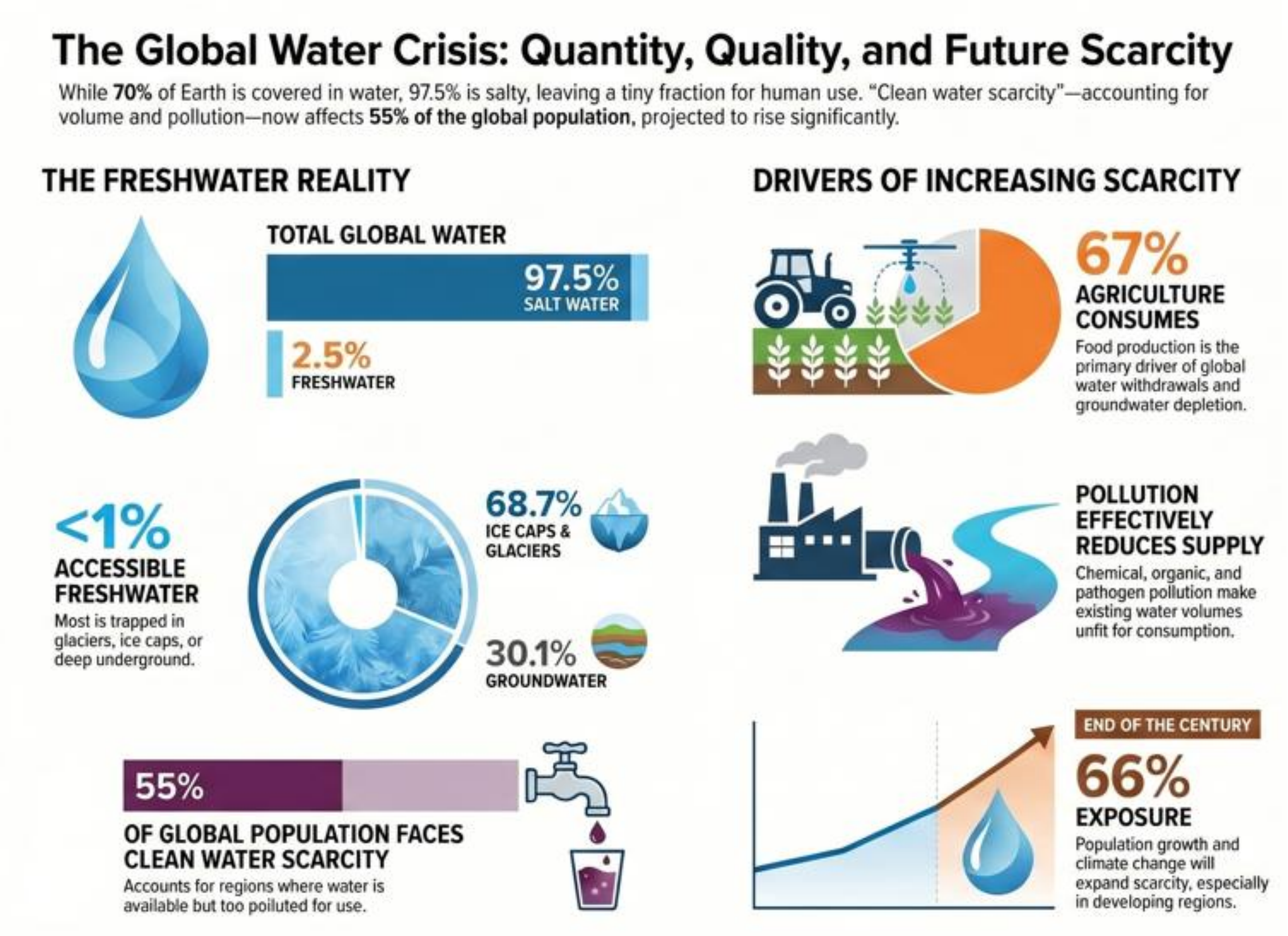
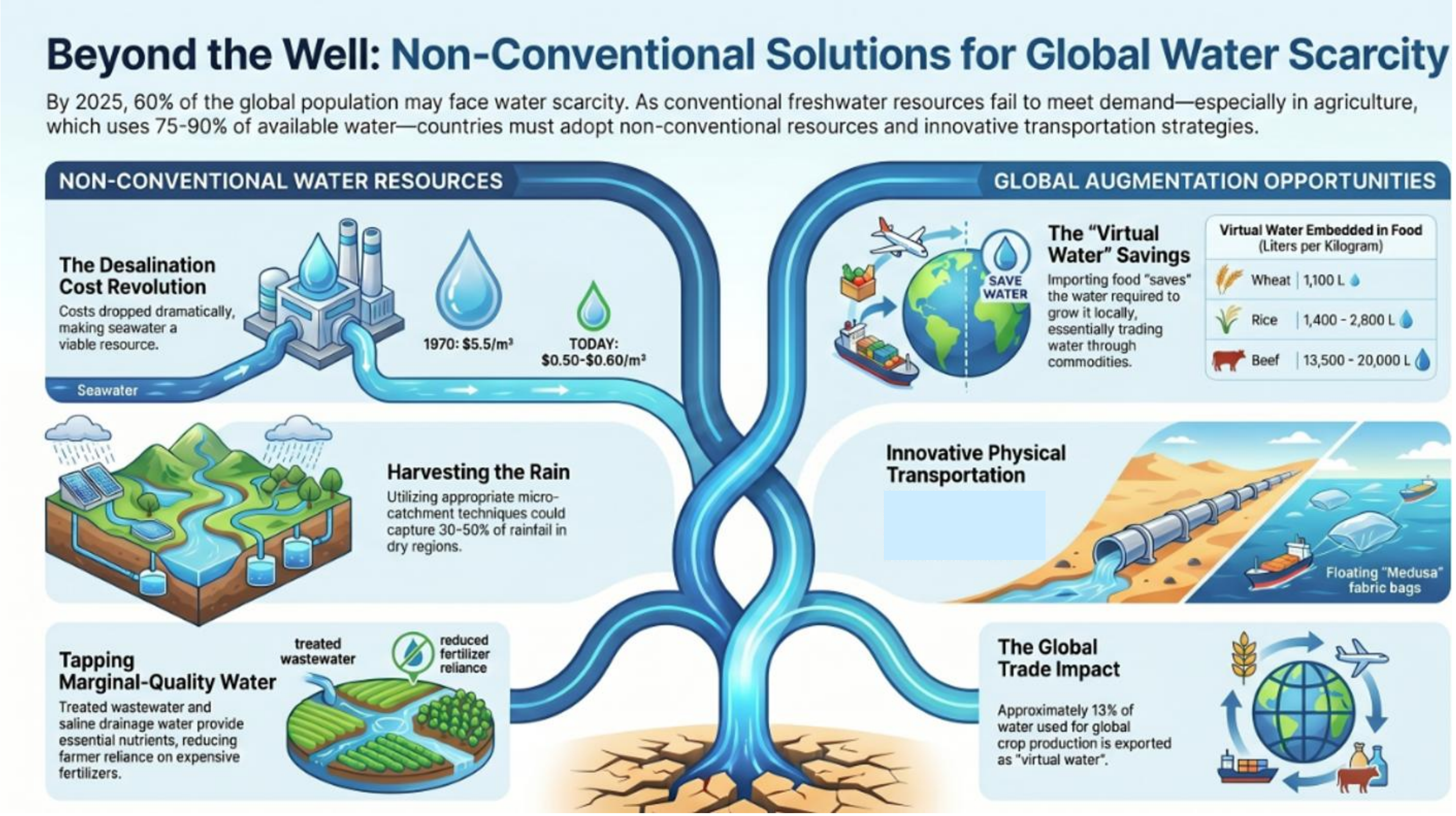
- Climate change intensifies water crisis worldwide.
- Climate change hotspot areas experience more severe impacts, leading to water imbalances
- Mediterranean is considered as a climate change hotspot region
- Cyprus is experiencing severe water scarcity over time



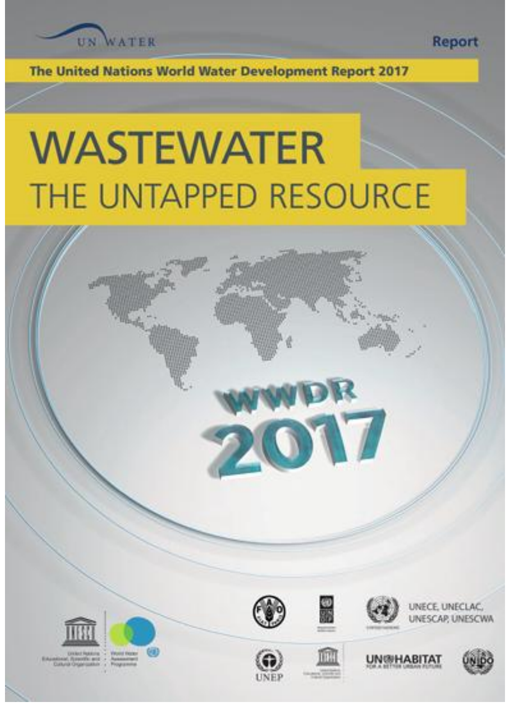
- **The exploitation of non-conventional water resources is a necessity**

- Desalination: is becoming cheaper due to technological advances (though, still costly, with high energy demands and potential environmental impacts, brine disposal)
- Water harvesting in dams and water conveyance through canals, pipes, or gravity flows
- Groundwater recharge
- The virtual water saving through food trade
- **Wastewater treatment and reuse**



- **Reclaimed water: The untapped resource**

The UN states that wastewater is not merely an alternative water source but a critical component of **water security, food security, climate adaptation, and the circular economy, crucial for reaching SDGs**



- **Over 80% of global wastewater is discharged untreated**, particularly in low- and middle-income countries.
- **Limited wastewater treatment and reuse infrastructure**, (2-15 % depending on regions)
- **High capital, operational, and energy costs**
- **Concerns over contaminants of emerging concern (CECs), pathogens, antibiotic resistance determinants (ARDs), salinity, and public health risks**
- **Fragmented regulations, inconsistent water quality standards, and inadequate risk-management frameworks** hinder large-scale adoption.
- **Low public awareness and limited social acceptance ("yuck factor")**
- **Wastewater is still widely perceived as a waste product rather than a valuable source of water, nutrients, energy, and other recoverable resources**, slowing the transition toward a circular economy.

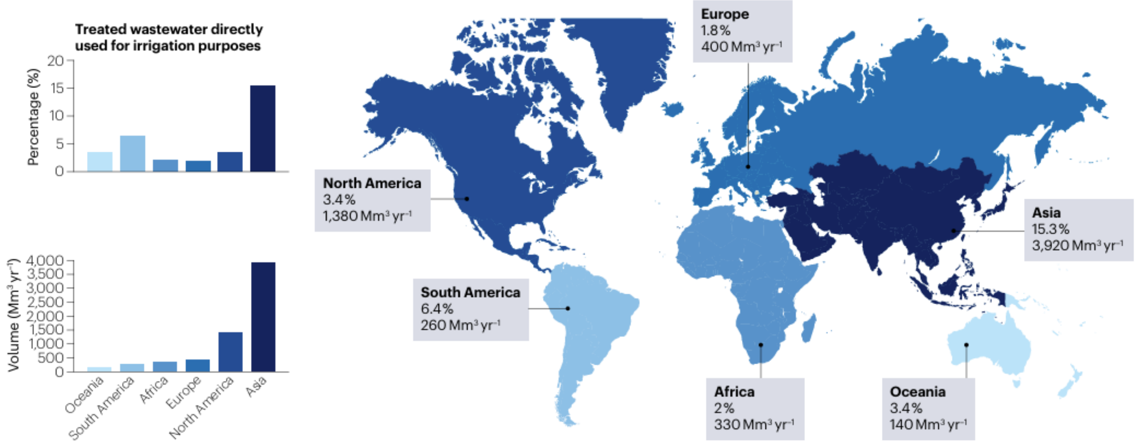


Fig. 1 | Annual volume and percentage of TW reused directly for irrigation. Global direct reuse of TW (with no or little dilution with freshwater) for irrigation varies among continents. Direct application for irrigation is highest in Asia on a continental level, and on regional levels, it is a prevalent practice in countries in Middle East and North Africa, Australia, the Mediterranean region, Mexico, China and the USA. The direct reuse of TW for irrigation is influenced by local water scarcity, availability of treatment infrastructure, presence and enforcement of regulatory measures, and economic motivations. Data for the figure are from refs. 44,46.

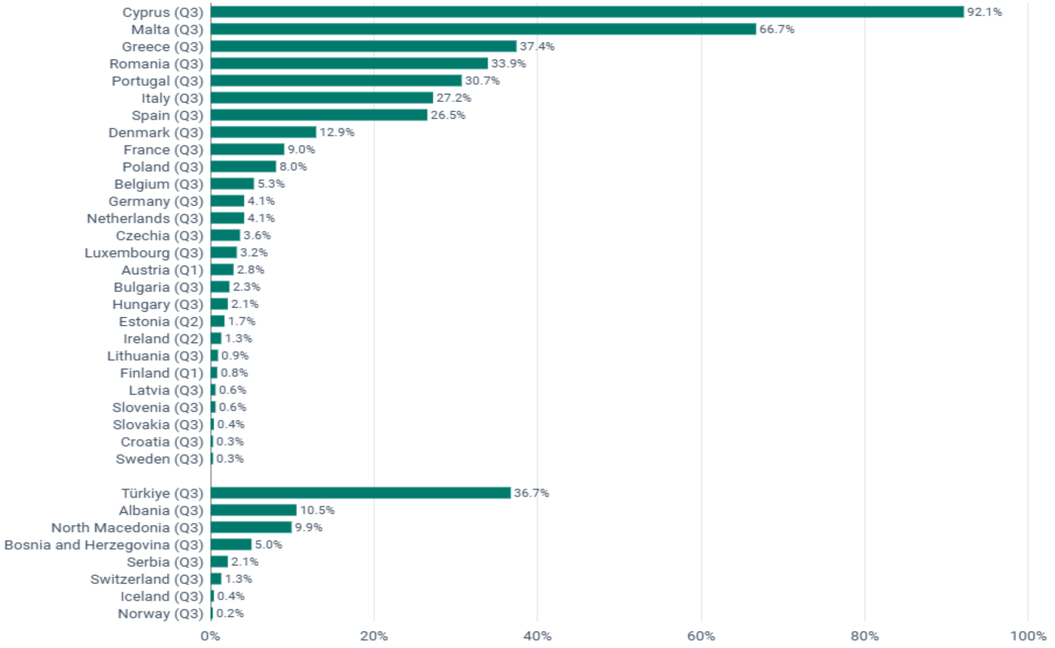
Reuse of reclaimed water

Success stories around the world, mostly driven by water scarcity (Israel, Cyprus, China, California)

- **The exploitation of non-conventional water resources is a necessity:**
- **The case of Cyprus**

- Cyprus has the highest water exploitation index across all European countries
- Potable water needs are tripled the last 30 years (population and tourism increases)
- **Desalination plants provide more than half of potable water demands**
- **Desalinated water is expected to cover all potable water needs during the next few years**
- The supply of drinking water will be completely independent of rainfall and therefore, freshwater resources

Figure 2. Worst seasonal water scarcity conditions for European countries in 2023, measured by the water exploitation index plus (WEI+)



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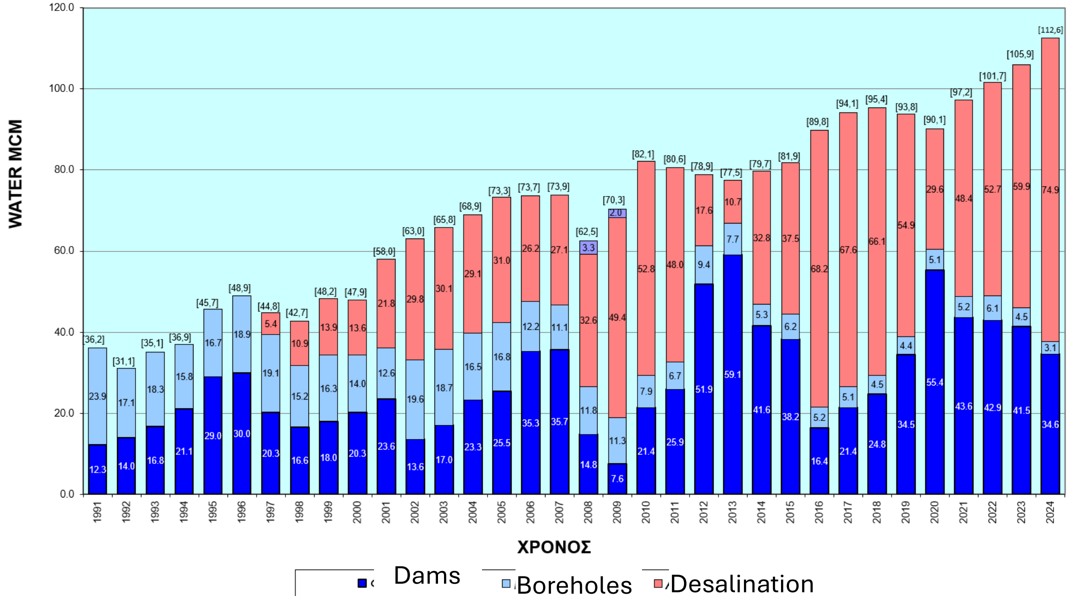
Govermental Water Works- Potable water sources (1991 - 2024)



Reclaimed Water:

An indispensable component of all water resources management schemes applied in the country

WHY a Strategic Solution

Benefits

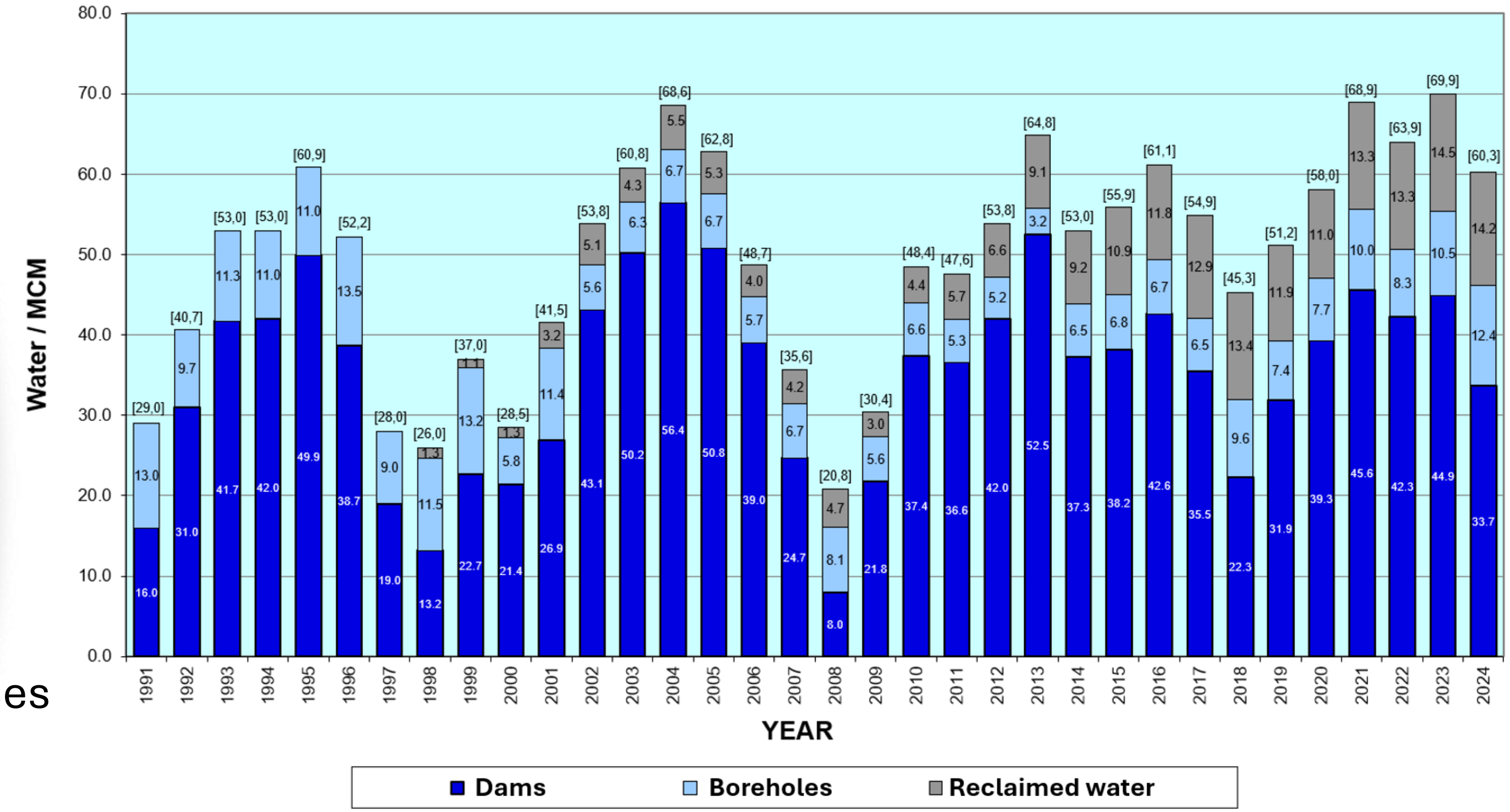
- Reliable irrigation water supply
- Recovery of nutrients (N, P, K)
- Reduced fertilizer requirements
- Circular economy opportunities
- Reduced pressure on groundwater resources

Agricultural benefits

- Irrigates nearly 20% of all irrigated agricultural land
- Yield increases reported for several crops
- Improved resilience during drought periods
- Enhance food security

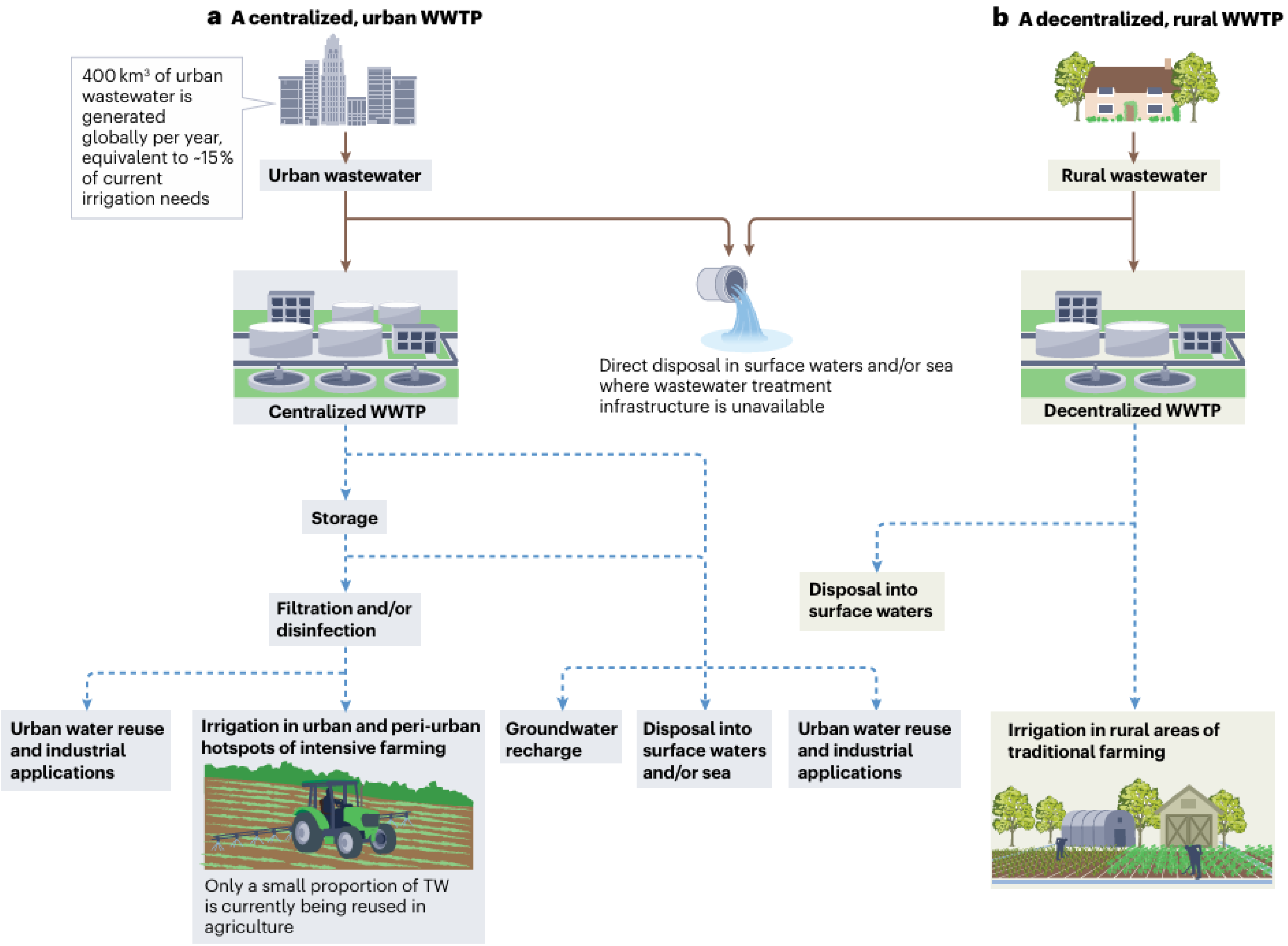
Governmental Water Works-Irrigation Water Sources

(1991 - 2024)



- The road for turning wastewater to irrigation water supporting agricultural hotspots areas



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- **The road for turning wastewater to irrigation water supporting agricultural hotspots areas**

Legislation

Reclaimed Water reuse in Cyprus is regulated by:

- The Water Pollution Control Laws, 106(I)/2002 to 2013
- The Water Pollution Control (Discharge of Urban Wastewater) Regulations of 2003, No. 772/2003
- The Code of Good Agricultural Practice Decree, No. 283/2023
- Integrated Water Management Laws of 2010, 79(I)/2010
- Regulation (EU) 2020/741 of the European Parliament and of the Council on minimum requirements for water reuse

Safety precautions for the proper use of water

- The use is prohibited by unauthorized persons
- Marking pipes with red line
- Clear signaling to alert the public that the water is undrinkable
- Hydrants and distribution system should have protection and always be in good operational condition

Irrigation practices	Methods of irrigation	Recommendations
Irrigation for grass, green areas with limited use, and forage crops	• groundwater irrigation, • drippers, low-capacity sprinklers, • surface irrigation, • high-capacity sprinklers - 300 m buffer zone	▼ cultivated forage, irrigation stops at least one week before harvest ▼ cultivated forage for grazing, dairy animals are not permitted.
Irrigation conditions for grass, green spaces with free use	• subsurface drip irrigation, • low angle Pop-up sprinklers (<15°) • irrigation during night • (no wind)	
Vineyard	• drip irrigation • micro sprinkler	• Where drops comes with contact with fruit, irrigation must stop two weeks before harvest • Collection of fruit from the ground should be avoided
Tree crops	• drip irrigation • Micro sprinkler	The collection of fruit from the ground is prohibited except in cases of nuts. Where irrigation drops comes in contact with fruit , irrigation must stop at least a week before harvest.
Vegetables that are cooked before consumption	• sub surface drip irrigation, sprinkler irrigation • drip irrigation	

Tertiary treated wastewater can be applied for the irrigation of all crops, except leafy vegetables and tubers and bulbs eaten raw

LIMASSOL PLANT	LARNACA PLANT	PARALIMNI – AYIA NAPA PLANT	VATHIA GONIA PLANT
CITRUS FRUITS	COWGRASS	CITRUS FRUITS	COWGRASS
FODDER CROPS AND INDUSTRIAL PLANTS (COWGRASS AND CORN)	CORN	OLIVE TREES	CORN
VEGETABLES	LOLIUM AND SUTAX	POTATOES	BARLEY
PUBLIC GREEN AREAS	PUBLIC GREEN AREAS	PUBLIC GREEN AREAS	FODDER CROPS
	FOOTBALL FIELDS	FOOTBALL FIELDS	GRASS PRODUCTION

The role of Research

From Research to Policy: Building Sustainable Reclaimed Water Reuse

Research enables:

- 🧪 **Advanced treatment technologies**
- 🌱 **Understanding contaminant fate in agroecosystems**
- 🥬 **Assessment of crop uptake and metabolism of CECs**
- 🦠 **Monitoring antimicrobial resistance dissemination**
- 📊 **Long-term field validation and One Health risk assessment**
- 📜 **Evidence-based regulations and public confidence**
- ♻️ **Circular economy and resource recovery**

Addressing challenges

Real field experiments, field surveys, lysimeters experiments, controlling greenhouse mesocosms experiments

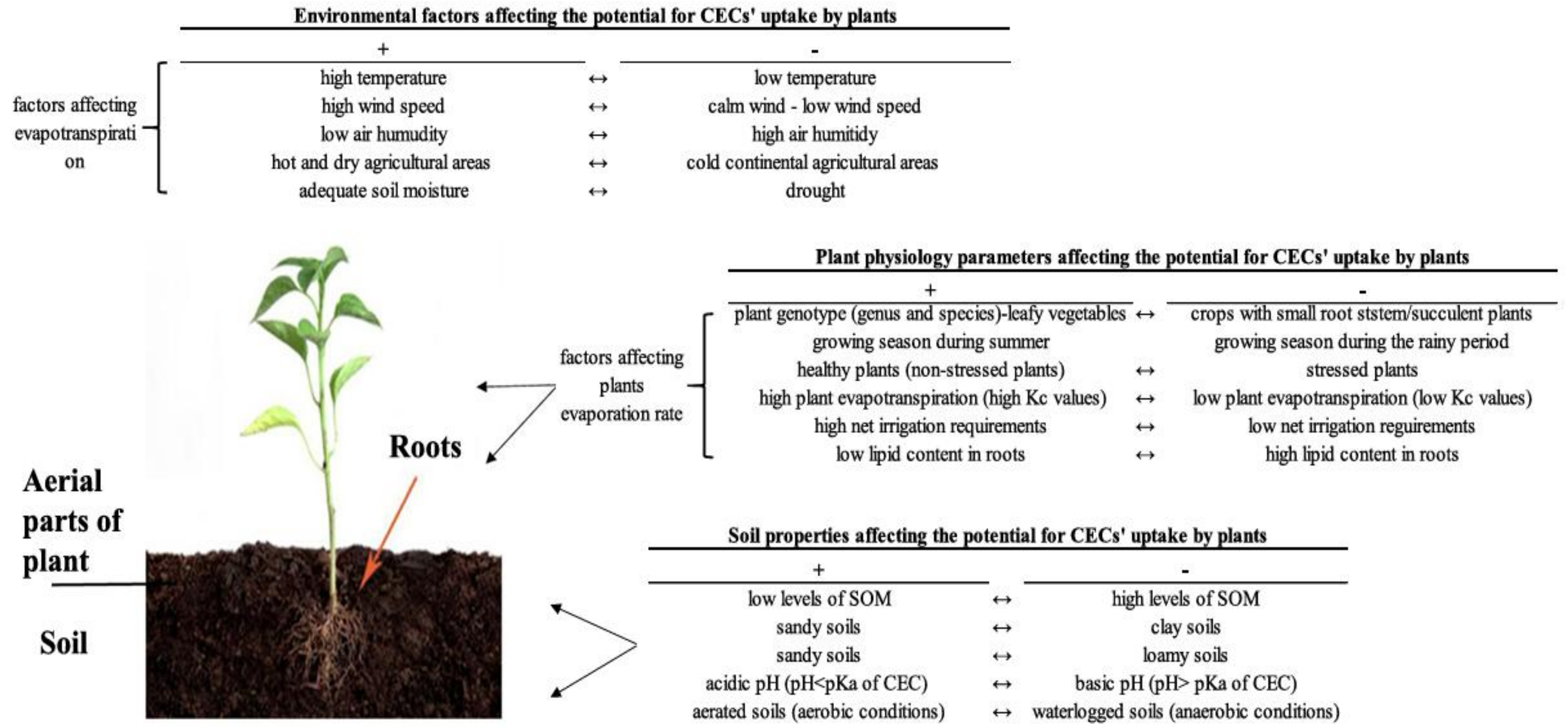


Fig. 1. The potential for uptake by and accumulation of CECs within the edible parts of crop plants is affected by a plethora of parameters, including plant physiology parameters, soil properties, and environmental conditions and perturbations. + and - indicates the factors that increase or decrease the potential for CECs uptake by crop plants, respectively.

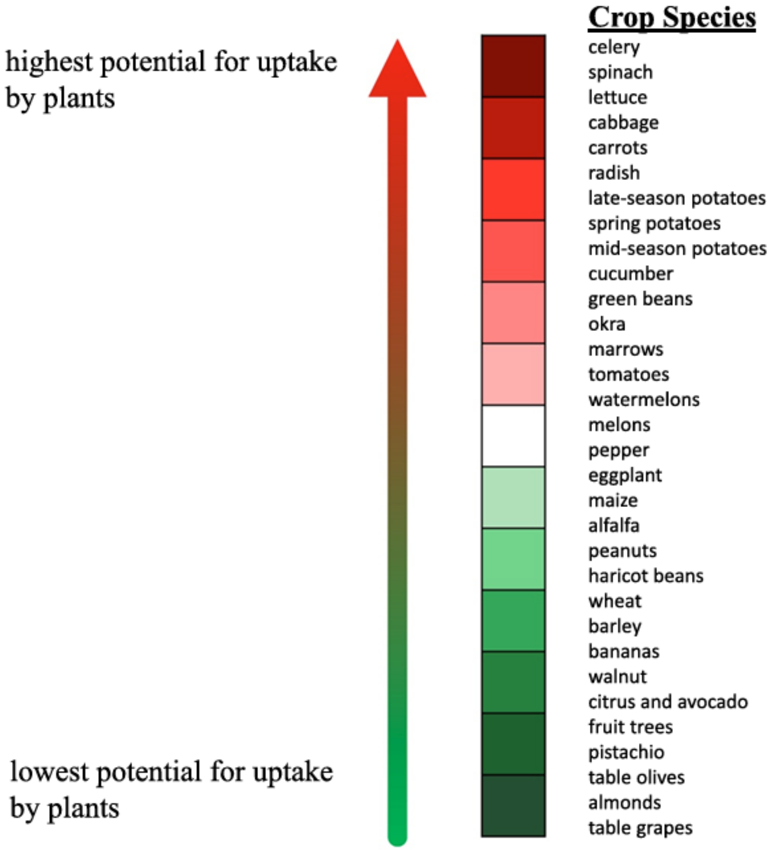
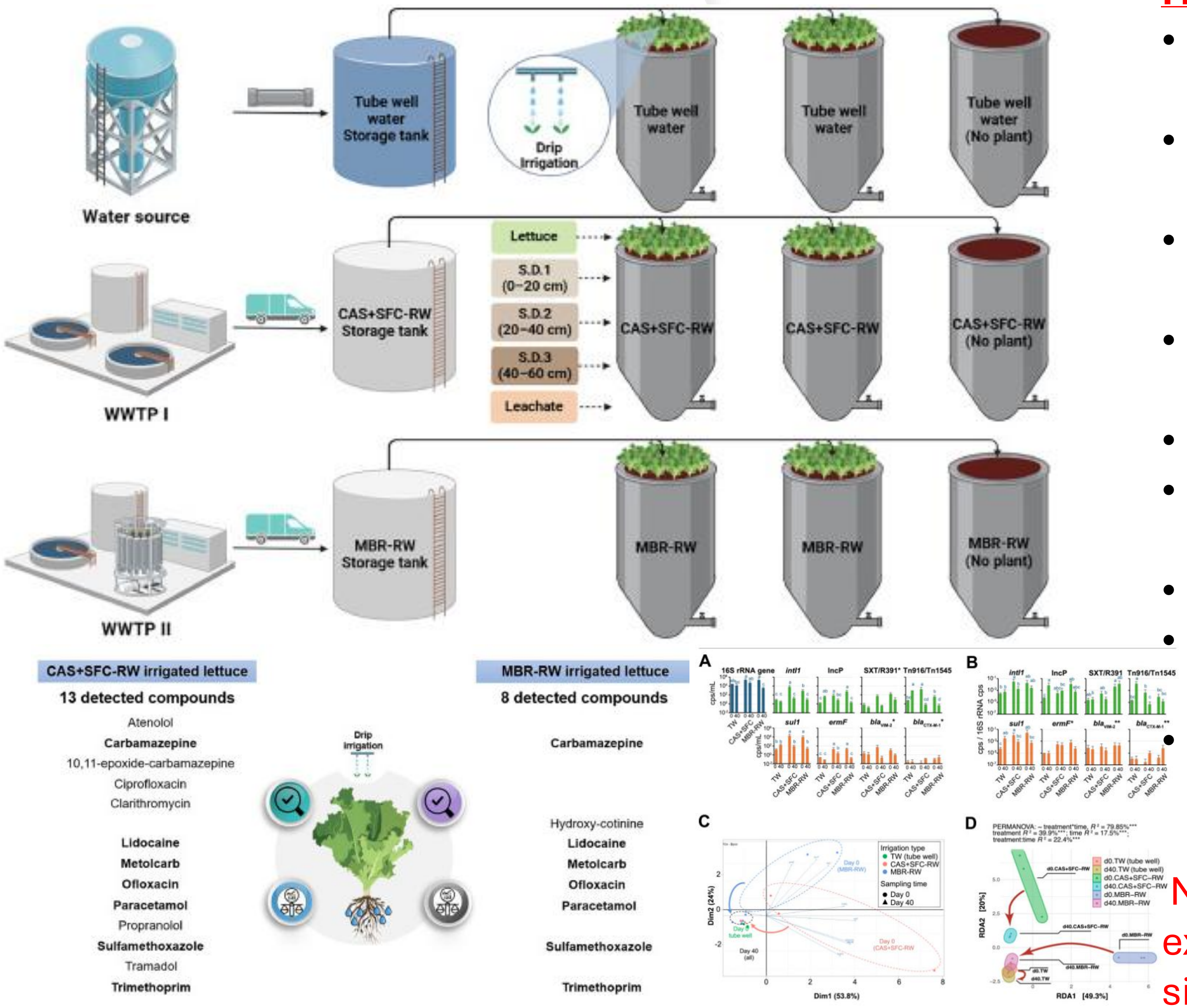


Fig. 2. Heat map showing the potential of the main crop species for CECs uptake. The highest potential for uptake is indicated with dark red; the lowest potential with dark green.

Impact of the wastewater treatment technology and storage on micropollutant profiles, microbiota, mobile genetic element and antibiotic resistance markers during reclaimed water irrigation in a water-soil-lettuce-leachate system



Highlights

- MBR-RW generally showed lower analyte levels than CAS+SFC-RW.
- Treatment trains defined the reclaimed water microbial community structures.
- Storage mitigated the reclaimed water health risk marker profiles.
- Micropollutant detection in RW does not ensure presence in soil or lettuce.
- only **13 micropollutants** were detected in lettuce
- Reclaimed water type significantly affected the upper soil layer microbial communities.
- Soil depth reduces micropollutant levels.
- Leachate shows micropollutants may leach through soil, impacting groundwater.
- The impact of the reclaimed water types on soil, dissipated with depth.

No unacceptable health risk according to the evaluated exposure scenarios; however, continuous monitoring and site-specific risk assessment remain essential.

WHAT’s NEXT

Investigating the environmental fate of micro/nano-plastics and PFAS in reclaimed water-irrigated agroecosystems

THANK YOU FOR YOUR ATTENTION

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