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A First of a kind Hub for circularity demonstrator for Attica and peripheral regions

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D7.1 Analysis for Attica water needs

Work Package: 07 Water Symbiotic Flows

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Publishable summary

The objective of deliverable D7.1, within the framework of the THESEUS project - *A First of a kind Hub for circularity demonstrator for Attica and peripheral regions*, is to conduct a comprehensive assessment of water needs across non-domestic sectors in Attica. The analysis aims to provide an evidence-based overview of sectoral water demand —both in terms of quantity and quality— and to identify potential synergies, water flow interactions, and circular water reuse opportunities, in alignment with European and national policies.

The research focuses on non-domestic sectors that drive water consumption in Attica, namely agriculture, livestock, industry, tourism and urban green areas. The methodology draws on multiple data sources, including EYDAP's consumption billing records, the regional River Basin Management Plan, Climate Change Adaptation strategies, statistics from ELSTAT, as well as surveys and interviews with key stakeholders. To structure the methodology, innovative approaches were employed to estimate distinct components of water use. These include: the disaggregation of water consumption billing records to monthly intervals, the development of seasonal coefficients derived from treatment plant data, and the application of time-series decomposition techniques to capture and analyse monthly variations and emerging trends.

The analysis highlights the spatial and temporal aspects of water use across all sectors. Agriculture, albeit limited in extent within Attica, shows a strong dependence on irrigation. Livestock farming is dispersed throughout the region and represents only modest overall consumption yet remains locally significant. Industrial demand —analysed separately for oil refineries— accounts for a substantial share of use, characterised by distinct seasonal peaks. Tourism generates high water consumption during the summer months, with surges concentrated in Central Athens and the Saronic islands. Irrigation of urban green areas further intensifies pressure on water supply in the summer period. Across all sectors, requirements for water quality —both fit-for-purpose and regulatory compliance— were identified, underscoring the potential of reclaimed water as a strategic resource.

The analysis extended beyond quantitative estimations to examine the European and national legislative framework (e.g. EU Regulation 2020/741, WFD 2000/60/EC, JMD 145116/2011), identifying existing gaps, challenges, and sector-specific water quality requirements. On this basis, the study demonstrated how a 'fit-for-purpose' approach can be operationalised in Attica, by aligning water quality standards with sectoral needs (agriculture, industry, urban and environmental uses) and enabling the safe substitution of potable water with reclaimed sources —thereby ensuring compliance while enhancing resilience and sustainability.

The deliverable also highlights limitations in available data, notably gaps in monitoring private abstractions, and outlines next steps to further refine demand assessments. Overall, this analysis underscores the potential for integrated, circular water-resource management in Attica, strengthening adaptive capacity to climate change, seasonal tourism and agriculture peaks, and increasing pressures of limited freshwater resources.

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Abbreviations

Abbreviations	Full name
CDF	Cumulative Distribution Function
CIS	Common Implementation Strategy
ELSTAT	Hellenic Statistical Authority
EMSY	National Register of Water Intake points
ESG	Environmental, Social, and Governance
EYDAP	Athens Water Supply and Sewerage Company
EU	European Union
FRMP	Flood Risk Management Plans
GDP	Gross Domestic Product
GWS	Ground Water System
I-US	Industrial Urban Symbiosis
JMD	Joint Ministerial Decision
LGOs	Local Government Organizations
RBMP	River Basin Management Plan
SMEs	Small and Medium-sized Enterprises
UFM	Union for the Mediterranean
WP	Work Package
WFD	Water Framework Directive
WWTP	Waste Water Treatment Plan

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1 Introduction

1.1 Setting the scene

The Region of Attica, home to nearly half of Greece's population and the core of its economic activity, faces increasing challenges in ensuring the sustainable and equitable management of its water resources. As a typical Mediterranean region, Attica combines high population density, intense urbanization, complex infrastructure systems, and diverse land uses. These pressures are compounded by the impacts of climate change—more frequent and prolonged droughts, rising temperatures, and strong seasonal variability in both water availability and demand.

Against this backdrop, water policy in Attica must navigate a delicate balance between meeting current needs, adapting to future uncertainties, and preserving environmental integrity. Although residential water consumption is relatively well monitored and managed through centralized systems, non-domestic uses—such as industry, agriculture, commercial activity, tourism, and public infrastructure—represent a significant portion of regional demand and often lack comprehensive oversight. These sectors exhibit diverse consumption patterns and quality requirements, which range from ultrapure water in manufacturing to reclaimed water for irrigation or municipal services.

The evolving European and national regulatory frameworks—including the EU Water Framework Directive, the Urban Wastewater Treatment Directive, and Greece's National Water Management Plans—emphasize the importance of demand-side management, sectoral integration, water reuse, and circular economy principles. Within this context, the Region of Attica is called upon to design and implement evidence-based water policies that go beyond traditional supply-side planning. Key policy objectives include improving the efficiency of water use across sectors, expanding the use of non-conventional resources (e.g., reclaimed water), enhancing climate resilience, and aligning regional practices with national and EU goals for sustainability, digitalization, and resource efficiency.

A prerequisite for effective policy design and implementation is a clear and data-driven understanding of how water is used across all sectors of the regional economy. This requires sector-specific demand quantification, identification of inefficiencies and overuse, assessment of reuse potential, and integration of future trends in urban development, economic activity, and climate scenarios.

This report contributes to that objective by offering an in-depth analysis of water demand per use category within the Region of Attica. It aims to support regional planning authorities, utilities, and stakeholders in crafting more targeted, adaptive, and inclusive water management strategies—anchored in data, informed by policy, and aligned with long-term sustainability goals.

1.2 Purpose of the deliverable

This deliverable, developed under the Horizon 2020 THESEUS project, intents to address the growing complexity of non-domestic water use in the Region of Attica through a comprehensive, data-driven analysis that captures both the quantitative and qualitative dimensions of water demand across key economic sectors, offering insights that are essential for future-proof planning and sustainable resource management.

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The main objective is to map water needs per sector —across industry, agriculture, tourism, services, and public infrastructure— and to evaluate how both volumes and water quality requirements shape current patterns of use and inform projections of future demand. This dual perspective lays the foundation for targeted policy-making, investment prioritisation, and integrated water planning aligned with circular economy principles.

A central pillar of the study is the concept of "fit-for-purpose" water use, which matches water quality to the specific requirements of each application. This approach promotes the substitution of potable water with alternative sources where appropriate, thereby reducing stress on freshwater supplies. For instance, industrial use spans a broad spectrum of quality needs—from ultrapure water required in pharmaceutical and electronics manufacturing, to lower-grade water suitable for cooling, cleaning, or aggregate processing. Similarly, reclaimed wastewater, when appropriately treated, can meet the needs for agriculture, landscape irrigation, street cleaning, and selected industrial operations, provided that the corresponding health and environmental standards are met.

The analysis aligns closely with key EU and national policy frameworks. It supports the implementation of EU Regulation 2020/741 on Water Reuse, which sets minimum quality requirements for agricultural reuse and is expected to expand in scope. It also reinforces the goals of the EU Water Framework Directive, the National Circular Economy Strategy, and anticipates the requirements introduced by the Recast Urban Wastewater Treatment Directive (EU 2024/3019), which mandates stricter monitoring, pollutant reduction, and sectoral accountability—especially from significant non-domestic sources such as industry, healthcare, and food services.

By linking estimated sectoral water demands to specific water quality categories and legal obligations, the deliverable enables a more strategic allocation of infrastructure investments—including decentralized treatment, industrial water loops, and urban reuse networks. It also provides a foundation for revisiting pricing structures and cost-recovery mechanisms that reflect the true cost and scarcity of water resources.

Ultimately, this deliverable supports the transition of Attica toward a climate-resilient, circular, and resource-efficient water economy, reducing reliance on conventional freshwater sources and enhancing the long-term sustainability of the region's water systems.

1.3 Relation with other tasks/deliverables

This analysis establishes the foundational evidence base for the formulation of a Strategic Master Plan on Water Circularity in the Attica Region (Task 7.6). By systematically mapping non-domestic water flows and identifying sector-specific needs, inefficiencies, and reuse opportunities, it supports the design of targeted fit-for-purpose interventions across industries, public services, and other economic sectors. The evidence generated supports the formulation of investment proposals for infrastructure (e.g. reuse networks, decentralized treatment systems), demand-side technologies, and digital monitoring solutions, while also contributing to the development of pricing and cost-recovery frameworks that promote efficiency and ensure equitable access. Beyond the technical dimension, the analysis also identifies regulatory gaps and integration opportunities, aligning water management with circular economy, environmental, and climate objectives. These insights provide the foundation for a coherent policy and governance framework that enables systemic change. Furthermore, the interaction and targeted engagement of the key water stakeholders, thought a comprehensive survey and questionnaires, actively mobilises the parties involved

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to co-create a shared Strategic Master Plan addressing water flows and circularity. Ultimately, the work lays the evidence base for prioritized, cost-effective, and stakeholder-informed action toward circular and resilient water systems in the region.

The deliverable is closely connected to other project components, notably:

- **Work Package 2 (Development of the Theseus framework):** The analysis underscores the need for a comprehensive stakeholder mapping across all sectors and governance levels. It identifies the key actors involved in, or affected by, non-domestic water use —including public authorities, industries, utilities, SMEs, academia, and civil society— thereby reinforcing the creation of a quadruple helix innovation ecosystem.
- **Participatory and co-creation methodologies:** To ensure that circular water solutions are both fit-for-purpose and socially accepted, the analysis adopts a structured stakeholder engagement approach. This includes targeted surveys and questionnaires to foster dialogue, build alliances and coalitions among stakeholders, and co-create shared value, enabling inclusive governance and joint decision-making at the regional level.
- **Data and Decision Support Tools (WP3/WP5/WP6/WP7)**: The detailed disaggregated analysis of demand—by volume, quality, temporal variation, and sector—feeds directly into modeling tools and decision support systems. This supports scenario planning, optimization of water reuse schemes, and the design of Industrial-Urban Symbiotic Systems, where reclaimed water or captured stormwater is shared across multiple users.

By generating this granular understanding, the study lays the foundation for strategically designing Industrial-Urban (I-U) symbiotic systems, that is, integrated networks where treated wastewater, process water, or captured stormwater can be reused or exchanged across adjacent or complementary users. Such systems aim to minimize freshwater abstraction, reduce discharges, and lower overall environmental and energy footprints, while creating tangible economic and operational benefits.

Ultimately, this approach fosters a paradigm shift from linear water management to circular resource planning, strengthening resilience, efficiency, and innovation within the broader regional strategy for sustainable development and climate adaptation in Attica.

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2 Study Area Overview

2.1 Geographic description

The Region of Attica, located in southeastern mainland Greece, is not only the political, economic, and cultural center of the country, but also a complex and diverse geographical area whose physical characteristics directly influence water availability, distribution, and demand. Covering approximately 3,800 km², the region encompasses the Athens metropolitan area — the capital of Greece — and adjacent municipalities that together form the Athens conurbation [1]. With a population approaching 4 million, or roughly 35% of the national total, Attica concentrates the highest density of domestic, industrial, commercial, and administrative activities in Greece, making it a critical case study for water resource management.

The region forms a peninsula bordered on three sides by the Aegean Sea: the Saronic Gulf to the west and south, and the South Euboean Gulf to the east. It also includes several inhabited and uninhabited islands, notably within the Saronic group (e.g., Salamina, Aegina, Hydra, Poros), whose insular water supply challenges differ from those of the mainland.

The terrestrial part of Attica is characterized by varied geomorphology that shapes settlement patterns, infrastructure development, and the hydrological network. The central Attica Basin — where Athens is situated — is encircled by four mountain ranges: Egaleo and Parnitha to the west and northwest, Penteli to the northeast, and Hymettus to the east-southeast [2]. Elevations range from near sea level to about 1,350 m [3]. These mountains act as natural boundaries that limit the spread of urban areas and influence surface runoff and groundwater recharge. Outside the basin, relatively flat plains such as Thriasio, Mesogeia, and Marathon host mixed land uses, including agriculture, which is an important non-domestic water consumer.

Attica is often divided into three main geomorphological zones: West–North Attica, the Attica Basin, and East Attica. The basin is characterized by dense urbanization, a complex transport network, and limited available land, while peripheral areas combine agricultural production with scattered settlements and industrial activities. Two main rivers cross the Athens basin: the Kifissos, the largest watercourse in the region with a catchment area of about 380 km² and an NNE–SSW flow direction, and the smaller Ilissos, now largely covered or diverted [2]. Urban sprawl, infrastructure encroachment, and intense rainfall events make certain parts of the region — particularly in the west — highly susceptible to flooding, an issue with direct implications for water infrastructure and emergency management.

Administratively, Attica is subdivided into eight regional units — Central Athens, North Athens, South Athens, West Athens, Piraeus, East Attica, West Attica, and Islands — and further into 66 municipalities [1]. The combination of coastal, mountainous, and lowland environments within a relatively small area creates a mosaic of water demand profiles, each influenced by population density, land use, and economic activity.

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Figure 1 Administrative Map of Attica: Regional boundaries and layout of the Attica peninsula (Source: Map of World)

The region is administratively divided into eight regional units, including Central Athens, North Athens, South Athens, West Athens, Piraeus, East Attica, West Attica, and Islands.

2.2 Population and demographics

Attica is the most populous region of Greece, hosting between 3.7 and 3.8 million residents as of 2024, which represents over 35% of the national population [4]. The region's demographic weight is concentrated in the Athens metropolitan area, which serves as the national economic and administrative hub, with substantial populations also in the suburbs of Greater Athens and in semi-rural districts.

The study area can be broadly divided into three interconnected geographical partitions: the dense urban core of central Athens, the suburban zone of Greater Athens, and the surrounding Attica region, which includes rural and peri-urban zones [5]. This spatial structure enables the study of urban–suburban–rural interrelations, which are critical aspect for understanding variations in resource demand and service

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provision. In 2021, Attica's average population density was about 1,000 inhabitants/km² [5], with markedly higher concentrations in central urban areas compared to the more dispersed settlements in rural districts.

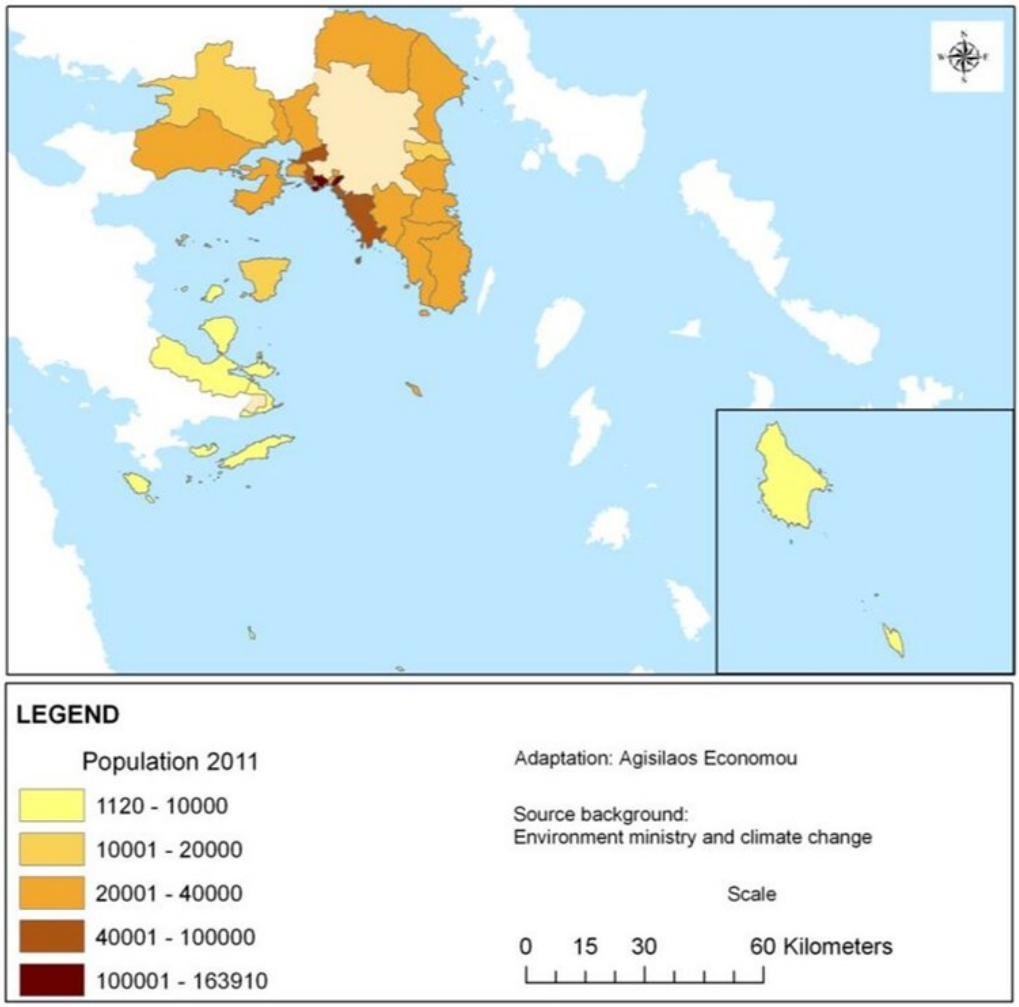


Figure 2 Concentrated population in the Athens metropolitan area and coastal zones (Population Density) (Source: Angelidis, Minas & Economou, Agisilaos, 2013)

Over the past two decades, demographic trends have oscillated between expansion and contraction. The population rose steadily through the 2000s, peaking at around 4 million in 2010, before declining to present levels. Within the Greater Athens area, Northern and Western districts experienced similar patterns of growth in the first decade and decline in the second, while Southern Athens experienced slower growth until 2008, followed by a more pronounced decrease after 2009. In contrast, rural areas outside the main conurbation — particularly Eastern and Western Attica — registered a gradual and continuous rise in their demographic share, increasing from 13.5% in 2000 to 20.1% in 2020. Since 2018, early signs of population recovery have appeared in Central Athens, although densities remain below historic peaks [5].

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The region's population is also characterized by significant diversity. Internal migration from other parts of Greece, coupled with more recent international migration flows, especially from Albania, Eastern Europe, and the Middle East, has steadily increased the proportion of foreign-born residents, enriching the region's multicultural profile. Parallel to this, aging is becoming more pronounced, with residents over 65 forming a growing share of the population. This demographic shift carries implications not only for healthcare and social support systems, but also for water demand patterns, as needs and usage habits differ between age groups. Furthermore, educational attainment in Attica is generally higher than the national average, reflecting its role as a professional, academic, and administrative center.

In sum, the combination of high-density urban cores, expanding suburban areas, gradually increasing rural populations, and diverse demographic profiles creates spatially and socially differentiated water demand patterns. Accurately capturing these dynamics is a prerequisite for assessing current and future sectoral water needs across the region.

2.3 Economic and industrial landscape

The Region of Attica is Greece's economic center, generating approximately 47–50% of the national GDP and concentrating about 36% of the country's population. Its GDP per capita is the highest among Greek regions — roughly 136% of the national average — although it remains below the EU average (90%) [6]. This concentration of economic activity underscores Attica's role as the administrative, commercial, and logistical heart of the country, while also highlighting disparities compared with other regions.

The regional economy is dominated by the services sector, which accounts for the largest share of output and employment. Key activities include banking and finance, public administration, education, healthcare, and tourism. Cultural heritage constitutes a significant pillar of tourism, with landmarks such as the Acropolis, the Acropolis Museum, and other historic sites attracting millions of visitors annually.

In addition to services, shipping and logistics represent another core component of the regional economy. Centered on the port of Piraeus — one of Europe's busiest — this sector functions as a major hub for maritime trade, passenger transport, and associated industrial services. Construction and real estate remain important economic drivers, particularly in urban and suburban areas experiencing growth.

Industrial and manufacturing activity is primarily concentrated in West Attica, especially in the Thriasio Plain, Aspropyrgos, Elefsina, and Megara [1], hosting large-scale facilities, logistics hubs, and energy infrastructure, and are home to a significant working-class population. In the east, the Mesogeia area combines smaller-scale industrial production with rapidly expanding services, office developments, and residential growth, supported by new infrastructure and transport links developed in the past two decades [1]. Along the eastern and southeastern coastline, former agricultural settlements have evolved into small towns characterized by second homes, vacation residences, and expanding tourist-related facilities.

Northern Attica exhibits a mixed economic profile, ranging from affluent residential areas on the slopes of Mount Parnitha to middle- and working-class communities located along major highways and industrial zones [1]. The Attica Region also encompasses islands in the Saronic Gulf, as well as Kythira and parts of the

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Argolis, where tourism and seasonal housing associated with Athenian residents play a central role in local economies.

In recent years, high-tech industries and innovation-oriented enterprises have begun to emerge, gradually diversifying the region's productive base and complementing its more traditional economic activities. While Attica's productivity level is the highest in Greece (124% of the national average), the last decade has seen a decline in both GDP and GDP per capita — by 3.7% and 3.1% respectively — reflecting the lingering impacts of the financial crisis and ongoing structural challenges [6]. These include high youth unemployment, pronounced economic disparities between the metropolitan core and peripheral areas, and an over-reliance on services. Addressing these imbalances is essential not only for promoting balanced regional growth but also for ensuring that infrastructure and resources — including water supply — can sustainably meet the diverse needs of the population and the economy.

2.4 Climate and environmental conditions

The climate of Attica is classified as Mediterranean under the Köppen system [7], characterized by hot, dry summers and mild, wet winters. Mean monthly temperatures, according to the Hellenic National Meteorological Service, range from approximately 8.8 °C in winter to 28.3 °C in summer, with annual rainfall averaging around 400 mm. Precipitation is unevenly distributed across the region — from about 350 mm in the lowlands of the Athens basin to over than 1,000 mm in mountainous zones — and occurs primarily between November and March [2]. Snowfall is rare along the coast but more frequent in the northern highlands. Seasonal temperature variability is pronounced, with summer heatwaves often exceeding 35 °C in July and August, while winter temperatures generally remaining above 10 °C. Humidity levels peaks in winter (75–80%) and falls to around 40–50% in summer, with annual sunshine exceeding 2,800 hours [8].

Topography and proximity to the sea generate marked microclimatic variation across the region. Coastal zones tend to be milder, northern suburbs are generally cooler, and higher elevations receive significantly more rainfall. Conversely, the urban Athens basin — surrounded by mountains such as Parnitha, Penteli, Aigaleo, and Ymittos — is prone to air stagnation, which traps pollutants and intensifies the urban heat island (UHI) effect [9]. Dense construction, extensive impervious surfaces, and limited green space results in elevated temperatures, reduce nocturnal cooling, and increased discomfort during heatwaves.

In recent years, the cooling influence of surrounding forested areas has been diminished by recurrent wildfires, particularly in Parnitha, Penteli, and Ymittos. The loss of vegetated cover has altered local microclimates, reduced natural temperature regulation, and exacerbated heat extremes [8]. Climate change has further intensified these trends, contributing to more frequent and prolonged heatwaves, declining precipitation, and increased rainfall variability.

These climatic and environmental conditions interact with social and economic pressures. Rising temperatures and more frequent heat extremes have led to a steady increase in energy demand for cooling, placing additional strain on infrastructure and energy supply systems. Reduced and erratic rainfall heightens drought risk and intensifies competition for water resources among urban, agricultural, and

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environmental sectors. Coastal aquifers face an elevated threat of seawater intrusion due to groundwater over-abstraction.

In addition, the combination of overpopulation, dense land use, and existing environmental stressors has amplified the impacts of flash floods, poor air quality, and recurring wildfires — phenomena that are particularly severe in East Attica and the mountainous areas. Seasonal tourism and recreational activities, especially during summer, further strain water and other essential resources, thereby contributing to potential conflicts over land use and resource allocation.

2.5 Brief description of Non-Domestic sectors

2.5.1 Agriculture

Irrigation is one of the most water-intensive sectors. Globally, over 70% of freshwater withdrawals are used for irrigation, while in Europe the figure stands at approximately 24% (UNESCO). Southern European countries, including Greece, however, rely heavily on irrigation due to prevailing climatic conditions.

Agricultural activity in Attica is limited, with main crops including olives, vines, potatoes, cabbages and tomatoes. The cultivated agricultural area in Attica, according to the 2020 Annual Statistical Survey of ELSTAT, amounted to 325,778 hectares. Of this, tree crops occupy 53%, arable crops 22%, vines 16%, and horticultural land 9%.

Spatial distribution varies across the region:

- **Strongly peri-urban zones (Acharnon and Marathon):** almost all arrable land is dedicated to horticultural and floricultural production.
- **Intermediate zones (Megaron-Mandra):** land distribution is more balanced; poultry and livestock farming are significant due to less fertile soil and unsuitable water for irrigation.
- **Distant peripheral zones (Erythron-Sykaminou):** arable crops, mainly cereal cultivation dominates.
- **Second most peripheral zone of Keratea-Spaton-Markopoulou**.: arable land of the farms is allocated exclusively to vines and tree crops, notably olives, reflecting historical and cultural traditions of wine production.

Peripheral areas are more favoured than non-peripheral areas in terms of proximity and short access times to the major consumer centres. Of the tree crops, the overwhelmingly largest part is covered by olive groves at 92.5%, followed by areas of trees for nuts (5%) and areas under citrus (1.5%). Among arable crops, the largest part is occupied by areas cultivated with cereals (62%), of which the largest part consists of durum wheat (68%), followed by barley (13%) and oats (10%). Irrigated areas amount to 133,631 hectares (~35% of cultivated areas). Horticultural land is irrigated at 88%, vines at 71%, tree land at 23% and arable land at 19%. Overall, olive groves, viticulture, horticulture, and floriculture constitute the primary agricultural activity in the region of Attica.

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2.5.2 Livestock

Attica hosts approximately 200,000-240,000 sheep and goats, 4,000 dairy cows, as well as poultry, pig farming, beekeeping, and cuniculture. Unregulated domestic animal farming has also expanded in recent years, despite legal prohibition. Goat and cow breeders, with about 1,800 livestock farms, operate across the countryside of Attica, including areas encroached by informal settlements.

Key livestock products include milk and meat, with pork accounting for roughly 8% of national production. Egg production reached 365,459 units in 2018, representing 26% of national output, while honey production totalled 528 tonnes constituting approximately 2.4% of the total production of the country (ELSTAT, 2020).

2.5.3 Industry

Industrial water demand in Attica accounts for just 3–4% of total consumption. Its concentrated and process-specific nature, however, causes local pressures but also offers significant potential for targeted wastewater reuse, particularly in specific industrial clusters. Major industrial zones are located in West Attica, including Elefsina, Aspropyrgos, and Thriasio Plain, as well as in East Attica, such as Paiania–Koropi, Markopoulo, and Rafina–Artemida. These areas host diverse activities including oil refining, metal recycling, food processing, logistics, and packaging activities. Daily water consumption per industrial unit typically ranges from 20 to 150 m^3, and it is precisely this regular and location-specific demand that presents a viable opportunity for reclaimed water applications.

Industrial reuse can support non-potable uses, such as equipment and vehicles cleaning, floor washing, cooling processes, fire protection systems, and irrigation of green areas within or around industrial facilities. Many zones are situated near existing or planned Wastewater Treatment Plants (WWTPs), such as those in West Attica (e.g., Thriasio WWTP) and East Attica (e.g., Koropi–Paiania and Rafina–Artemida WWTPs), facilitating integration into centralized or decentralized reclaimed water networks (e.g. sewer mining).

Promoting industrial reuse in Attica aligns with key European policy directives, including Regulation 2020/741 on minimum quality requirements for water reuse, the EU Circular Economy Action Plan, and the Industrial Emissions Directive, while supporting climate resilience and resource efficiency, targets set under the European Green Deal. Sub Substituting reclaimed water for freshwater reduces abstraction pressures, enhances water security, and complements corporate sustainability objectives (ESG).

Furthermore, reclaimed water supplied to industrial zones can improve the financial viability of reuse schemes, as demand remains relatively stable year-round. Localized reuse also minimizes transmission losses and reduces energy consumption for pumping and distribution, particularly when end-users are located near WWTPs. During periods of reduced industrial activity, surplus effluent may be redirected to managed aquifer recharge, supporting groundwater restoration efforts in overexploited basins.

Despite modest overall consumption in Attica, the industrial sectors' clustering, infrastructure proximity, and consistent demand patterns make it ideal for integrated reclaimed water use. Strategically

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incorporating industrial reuse into the region's water resource management framework enhances system resilience, promotes circularity, and delivers both environmental and economic benefits.

2.5.4 Tourism

Tourism is a key economic pillar in Attica, significantly contributing to GDP and employment. In 2023, the region accounted for 19.2% of all tourist arrivals in Greece and nearly 10% of overnight stays, ranking second nationwide in arrivals after Crete. Over 12 million overnight stays were recorded in hotels and campsites, with peak occupancy during the summer months of July and August exceeding 60%.

Tourism is concentrated in urban and cultural destinations, notably Athens and Piraeus, and the Saronic islands (e.g., Aegina, Hydra, Spetses), attracting predominantly international visitors (over 70% of stays), especially from Germany, the UK, France, and the USA. Seasonal activiy peaks between April and October, underscoring strong temporal variability in water demand.

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3. Approach and Methodology for the Analysis of Water Needs per Use in the Attica Region

3.1 Legislative and Regulatory Framework

Climate change stands as one of the most critical environmental challenges, threatening global biodiversity and the integrity of ecosystems. Scientific evidence increasingly confirms that human activities and industrial practices are the principal contributors to this escalating crisis.

A variety of adverse effects have already "emerged," including elevated average temperatures, lower precipitation and runoff, as well as a reduction in ice areas and snowfall. The future of the planet suffering from advancing climate change seems rather bleak, as uncontrolled global warming is anticipated to result in a range of extreme weather events such as heatwaves, droughts, floods, wildfires, ice melting, etc. having numerous environmental, social and economic consequences. The Mediterranean region is acknowledged as a particularly vulnerable hotspot, marked by pronounced variability in temperature, atmospheric pressure, and precipitation over both space and time. These shifts amplify exposure to extreme events, particularly prolonged heatwaves and droughts. In Attica, the ongoing climate change in combination with unsustainable management of freshwater resources and water pollution, has contributed to persistent water scarcity, most acutely in the summer months, when excessive tourism puts additional pressure to the already limited freshwater supplies.

In this context, there is a rising endeavour to explore alternative water sources for non-potable applications drawing the interest of researchers, community members, and policymakers. Reclaimed wastewater represents a strategic viable alternative to potable water in various sectors including industries, agriculture and urban environments. By substituting freshwater in these sectors, reclaimed water helps conserve scarce potable supplies, reduce pressure on aquatic ecosystems, and limit pollution from untreated wastewater discharges.

In the light of the escalating climate crisis, the European Union has developed and implemented several mitigation strategies and action plans in the form of policy frameworks and Directives striving to safeguard water resources and strengthen resilience among Member States. The following sections provide an overview of three major EU action plans for an integrated water management, as well as the key legislative instruments for water protection and resilience, followed by their adaptation and incorporation into the national legislative system of Greece, as summarized in Table 1.

Table 1 List of EU Action Plans and Directives and National Regulations

Name	Type	Scope
Green Deal	EU Action Plan	Establishment of an integrated policy framework for climate change adaptation, environmental protection and sustainable growth
Water Resilience Strategy	EU Strategy	Establishment of an integrated water management strategy for the enhancement of the robustness, quality and sustainability of water resources

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Name	Type	Scope
Union for the Mediterranean	EU Action Plan	Establishment of an integrated water management action plan for addressing environmental, social and economic challenges in the Mediterranean region related to the climate-change-driven water scarcity
Water Framework Directive (WFD) 2000/60/EC	EU Directive	Establishment of an integrated water management framework for the preservation, protection and improvement of water resources
Urban Wastewater Treatment 2024/3019/EC	EU Directive	Establishment of a framework for the collection, treatment and disposal of urban wastewater for the protection of the environment and public health, the climate change adaptation and the promotion of circular economy
Water Reuse Regulation 2020/741/EC	EU Regulation	Establishment of a framework for the safe water reuse for agricultural irrigation
Water Management and Protection-Adaptation to the Water Framework Directive 2000/60/EC	National Regulation	Adaptation to the WFD 2000/60/EC
Joint Ministerial Decision 5673/400/97: "Measures and conditions for the treatment of domestic wastewater"	National Regulation	Adaptation to the 91/271/EC Directive
Joint Ministerial Decision 191002/2013 "Amendment of the JMD 145116/2011: Establishment of measures, conditions and procedures for the reuse of treated wastewater and other provisions"	National Regulation	Establishment of a legislative framework for the safe water reuse for agricultural irrigation, aquifer recharge, industrial applications and other urban uses

3.1.1 European Level

3.1.1.1 EU Policy Frameworks

EU Green Deal

The European Green Deal [10] is a holistic policy initiative introduced by the European Union (EU) in December 2019, designed to address climate change and environmental deterioration while supporting sustainable economic development and social justice. Through the integration of sustainability into every aspect of policy and governance, the EU aims to establish a resilient and sustainable future for its citizens and the planet. The action plan is centred on mitigating climate change and promoting climate adaptation, to tackle the inevitable impacts of the ongoing climate crisis, while also prioritizing the protection and

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preservation of the environment. In pursuit of this objective, the EU encourages the adoption of innovative and eco-friendly technologies and practices in multiple economic sectors including agriculture, energy production, industry and transportation, thus aiming to facilitate the shift towards a sustainable and zero net emission circular economy. Special consideration has been given to the issue of just transition, ensuring that the areas most affected by the transition receive the support needed to meet the EU Green Deal's objectives.

Main objectives of the EU Green Deal

Climate Neutrality by 2050

The central goal of the Green Deal is to establish Europe as the first climate-neutral continent by 2050. This would require a gradual decarbonization and elimination of the dependency on fossil fuels, thereby achieving zero net greenhouse gas emissions, while also ensuring that all economic sectors are involved in this endeavour. In particular, the Green Deal has set an interim target of reducing greenhouse gas emissions by a minimum of 55% by 2030 compared to 1990 levels. This target is legally binding as stipulated in the EU Climate Law adopted in 2021. On top of that, the Commission proposed in February 2024 another mid-term climate target for the EU aiming to reduce net greenhouse gas emissions by 90% by 2040 in comparison to 1990 levels, thus ensuring that the EU can uphold its commitment to climate neutrality by 2050.

Preservation of the Environment

The Green Deal emphasizes a dedication to reducing the air, water, and soil pollution levels through various initiatives, such as enforcing more stringent air quality regulations, reducing greenhouse gas emissions, encouraging environmentally friendly transportation options, tightening regulations on hazardous chemicals, promoting sustainable agricultural practices to protect soil health, as well as ensuring the efficient implementation of the Water Framework Directive (WFD) coupled with measures to mitigate agriculture originated nutrient pollution of water bodies. It also promotes a circular economy model, which aims to minimize waste generation and encourages the reuse of materials. This includes initiatives to improve product design, enhance recycling, and reduce single-use plastics. In addition, the Green Deal declares the commitment to protect and restore the biodiversity of Europe's ecosystems. This involves implementing the EU Biodiversity Strategy for 2030, which aims to reverse biodiversity loss and restore ecosystems across the continent, particularly those with high carbon storage potential. It also intends to incorporate biodiversity aspects into policies affecting multiple sectors including agriculture, fishery, forestry and urban planning, thus building a safety net against climate change and natural disasters and ensuring the conservation of habitats and species. While the strategy is designed to address the challenges faced by all types of ecosystems (coastal, marine, alpine, urban etc.), it also provides a robust set of measures aiming at safeguarding aquatic ecosystems and address water related issues. In particular, the EU Biodiversity Strategy requires the enhancement and expansion of the current Natura 2000 network of protected areas, which presently accounts for roughly 18% of Europe's land and 8% of its marine territory, with the objective of achieving 30% protection of EU land and sea areas by 2030. It also calls for strict protection of at least 10% of the aforementioned protected areas and especially all remaining EU primary and old-growth forests. Furthermore, the strategy emphasizes the need for all Member States to accelerate the implementation of relevant existing legislation, such as the Water Framework Directive and the Marine

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Strategy Framework Directive, and to ensure that by 2030, a minimum of 30% of EU protected species will be in favourable conservation or at least exhibit an upward trend. The strategy also includes a commitment to restore at least 25,000 km of rivers to a free-floating state and to restore deteriorated ecosystems, such as wetlands and floodplains, by 2030, while also implementing measures to promote more selective and sustainable fishing practices that protect marine biodiversity.

Key areas of action of the EU Green Deal

Agriculture

The Farm to Fork Strategy, being a vital element of the Green Deal, seeks to establish a fair, healthy, and environmentally sustainable food system. It prioritizes the reduction of pesticide and fertilizer use, the promotion of organic farming, the promotion of higher animal welfare standards, the reduction of food waste and the adoption of sustainable food production practices.

Energy

The Green Deal presents a roadmap for shifting to renewable energy sources, in order to achieve the necessary decarbonization and reach EU's carbon neutrality targets by 2050. This transition will require a substantial increase in the share of renewable energy within the EU's energy mix, thus reducing the dependence on fossil fuels, the promotion of energy efficiency through modern high-performance infrastructure and eco-designed products, all while ensuring a safe and cost-effective energy supply system.

Industry

As an essential element of the EU Green Deal, the Industrial Strategy seeks to transform the industrial sector to enable a shift towards a climate-neutral circular economy. In this context, the EU Green Deal introduces a variety of initiatives focused on enhancing sustainability, reducing emissions and improving competitiveness. Such actions include the promotion of clean low-carbon technologies and production practices, as well as the development of new circular economy business models to reduce the industries carbon footprint and minimize waste production.

Transportation

The Mobility strategy aims to establish a safe, efficient and eco-friendly transportation system. The actions taken for the transition towards a sustainable and low emission transport include the promotion of renewable low-carbon fuels to achieve the required decarbonization of the transportation sector, the gradual transition to zero-emission vehicles and the improvement of infrastructure and public transport systems. The main objective is a 90% reduction of emissions from the transport sector by 2050.

Transition to zero net emission

Just Transition Mechanism

Recognizing that the transition to a green economy may have extended socio-economic impacts, especially in carbon-intensive regions or areas with a significant workforce engaged in fossil fuel industries, the Green Deal introduces the Just Transition Mechanism. This mechanism aims to assist regions, industries and workers that may be adversely affected by the transition, through the Just Transition Fund and a dedicated

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platform offering technical and advisory assistance, thus ensuring that the shift to sustainability is fair and inclusive.

Research and Innovation

The Green Deal highlights the need for increased funding in research and innovation to develop new technologies and solutions that effectively address climate change and environmental challenges. Therefore, research projects and initiatives are encouraged to focus on innovative solutions that reduce emissions and enhance sustainability. In this context, the EU's research and innovation program, Horizon Europe, being aligned with the goals of the Green Deal supports projects that focus on climate action, sustainable development, and the green transition, encouraging collaboration among researchers, businesses, and public authorities.

International Cooperation

The EU Green Deal emphasizes the importance of global cooperation in addressing climate change. The EU aims to lead by example and encourage other countries to adopt similar ambitious climate policies.

EU Water Resilience Strategy

The EU Water Resilience Strategy [11] is a central part of the European Green Deal and aims to enhance the robustness of water systems across Europe in the face of climate change, population growth, and increasing water demand. The strategy is focused on developing an integrated water management plan seeking to establish resilience and sustainability as core elements of water management practices, while also providing secure and affordable water supply for the global population as well as fair and equal access, thus ensuring water equality for current and future generations.

Central Goals of the Water Resilience Strategy

Water Safety Improvement

The EU Resilience Strategy was developed based on the principle that “water is a human right and a public good”. Therefore, all initiatives and policies involved are designed to ensure equal distribution of water resources, as well as a reliable and affordable water supply for all individuals.

Water Resources Preservation

Improper management of water resources and pollution coupled with climate change and environmental deterioration disrupt the water cycle undermining both resilience and sustainability. Thus, the current strategy aims to restore and protect water bodies and aquatic ecosystems to preserve a well-functioning water system and sustainable water supply.

Building a water-smart economy

Efficient use and control of water resources are essential elements for the transition towards a water resilient and sustainable economy, with water systems able to adapt to the challenges posed by climate change. For this purpose, the EU Resilience Strategy advocates for initiatives and supports actions focused on the reduction of water demand and the minimization of losses across water distribution networks,

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promoting water saving and reuse practices in all economic sectors, particularly in areas facing prolonged water shortages.

Critical Components of the Water Resilience Strategy

Integrated Water Management

The EU Resilience Strategy promotes the adoption of an integrated water resources management (IWRM) to facilitate a comprehensive approach to managing water resources, considering the interrelations between different water uses and ecosystems. The existing EU framework for the regulation of freshwater management provides a strategic roadmap for action. It consists of the Water Framework Directive (2000/60/EC), which aims to achieve good status of all water bodies by 2027, the Flood Management Directive (2007/60/EC), which is designed for the assessment and management of flood risks, and the Nature Restoration Regulation (2024/1991), which supports water quantity management and enhances resilience against both floods and droughts through the implementation of nature-based solutions. Building on these regulations, the EU Resilience Strategy further promotes efficient and sustainable water management focusing on measures aiming to enhance efficient use, reduce losses and water demand, as well as on technologies ensuring safe water reuse. In particular, the action plan encourages the reclamation of wastewater for its safe application in agriculture according to the Water Reuse Regulation 2020/741/EC along with several sustainable agricultural practices introduced by the Common Agricultural Policy. In addition, water reuse in industries is also strongly recommended aiming to the enhancement of the use of reclaimed water in the production process.

Water Quality and Pollution Control

Protecting water quality is a priority and a serious challenge, considering that, according to the Report of the Commission to the Council of the European Parliament on the implementation of the WFD (2000/60/EC), only 26.8% of surface water bodies had a good chemical status in 2021. The EU suffers from extensive pollution of surface waters originating from agricultural runoff, industrial and mining discharges, as well as wastewater produced by waste management, while there is also the emerging issue of increasing detection of persistent pollutants, such as PFAs. This level of pollution is the root of environmental deterioration and biodiversity disruption, while increasing the risk of water-borne diseases and antibiotics resistance. Hence, the strategy includes mitigation measures and initiatives to reduce pollution and restore the aquatic ecosystems, ensuring that water bodies meet quality standards. Such actions include the efficient implementation of the Nitrates Directive and the development of an integrated nutrient management plan, which promotes practices aiming for nutrient recovery, thus reducing nutrient pollution and the application of synthetic fertilizers. In addition, the Commission encourages research efforts for the development of innovative and cost-effective technologies aiming to the detection and remediation of persistent chemicals.

Improvement of Infrastructure

Access to safe water is a fundamental human right, and equal access to it is an issue of social justice. Therefore, the current strategy supports efforts to upgrade infrastructure and sanitation facilities, aiming to ensure that the entire population has fair access to safe and clean water.

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Drought and Flood Management

The strategy is set to promote the robustness of water resources against both droughts and floods and outlines suitable management approaches in the context of the existing EU Framework, including the development of River Basin (RBMPs) and Flood Risk Management Plans (FRMPs) and the publication of a Technical Guidance for the development of Drought Management Plans, that incorporate nature-based solutions and water-saving practices as an attempt to tackle water scarcity and enhance water resilience. In particular, the strategy strongly encourages the adoption of nature-based solutions in urban areas aiming to retain and store water on land, thus reducing the impacts of drought and floods. Apart from this, water retained on land could be used for groundwater retention, biodiversity protection and soil health improvement.

Reduction of water demand

Reduction of water demand across all economic sectors is a core part of sustainable and efficient water management. The initial target of the EU requires the enhancement of water efficiency by at least 10% by 2030 in all economic sectors. In that regard, the EU Water Resilience Strategy supports water saving practices and suggests several initiatives in that direction, such as the introduction of minimum performance standards regarding water consumption in water-intensive industries, like data centers. In order to minimize water consumption in the energy production sector, it also encourages research activity for the exploration of efficient and cost-effective dry cooling methods.

Digitalization and Innovation

Optimized control of water resources plays a pivotal role in creating a sustainable water system. However, a significant part of water consumption is lost, due to leakages in the distribution networks or impossible to monitor, due to direct abstraction by users. Thus, the strategy promotes the use of digital technologies and innovative tools to improve water management and minimize losses. This includes smart water metering systems, remote sensors and data collection and monitoring.

UFM Water Policy Framework

The Union for the Mediterranean (UFM) Water Policy Framework [12] is a strategic initiative established in 2008. UFM consists of 42 countries, including EU member states and Mediterranean partner countries aiming to address the pressing water challenges faced by the region, including water scarcity and pollution, as well as the impacts of climate change. By promoting an integrated and sustainable water management based on WEFE nexus approach and fostering regional cooperation through the development of several projects and initiatives, the UFM aims to ensure the availability and quality of water resources for current and future generations in the region, ultimately contributing to the sustainable development of the Mediterranean region.

Core objectives of the UFM Water Policy Framework

Preservation of resources and habitats and reduction of pollution

Healthy ecosystems constitute a vital element for human health, as well as for developing prosperous and sustainable societies. Constant pollution and improper use have caused extended damage to natural resources and habitats, while an additional challenge is posed by the aggravating climate change. The UFM

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strategy aims to promote and take steps towards the implementation of the WEFE approach for water resources management, thus achieving the goals concerning sustainable development introduced by the Agenda 2030 of the UFM region.

Protection of public health

Water is essential for human life and access to safe and clean water should be an undisputable right for every human being. The UFM water agenda is set to contribute to the effort for the horizontal coverage of water and sanitation needs on a global level, while also achieving stable and sustainable water services in the region.

Enhance regional cooperation to tackle water-related issues

Cooperation and cross-regional assistance among the UFM member states is crucial to address shared water challenges and promote best practices for the achievement of water-resilient and sustainable economies across the Mediterranean area. The UFM strategy encourages the sharing of knowledge, as well as policy and technology know-how among the UFM member states, aiming to promote collective development, while also taking lessons from the failures.

Climate change adaptation

Climate change has a strong effect on the temporal and spatial distribution of water resources, resulting in multiple environmental, social and economic consequences in the Mediterranean region, which is already under excessive water stress facing the danger of water scarcity. The framework recognizes the impacts of climate change on water resources and promotes strategies and mitigation measures for adaptation, including wastewater reuse, rainwater harvesting, groundwater recharge and campaigns to raise public awareness.

Main thematic areas of action of the UFM Water Policy Framework

Cross-sectoral water resources management based on WEFE Nexus

The Framework encourages the integrated and sustainable management of water resources across the Mediterranean region according to the WEFE Nexus approach. WEFE Nexus refers to the interconnections between water, energy, food and environment and describes how one sector influences the other. For instance, water is essential for agricultural production, energy generation, and maintenance of healthy ecosystems; however, climate change-driven water scarcity and pollution impact water availability and quality, thus affecting food security and energy production. The WEFE Nexus approach emphasizes the need for the integrated management of these critical resources to promote sustainability and resilience, particularly in regions facing resource scarcity and environmental challenges, such as the Mediterranean area. The UFM strategy aims to promote the WEFE Nexus approach for the integrated water resources management by building a policy framework, which will facilitate and coordinate policy interventions, investments, dissemination campaigns and local pilot applications across the Mediterranean area, to promote sustainable water management practices in the region.

Water-Employment Migration (WEM)

Water scarcity, aggravated by excessive tourism and climate change, constitutes a crucial challenge for the Mediterranean region. Water availability limitations are the root causes of multiple social and environmental issues, including food insecurity, ecosystems deterioration, unemployment, conflict and

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instability, which have led to extended “water-related” migration. The current strategy aims to introduce the Water-Employment-Migration approach to water management and government practices. This concept constitutes an integral action plan consisting of policy interventions, guidelines for governance systems, dissemination activities, investment motives and pilot applications. The WEM approach focuses on assisting countries of migration origin, transit and hosting in developing and implementing effective water policies and governance frameworks, to address “water-related” migration, as well as potential water stresses induced by migration and displacement, thus increasing water related employability and promoting sustainable development.

Water and Sanitation Hygiene (WASH)
The UFM emphasizes the importance of reducing water and land pollution, thus protecting public health, habitats and ecosystems biodiversity, while improving the living standards of the population. The UFM water agenda is a tool designed to support the global effort for the fair and equal access to safe and clean water, while also ensuring reliable and sustainable water services within the region. The UFM strategy also encourages cross-regional cooperation and proposes a sustainable platform among water utilities and operators created to facilitate the exchange of knowledge and technological know-how among the member states, including sanitation services and wastewater reclamation, thus working towards the achievement of the sanitation and water sustainable development goals of the 2030 Agenda.

Water and climate change actions
The framework highlights the vulnerability of the Mediterranean region to aggravating climate change, facing excessive water shortages and deterioration of water resources. The proposed strategies for adaptation include updated legislation frameworks, the implementation of water projects according to the WEFE Nexus approach, technology transfer among member states, campaigns to raise public awareness, groundwater recharge and the promotion of non-conventional water resources, such as desalination, wastewater reuse and rainwater harvesting.

3.1.1.2 EU Directives and Regulations

The Water Framework Directive 2000/60/EC and associated amendments

The Water Framework Directive (WFD) 2000/60/EC [13] constitutes a cornerstone of the EU water policy and was a huge step towards the protection and improvement of the quality of water resources across Europe, which are under constant pressure, due to increasing demand for high quality water. The main purpose of the WFD was to provide a set of common principles among the Member States and a policy framework for the integrated water management on a Community level aiming to preserve, protect and improve the quality status of EU water bodies and encourage sustainable water use, while paying special attention to habitats with diverse conditions requiring specific treatment. This Directive was set to serve as a foundation for further discussion aiming to the future integration of the values of sustainable water management and protection into other sectors, including energy, transport and agriculture.

The WFD is developed based on certain principles, which provide the main guidelines for the adoption of the appropriate actions and measures. The most fundamental principle is the treatment of water as heritage to be preserved and defended, instead of a commercial product. Also, the Directive promotes preventive action against pollution incidents, which should be taken at the source of the environmental

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pressure. Finally, to ensure environmental protection, the WFD guidelines are based on the polluter-pay principle, according to which the pollutant should bear the cost of the caused damage.

Main Objectives

Integrated Water Policy in the Community
The Directive identifies the need to establish a holistic approach of water management on a community level. Therefore, the entire Directive was developed treating the water cycle as an integral part and designing action plans on the basis of river basin, thus contributing to the improvement and preservation of Europe's water bodies, the mitigation of the effects of floods and droughts, as well as to the resolution of transboundary problems concerning the management of water resources.

Environmental Protection
The WFD provides an integrated policy framework aiming to protect, preserve and improve the quality status of EU water resources, including inland surface waters, transitional and coastal water bodies and groundwater, thus protecting and enhancing aquatic ecosystems, along with other types of habitats depending on them. The corner milestone of this effort was the achievement of "good status" for all water bodies across the EU by 2015. Central part of the promoted strategy aiming to the environmental preservation and quality improvement is the prevention of further deterioration and the progressive reduction of hazardous discharges and emissions. This would be achieved by controlling pollution at source through the introduction of environmental quality standards and emission limit values.

Sustainability
The Directive strongly encourages sustainable utilization of water resources by providing strategies and tools that balance ecological, economic, and social needs and encourage users to adopt a responsible and rational behaviour regarding water use.

Key Aspects

Integrated Water Management on River Basin Level
The WFD establishes a holistic approach to water management, considering the entire river basin as a unit rather than focusing on individual water bodies. Thereby, it is necessary that all river basin districts are identified and that all measures will be applied for the whole of each district. In particular, the Directive mandates the development of River Basin Management Plans (RBMPs) for each river basin district, which must include the assessment of the status of water bodies, the identification of pressures and impacts of human activity on water quality, as well as an economic analysis of water use.

Protection of Water Bodies
The goal of this Directive is the protection, enhancement and restoration of all water bodies across EU. The developed strategy is strongly based on the prevention of accidental environmental deterioration, as well as on the progressive reduction of pollution by the contamination control at source and the introduction of quality standards and emission and discharge limit values. To quantify this objective, the WFD suggests the characterization and classification of all water bodies according to their ecological and chemical status, aiming to achieve a "good status" for all water bodies, as well as compliance with standards and objectives regarding protected areas, by 2015. In the case of surface waters, the ecological status is assessed through multiple quality elements, including biological and hydro-morphological elements, chemical and physicochemical parameters and the presence of priority pollutants and other hazardous substances. High

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status is thereby achieved, when there are no detected variations of the quality elements caused by human activity and their values are those associated with undisturbed conditions. Accordingly, good and moderate status refer to low and moderate anthropogenic alteration of the quality elements, respectively. When it comes to groundwater, the quality elements examined are the quantitative status, in terms of the balance between abstraction and recharge, and the chemical status, in terms of conductivity and contaminant concentration. The "good status" in this case refers to groundwater bodies with no indication of saline or other intrusions and pollutant concentrations that do not threaten the quality status of connected surface water bodies or dependent ecosystems.

Program of measures

The WFD mandates the establishment of the appropriate program of measures for each river basin district, to achieve the objectives of this Directive regarding environmental protection and sustainability. In fact, the WFD inserts several minimum requirements in form of "basic measures", such as the strict control of the abstraction and recharge of groundwater and the prohibition of pollutant discharges into the aquifer to avoid contamination, the establishment of emission limits for point and diffuse source discharges, as well as the prevention of the accidental pollution by the utilization of digital tools that detect pollutant losses into the aquatic environment, caused by unexpected and hardly predictable events. Nevertheless, the Directive encourages the adoption of supplementary measures, if needed, including, among others, legislative, administrative and economic tools, emission controls, restoration of wetlands, rehabilitation projects, as well as sustainable industrial and agricultural practices, such as water-saving irrigation techniques and water reuse.

Cost recovery

The WFD encourages the adoption of water pricing policies, that provide the users with adequate incentive for sustainable water use, while also contributing to the cost-recovery of water services, in accordance with the economic analysis of water use and with the pollutant-pay principle.

Strategies against pollution

The WFD announced the adoption of measures and strategies against water pollution aiming to the progressive reduction of the discharges, emissions and losses or pollutants and, in particular, to the elimination of the discharges of priority hazardous substances. For this purpose, the Commission has declared an effort to identify the most suitable control processes for both point and diffuse pollution sources and to submit proposals for quality standards regarding priority substances. This was implemented by the 2008/105/EC Directive, which serves, among others, as an amendment for the WFD. The main purpose of that Directive was the establishment of Environmental Quality Standards (EQS) for priority substances and other pollutants, in order to facilitate the achievement of the WFD objectives. In fact, it identifies 33 priority hazardous substances and proposes the annual average and the maximum allowable concentration for surface waters.

Implementation and Compliance

River Basin Management Plans

Each EU Member State is responsible for implementing the WFD within its territory, including the development of RBMPs. In particular, each Member State should design the appropriate RBMP, which should include the characterization of the water bodies lying in each river basin district, the description of the environmental pressures caused by human activities, the identification of protected areas and monitoring networks, as well as a list with the environmental objectives and the economic analysis for

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water use. It should also incorporate the list with the program of measures adopted for each river basin district and the competent authorities responsible for the implementation of the WFD requirements.

Monitoring and Reporting
Each Member State is responsible for monitoring and reporting on the status of their water bodies and the progress made towards achieving the objectives set out in this Directive regarding surface water bodies, groundwater and protected areas. They should develop monitoring programs for the ecological and chemical status of surface waters, as well as for the quantitative and chemical status of groundwater.

Public Participation
The WFD emphasizes the importance of actively involving the public in the implementation of this Directive. This includes the publication of all the important documents, such as the RBMPs along with a timetable for their implementation, as well as giving time for consultations on RBMPs and the opportunity for stakeholders to contribute to their development.

Challenges and Criticism

As a matter of fact, the implementation of the WFD proved to be more difficult and complicated than initially expected. According to the "Blueprint to safeguard Europe's water resources", an EU initiative published in 2012 aiming to evaluate the progress of the WFD implementation and address the obstacles that prevent its success, only 43% of the EU surface water bodies had achieved "good" ecological status. This level of progress was expected to increase to just 53% by 2015. Also, there was a significant lack of data regarding the chemical status of water bodies, as the 40% was characterized by an unknown status, due to insufficient monitoring in many Member States. It was clear that many Member States had faced challenges in meeting the deadlines for RBMPs and achieving good status for all water bodies; therefore, many of them requested extensions to meet the WFD goals. The failure to achieve the WFD objectives within the 15-year timeline was attributed to several factors, including the insufficient use of economic tools that led to inadequate incentives for involved stakeholders to comply with the WFD recommendations, the lack of sufficient financial support to undertake the investment costs for the application of the WFD measures, the poor governance and lack of effective coordination, the knowledge gaps, which undermined the social support for the WFD implementation, as well as the lack of sufficient and on-time guidelines on an EU level, as for instance the absence of guidance in the face of climate change and its impacts in the 2000/60/EC.

In order to support Member States in implementing the Water Framework Directive (WFD) and its associated legislation, the European Commission launched the "Common Implementation Strategy (CIS) for the WFD" initiative in 2001. The CIS was designed to build a shared understanding and approach among EU Member States regarding the planning process promoted by the WFD. It aimed to facilitate the WFD implementation, by providing practical guidance to Member States on various aspects of the WFD, including the development of River Basin Management Plans (RBMPs), and monitoring programs, the establishment and implementation of the program of measures, as well as the efficient stakeholder engagement. It also aimed to enhance cooperation among Member States encouraging the sharing of experiences, best practices, and lessons learned. In light of the challenges regarding the WFD implementation identified in the "Blueprint to safeguard Europe's water resources" and the review of the WFD in 2019, the CIS focused on additional objectives, such as the contribution to the WFD improvement

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and the integration of water management with policy objectives of other sectors (agriculture, transport, energy etc.).

Urban Wastewater Treatment Directive 2024/3019/EC

The 2024/3019/EC [14] constitutes a recast of the former 91/271/EC Directive focusing on the treatment of urban wastewater. Ever since its first establishment, the 91/271/EC Directive has been amended several times, thus it was considered necessary to be replaced by a more updated and complete regulation. The 91/271/EC set the legal framework for the collection, treatment and discharge of urban wastewater, as well as of biodegradable wastewater from certain sectors, thus contributing to the protection of the environment from the discharge of inadequately treated wastewater. The current Directive follows the same path with additional provisions regarding the protection of public health, the transparency in wastewater management, the climate change adaptation and the fair access to sanitation services for the entire population. It is also set to improve several limitations of the former framework or unaddressed environmental issues by introducing new parameters for examination or by strengthening existing quality standards and emission limits. Overall, this Directive provides a thorough framework aiming to address current and emerging environmental issues and threats based on the latest research findings regarding priority hazardous substances and promoting the application of advanced technologies for the efficient treatment of urban wastewater and ultimately the protection of the environment and public health.

Main objectives

Protection of the environment and public health

The replacement of the 91/271/EC was decided, due to several important weakness of that framework regarding significant sources of pollution caused by urban wastewater discharges. In fact, the 91/271/EC did not address the severe environmental challenges posed by stormwater overflows and polluted urban runoff -which are expected to increase due to urbanisation and the aggravating climate change-, discharges from small agglomerations without collecting systems -as they were not covered by that framework-, and potential dysfunctional individual systems. It, also, did not take into account the emerging public health threats, due to the extended discharges of micropollutants into the aquatic environment. Additionally, while eutrophication levels of the EU water bodies were significantly reduced by the application of the 91/271/EC Directive, nutrient pollution is still a significant environmental problem of the Union. Therefore, the current Directive was developed to provide a solution to these issues. In particular, the 2024/3019/EC introduces more stringent population equivalent (p.e.) limits of agglomerations, for which a collecting system is mandatory, as well as higher mandatory levels of urban wastewater treatment. It, also, establishes more stringent obligations for Member States regarding the monitoring and control of individual treatment systems, thus ensuring their safety and efficiency. Furthermore, the new framework demands the development of integrated urban wastewater management plans to minimize pollution at source and reduce the impact of stormwater overflows and contaminated urban runoff. Finally, the new Directive introduces the urban wastewater surveillance, aiming to the detection of certain viruses in urban wastewater, as an indication of an emerging epidemic or pandemic, thus providing a safety layer to protect public health.

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Ensure fair access to sanitation services

A significant limitation of the former Directive was the lack of attention paid to the inclusiveness of sanitation services. The 2024/3019/EC encourages actions to ensure that a sufficient number of safe sanitation facilities is fairly accessible for the entire population, with particular respect to vulnerable groups.

Climate change adaptation

As a matter of fact, wastewater treatment constitutes an energy-intensive sector with high methane and nitrous oxide emissions, which are two of the most impactful greenhouse gases (GHGs). However, there is a great potential for energy and resource recovery in wastewater treatment, which is only slightly used so far. As experience has showcased, in lack of a clear and specific legal framework, the valorisation of this potential will only be making minor progress. Therefore, the approach of an integrated urban wastewater management established by the 2024/3019/EC sets specific objectives for energy recovery and renewable energy production in wastewater treatment facilities, aiming to balance energy consumption and production, thus contributing to the achievement of the Energy Neutrality objective established by the 2021/1119 EU Regulation. This Directive is also set to actively contribute to the climate change adaptation of the wastewater sector through the progressive reduction of GHG emissions, while also encouraging resource recovery from sludge and wastewater reclamation intended for several sectors including agriculture.

Transparency in wastewater governance

According to the former framework on wastewater treatment, Member States should ensure that the competent authorities publish a report on sludge and wastewater disposal every two years. However, the evaluation of the 91/271/EC performed by the Commission in 2019 demonstrated the necessity to increase the transparency in wastewater management. Thus, the current Directive sets certain obligations for the Member States, which should ensure that online and up-to-date information regarding wastewater collection and treatment is available for the public, along with key performance indicators of the wastewater treatment sector.

Key Provisions

Collecting and Individual systems

The 2024/3019/EC Directive provides a more stringent and thorough framework regarding collecting and individual systems, when compared to the former 91/271/EC. After the recognition of the environmental pressures caused by the domestic wastewater discharges from small agglomerations, the population equivalent (p.e.) limit, above which a collecting system is mandatory, was reduced from 2000 p.e. to 1000 p.e. As for the individual systems, the 91/271/EC mandated that Member States ensure that their application offers the same level of protection, as would be provided by the required treatment stage based on the p.e. level. The 2024/3019/EC introduces additional obligations for Member States, which should make certain that these systems are included in a register and are frequently monitored and controlled. The Commission also declared the commitment to proceed to implementing acts, in order to introduce minimum requirements for the design, operation and maintenance, as well as for the inspection frequency of those systems.

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Mandatory treatment stages

The 91/271/EC Directive introduced a basic framework making the first steps towards the reduction of the impact of urban wastewater discharges aiming to the protection of the environment and public health. The minimum treatment stages set by that regulation required the application of secondary treatment (biological treatment followed by secondary settlement for the removal of biodegradable organic carbon) for agglomerations of 10.000 p.e. and above, while the additional removal of nutrients was mandatory in the cases, when the treated wastewater was disposed into receiving bodies sensitive to eutrophication. Despite the fact, that this regulation led to a significant reduction of nutrient concentrations in water bodies, eutrophication is still an unresolved environmental challenge. Additionally, micropollutant accumulation in the aquatic environment constitutes an emerging issue threatening public health. Therefore, the current Directive establishes a more thorough and stringent legal framework (see Table 2) demanding the application of secondary treatment to domestic wastewater produced from agglomerations of 1.000 p.e. and above. In the case of agglomerations of 150.000 p.e. and above, the Directive mandates the application of tertiary treatment (removal of total nitrogen and total phosphorus) by 2039 and the application of quaternary treatment by 2045. In the case when the treated wastewater is disposed in water bodies sensitive to eutrophication or to receiving waters with high micropollutant accumulation risk, the demanded treatment stages for agglomerations of 10.000 p.e. and above are tertiary and quaternary treatment, respectively.

Wastewater surveillance

The 2024/3019/EC Directive aims to decisively contribute to the protection of public health by introducing the surveillance of urban wastewater. Therefore, it mandates the collection of public health data from urban wastewater concerning the presence of certain viruses, including SARS-COV-2 virus and its variants, poliovirus, influenza virus and emerging pathogens, which can serve as a warning signal to prevent epidemics or pandemics. The current framework also requires the monitoring of domestic wastewater regarding the presence of antimicrobial agents and their metabolites, as well as antimicrobial-resistant bacteria and their genes, in order to evaluate and expand scientific knowledge on the antimicrobial resistance in urban wastewater.

Access to sanitation

The lack of fair access in the sanitation services constitutes a severe problem entirely unaddressed by the former legal framework. Thus, the 2027/3019/EC Directive is set to take a decisive initiative aiming to ensure equal access to safe sanitation facilities for the entire population, while paying special attention on the needs of vulnerable or marginalised groups. In particular, according to the requirements of this Directive, Member States should identify the severity of this issue in their territory by 2029 and encourage the establishment of a sufficient number of sanitation facilities in public spaces and public buildings, while ensuring safety and fair access for all.

Extended producer responsibility

The wide application of quaternary treatment required by the 2024/3019/EC for the removal of micropollutants is rather cost-intensive. In order to make this treatment method cost-effective for operators and achieve compliance of the wastewater treatment sector with the polluter-pay principle, the current Directive introduces the approach of the extended producer responsibility. According to this concept, the producers of products made of substances, which are sources of micropollutants in domestic wastewater, must take responsibility and bare at least the 80% of the investment and operational costs of

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the quaternary treatment along with additional costs regarding the collection and verification of data concerning products placed in the market.

Non-domestic wastewater discharges

The uncontrolled disposal of industrial wastewater into urban wastewater collecting systems and treatment plants can cause significant damage to the facilities and hinder the compliance with the requirements of this and other associated EU Directives regarding the protection of the environment and public health. Therefore, Member States should make certain that the competent authorities will identify and manage the discharges of non-domestic wastewater into collecting systems and urban wastewater treatment plants, by adopting prior regulations or by granting specific authorizations in coordination with the operators of the collecting systems and treatment facilities. Such measures should guarantee that the industrial discharges meet certain requirements before entering collecting systems and treatment plants, thus ensuring the protection of the health of the working staff, the minimal impact on the collecting system and the wastewater treatment plant, including its operation and recovery capacity, and the compliance with other EU Directives including the WFD 2000/60/EC regarding the quantitative and qualitative status of recipient water bodies. In the case of biodegradable non-domestic discharges from industries, such as fish- or potato-processing industries and breweries, with a load of 4.000 p.e. and above, Member States can establish certain regulations for the direct disposal of this wastewater without entering a treatment facility, as long as the requirements of this Directive regarding the protection of the environment and public health are fully met.

Energy neutrality

A central part of the 2024/3019/EC objectives is the contribution to the adaptation of the wastewater treatment sector to climate change by progressively reducing GHG emissions, while also aiming to contribute to the achievement of the goal regarding energy neutrality by 2050, as established by the 2021/1119 regulation. Therefore, the current Directive mandates the conduction of energy audits to all urban wastewater treatment plants and the corresponding collecting systems receiving a load of 10.000 p.e. and above by 2032. Such audits should identify the potential for the reduction of energy consumption and optimize the production of renewable energy, particularly in terms of biogas production and use of waste heat, while ensuring the reduction of GHG emissions. Additionally, Member States should ensure that, at national level, the total annual production of renewable energy, as any part of the operation of wastewater treatment plants receiving a load of 10.000 p.e. and above, counterbalances the total annual energy consumption of these plants by 2045.

Water reuse and resource recovery

Water and resources scarcity constitute a severe environmental problem, which is continuously aggravated by the ongoing climate change. Thus, the need to find alternative sources of water and other substances essential for human societies and economies is constantly growing. In contrast with the 91/271/EC, the current Directive identifies this issue and puts an effort to pave the path towards its solution. Therefore, it requires from Member States to promote the reuse of treated wastewater -particularly in “water-stressed” areas- in line with the 2000/60/EC Directive and the 2020/741/EC regulation, while ensuring that this will not pose any threat to the environment or human health. It, also, encourages the adoption of a sludge management approach according to the 2008/98/EC, which should be based on the design of urban wastewater treatment plants that focus on the prevention of sludge production and its preparation for

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reuse and resource recovery -especially for nitrogen and phosphorus-, while minimizing the impact on the environment and public health.

Implementation and compliance

Integrated wastewater management plans

Member States should prepare and establish the integrated wastewater management plans for all agglomerations of 10.000 p.e. and above at the latest by 2039. Their content should include the description of the initial conditions in the area under examination and the specific objectives to reduce pollution caused by stormwater overflows. Also, the plans should present the adopted measures to meet these goals. When deciding the mitigation measures, the 2024/3019/EC Directive encourages Member States to prioritize the application of suitable solutions to prevent the flow of unpolluted rainwater into the sewers, such as natural water retention and rainwater harvesting, and increase the development of green and blue areas in the urban environment, which reduce the impermeable surfaces, thus limiting stormwater overflows. After their development, the plans should be reviewed every six years and improved when necessary.

Monitoring

The 2024/3019/EC Directive sets various obligations for Member States to ensure the efficient implementation of the current regulation. At first, Member States should monitor all collecting systems to control stormwater overflows and urban runoff. Also, they should closely monitor the discharges from urban wastewater treatment plants, as well as the amount, composition and disposal of the produced sludge to ensure treatment efficiency and verify the compliance with the requirements of this and other associated Directives. When the treated wastewater is reused in agriculture for irrigation, the Member States should make certain that the annual and monthly quantities of treated wastewater along with their nutrient content and the time period of their application are effectively managed in accordance with the water and nutrient demand of the crops. In the case of facilities receiving a load of 10.000 p.e. and above, the Member States should ensure that the competent authorities monitor (a) the GHG emissions -at least in terms of carbon dioxide, nitrous oxide and methane-, (b) the inlets and discharges of the wastewater treatment plants to verify the compliance with the current Directive regarding the concentration of conventional pollutants, PFAs and microplastics, as well as (c) the energy equilibrium of the facility, in order to ensure that the renewable energy production counterbalances the energy consumption. In that regard, the Commission has declared the commitment to develop implementation acts for the estimation and modelling of GHG emissions and microplastics, as well as the measurement of PFAs.

Risk assessment and management

According to the 2024/3019/EC, Member States should identify and evaluate the risks related to the discharge of urban wastewater for the environment and human health according to the current and other associated Directives by the end of 2027. After the detection of these risks, Member States should consider the adoption of suitable mitigation measures, if necessary, including the application of more stringent quality standards for the treated wastewater, to address any threats for the environment or public health. The risk management plans should be reviewed every six years and accordingly optimized where needed.

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Public information

Transparency in wastewater management stands as one of the main objectives of this Directive. Member States must make certain that all information concerning the collection and treatment of wastewater are available and easily accessed by the public. Also, in the cases when the treatment costs are covered by a water tariff system, Member States should ensure that all households of agglomerations of 10.000 p.e. (or preferably 1.000 p.e.) receive regularly information regarding the compliance with the requirements of this Directive, as well as personalized information for the household regarding the annual collected and treated volume of wastewater.

Overall, it is clear that the requirements and quality standards set by the 2024/3019/EC are more stringent and thorough compared to the 91/271/EC having lower allowed pollutant concentrations and p.e. limits for the mandatory application of collecting systems and higher treatment stages, while also introducing additional demands regarding energy neutrality and GHG emission control, as well as public health indicators, as shown in Table 2.

Table 2 Quality standards of the 91/271/EC and the 2024/3019/EC Directives

Quality Standards		91/271/EC	2024/3019/EC
Mandatory collecting system		2.000 p.e. and above	1.000 p.e. and above
Mandatory Treatment Stages	Secondary Treatment	10.000 p.e. and above and 2.000 p.e. and above when disposed into freshwater or estuaries	1.000 p.e. and above
	Tertiary Treatment	10.000 p.e. and above when disposed into water bodies sensitive to eutrophication	150.000 p.e. and above and 10.000 p.e. and above when disposed into water bodies sensitive to eutrophication
	Quaternary Treatment	-	150.000 p.e. and above and 10.000 p.e. and above when disposed into water bodies sensitive to micropollutant accumulation

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Quality Standards		91/271/EC	2024/3019/EC
Number of samples		**2.000-9.999 p.e.**: 12 the first year and then 4/year **10.000-49.999 p.e.**: 12/year **50.000 p.e. and above:** 24/year	**1.000-9.999 p.e.**: 1/month **10.000-49.999 p.e.**: 2/month, for micropollutants: 1/month **50.000-149.999 p.e.**: 1/week, for micropollutants: 2/month **150.000 p.e. and above:** 2/week, for micropollutants: 2/month
Quality indicators	Secondary Treatment	Biochemical Oxygen Demand (BOD5)/Total Organic Carbon (TOC), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS)	Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD)/Total Organic Carbon (TOC), Total Suspended Solids (TSS)
	Tertiary Treatment	Total Nitrogen (TN), Total Phosphorus (TP)	Total Nitrogen (TN), Total Phosphorus (TP)
	Quaternary Treatment	-	Amisulprid, Carbamazepine, Citalopram, Clarithromycin, Diclofenac, Hydrochlorothiazide, Metoprolol, Venlafaxine, Benzotriazole, Candesartan, Irbesartan, mixture of 4-Methlbenzotriazole and 5-methyl-benzotriazole
Energy neutrality		-	Balance between the annually produced (recovered) and consumed energy at a national level
GHG emissions reduction		-	Encouraged
Water reuse and resource recovery		Encouraged	Encouraged
Water surveillance		-	Monitoring of anti-microbial resistance and the presence of SARS-COV-2 virus and its variants, poliovirus, influenza virus and emerging pathogens

Water Reuse Regulation 2020/741/EC

Climate change and the subsequent extreme weather conditions constitute a major environmental challenge for Europe, having multiple impacts on the environment and particularly on the water resources of the continent, thus leading to a prolonged water scarcity. In 2020 the EU Commission, having identified this issue, aimed to establish a legislative framework regarding the reuse of treated wastewater. In many aspects, water reuse is a completely viable solution to respond to the water shortage problem, as it can limit the extraction of freshwater and reduce pollution of water bodies, while also promoting sustainable

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water management and circular economy. Also, water reuse has a lower environmental footprint compared to other alternatives for water supply; yet its application is still rather limited, partially due to the lack of common environmental and human health standards among Member States and the high investment cost needed for the upgrade of wastewater treatment plants to meet the water quality standards for reuse. Thus, the current Regulation seeks to provide a thorough and all-inclusive framework to facilitate the safe and cost-efficient water reuse in the Union.

Main objectives

Respond to water scarcity and promote sustainability

Water scarcity stands as one of the main environmental challenges of the 21st century arising from the ongoing climate change, which is a major cause of unpredictable weather events and prolonged droughts, while being aggravated by the extended pollution and the unsustainable management of water resources. Wastewater reclamation and reuse for non-potable applications can serve as a key response to the matter enabling climate change adaptation across Europe. First and foremost, it constitutes a favourable option, as it provides the opportunity to simultaneously reduce freshwater use and pollution by minimizing freshwater extraction and wastewater disposal into water bodies. Furthermore, water reuse for agricultural irrigation facilitates nutrient recovery from wastewater, in particular nitrogen, phosphorus and potassium, thus restoring their biochemical cycles and minimizing the use of chemical fertilizers. In view of these advantages, the Commission introduced the 2020/741/EC Regulation, as an attempt to establish a framework of minimum requirements for reclaimed wastewater intended for water reuse, thus contributing to the development of an integrated wastewater management and promoting climate change adaptation and circular economy.

Protection of the environment and human and animal health

Wastewater reclamation constitutes an environmentally beneficial method to address water shortages. Apart from its contribution to the reduction of water resources pollution, it causes lower environmental pressure compared to other alternatives for water supply, such as water transfer and desalination. However, the potential of water reuse is only barely valorised in the Union, partially due to barriers regarding concerns about the protection of human health. Thus, the 2020/741/EC Regulation was developed based on the principles of environmental, human and animal health protection. It provides a comprehensive framework introducing a set of minimum quality, monitoring and risk management requirements aiming to ensure safe water reuse for agricultural irrigation, while demanding the complete alignment with the WFD 2000/60/EC Directive, as well as with the 98/83/EC Directive (currently with its 2020 amendment, 2020/2184/EC Directive) and the 852/2004 Regulation, regarding quality requirements for water intended for human consumption and hygiene of food stuffs, respectively.

Key Provisions

Reused water quality and monitoring standards

The current Regulation sets minimum requirements for water reuse for irrigation purposes in terms of the quality of the reclaimed wastewater, the monitoring process and the necessary control frequency. In particular, the minimum standards are determined by the classification to a reclaimed water quality class, which is based on the crop category and the applied irrigation method. For each quality class the

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2020/741/EC Regulation defines the required treatment stages, as well as the quality parameters and the minimum sampling frequency for routine monitoring of reclaimed wastewater intended for irrigation, while also encouraging other non-potable applications, such as industrial reuse. In the case of the first quality class, or when the facility is new or technologically upgraded, the Regulation demands additional validation monitoring of the indicator microorganism of three groups of pathogens, namely bacteria, viruses and protozoa. The quality standards set by this Regulation are summarized in Table 3. The operator of the reclamation facility should make sure that the quality of the reclaimed wastewater and the applied monitoring process comply with the standards established by this regulation, as well as with other possible requirements set by the competent authorities, in order to minimize the risks for the environment and human and animal health related to water reuse.

Table 3 Minimum quality and monitoring standards of the 2020/741/EC for water reuse

Reclaimed water quality class	Crop category	Irrigation method	Treatment stage	Quality parameters	Sampling frequency
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	Secondary treatment, filtration and disinfection	E.coli	1/week
				Biochemical Oxygen Demand (BOD_5)	1/week
				Total Suspended Solids (TSS)	1/week
				Turbidity	Continuous
				Legionella spp.	2/month
				Intestinal nematodes	2/month or as determined by the reclamation facility operator according to the number of eggs in wastewater entering the reclamation facility
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	All irrigation methods	Secondary treatment and disinfection	E.coli	1/week
				Biochemical Oxygen Demand (BOD_5)	According to the 91/271/EEC, see Table 2
				Total Suspended Solids (TSS)	According to the 91/271/EEC, see Table 2
				Legionella spp.	2/month

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Reclaimed water quality class	Crop category	Irrigation method	Treatment stage	Quality parameters	Sampling frequency
	meat-producing animals			Intestinal nematodes	2/month or as determined by the reclamation facility operator according to the number of eggs in wastewater entering the reclamation facility
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	Secondary treatment and disinfection	E.coli	2/month
				Biochemical Oxygen Demand (BOD_5)	According to the 91/271/EEC, see Table 2
				Total Suspended Solids (TSS)	According to the 91/271/EEC, see Table 2
				Legionella spp.	2/month
				Intestinal nematodes	2/month or as determined by the reclamation facility operator according to the number of eggs in wastewater entering the reclamation facility
D	Industrial, energy and seeded crops	All irrigation methods	Secondary treatment and disinfection	E.coli	2/month
				Biochemical Oxygen Demand (BOD_5)	According to the 91/271/EEC, see Table 2
				Total Suspended Solids (TSS)	According to the 91/271/EEC, see Table 2
				Legionella spp.	2/month
				Intestinal nematodes	2/month or as determined by the reclamation facility operator according to the number of eggs in wastewater entering

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Reclaimed water quality class	Crop category	Irrigation method	Treatment stage	Quality parameters	Sampling frequency
					the reclamation facility

Overall, the minimum quality standards for water reuse set by this Regulation in combination with the 2024 amendment of the 91/271/EC Directive regarding the urban wastewater treatment (2024/3019/EC) indicate a clear shift in the approach of water and wastewater management on an EU level. As declared in the 2020/741/EC Regulation, a major obstacle for water reuse is the high investment cost required for the upgrade of the wastewater treatment plants to meet the minimum standards of reclaimed wastewater. However, the 2024/3019/EC Directive reduces the p.e. limit, above which a collecting system and subsequent secondary treatment are mandatory, thus ensuring that the biggest part of wastewater produced in the Union will be at least biologically treated for the removal of organic matter, which is a mandatory treatment stage for all quality classes defined in the 2020/741/EC regulation. The 2024/3019/EC Directive also increases the minimum quality standards for tertiary treatment and introduces additional required treatment stages for the removal of micropollutants. These demands will inevitably force Member States to proceed to the construction of several new wastewater treatment plants and the upgrade of existing facilities, which will produce highly treated wastewater, thus facilitating the achievement of the 2020/741/EC regulation standards and the wider application of wastewater reclamation.

Risk management

Competent authorities of each Member State should ensure that risk management plans will be developed by the responsible stakeholder, which could be the reclamation facility operator or other involved parties. Risk management plans aim to detect and manage risks associated with wastewater reclamation and reuse in agriculture, thus ensuring that the reused water is safe and does not compromise the preservation of the environment or human and animal health. Such plans should include a detailed and comprehensive description of the entire wastewater reclamation system from the point of entry of urban wastewater into the treatment facility to the point of water reuse, as well as the identification of all involved parties, along with the description of their roles and responsibilities. Also, risk management plans should evaluate the possibility of accidents, including failure or contamination of the water reuse system and leakages, They should, also, identify the associated hazards entering the water reuse systems, especially pollutants and pathogens, the vulnerable ecosystems and populations exposed to that risk and the expected impact on the environment or human and animal health. In order to respond to those risks, these plans should ultimately assess and implement suitable mitigation strategies, which could take the form of preventive measures, such as additional disinfection and pollutant removal and establishment of minimum safety distances, or supplementary requirements, such as stricter quality standards regarding several substances, including heavy meals, pesticides and pharmaceuticals.

Transparency and awareness raising

Transparency in wastewater treatment and reclamation is a key element enhancing the confidence of the population in water reuse. For that purpose, Member States should ensure that all information regarding wastewater reclamation is available to the public in a clear, detailed and updated form. Such information includes the quantity and quality of reclaimed wastewater, the permits granted by the competent

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authorities and the corresponding compliance verifications. Also, water reuse in agriculture could be further encouraged by awareness-raising campaigns informing the public regarding its associated benefits of water saving and water shortages limitation. Finally, Member States should organize information and training campaigns for end-users to ensure the safe application of reclaimed wastewater, thus protecting the environment and the human and animal health.

Implementation and Compliance

Reclaimed water permit

All stakeholders involved in water reuse systems, including the reclamation facilities operators and end-users, must possess a permit for their activity, which is granted by the competent authorities and defines the responsibility of each involved party based on the outcomes of the risk management plan. The information contained in the permit should include the quality class/classes of the reclaimed water followed by the agricultural use for each class, as well as the values of the quality parameters of the reclaimed wastewater in relation to the standards set by this regulation. Permits should also specify possible additional or preventive measures taken by the facility operator to eliminate unacceptable risks to the environment or human and animal health, as well as the validity period and the point of compliance. Permits should by regularly reviewed and updated, in particular in the case of a significant change in the capacity or the equipment of the facility, or when there have been changes in the climatic conditions altering the ecological status of surface water bodies.

Compliance verification

Competent authorities of Member States must regularly verify the compliance with the conditions referred in the permit through field inspections and monitoring data. In the absence of compliance, competent authorities should demand the adoption of measures to achieve compliance and the information of all affected parties, such as end-users, while in the case of a severe risk to the environment or to the human and animal health, competent authorities should suspend the validity of the permit until the restoration of compliance.

3.1.2 National and Regional Level

Water Management: Water Framework Directive adaptation

The WFD was incorporated in the National Legislative System of Greece in 2003 through the 3199/2003 regulation “Water Management and Protection-Adaptation to the Water Framework Directive 2000/60/EC”, while further adjustment to the WFD requirements was achieved by the 51/2007 Presidential Decree. The 3199/2003 regulation contains the identification of all competent authorities and the detailed description of their roles and responsibilities for the implementation of the WFD objectives. In particular, according to this regulation, a National Water Committee was established consisting of 6 Ministers, which is responsible for the policy design regarding water resources management and protection, the identification of the river basin districts and the regional authorities responsible for each district, as well as for the development of strategies and processes aiming to the cost recovery from water services. Cost recovery processes are designed in accordance with the WFD and with respect to the polluter pay principle, taking into consideration the characteristics of each river basin district, the identification of pressures caused by human activity, the economic analysis of water use, as well as the geographic and climatic conditions of the area. Furthermore, the regulation mandates the establishment of a Central Water Agency

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in the Ministry of Environment and Energy, responsible for the development and monitoring of national programs for the efficient management and preservation of water resources, which must be approved by the National Water Committee. Also, the 3199/2003 regulation requires the establishment of Water Departments in each region by the National Water Committee, which are responsible for the development of the RBMPs for the river basin districts lying in their territory, aiming to the protection, preservation and improvement of all water bodies; thus, preserving the aquatic environment and ecosystems. Regional authorities should also design the programs of measures aiming to the prevention and progressive reduction of the discharges and emissions of contaminants, while also taking supplementary measures for the elimination of priority hazardous substances. Finally, the 3199/2003 law provides some general water use regulation to ensure sustainability and long-term protection and preservation of water resources. Further adaptation to the 2000/60/EC Directive was committed by the 51/2007 Presidential Decree, which provided a detailed description of the WFD and the responsibilities of the competent authorities in accordance with the 3199/2003 regulation.

Urban Wastewater Treatment Framework-JMD 5673/400/97

The adaptation to the 91/271/EC was conducted by the Joint Ministerial Decision (JMD) 5673/400/1997: "Measures and conditions for the treatment of domestic wastewater", which contains a full description of the requirements of the 91/271/EEC Directive regarding the design and construction of collecting systems and treatment facilities, as well as the minimum quality and monitoring standards and mandatory treatment stages. It also includes a comprehensive description of the roles and responsibilities of all involved parties, as well as more specific requirements concerning wastewater and sludge disposal and potential reuse.

Main Objective

Main objective of the JMD 5673/400/97 is the adaptation to the 91/271/EEC regarding the collection, treatment and disposal of urban wastewater and wastewater from certain industrial sectors aiming to the protection of the environment and public health.

Key Provisions

Collecting system and treatment stages

The 91/271/EEC established a solid framework for the collection and treatment of domestic wastewater by introducing certain quality standards for the disposal of treated wastewater into water bodies -taking into consideration the characteristics of the recipient body-, as well as p.e. limits, above which a collecting system and treatment are mandatory. The detailed description of the 91/271/EEC requirements regarding wastewater treatment and collection are summarized in Table 2.

Sensitive areas

Wastewater disposed into areas, which are characterized as "sensitive" to eutrophication require additional treatment according to the 91/271/EEC, as shown in Table 2. Thus, a list of sensitive and less sensitive areas should be established by a JMD among the Ministries of "Environment and Energy", "Interior", "Health and Welfare" and "Rural Development and

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Food", to ensure that the characteristics of these areas will meet the requirements of this JMD by 2004.This list should by reviewed and improved -if necessary- every four years.

Industrial wastewater

Industrial wastewater discharges could enter domestic wastewater collecting systems after the application of pre-treatment processes, which should ensure that these discharges meet certain requirements, thus ensuring the protection of the health of working people, the avoidance of any damage to the collecting systems or to the wastewater treatment facilities and operation efficiency, as well as the environmentally safe disposal of the treated wastewater and the produced sludge. In order to dispose industrial wastewater to the urban collecting systems, the industry operator should receive a permit granted by the local authorities managing the "water supply and drainage" network, which verifies the compliance with the aforementioned requirements. Also, biodegradable industrial wastewater originating from several industries, including milk-processing, meat industries and breweries, with a load of 4.000 p.e. and above can be directly disposed to the aquatic environment, after the operator receives a permit from regional authorities, which verifies the compliance with environmental requirements established by the competent authorities according to the Regulation 1650/86 for the protection of the environment and other associated regulations.

Wastewater and sludge disposal

In alignment with the 91/271/EEC, the JMD 5673/400/97 prioritizes -when appropriate- the wastewater reclamation and sludge recovery and reuse. In any case, competent authorities should grant the relevant permits after they ensure that the reuse or disposal of the treated wastewater and the produced sludge is carried out according to the characteristics of the recipient water body and the requirements of the national legislation regarding the protection of the environment.

Monitoring

Regarding the disposal of the treated wastewater and the sludge, regional authorities should carry out regular and spontaneous controls to verify the compliance with the requirements of the granted permits and to determine the quantity and composition of the sludge. The minimum monitoring standards set by the 91/271/EEC in terms of sampling frequency are summarized in Table 2.

Existing Water Reuse Framework-JMD 191002/2013 (amendment of 145116/2011)

Prior to the EU 2020/741/EC regulation, Greece established a legislative framework for wastewater reclamation and reuse in 2011. The Joint Ministerial Decision (JMD) 145116/2011 "Establishment of measures, conditions and procedures for the reuse of treated wastewater and other provisions" introduced in 2011 and amended in 2013 contains specific requirements for the reuse of treated urban wastewater for agricultural irrigation, aquifer recharge, as well as industrial applications and other uses in urban environments.

Main objectives

The primary goal of this regulation is the development of a robust legislative framework for the safe reuse of treated urban wastewater, while safeguarding the environment and public health. In particular, it aims to establish wastewater reclamation as a viable solution for non-potable uses, as an attempt to preserve

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water resources and mitigate water shortages, which are exacerbated by the ongoing climate change, while also enabling the recharge of aquifers, which suffer from prolonged water limitations and saline intrusion. Thus, this regulation establishes certain minimum requirements for the application of reclaimed domestic wastewater for agricultural irrigation, aquifer recharge, industrial uses and reuse in urban areas. In the case of treated industrial wastewater, reuse can only take place for certain applications, namely (a) "restricted" irrigation, (b) industrial uses and (c) aquifer recharge by diffusion of wastewater through the ground (for groundwater bodies, which are not used for potable water supply), all of which will be described in the following sections.

Key provisions

Agricultural irrigation

The level of treatment required for the reuse of wastewater for agricultural irrigation depends on the type of the crops and the applied irrigation technique. According to this regulation, there are two types of applications identified, namely the "restricted" and the "unrestricted" irrigation. The restricted"irrigation" is basically applied to crops, when the edible part is not in direct contact with the ground or when their products are either not intended for human consumption or they are consumed after they have been subjected to thermal of some other kind of processing. In regard to the irrigation technique, sprinkling is not applicable, while several preventive measures should be adopted, including the restriction of the irrigated area, so that it won't be accessible for humans and animals. In contrast, "unrestricted" irrigation can be applied to all types of crops, without any limitations regarding the accessibility of the area or the irrigation method. The minimum level of treatment demanded for each irrigation type is shown in Table 4.

Both irrigation types require the development of a design and implementation study for every season of the year prior to their application. Such plans should contain the complete description of the calculations and the design approach for each solution, including the required surface area and the balance of water, organic matter, nutrients and other important trace elements to determine the maximum load of wastewater that can be applied. The implementation plans should also lay down in detail the monitoring programmes regarding the quality standards of the reclaimed wastewater, the ground and the crops, as well as any potential supplementary safety and information measures adopted to ensure the protection of the environment and public health.

Aquifer recharge

Another potential option for water reuse is the discharge of adequately treated wastewater into groundwater bodies, aiming to elevate the water level to readjust to the aquifer's natural conditions and prevent saline intrusion, as well as to control potential ground subsidence and create a storage to balance seasonal fluctuations of water demand for agricultural irrigation. The aquifer recharge can be implemented either directly by drilling or by diffusion through the ground. In the case of direct recharge, the wastewater must by subjected to tertiary or advanced treatment (apart from the mandatory biological secondary treatment) to remove soluble organics, such as ultrafiltration or other equally efficient processes. When the wastewater discharges are diffused through the ground, the advanced treatment can be avoided, if the natural filtration through the ground is proven sufficient for the organics removal. The mandatory treatment stages and monitoring standards for aquifer recharge with treated wastewater are summarized in Table 4.

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A design and implementation study must be carried out for the aquifer recharge with treated wastewater, which should include the evaluation of the quantitative and qualitative status of the reclaimed wastewater and the groundwater body, and the achieved wastewater dilution, as well as the identification of specific implementation measures and monitoring programmes based on the aforementioned analysis and the adopted recharge method. The study should also incorporate a hydro-geological analysis, which should verify that the groundwater body is not used for potable water supply and assess -among others- the depth of both the aquifer and the point of recharge, as well as the characteristics and permeability of each ground layer.

In case the aquifer is or will be used for potable water supply, the wastewater must be processed through secondary and advanced treatment, specifically through at least ultrafiltration or other methods of equal efficiency (see Table 4). Also, the corresponding hydro-geological study should include additional assessments regarding other potential abstraction points in the surrounding area, which could be affected. It should also verify that the safety and quality status of the groundwater body intended for potable water supply is not compromised. Finally, it should incorporate a techno-economic analysis, proving that the artificial aquifer recharge is the only viable option for wastewater reclamation.

Urban reuse

Urban reuse of treated wastewater constitutes an advantageous option to cover the water demand for non-potable uses in urban environments, including green areas, fire stations, fountains and road cleaning, without the abstraction of freshwater. Each application should be individually evaluated through a design and implementation study, which should lay down the minimum requirements, in terms treatment processes, monitoring frequency and microbiological and chemical quality standards, as well as any other additional measures adopted to ensure the protection of the environment and public health. The minimum requirements for urban reuse are shown in Table 4.

Industrial reuse

Treated wastewater can be reused in industry for several applications, including cooling systems, boilers and other industrial processes, apart from industries of products intended for human consumption. Internal wastewater recirculation is not considered a reuse, according to this regulation, and can be applied to industries including the ones of products intended for human consumption, as long as it is ensured that there is no direct contact with products. In the case of wastewater reuse for a one-time cooling application, the required treatment level is lower compared to the rest of industrial uses, as shown in Table 4. The corresponding design and implementation study for a certain application should describe the minimum requirements, as well as potential additional limitations for the reuse of treated wastewater. The quality standards for industrial reuse, according to this regulation, are summarized in Table 4.

Water reuse permits

Water reuse permits for a certain application are granted by the regional authorities and include, among others, the terms and conditions for the reuse of treated wastewater according to the type of application, the quantity of the reclaimed wastewater and the corresponding quality standards for that certain application, the obligations of the user, as well as the validity period and the time period of application.

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Table 4 Minimum quality and monitoring standards of the JMD 191002/2013 for water reuse

Reuse application	Required treatment stages	Quality parameters	Sampling frequency
"Unrestricted" irrigation	Secondary biological treatment and tertiary treatment and disinfection	E. coli	0-49.999 p.e.: 2/week 50.000 p.e. and above: 4/week
		Biochemical Oxygen Demand (BOD_5)	According to JMD 5673/400/97
		Total Nitrogen	According to JMD 5673/400/97
		Total Phosphorus	According to JMD 5673/400/97
		Total Suspended Solids (TSS)	According to JMD 5673/400/97
		Residual Cl_2	Constantly
		Turbidity	0-49.999 p.e.: 2/week 50.000 p.e. and above: 4/week
"restricted" irrigation	Secondary biological treatment and disinfection	E. coli	1/week
		Biochemical Oxygen Demand (BOD_5)	According to JMD 5673/400/97
		Total Nitrogen	According to JMD 5673/400/97
		Total Phosphorus	According to JMD 5673/400/97
		Total Suspended Solids (TSS)	According to JMD 5673/400/97
		Residual Cl_2	Constantly
Aquifer recharge: Direct discharge of treated wastewater into groundwater bodies that are not used for potable water supply	Secondary biological treatment and advanced treatment and disinfection	TC	0-49.999 p.e.: 3/week 50.000 p.e. and above: 7/week
		Biochemical Oxygen Demand (BOD_5)	According to JMD 5673/400/97
		Total Nitrogen	According to JMD

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Reuse application	Required treatment stages	Quality parameters	Sampling frequency
			5673/400/97
		Total Phosphorus	According to JMD 5673/400/97
		Total Suspended Solids (TSS)	According to JMD 5673/400/97
		Residual Cl_2	Constantly
		Turbidity	0-49.999 p.e.: 2/week 50.000 p.e. and above: 4/week
Aquifer recharge: Diffusion of treated wastewater through ground into groundwater bodies that are not used for potable water supply	Secondary biological treatment and disinfection	E. coli	1/week
		Biochemical Oxygen Demand (BOD_5)	According to JMD 5673/400/97
		Total Nitrogen	According to JMD 5673/400/97
		Total Phosphorus	According to JMD 5673/400/97
		Total Suspended Solids (TSS)	According to JMD 5673/400/97
		Residual Cl_2	Constantly
Industrial reuse apart from cooling water for a one-time application	Secondary biological treatment and tertiary treatment and disinfection	E. coli	0-49.999 p.e.: 2/week 50.000 p.e. and above: 4/week
		Biochemical Oxygen Demand (BOD_5)	According to JMD 5673/400/97
		Total Nitrogen	According to JMD 5673/400/97
		Total Phosphorus	According to JMD 5673/400/97
		Total Suspended Solids (TSS)	According to JMD 5673/400/97
		Residual Cl_2	Constantly

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Reuse application	Required treatment stages	Quality parameters	Sampling frequency
		Turbidity	0-49.999 p.e.: 2/week 50.000 p.e. and above: 4/week
Industrial reuse: Cooling water for a one-time application	Secondary biological treatment and disinfection	E. coli	1/week
		Biochemical Oxygen Demand (BOD_5)	According to JMD 5673/400/97
		Total Nitrogen	According to JMD 5673/400/97
		Total Phosphorus	According to JMD 5673/400/97
		Total Suspended Solids (TSS)	According to JMD 5673/400/97
		Residual Cl_2	Constantly
Urban reuse	Secondary biological treatment and advanced treatment and disinfection	TC	0-49.999 p.e.: 3/week 50.000 p.e. and above: 7/week
		Biochemical Oxygen Demand (BOD_5)	According to JMD 5673/400/97
		Total Nitrogen	According to JMD 5673/400/97
		Total Phosphorus	According to JMD 5673/400/97
		Total Suspended Solids (TSS)	According to JMD 5673/400/97
		Residual Cl_2	Constantly
		Turbidity	0-49.999 p.e.: 2/week 50.000 p.e. and above: 4/week

Table 3 and 4 present the minimum quality and monitoring standards for wastewater reclamation and reuse established in the EU and national framework, respectively. The 2020/741/EC regulation contains minimum requirements for the reuse of wastewater in agriculture, depending on the category of the crops

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and the irrigation method applied, while industrial applications are encouraged. The national framework is more thorough, as it includes provisions and certain requirements for more applications apart from agricultural irrigation, namely industrial reuse, aquifer recharge and urban reuse.

As regards to agricultural reuse, the EU framework distinguishes four reused water quality classes (A, B, C, D), while the JMD 191002/2013 sets minimum requirements depending on the applied irrigation technique, thus identifying two applications, namely the "restricted" and "unrestricted" irrigation. Based on the definitions provided in both frameworks regarding the crop categories and the irrigation methods, as well as on the demanded level of treatment and the quality standards, it could be supported that the quality classes A and C of the 2020/741/EC are corresponding to the "unrestricted" and "restricted" irrigation of the JMD 191002/2013, respectively, having the same requirements regarding the minimum treatment level. However, the elementary standards established in the EU framework regarding the quality and monitoring standards of quality class A are more stringent compared to the JMD 191002/2013 requirements for "unrestricted" irrigation, demanding lower pollutant concentrations and more frequent sampling. Nevertheless, it should be noted that the quality standards of the 2020/741/EC are in general stricter compared to the national framework, as it mandates the evaluation of additional microbiological parameters, to verify the safe application of treated wastewater for agricultural irrigation.

Overall, the EU framework could be characterized as more thorough and stringent than the national regulation and, therefore, safer, while the JMD covers a wider spectrum of potential applications of wastewater reclamation; thus, both frameworks should be further expanded, specified and occasionally strengthened, to ensure the safe and efficient water reuse for the widest range of applications possible. In any case, the establishment of these regulations is a decisive and promising step towards the establishment of water reuse as a safe and viable option to protect and preserve freshwater resources.

3.2 Fit for Purpose Water use approach and Quality Requirements

In recent decades, natural resources have come under increasing pressure due to intensive exploitation, human activity, and the effects of climate change [15]. Among the most severely impacted resources, water stands out as perhaps the most vulnerable [16]. Shifts in rainfall patterns, prolonged periods of drought, and ever-growing demand — especially in densely populated urban areas — have placed considerable strain on its availability [17]. Under these conditions, the development and implementation of effective strategies for the sustainable management of water resources have become essential, wherever this is technically and institutionally feasible.

Within this context, the region of Attica presents a particularly interesting case — an area characterized by a high degree of urbanization and limited water availability. Specifically, Attica experiences low annual rainfall — averaging just 400 mm [18] — and lacks natural or artificial reservoirs within its water district. At the same time, the region's large population significantly burdens overall water demand, making water management a particularly challenging task.

Based on the findings of the second revision of the River Basin Management Plan (RBMP) for the Attica district, total annual water abstractions amount to approximately 490 hm^3. The majority of this volume — around 80.66% — is allocated to domestic use, with the remainder distributed among other categories: 13.34% for agricultural use, 5.76% for industrial use, and only 0.24% for livestock.

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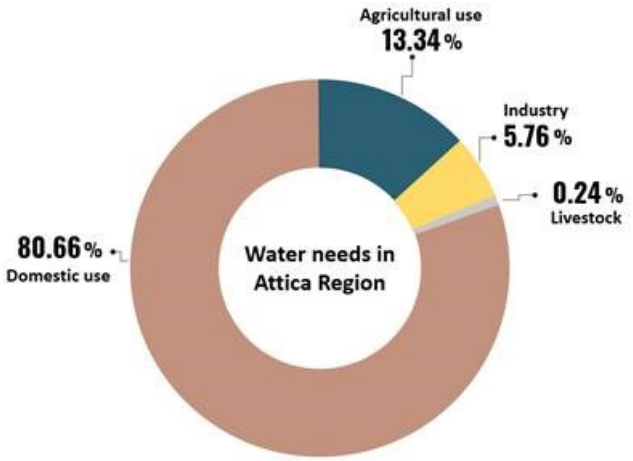


Figure 3 Distribution of Water Needs in the Attica Region

In the context of this study, the analysis for water needs per use for the whole Attica region focuses on non-domestic water flows. Nevertheless, it is essential that the assessment not to be limited to quantitative terms alone. Equally important is the integration of qualitative considerations, ensuring that the estimated water volumes are gradually matched with the appropriate quality levels required for each specific use. In this way, the "fit-for-purpose" approach is incorporated into the methodology, fully aligned with both the European and national regulatory frameworks — notably, the European Regulation on Water Reuse (EU 2020/741).

In practical terms, fit-for-purpose water use means aligning the quality of a specific water source with a final use for which that quality is sufficient. Applying this principle ensures that the appropriate treatment process is selected for the intended use, avoiding unnecessary expenditure, energy consumption, and greenhouse gas emissions [19].

Such principles are increasingly embedded within a broader transformation of water management practices, moving toward decentralised, adaptive, and sustainability-driven approaches.

Traditionally, water resource management focused primarily on the development of water supply infrastructure, aiming to meet water demand and protect public health through wastewater treatment facilities. Over time, priorities expanded to include protection against natural disasters, such as floods, by constructing dams and other technical retention works [20].

Today, the water management landscape is evolving significantly, shifting toward a more holistic and environmentally conscious approach. In this context, the concept of "waterway communities" emerges, placing emphasis on environmental protection, while "water cycle communities" seek to ensure the rational use of limited natural resources — as previously discussed. At the same time, the idea of "water sensitive communities" gains traction, aiming to build resilient and sustainable societies in the face of modern environmental and hydrological challenges [20].

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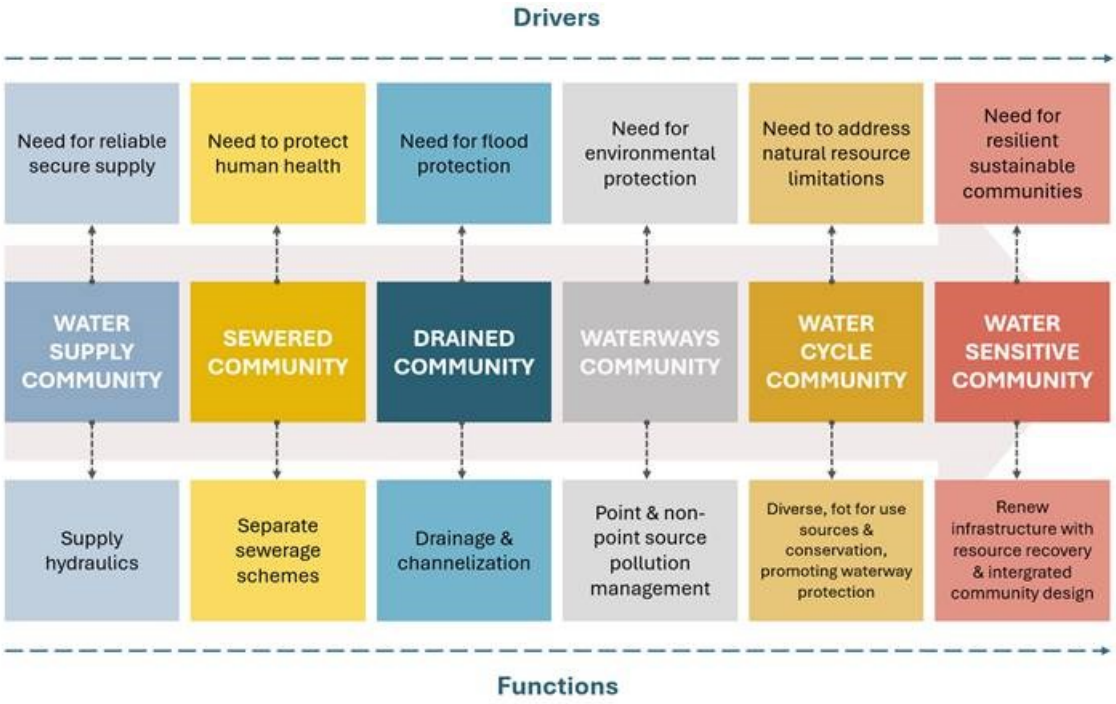


Figure 4 Urban water management transitions framework

Within this evolving framework, water reuse plays a crucial role as a tool for achieving these goals. In practice, water reuse refers to the treatment and reuse of already-used water before its final return to the natural environment [21]. Following the fit-for-purpose logic, water can be repurposed for a range of applications — such as irrigation in agriculture, watering urban green spaces, washing vehicles and streets, flushing toilets, and even in industrial processes (e.g., tank cleaning or use in cooling towers).

To effectively implement this approach, the use of local (on-site) treatment systems is particularly important. Specifically, collecting and treating water close to the point of generation and reuse reduces the need for transportation to central facilities, thereby lowering overall management costs [22].

The primary aim of on-site treatment is to provide more cost-effective solutions compared to conventional methods, which often treat raw water to a high standard even when such quality is unnecessary for the intended use. The on-site reuse approach draws on similar technological principles as those used in traditional water and wastewater treatment but adjusts the level of treatment to match the quality requirements of each specific end use [22].

Nevertheless, existing water supply practices in many regions continue to reflect a one-size-fits-all approach — treating and distributing all water to potable standards, even when this level of quality is unnecessary.

It is important to highlight that, traditionally, water needs related to domestic supply, irrigation of urban green spaces or agricultural land, and industrial activities have been largely met through centralized water supply networks. This involves the use of fully treated potable water, regardless of the intended application. In addition, groundwater resources — accessed through wells and treated as required — are also commonly used.

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The widespread use of such high-quality water, even for applications that do not require it, results in a significant waste of natural resources and increases pressure on the hydrological balance, particularly in regions with limited water availability. Following these uses, water typically flows into distinct waste streams depending on its origin:

- Greywater and blackwater from domestic uses (such as bathrooms, washing machines, and toilets),
- Agricultural runoff when used in crop irrigation,
- Industrial effluents from production processes.

Moreover, in urban environments, additional water flows often remain underutilized — such as stormwater runoff from rainfall and rainwater collected from building rooftops [23].

These streams, when properly treated under appropriate conditions, can serve as alternative water sources. They align directly with the fit-for-purpose approach, which calls for matching water quality to the specific requirements of its intended use — without resorting to excessive treatment when it's not necessary. In summary, the main alternative water sources that can be utilized for fit-for-purpose applications include:

Stormwater: Surface runoff from rainfall that collects on urban surfaces such as roads and sidewalks.
Rainwater: Water harvested from building rooftops using rainwater collection systems.
Greywater: Lightly contaminated wastewater from showers, sinks, and washing machines (excluding kitchen and toilet wastewater).
Blackwater: Wastewater from toilets and kitchen sinks, typically containing high organic and microbial loads.
Agricultural runoff: Water that runs off from agricultural fields, potentially containing fertilizers, pesticides, and organic matter.
Industrial effluent: Liquid waste produced by industrial processes, which may include chemical residues, heavy metals, or organic pollutants.

Planning Fit-for-Purpose Water Reuse: A Step-by-Step Approach

To ensure that fit-for-purpose water reuse is not only conceptually sound but also operationally feasible, a structured and well-defined planning framework is required. While the previous sections outlined the principles and potential benefits of aligning water quality with specific uses, the actual implementation process must be grounded in clear steps, technical assessments, and policy integration.

This becomes particularly important given the multiple conditions that must be met for water reuse to be considered viable. As highlighted in EU-level guidance [24], reuse initiatives must ensure:

- That the water quality is appropriate for the intended use and safe for users and the environment,
- That sufficient quantities can be reliably delivered,
- That the costs remain reasonable and competitive with other sources,
- That public acceptance and stakeholder alignment are in place, and
- That institutional roles and legal responsibilities are clearly defined.

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Furthermore, planning for water reuse should be embedded in broader water and land management instruments — including river basin management plans (RBMPs), regional development programs (RDPs), and spatial planning tools — to ensure consistency, coordination, and long-term sustainability.

To support this integrated approach, the following step-by-step framework has been developed. It outlines the key actions required for designing, evaluating, and implementing fit-for-purpose reuse schemes in a technically robust and policy-compliant manner:

Table 5 Operational Planning Guide for Fit-for-Purpose Water Reuse

Step	Action	Fit-for-purpose Focus	Description
1	Identify Water Needs by Use	Define required quantity and quality per end-use	E.g., irrigation, cooling, toilet flushing, industrial cleaning
2	Assess Available Water Sources	Map potential alternative sources and their quality profiles	E.g., greywater, rainwater, stormwater, treated effluent
3	Evaluate Fit & Gaps	Match source quality to end-use requirements	Identify uses that can be directly served and those needing treatment
4	Define Treatment Requirements	Specify treatment level to reach fit-for-purpose quality	Based on EU and national standards (e.g. EU Reg. 2020/741)
5	Conduct Risk Assessment	Ensure water reuse is safe for users and environment	Evaluate microbial, chemical, and operational risks
6	Estimate Costs & Feasibility	Analyze whether the solution is viable and cost-effective	Compare with conventional supply options
7	Ensure Institutional & Legal Support	Embed reuse plans into governance, responsibilities, and regulation	Include contracts, responsibilities, and stakeholder engagement
8	Implement & Monitor	Apply the reuse system and monitor water quality over time	Ensure sustained fit-for-purpose compliance and safety

This eight-step framework provides a comprehensive roadmap for the design and implementation of fit-for-purpose water reuse systems. Each step is interconnected, forming a logical sequence that ensures technical adequacy, regulatory compliance, and operational feasibility.

Steps 1 and 2 lay the foundation for context-specific reuse planning. Identifying water needs by use ensures that demand is clearly defined, while assessing available sources establishes what is realistically achievable based on local hydrological and infrastructural conditions.

Step 3 is critical for evaluating the suitability of different water flows for specific applications. This step bridges the gap between theory and practice, by identifying which uses can be directly served with existing

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quality levels and which require further treatment. It aligns closely with the "fit-for-purpose" principle promoted by EU Regulation 2020/741.

Step 4 focuses on defining appropriate treatment requirements. These must reflect not only the technical needs of each use but also national and European safety standards. Over-treatment should be avoided to reduce unnecessary costs and environmental burdens.

Step 5, the risk assessment, is indispensable for ensuring that water reuse does not compromise public health or environmental integrity. It involves the evaluation of microbiological, chemical, and operational risks, and supports the development of safe and site-specific treatment and monitoring strategies.

Step 6 introduces economic feasibility into the equation. Beyond the technical potential, projects must be assessed in terms of affordability, competitiveness with conventional supply options, and long-term sustainability. This includes consideration of lifecycle costs, energy use, and externalities.

Step 7 highlights the institutional and legal dimensions of reuse. Successful implementation depends on well-defined roles, contractual clarity, and strong stakeholder engagement. It is also essential to avoid overlaps or unintended cross-connections between reused water and potable water systems, which could pose serious health risks.

Step 8 emphasizes the importance of continuous monitoring and adaptive management. Implementing reuse is not a one-time action, but an evolving process that requires ongoing quality control, compliance tracking, and system optimization.

Together, these steps reflect a balanced integration of engineering, policy, environmental protection, and public health. They are consistent with EU guidance on water reuse and can be adapted to a wide range of regional or local contexts.

Water treatment requirements and quality standards

As previously discussed, the fit-for-purpose approach is fully aligned with both European and national regulatory frameworks — most notably, EU Regulation 2020/741 on water reuse. To comply with these frameworks, the reuse of collected water must be subject to appropriate treatment depending on its intended use, ensuring that quality standards are met while safeguarding public health and environmental protection.

Determining the necessary treatment steps is essential, as the suitability of treated water depends directly on its quality, which in turn depends on the treatment processes applied. Treatment requirements must always be defined in accordance with both local conditions and relevant legislation and must be proportionate to the intended reuse application.

Depending on the source and the final use of the water, most reuse systems follow a three-stage treatment structure: primary, secondary, and tertiary treatment. Each stage serves a specific function and contributes to achieving the required water quality [25].

First of all, primary Treatment: This is the first essential step for almost all types of water sources — including rainwater, stormwater, greywater, blackwater, and industrial effluents. Its main purpose is to remove non-biological solids**,** coarse organic matter, and fatty substances that could interfere with later

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processes. Typical primary treatment components include: a) Screens (coarse and fine) for removing large particles, b) Settling tanks for sedimentation of solids, c) Grease traps to remove oils and fats. Additionally, Secondary Treatment: Most alternative water sources contain dissolved or fine organic material that cannot be captured in primary treatment. The secondary stage uses biological processes — such as activated sludge systems, constructed wetlands, or trickling filters — to break down organic compounds. This step can also be configured to target nutrient removal, particularly nitrogen and phosphorus, which are critical for uses such as agricultural irrigation or aquifer recharge where nutrient loads must be controlled. Finally Tertiary Treatment: Tertiary treatment — often referred to as "polishing" — is highly dependent on the specific reuse application, the source water quality, and regulatory thresholds. It provides an additional level of purification, targeting microbial safety, chemical contaminants, and aesthetic quality. Common tertiary processes include a) Filtration (e.g. sand, membrane), b) Disinfection (e.g. chlorination, UV, ozone), c) Deionization or advanced oxidation where applicable.

This tiered approach allows for flexibility in designing treatment trains that are both efficient and tailored to specific reuse scenarios. To better illustrate how different water sources relate to treatment levels and potential end uses, a visual overview has been developed.

The following figure (Figure 5) provides a structured synthesis of the main alternative water sources, the corresponding treatment steps required, and their respective reuse applications. Each connection highlights the minimum treatment level necessary to meet the fit-for-purpose criteria, while ensuring compliance with EU regulations and maintaining operational efficiency.

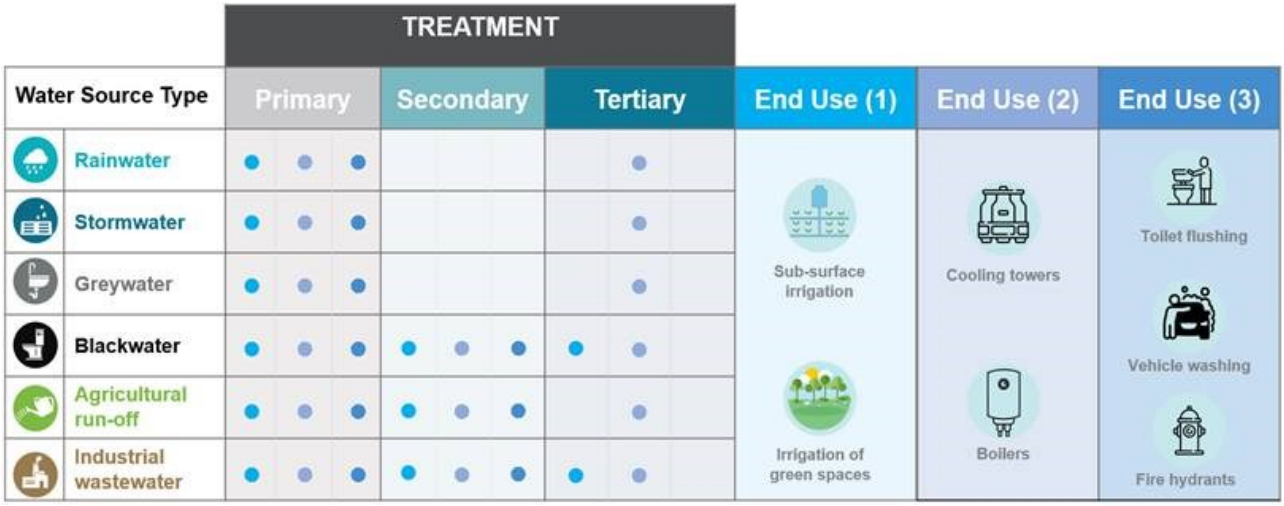


Figure 5 Water treatment processes for differing end uses

As shown in the figure, not all water sources require the same level of treatment to become suitable for reuse. For example, rainwater and stormwater may only need basic filtration and disinfection for uses such as sub-surface irrigation, whereas blackwater and industrial effluent demand more comprehensive treatment, particularly if they are intended for reuse in toilet flushing or boiler systems.

This matrix approach supports decision-makers in evaluating water reuse options based on source availability, treatment feasibility, and end-use suitability, in full alignment with regulatory standards and risk management principles.

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Communicating about water reuse with stakeholders

The successful implementation of water reuse schemes — particularly those based on the fit-for-purpose approach — depend not only on technical feasibility but also on effective stakeholder engagement. Ensuring that stakeholders understand the rationale, regulatory alignment and broader benefits of reuse is essential to building trust and achieving acceptance.

Key communication messages are essential to help stakeholders appreciate that using water of an appropriate quality for each intended use can significantly reduce reliance on potable water sources, resulting in both cost savings and more sustainable resource use. Common concerns often revolve around whether the reuse of wastewater, rainwater, or stormwater is consistent with national and EU regulations. It is therefore important to highlight that the fit-for-purpose model is fully aligned with legal standards such as EU Regulation 2020/741, which defines strict quality and safety criteria tailored to specific reuse applications.

Another key message is that the suitability of reused water is determined by its quality and treatment, not merely by its origin. Properly designed and maintained on-site systems can be as safe and effective as conventional centralised treatment facilities — especially when used at a smaller, decentralized scale. Communicating these facts can reduce resistance, build trust, and increase acceptance.

In addition, highlighting the wider benefits of recycled water — such as securing supply during periods of high demand, alleviating stress on existing infrastructure, and supporting climate resilience — can further reinforce the value of water reuse to various interest groups.

Stakeholder mapping is crucial step, distinguishing between internal and external actors [19]. Internal stakeholders are those with a direct interest in the system itself — such as building owners, farm operators, industrial facility managers, and onsite system designers or contractors. For these actors, communication should focus on cost-effectiveness, regulatory compliance, operational simplicity, and in some cases, brand reputation and innovation leadership. Occupants and end-users must be informed about the ease of use, safety, and tangible benefits, while facility managers seek reliability, low-maintenance and efficiency.

External stakeholders include regulatory authorities, who need to be confident that water reuse protects public health and environmental quality, supports resource conservation, and complies with legal codes. Water utilities may see water reuse as a way to relieve demand on supply networks and increase system resilience, while financial institutions or investors are interested in risk mitigation, long-term asset value and with sustainability goals (ESG).

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Internal Stakeholders		
	Developer/Owner	• Cost efficiency • Regulatory compliance • Brand enhancement
	Design Team	• Positive industry reputation • New expertise
	Occupants	• Ease of use • Control over rate increases
	Facility Manager	• Seamless, cost effective, reliable operations
External Stakeholders		
	Regulators	• Protect public health and water quality • Conserve scarce resource • Enforce code compliance
	Unilities	• Guarantee water supply • Maintain revenue
	Financial Institutions	• Avoid risk • Maintain long-term value of investment

Figure 6 Stakeholder Roles and Interests in Fit-for-Purpose Water Reuse

Ultimately, the success of a fit-for-purpose water reuse system depends on early, transparent, and tailored communication with all relevant stakeholders. By proactively addressing specific concerns and clearly demonstrating both individual benefits (e.g., cost savings, operational reliability) and collective gains (e.g., resource conservation, resilience, environmental protection), trust can be built and cooperation fostered. This inclusive approach ensures that water reuse systems are not only technically viable but also socially accepted, enabling their effective and sustainable implementation.

3.3 Data sources and collection methods

This study relied on a broad set of data sources, combining operational datasets, strategic planning records and official statistics to ensure both accuracy and contextual depth. The primary dataset was provided by the Athens Water Supply and Sewerage Company (EYDAP), covering water consumption across all consumer categories in Attica region. Raw data extracted from EYDAP's databases were preprocessed (Section 3.3.1) into disaggregated monthly time series, enabling a detailed analysis of both spatial and temporal consumption patterns.

In addition, EYDAP supplied export values from its water treatment plants, which represent the total volume of water entering the distribution system from all available sources. These data, provided in monthly time steps, was utilized for supporting the methodological disaggregation of consumption values as it is presented in Section 3.3.1.

To complement operational data, supplementary information and relevant data were obtained from official government documents and reports, which study and assess the existing water sector characteristics and guide the long-term strategic objectives in water resources management. Two key references were particularly important:

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1. **River Basin Management Plans (RBMP) – 2nd revision (Greek: Σχέδια Διαχείρισης Λεκανών Απορροής):**
   These plans are the cornerstone of integrated water management in Greece, focusing on achieving good water quality and preventing further deterioration of water bodies, developed in accordance with the requirements of the EU Water Framework Directive (2000/60/EC) and are updated every six years. The RBMP for the Attica Water District was used extensively for understanding regional water demand, supply availability, and regulatory targets. Beyond its primary content, the RBMP served as a rich repository of historical data, bibliographical references and links to external studies on water quantity and quality as well as management practices, relevant frameworks and methodologies. A more detailed discussion of the RBMP contribution is provided in Section 3.3.2.

2. **Regional Climate Change Adaptation Plan for Attica (Greek: Περιφερειακό Σχέδιο Προσαρμογής στην Κλιματική Αλλαγή – ΠεΣΠΚΑ):**

   The Regional Climate Adaptation Plans are strategic policy documents developed in accordance with the Greek Law 4414/2016, aiming to assess regional vulnerabilities to climate change, identify critical sectors at risk, and propose efficient short/mid and long-term adaptation measures for each sector. The Attica Plan outlines expected climate impacts on natural resources, infrastructure, and population, with water resources being a central focus. In this study, Regional Climate Change Adaptation Attica Plan, such as the RBMP, were used to document useful present information about water resources and management, as well as identify climate-related pressures on water supply. It also includes references to sector-specific studies, datasets, and national guidelines that were examined, studied and incorporated. The role of this Plan in shaping the present methodological approach is described in Section 3.3.3.

Lastly, a variety of peer-reviewed research articles, technical reports, and official statistics from the Hellenic Statistical Authority (ELSTAT) were obtained and enhanced our knowledge and documentation for Attica water resources. ELSTAT data provided essential demographic and spatial indicators in different sectors — for example, population distribution and tourism activity — that were directly relevant to water demand analysis. Further details about these sources are provided in Section 3.3.3.

3.3.1 EYDAP data collection and preprocessing

3.3.1.1 Billed consumption data

The billed consumption dataset provided by EYDAP S.A., consists of 12 plain-text files (txt) each of which contains approximately 220.000 water meters, covering the period 04/2010-09/2024. Therefore, full-year consumption is recorded for the years 2011-2023. In total, the dataset in all 12 files includes approximately 2,120,000 hydrometers. The raw files are structured as irregular time series, with records typically collected on bimonthly or quarterly basis, depending on the individual meter reading schedule. An illustrative subset of the raw file structure is shown in Table 6 for a small subset of data.

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Table 6 Structure of raw consumption data provided by EYDAP

Year	ID	Type	Municipality	From	To	Volume (m^3)
2024	6	B1	ATHENS	30/06/2024	01/10/2024	10
2024	6	B1	ATHENS	02/04/2024	29/06/2024	13

The indicators (columns) referred to in the consumption files are listed in the Table 7, with their descriptions. In total, more than 120 municipalities are listed in EYDAP data.

Table 7 Description of each indicator from raw consumption data

Indicator	Description
Year	Year of measurement
ID	Consumer unique ID number
Type	Type of consumer
Municipality	Consumer's location
From	Date from which measurement started
To	Date from which measurement ended
Volume (m^3)	Total volume of water consumed between 'From' and 'End' dates

The different 'Type' uses are marked with different letters. In total, 42 distinct categories of water use are labeled with a specific type of code. Examples are presented in the Table 8.

Table 8 Examples of different 'Types' of consumers, with their unique identifier

Type	Identifier
E	Professional
K2	Urban green

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B1	General type (usually households)
D	Municipal

3.3.1.2 Water outputs data from the Water Treatment Plants

Monthly output data from the four main treatment plants — Galatsi WTP, Acharnes WTP, Polydendri WTP, and Aspropyrgos WTP — were provided in Excel format, covering the period 2010 – 2024. These data represent the total inflows entering EYDAP's distribution network from all available sources.

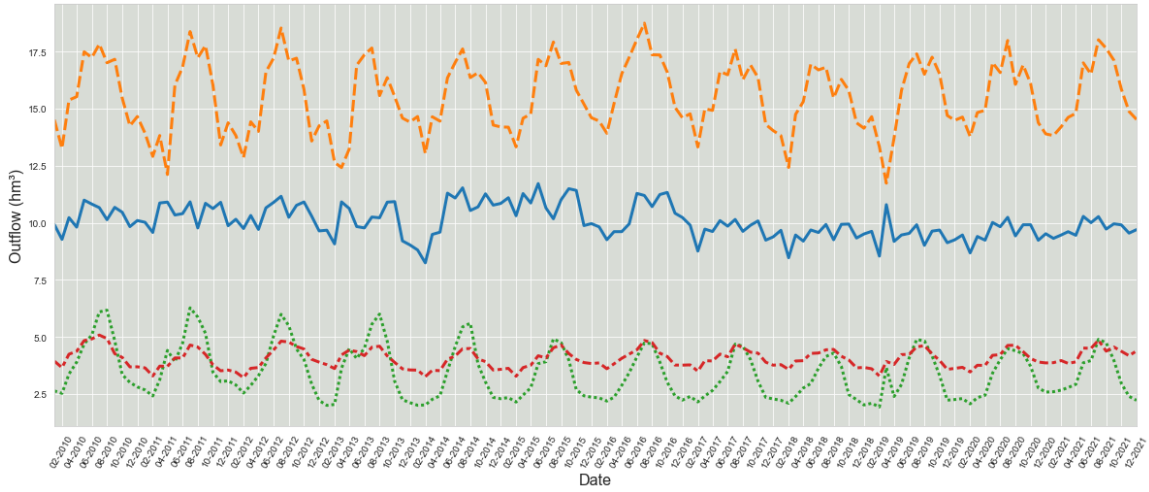


Figure 7 Attica WTP outflow time series in monthly step. Galatsi WTP, Acharnes WTP, Polydendri WTP, and Aspropyrgos WTP are visualized with blue, yellow, green and red lines respectively

3.3.1.3 Focus on Urban Green Consumption

Urban green water consumption was identified through the type identifier 'K2' in EYDAP's billing consumption records. No other institutional, open-source or official datasets/reports/plans provided information specific to water use in green spaces (parks, public lawns, landscaped areas).

The dataset contains both spatial information—in the form of the municipality where each consumption record is located—and temporal coverage, as each record covers a defined period between two measurement dates. This dual resolution enables disaggregated analysis of urban green water demand across time and space.

This data is further utilized and analysed in Section 4.5, which presents the estimation of water needs for urban green areas.

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3.3.1.4 Focus on industrial consumption

Industrial water use was studies through billed consumption data provided by EYDAP, categorized under tariff type 'E'. This tariff type is labelled as "professional", encompassing a wide spectrum of non-residential users. While it does not exclusively represent industrial consumers—since it also includes businesses such as restaurants, retail stores, and service providers, it does capture a substantial portion of industrial activity within the region. Given that industrial users are embedded within this category, the 'E' tariff data can be reasonably used to infer general seasonal and consumption patterns for industrial demand, but not to estimate absolute volumes of industrial use, due to the mixed nature of the category. This limitation for tariff type 'E' billed consumers is acknowledged as a constraint of the dataset.

A notable exception is Hellenic Petroleum (ELPE), which is billed under a separate tariff category, labelled as 'EP', which is specifically designated for Oil Industry. or ELPE, a complete and continuous billed consumption record was available for **2010–2024**, enabling a detailed time-series analysis independent of the broader "E" category.

3.3.2 Data collection from National River Basin Management Plans (RBMPs)

The River Basin Management Plans (RBMPs) are central instruments for both EU compliance and national water resource management. Developed under the **EU Water Framework Directive (2000/60/EC)**, they provide assessments of water status, define environmental objectives, establish monitoring frameworks, and outline programs of measures.

For this study, the RBMP for the Attica Water District was used as a primary source for analysis of anthropogenic pressures, estimating sectoral water demands (supply, irrigation, livestock and industrial use) and identifying regulatory targets.

The methodology used in each sector is described briefly below.

3.3.2.1 Methodological framework for estimating irrigation demands

According to RBMP's issue related to human-made pressures on waterbodies, the first step before estimating the demands is data collection. Specifically for irrigation, the RBMPs derive geospatial and statistical and hydrological datasets from a variety of sources:

- Payment and Control Agency for Guidance and Guarantee Community Aid (OPEKEPE): offers geospatial data of declared crops (for the year 2020)
- Hellenic Statistical Authority (ELSTAT) provides statistical data for undeclared crops.
- National Register of Water Intake points (EMSY): significant data for groundwater systems
- Water Services Monitoring and Oversight Mechanism: data on groundwater abstraction.

Supplementary information is found in the first revision of the river basin management plan, the ministerial decision 120.344/11-2-92 "*Modernization of the methodology for calculating water needs used in the agricultural engineering studies of land reclamation projects and adaptation to Greek conditions*", Circular of the Ministry of Agriculture AP 144380/22-1-1990 on the provision of instructions and clarifications

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concerning the preparation and control of agro-economic/ agro-technical studies of land reclamation projects, climatic data from certified meteorological stations and other sources such as personal communication, and previous experience.

The methodology followed captures the pressure asked due to irrigation demands of the reference year 2020, as irrigation does not exert a constant pressure on water bodies but is highly dependable on the year's rainfall levels. Utilizing OPEKEPE's crop code, area and waterflag (CROPCODE, Shape_Area, WATERFLAG), the process is divided according to whether the consumption takes place outside or inside the collective networks.

For private intakes (outside collective networks), one of the Blaney-Griddle empirical, Penman modified, Blaney-Griddle modified methods is used in addition to representative climate data, as defined in the relevant circulars of the Ministry of Rural Development and Food.

For the collective networks, consumption is estimated using approved quantities, operator inventories, and earlier calculations. In regions with limited OPEKEPE coverage, **ELSTAT data** are used as supplementary input. Final results are reported by **water body type (surface water or groundwater)**, capturing irrigation as a variable, climate-dependent pressure rather than a static demand.

3.3.2.2 Methodological framework for estimating livestock water demands

To estimate water demands from livestock farming, data on the type and number of animals were collected primarily from OPEKEPE and the Department of Agricultural Economy and Veterinary of the Regional Unit of Attica. For undeclared farms, complementary data were obtained from ELSTAT. Additional inputs were derived from the first revision of the RBMP, personal communications and expert judgement.

Utilizing the abovementioned datasets, as well as considering feeding practices and environmental conditions, the daily water supply needs per species were determined. Values were cross-checked with estimates from the first RBMP revision and supported by a literature review.

Where appropriate, water needs for cleaning purposes and distribution network losses were incorporated into the total demand calculations.

Table 9 Daily water needs per livestock species

Animal species	Weight per species (kg per capita)	Daily needs in dry food (% AW)	Daily needs in dry food (kg per capita/day)	Water needs (Lt/ kg of dry food/day)	Daily water needs (Lt per capita/day)
Labour animals	a = 454	1,3%	a*0.013	3.5	a*0.013*3.5
Cattle	b = 475	1,3%	b*0.013	4.5	b*0.013*4.5

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3.3.2.3 Methodological framework for estimating industrial water demands

For the industrial sector, data were primarily sourced from Water Services Monitoring and Oversight Mechanism. In cases where such data were not available, supplementary information was collected through municipal contacts. The first revision of RBMP as well as the expert judgement were also beneficial. Other sources of information for industrial water demands were drawn from the Department of Oil at the Horticultural Products and Utilization of the Ministry of Rural Development and Food, the National Authority for Geological and Mining Research (EAGME) and the National Register of Water Intake points (EMSY).

Using these inputs, the RBMPs identified the concentrated and large industrial consumers with independent water supplies and adhere to Ministries of Development and Investments guidelines for estimation of water needs. For industrial units lacking direct consumption data, water needs were estimated by correlating production capacity with comparable facilities within the same industrial sector. Water demands were calculated per municipality and added to water supply needs when served by the same network. In the opposite case, for industries served by independent intakes, **annual discharges** were estimated by considering both **network losses** and **deficits**, using the following relation:

$$Discharge = needs \cdot \frac{1 - deficit}{1 - losses} \quad (1)$$

3.3.3 Data collection from other sources

To complement the above datasets, additional sources were utilized to capture sectoral water demand, particularly for the tourism sector. Tourism water consumption was assessed by integrating data from multiple governmental and public sources, including:

- Hellenic Statistical Authority (ELSTAT)

- Overnight stays in hotel-type accommodation and campsites (by Regional Unit). This data provides insights into the spatial distribution and volume of tourism activity.
- Latest available tourism statistics (arrivals, overnight stays, hotel occupancy rates) – 2023 as the most recent year.
- Overnight stays at campsites (by Regional Unit, 2023): dataset specifically focused on camping activity.

- Hotel Chamber of Greece

- The registry available at grhotels.gr was utilized to retrieve the complete list of hotel and camping facilities across the country. This included detailed information at the municipal level such as the number of beds, star classification, and operational features.

- Institute of the Greek Tourism Confederation (INSETE):

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- Tourism statistics from insete.gr/perifereies were used to complement regional-level data. These include time series (2010–2021) of key tourism indicators such as arrivals, overnight stays, and occupancy rates for hotel accommodations, broken down by Regional Unit.

To ensure data reliability and completeness, data from these sources were systematically cross-referenced wherever overlapping indicators existed. Where data discrepancies or gaps occurred, supplementary information from alternative datasets was used to fill missing values.

3.4 Data Analysis and Methodology

3.4.1 Billed consumption disaggregation to monthly step methodology

The raw consumption data provided by EYDAP was not directly suitable for the application of statistical methods or advanced analyses. As previously noted, the dataset was based on irregular measurement intervals, which hindered systematic processing and analysis. To overcome this limitation and enable systematic analysis for extracting meaningful insights, the dataset was pre-processed to generate time series with a consistent monthly resolution for all consumption records.

This pre-processing step ensured the creation of homogeneous time series with a consistent monthly resolution, thereby facilitating the application of further methodologies (e.g., demand pattern detection, seasonal analysis, and forecasting).

The pre-processing methodology is outlined below as an algorithm implemented through an iterative (loop-based) procedure, applied individually to each of the ~2,120,000 consumption entries provided by the company. Two weighting factors—monthly and seasonal—were defined to guide the temporal allocation of consumption between measurement dates. These factors were computed separately for each time series and for every time step within it. In total, ~118,000,000 entries were disaggregated into monthly step and summed respectively to the corresponding month of measurement.

The disaggregation algorithmic procedure is presented below:

Algorithm: Disaggregation Method for Converting Time Series to Monthly Time Steps
Input Data: .txt files containing raw consumption records Seasonal weighting coefficient table based on water outputs from the treatment plants (WTPs)*
Output Data: .csv files containing disaggregates time series with monthly resolution
For each of the ~2,120,00 consumption records (*indexed by i)*: For each measurement (*indexed by k)* from the first to the last reading of record *i*: Identify*:* Start Date *('From'),* Last day *('To'),* volume *('Volume')* Compute: Duration (D) = *'From' – 'To' (in days)* Disaggregate duration D into number of days per month within D. Let array $MM = days\ per\ month\ in\ D$

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Monthly distribution weights: $w_1 = [MM/D]$

$$w_1 = [MM/D]$$

Seasonal adjustment weights (from WTP coefficient table):

$$w_2 = \frac{(coeff.of\ each\ month\ \in\ D)}{sum\ of\ all\ such\ coefficients}$$

Compute normalized allocation weight for each month: $w = w_{1,j} * w_{2,j}$, where j the number of months inner duration time D

Allocate volume to month $j\ Vi, j\ += Volume * w_{1,j} * w_{2,j}/w$

** The procedure for calculating the seasonal coefficients is described in Section 3.4.2*

*** The normalization factor is applied to adjust the results such that the total monthly volume allocation matches the originally reported volume for each respective measurement period.*

The monthly weighting factor (w_1) was defined under the initial assumption that consumption is evenly distributed across the total number of days of the measurement period (D). In contrast, the seasonal weighting factor (w_2) adjusts this assumption by assigning different weights to each month, taking seasonal variation into account. The final allocation weight for each month is the product of these two factors. The seasonal coefficients were derived from the outflow records of the Attica Water Treatment Plants (WTPs), and the methodology for their calculation is described in Section 3.4.2. A schematic representation of the method is provided in Figure 8, illustrating the disaggregation of an example recording measurement with a recorded consumption of 10 m³ over a 98-day period.

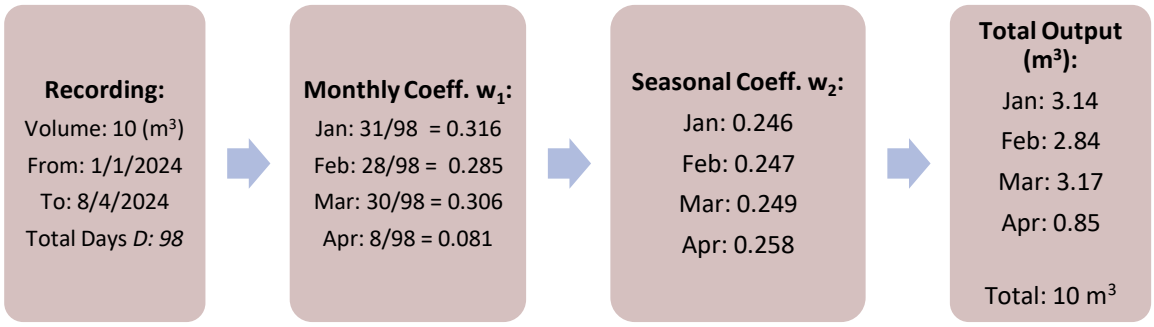


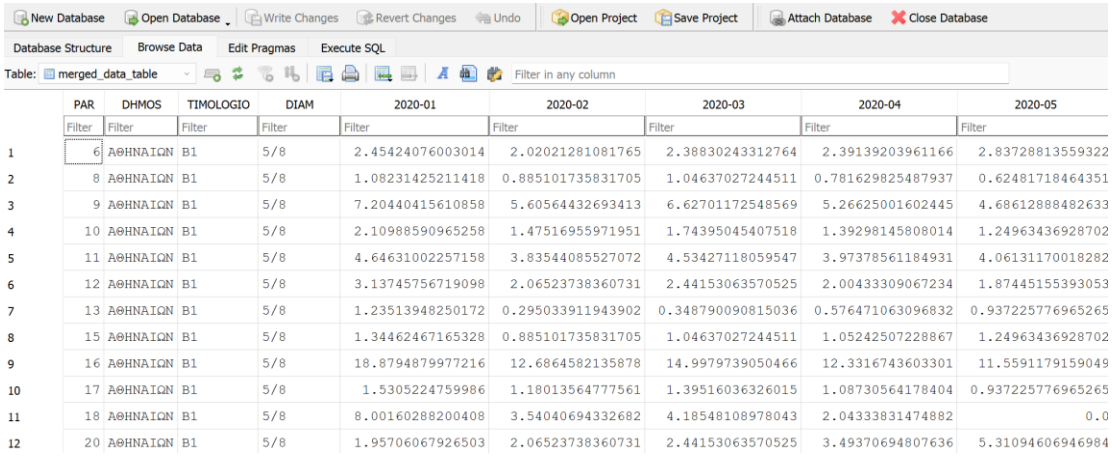
Figure 8: Example demonstration of disaggregation methodology for one example measurement recording of 10 m3 volume and total duration of 98 days. In the right (last box) are presented the disaggregated values of each month.

The abovementioned methodological data preprocessing was implemented using Python 3.12. The execution time of the full algorithm totalled approximately 11 hours, using a computer with a 4.00 GHz processor. The output, consisting of the final disaggregated time series tables, was initially saved in .csv format and subsequently integrated into a unified SQL database to ensure optimized access, efficient querying, and structured data management.

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The original .txt files provided by EYDAP were not reused; all subsequent processing was performed using the curated and structured data stored in the SQL database (Figure 9).



New Database | Open Database | Write Changes | Revert Changes | Undo | Open Project | Save Project | Attach Database | Close Database

Database Structure | Browse Data | Edit Pragmas | Execute SQL

Table: merged_data_table | Filter in any column

	PAR	DHMOS	TIMOLOGIO	DIAM	2020-01	2020-02	2020-03	2020-04	2020-05
	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter
1	6	ΑΘΗΝΑΙΩΝ	B1	5/8	2.45424076003014	2.02021281081765	2.38830243312764	2.39139203961166	2.83728813559322
2	8	ΑΘΗΝΑΙΩΝ	B1	5/8	1.08231425211418	0.885101735831705	1.04637027244511	0.781629825487937	0.62481718464351
3	9	ΑΘΗΝΑΙΩΝ	B1	5/8	7.20440415610858	5.60564432693413	6.62701172548569	5.26625001602445	4.68612888482633
4	10	ΑΘΗΝΑΙΩΝ	B1	5/8	2.10988590965258	1.47516955971951	1.74395045407518	1.39298145808014	1.24963436928702
5	11	ΑΘΗΝΑΙΩΝ	B1	5/8	4.64631002257158	3.83544085527072	4.53427118059547	3.97378561184931	4.06131170018282
6	12	ΑΘΗΝΑΙΩΝ	B1	5/8	3.13745756719098	2.06523738360731	2.44153063570525	2.00433309067234	1.87445155393053
7	13	ΑΘΗΝΑΙΩΝ	B1	5/8	1.23513948250172	0.295033911943902	0.348790090815036	0.576471063096832	0.937225776965265
8	15	ΑΘΗΝΑΙΩΝ	B1	5/8	1.34462467165328	0.885101735831705	1.04637027244511	1.05242507228867	1.24963436928702
9	16	ΑΘΗΝΑΙΩΝ	B1	5/8	18.8794879977216	12.6864582135878	14.9979739050466	12.3316743603301	11.5591179159049
10	17	ΑΘΗΝΑΙΩΝ	B1	5/8	1.5305224759986	1.18013564777561	1.39516036326015	1.08730564178404	0.937225776965265
11	18	ΑΘΗΝΑΙΩΝ	B1	5/8	8.00160288200408	3.54040694332682	4.18548108978043	2.04333831474882	0.0
12	20	ΑΘΗΝΑΙΩΝ	B1	5/8	1.95706067926503	2.06523738360731	2.44153063570525	3.49370694807636	5.31094606946984

Figure 9: Snapshot of the generated SQL database of disaggregated water consumption time series

3.4.2 Extraction of Seasonal Coefficients from WTP Data

The extraction of seasonal coefficients was necessary for the disaggregation of billed consumption data into monthly time series (see Section 3.3.1). The seasonal coefficients serve as adjustment factors to allow for a more representative monthly allocation of water volumes derived from billing records with durations longer than one month. The value of incorporating seasonal coefficients aligns with the observation made by Billings and Jones [26], namely that water consumption exhibits strong seasonality—typically rising during summer months and declining during winter.

For this study, seasonal coefficients were derived from 15 years of water outflow data (2010–2024) from the Attica Water Treatment Plants (WTPs), provided by EYDAP. To derive the coefficients, the monthly seasonal coefficient value for each year was calculated by dividing the monthly water outflow volume by the total annual volume provided by all WTPs in that year. Specifically, for each year $y \in \{2010,2024\}$ and each month $m \in \{1,12\}$, the monthly seasonal coefficient is calculated as:

$$SC_{m,y} = \frac{V_{m,y}}{\sum_{m'=1}^{12} V_{m',y}} \quad (2)$$

where:

$SC_{m,y}$ is the seasonal coefficient for month *m* in year *y*, and

$V_{m,y}$ is the outflow volume from all WTPs for month *m* in year *y*.

The final seasonal coefficient for each month was obtained by averaging the corresponding values over the eleven-year period as:

$$SC_m = \frac{1}{12} \sum_{y=2010}^{2024} SC_{m,y} \quad (3)$$

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The results are presented both graphically and in tabular form in Figure 10. The figure also includes 5th and 95th percentiles as confidence intervals over the 15-year period, along with reference seasonal coefficients from the literature [26]. The Jones coefficients were derived from water consumption data in the province of Alberta, Canada, for the decade 1980–1989 and are shown for comparison purposes only.

The analysis reveals that July consistently records the highest water consumption in the system, accounting on average for 9.64% of the annual water volume in the EYDAP network, while February exhibits the lowest consumption, corresponding to 7.08% of the annual volume.

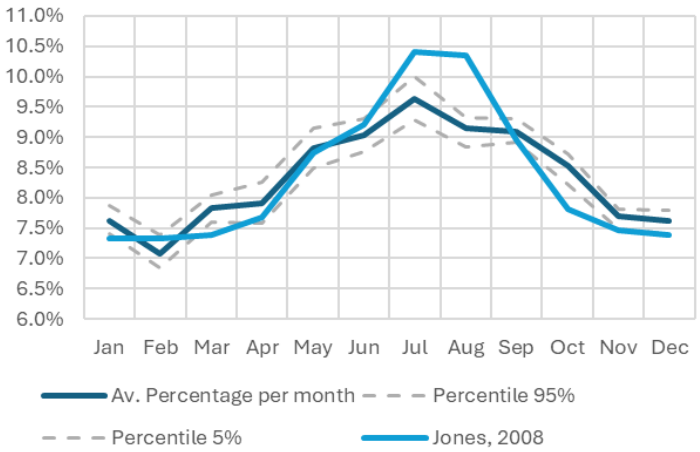


Figure 10: Weighting seasonal coefficients based on WTP Attica data

These estimates also consider the number of days in each month. When examining daily consumption rates, it is found that January has the lowest average daily consumption, with $7.61\%/31 < 7.08\%/28$, even lower than February's. This analysis highlights the variation in monthly consumption. For example, the maximum seasonal deviation—between July and February—amounts to approximately 36%, calculated as the ratio 0.964 / 0.708.

3.4.3 Time series decomposition (trend and seasonality)

This section outlines the methodology applied to extract seasonal patterns from EYDAP's water consumption data, focusing on cases where decomposition was required to isolate and interpret the seasonal component of the time series. The analysis was performed on various regionally or sectorally aggregated time series, to capture the seasonal profile of different water uses (See Chapter 2). Here is a theoretical overview of the decomposition approach employed, the mathematical formulation, and the steps followed to separate the trend, seasonality, and residual components of the time series.

Time series decomposition is a statistical technique that separates a time series into three main components: trend, seasonality, and residual (or noise). In this study, an additive model was applied, which is mathematically expressed as:

$$Y_t = T_t + S_t + e_t, \tag{4}$$

where:

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- Y_t = observed value of the time series at time t.
- T_t = trend component (long-term increases or decreases representing slow changes in the mean overtime)
- S_t = seasonal component (systematic short-term, regular patterns that repeat over specific periods (e.g., monthly or quarterly), often related to the natural seasonal cycle of the year)
- e_t = residual or random noise (represents the random variation remaining after removing the trend and seasonality).

Several methods for time series decomposition are discussed in the literature. The methodology adopted in this study is known as the classical decomposition approach. It begins with the estimation of the trend component by applying a convolution filter, as described in Zhao and Wei (2003) [27]. Filtering a time series refers to the process of removing a range of frequencies, retaining only those of interest to isolate the trend. Specifically, a moving average is often used to smooth the series and extract the slow-moving trend. To estimate the seasonal component, the average value for each month is calculated after removing the trend from the original series. The monthly values are then centered to ensure that their sum across a full seasonal cycle is zero:

$$\sum_{m=1}^{12} S_m = 0 \tag{5}$$

where S_m is the seasonal component for month m.

The decomposition process was achieved using Python and the Statsmodels library, which provides a standard implementation of the classical decomposition framework.

3.5 Survey and interview design

A comprehensive analysis of regional water demand by use is essential for the accurate allocation of resources, targeted infrastructure planning, and the development of circular water reuse schemes, in line with European legislation on “fit-for-purpose” water use. The absence of such a framework risks undermining the effectiveness and sustainability of investments, as well as the long-term availability of water resources.

In the Attica region, EYDAP has already conducted a pilot analysis in Eastern Attica, including a detailed mapping of relevant stakeholders and their specific needs. Within the framework of the “THESEUS” project—and specifically under Task 7.1—this approach is now being expanded to cover the entire region of Attica.

The primary objective of this initiative is to develop an enhanced water demand management framework across the region, with the ultimate goal of reducing overall water flows across all user categories. This integrated analysis focuses exclusively on non-domestic water uses. However, its implementation is confronted with several challenges, including significant data gaps on non-domestic consumption, lack of

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adequate monitoring stations, and the presence of off-network water abstractions, all of which hinder reliable estimation of both water volume and quality.

To address these challenges, targeted primary data collection was employed, using structured questionnaires and interviews with representatives from the industrial sector, academic institutions, local authorities, and social stakeholders across Attica. This process also aimed to strengthen cooperation among stakeholders.

Following the early identification of the problem and the analytical documentation of the associated barriers, the development of structured questionnaires was deemed an appropriate strategy to obtain quantitative data and extract qualitative insights. This dual approach ensures an analysis that is both comprehensive and operationally relevant to managing Attica's water needs, as illustrated in Figure 11.

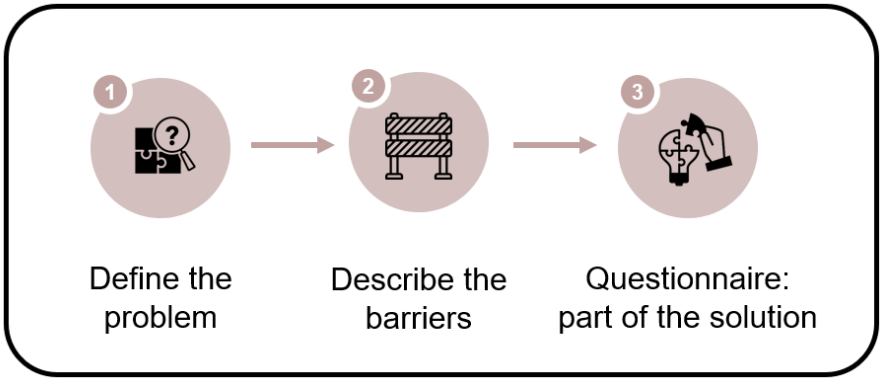


Figure 11 Three-step approach for identifying water management challenges and collecting data through questionnaires

The methodology behind the development of the THESEUS questionnaire for assessing water needs by use in Attica followed a structured, goal-oriented approach. Its central aim was to collect quantitative data, knowledge, and practical experience from key non-domestic water users in the region. The analysis assesses water requirements for each use category, and importantly, the qualitative dimension of water was also incorporated—so that calculated volumes of demand can be linked to fit-for-purpose uses. This ensures alignment with European and national legislation on water reuse and sustainable management.

To guarantee the completeness of this analysis, the questionnaire was distributed to a broad range of stakeholders, including the Attica Region, municipal authorities, industrial enterprises, representatives of the agricultural sector and actors in the tourism sector. This wide distribution enabled a thorough mapping of non-domestic water use needs and challenges (Figure 12). To ensure the accuracy and richness of the responses, the questionnaire included both open-ended and closed-ended formats such as multiple-choice questions, short answers, ranking questions, drop-down lists, and extended free-text responses. This structure allowed for detailed quantitative assessment as well as an in-depth qualitative understanding of water use across sectors.

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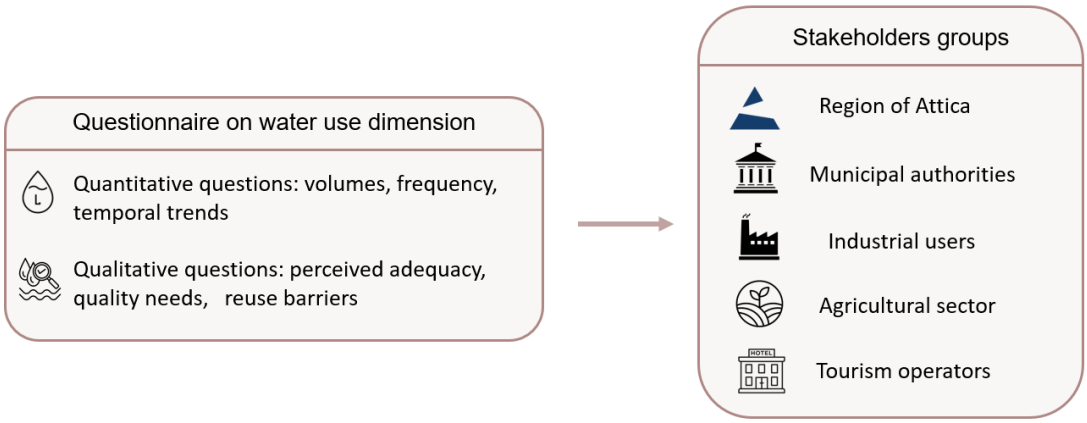


Figure 12 Structure of the THESEUS questionnaire and targeted stakeholder groups for assessing non-domestic water use needs in the Region of Attica.

The questionnaire was developed using **Google Forms**, a user-friendly online platform widely used for surveys and data collection. It was designed in Greek, ensuring accessibility and clarity for all participants—particularly those representing local or regional authorities, businesses, and local stakeholder groups. Access to the questionnaire is available at the following link: Theseus Questionnaire Task 7.1

Which of the following categories do you belong to?
○ Attica Region
○ Municipality
○ Industry
○ Agricultural Sector
○ Tourism Sector

Table 10 Non-domestic water use stakeholder groups in the Region of Attica

Depending on the selected category, respondents were directed to the respective sections of the questionnaire. However, all respondents were required to answer a common core of questions, structured as follows (Table 11):

Table 11 Sections of the THESEUS questionnaire

Section A: Quantitative data on water demand
Section B: Qualitative data on water demand

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Each category received nearly identical questions, with only minor variations to reflect specific sectoral characteristics.

Section A: Quantitative Data on Water Demand

Table 12 Overview of quantitative questions on water demand per sector

No.	Question	Question Type	Options / Scale
	Horizontal questions		
1	How is water use percentage-wise distributed?	Percentage per use	Water Supply, Irrigation, Livestock, Industry, Other Uses
2	What is the monthly volume of water required for irrigating green spaces?	Open-ended	—
3	What is the water demand for other uses (e.g., tourism)?	Open-ended	—
4	What are the projected trends in water demand by use (in your sector)?	Scale 1–5	Uses adapted per sector (e.g., irrigation, production, cooling)
5	Which adaptation measures are most important for addressing water sufficiency (in your sector)?	Scale 1–5	Measures adapted per sector (e.g., reuse, infrastructure, training)
6	What is the seasonal variation in water demand by use?	Open-ended	Uses vary per respondent
7	Which factors affect water demand the most (in your sector)?	Scale 1–5	1 = Decrease significantly … 5 = Increase significantly
	Sector specific question		
8	What is the water volume required for irrigating agricultural areas?	Open-ended	—
9	What is the water volume required for industrial needs?	Open-ended	—

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Section B: Qualitative Data on Water Demand

Table 13 Overview of qualitative questions on water demand per sector

No.	Question	Question Type	Options / Scale
1	What are the sources of water you use?	Multiple choice	Network, Borehole, Rainwater, Recycled
2	For what purposes do you use the sources you listed?	Open-ended	—
3	Have you observed water quality issues in the sources used?	Dual: YES/NO + Open-ended	If YES: Specify source and type of issue
4	Have you implemented measures to improve water quality?	Dual: YES/NO + Open-ended	If YES: Specify source and measures
5	Do you observe seasonal variations in water quality?	Dual: YES/NO + Open-ended	If YES: Specify source and variations
6	How do you assess water quality based on specific criteria?	Scale 1–5	Criteria: Hardness, Odor/Taste, Clarity, Temperature
7	How do you ensure water meets required quality standards?	Open-ended	—
8	Do you perform tests for micropollutants/microplastics?	Dual: YES/NO + Open-ended	If YES: Specify source and frequency
9	Is the water quality of each source: a) appropriate or b) higher than required?	Choice between A or B + Open-ended	If B: Have you taken or plan to take measures? Which ones?
10	Is there a Wastewater Treatment Plant (WWTP) within your area of jurisdiction?	Dual: YES/NO + Open-ended	If Yes is the reclaimed water used for any purpose? Specify the use
			If NO, what is the main reason why the reclaimed water is not being utilized? Do you believe it could be used in the future? If yes, for which purpose(s)?

Given the complexity and time-consuming nature of survey-based data collection—particularly when it requires ongoing follow-up with stakeholders—the response rate at this stage is not expected to be

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extensive. Nevertheless, the insights obtained through this process provide direct input into the Master Plan, complementing the quantitative analysis of regional water demand. Thus, even partial or incomplete responses contribute valuable information, offering a broader and more representative understanding of non-domestic water needs in Attica.

3.6 Limitations of data

When evaluating the available data and methodological framework, several key limitations must be acknowledged.

- Restricted temporal scope of RBMPs. River Basin Management Plans (RBMPs) generally do not include detailed historical time series but instead refer to specific reference years. This restricts the ability to detect long-term trends or conduct comparative analyses.
- Insufficient geographic resolution. The lack of detailed spatial data hinders regional and sub-regional assessments of water use, limiting the accuracy of geographically targeted planning and interventions.
- **Groundwater data gaps.** Information on groundwater systems is incomplete. In particular, there is inadequate reporting on private boreholes and drillings, which represent a significant but poorly monitored share of water abstraction.

These limitations highlight the importance of combining secondary data sources (e.g., RBMPs, WTP outflows) with primary data collection (surveys, interviews), so as to develop a more accurate and operationally useful picture of water demand and availability in the Attica region.

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4. Water Demand Analysis

4.1 Agriculture

This section presents the analysis of water demand in the agricultural sector. Data on agricultural water needs were mainly derived from the River Basin Management Plans (RBMPs) (See Section 3.3.2). In Attica, irrigation requirements are typically met through surface or groundwater sources, with the latter being predominant. The following subsections summarize the main findings regarding agricultural water consumption, along with its spatial and temporal distribution.

4.1.1 Water consumption

In the Attica region, irrigation water demand is met exclusively by groundwater abstractions. For the reference year 2020, total agricultural withdrawals were estimated at ~65 hm³, of which more than 99% originated from private drillings. This figure highlights the sector's heavy dependence on non-monitored, off-network groundwater resources, raising questions about both the sustainability and regulation of agricultural abstractions in the region.

4.1.2 Spatial and temporal variability

Agricultural water withdrawals were calculated per Groundwater System (GWS) with results presented in Table 14. The corresponding map in Figure 13 illustrates the spatial distribution of irrigation demand across Attica. Among the GWSs, the Megara – Alepochori aquifer system accounts for the largest abstraction volumes, reflecting the extensive agricultural land use in that area.

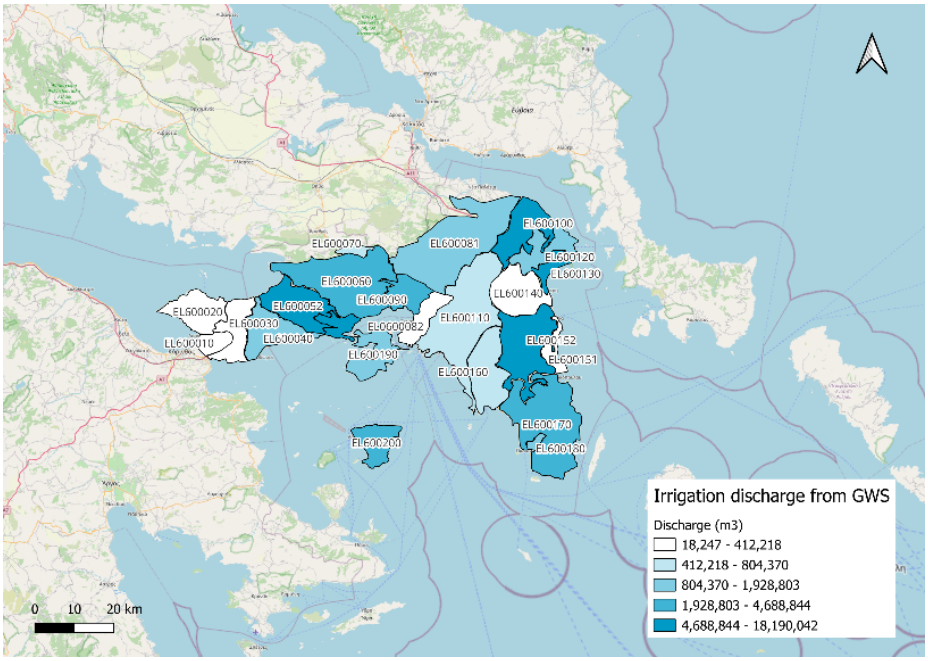


Figure 13: Irrigation discharges from GWS across Attica (Source: Attica's RBMP)

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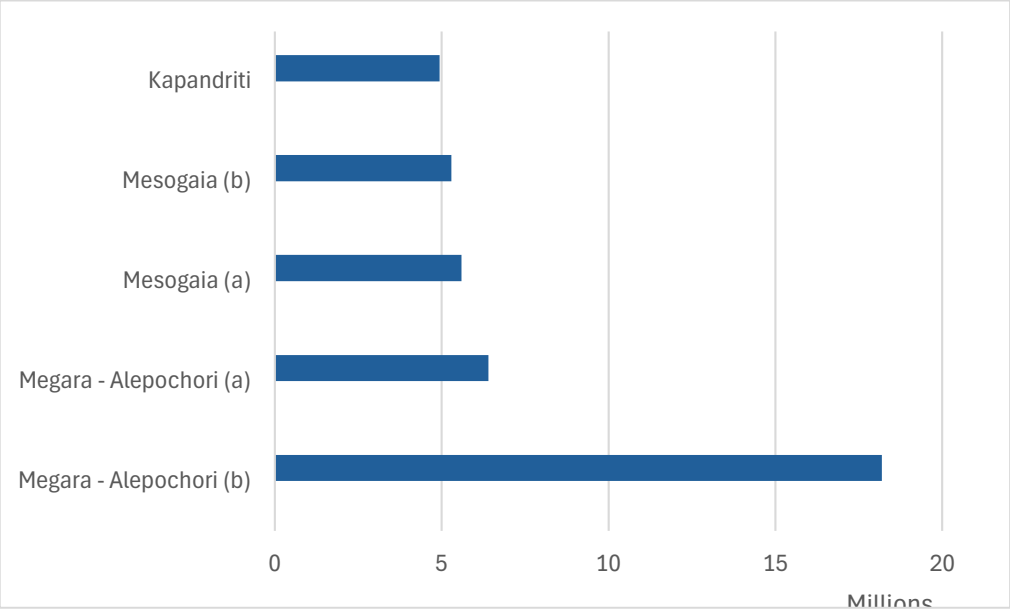


Figure 14: Top five withdrawals from GWS (Source: Irrigation discharges data from RBMP)

Table 14: Top 10 discharges for irrigation purposes (Source: Attica's RBMP)

GWS Name	GWS Code	Discharges (m^3)
Megara - Alepochori (b)	EL0600052	18,190,041
Megara - Alepochori (a)	EL0600051	6,399,207
Mesogaia (b)	EL0600152	5,597,003
Marathonas (b)	EL0600130	5,290,765
Kapandriti	EL0600100	4,933,869
Aigina	EL0600200	4,321,305
Lavreotiki	EL0600170 (private)	3,710,297
Patera	EL0600060	3,392,312
Thriasio	EL0600090	2,047,122
Marathonas (a)	EL0600120	1,899,223
Gerania - Mavrovouni	EL0600040	1,712,267
Parnitha (81)	EL0600081	1,513,519

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GWS Name	GWS Code	Discharges (m^3)
Anavissos	EL0600180	1,312,104
Salamina	EL0600190	831,169
Oinoi	EL0600070	697,176
Imittos	EL0600160	696,055
Kifisos River Basement	EL0600110	482,484
Central Gerania - Kalamaki	EL0600030	412,218
West Gerania	EL0600020	412,218
Thiva - Asopos - Schimatari	EL0700210	395,986
Loutraki	EL0600010	275,581
Antikira - Kithaironas	EL0700230	252,079
Penteli	EL0600140	212,952
North-East Parnitha	EL0600082	92,903
Skourta - St. Thomas	EL0700220	84,734
Agkistri	EL0600210	65,289
Mesogaia (α)	EL0600151	18,247
Lavreotiki	EL0600170 (collective)	150,617

While the RBMP data provide a useful reference snapshot, they do not capture inter-annual fluctuations in agricultural demand, which are strongly influenced by climate variability (heatwaves, droughts) and crop selection. Moreover, in the absence of detailed temporal information, the seasonal patterns of agricultural water demand remain unidentified. Consequently, any attempt to estimate intra-annual variability would entail a considerable degree of uncertainty, limiting the robustness of temporal allocation for this sector.

4.2 Livestock

Water demand for livestock farming varies significantly by animal species and production system. In Attica, the sector is relatively small compared to agriculture but remains locally important. According to the

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RBMPs (reference year 2020), there are approximately 1,138 farms in operation, most of which raise sheep, goats, and poultry, while smaller shares correspond to cattle, pigs, rabbits, and horses.

4.2.1 Water consumption

Livestock water needs are typically met through connections to the public water supply networks. In cases where direct connection is not feasible, farmers often rely on filling tanks from their household supply. In addition, Local Government Organizations (LGOs) (Greek: OTA) sometimes install dedicated livestock water points in villages and pastures, or transfer water during the summer months when demand peaks.

It is concluded that, according to RBMP data for 2020, total withdrawals for livestock farming amounted to 1,131,253 m^3 per year, of which approximately 93% originated from groundwater systems (GWSs) via municipal supply networks.

4.2.2 Spatial and temporal variability

Withdrawals for livestock farming show clear spatial disparities across Attica. Table 15 presents the discharges per LGO, while Figure 15 illustrates the geographic distribution. The highest withdrawal volume is recorded in Megara (West Attica), reaching 518,539 m^3, whereas the lowest is observed on the island of Aegina, with only 2,872 m^3.

With respect to temporal patterns, the available RBMP data provide only annual totals. Consequently, seasonal variations in livestock water demand cannot be directly quantified. Nevertheless, it is reasonable to infer that consumption peaks during the summer months, due both to higher temperatures (increasing animal drinking needs) and the additional water requirements for cleaning and cooling. However, in the absence of systematic monitoring, such seasonal dynamics remain uncertain and qualitatively inferred rather than empirically measured.

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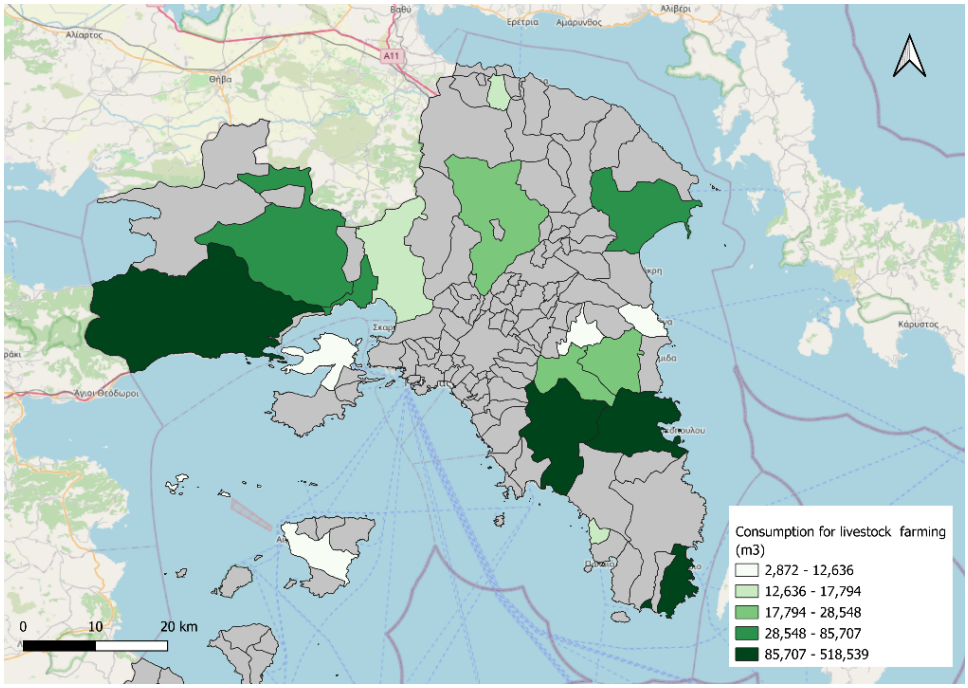


Figure 15: Discharges per LGO for livestock farming purposes (Source: Attica's RBMP)

Table 15: Withdrawals for livestock farming purposes per LGO (Source: Attica's RBMP)

Region	LGO	Discharges (m^3)
Corinth	Loutraki	35,108
West Attica	Megara	518,539
West Attica	Mandra - Eidillia	57,234
East Attica	Acharnes	22,912
East Attica	Oropos	14,734
East Attica	Aspropirgos	14,552
East Attica	Eleusina	32,305
East Attica	Marathonas	33,931
East Attica	Rafina - Pikermi	5,082
East Attica	Pallini	5,082
East Attica	Markopoulo	126,943

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East Attica	Kropia	92,825
East Attica	Paiania	18,985
East Attica	Spata – Artemida	18,985
East Attica	Saronikos	17,000
East Attica	Lavreotiki	102,001
Islands	Salamina	12,156
Islands	Aigina	2,872

As in the agricultural sector, livestock farming water demands are estimated only at the yearly level, excluding seasonal variability and thus disabling more detailed temporal analysis.

4.3 Industry

The industrial sector in Attica is the most populous and economically active in Greece, and therefore water requirements are substantial to support efficient operation. According to Attica's RBMP, approximately 640 industries are active in Attica Figure 16.

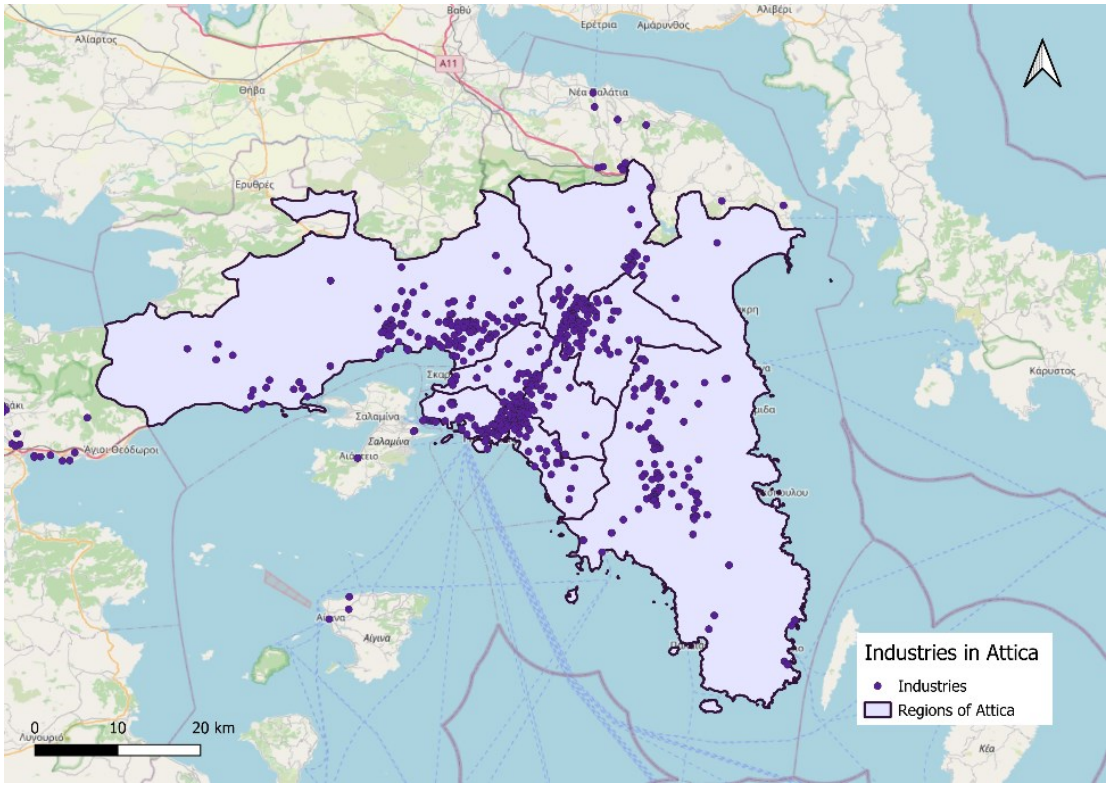


Figure 16: Map of industries in Attica (Source: RBMP)

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Table 16 presents the distribution of industries operating in Attica.

Table 16: Number of industries operating per region

Region	Number of industries
West Attica	164
East Attica	185
Peiraeus	90
Central Athens	30
West Athens	60
North Athens	38
South Athens	69

As illustrated, the vast majority of industries operate in West and East Attica, the two areas which cover the largest portions of the region's territory and are situated away from the highly urbanized centre of Athens. By contrast, Piraeus and South Athens register relatively high numbers of industries despite limited available space and dense population.

For industrial water consumption, data from official government reports were combined (e.g. regional climate adaptation plans for Attica) with EYDAP billed consumption datasets (see Chapter 3 for details).

However, as highlighted in subsection 3.3, the EYDAP dataset does not provide a distinct tariff category exclusively for industrial users. This limitation complicates the extraction of a complete and reliable time series of industrial water consumption. Instead, analysis partially relies on the 'E' tariff, which, although covering a broad range of professional users, provides a representative signal of industrial-type consumption. To complement this, total industrial water use was derived from official government sources, corresponding to the reference year 2020.

4.3.1 Water consumption

Industrial water use accounts for approximately 5.76% of total water abstractions in Attica. which translates to an estimated 28,240,000 hm^3/year. According to the data available, total industrial abstractions within the district amount to 11,870,503 m^3/year. These abstractions can be disaggregated based on the two main sources supplying industry:

- Public water providers (e.g., utilities), which deliver 3,832,302 m^3/year
- Private boreholes, which contribute the majority of volume with 8,038,201 m^3/year

By source type, the same quantity of abstraction within the district amount is divided to:

- Groundwater systems supplying the main share of 10,997,078 m^3/year
- Surface water systems supplying a relatively small share of 873,425 m^3/year

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The only surface water system within the district of Attica stands the artificial lake of Marathon. It should also be noted that additional abstractions for industrial use originate from outside Attica's boundaries, specifically from the Mornos–Evinos surface water system.

4.3.2 Spatial and temporal variability

Because EYDAP billed consumption data lack a dedicated industrial category, a filtering methodological assumption was applied to isolate likely industrial users from the broader set of professional consumers billed under tariff type 'E'. The following steps were implemented:

- The average annual water consumption of each distinct consumer with tariff type 'E' was calculated over the available time period.
- A cumulative distribution function (CDF) of average annual consumption per consumer was produced. This visual representation helped to identify thresholds of consumption that separate small-scale users (e.g., small businesses, restaurants, offices) from large-scale consumers (e.g., factories, industrial facilities).
- Based on the CDF, a threshold was defined above which consumers are assumed to predominantly represent industrial activity. This threshold was selected to exclude small-scale professional users while retaining high-volume accounts likely associated with manufacturing or large facilities.
- Temporal consumption patterns of these high-volume 'E' consumers were analysed to identify seasonal trends.

Figure 17 illustrates the empirical cumulative density function (CDF) of average annual consumption for all business consumers, marked with tariff type 'E' on EYDAP data.

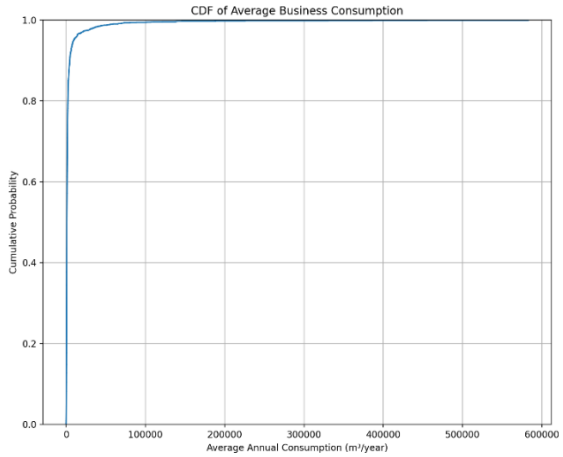


Figure 17: Empirical cumulative density function of average annual consumption of business consumers. Source: EYDAP billing data, E type

We assume a threshold of top 5% as indicative for separating light and heavy industry from small businesses (e.g., cafes, offices). A 5% threshold based on the CDF plot leads to approximately 10.000 m^3/year which can be considered acceptable as a lower bound for industrial-scale water consumption.

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Based on this classification, the seasonality of the industrial sector was examined under the assumption that these consumers predominantly represent the industrial activity in Attica.

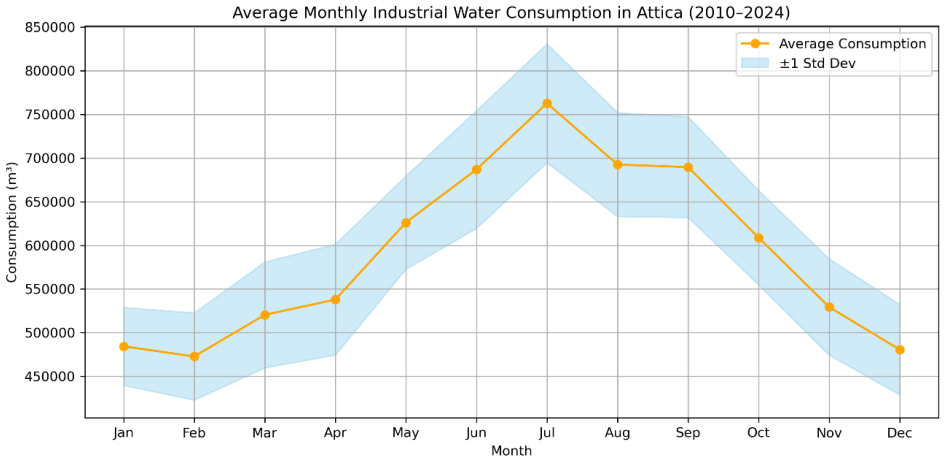


Figure 18: Average monthly urban green water consumption in Attica for period 2010-2024. Source: EYDAP billing data, E type

Figure 18 illustrates a clear seasonal pattern in industrial water consumption. Demand increases significantly during the warmer months, with a pronounced peak in July at approximately 770,000 m^3. This surge likely reflects intensified operational requirements, such as cooling processes and higher production volumes. Conversely, February records the lowest demand, nearly 40% lower than summer peak, highlighting notable seasonal fluctuations in industrial activity.

To assess spatial variability, the same methodological assumption was applied—considering the top 5% of professional tariff ('E') consumers as representative of industrial users. Aggregating their total consumption by regional unit enables the identification of areas with the highest industrial water demand within Attica. Table 17 summarizes the percentage distribution of industrial consumption per regional unit, highlighting the areas where water demand from industrial activity is most pronounced.

Table 17: Percentage of total consumption of industrial use per region

Regional unit	Percentage of consumption
East Attica	35.13%
North Athens	17.94%
West Attica	14.85%
Central Athens	14.37%
Piraeus	9.37%
South Athens	5.99%

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West Athens	2.36%

4.3.3 Oil industry

The oil industry in Attica is represented in the EYDAP billed consumption dataset under a dedicated tariff type labeled 'EP', which is specifically assigned to large-scale petroleum-related activities. This separate classification allows for the detailed analysis of water consumption data for the oil sector, distinct from other professional or industrial users. Based on EYDAP data, Table 18 presents the annual water needs of the oil industry for three reference years: 2013, 2018, 2023.

Table 18: Annual water consumption of oil industry for three reference years

	2013	2018	2023
Oil industry consumption (hm^3)	8.41	8.92	9.41

The corresponding seasonal consumption pattern of the oil industry is depicted in Figure 19 according to EYDAP data, highlighting higher water usage during the **summer months**, which likely reflects increased operational activity, including elevated cooling demands.

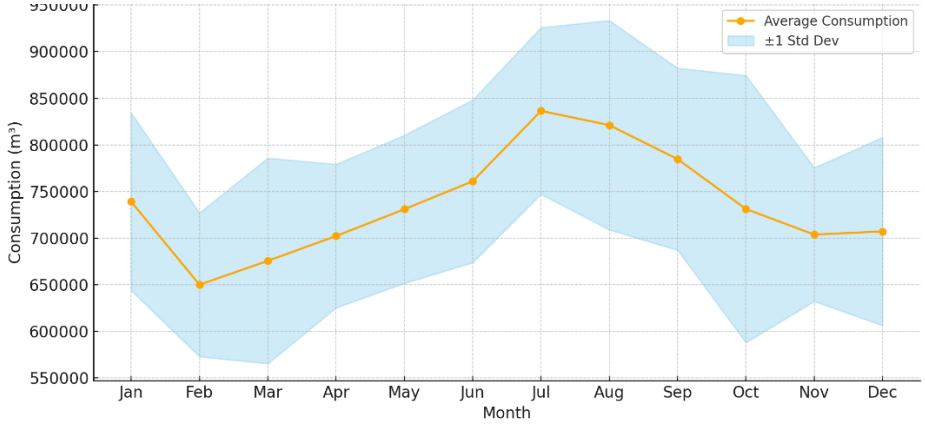


Figure 19: Average monthly water consumption for oil industry. Source: EYDAP billing data, 'EP' type

Figure 20 visualizes the Seasonal-Trend decomposition using Loess (STL) analysis, confirming a strong seasonal component in water consumption, as well as a noticeable upward trend over the period 2022-2024. The residual component exhibits only minor fluctuations, suggesting limited uncertainty in the estimated water needs of the oil industry.

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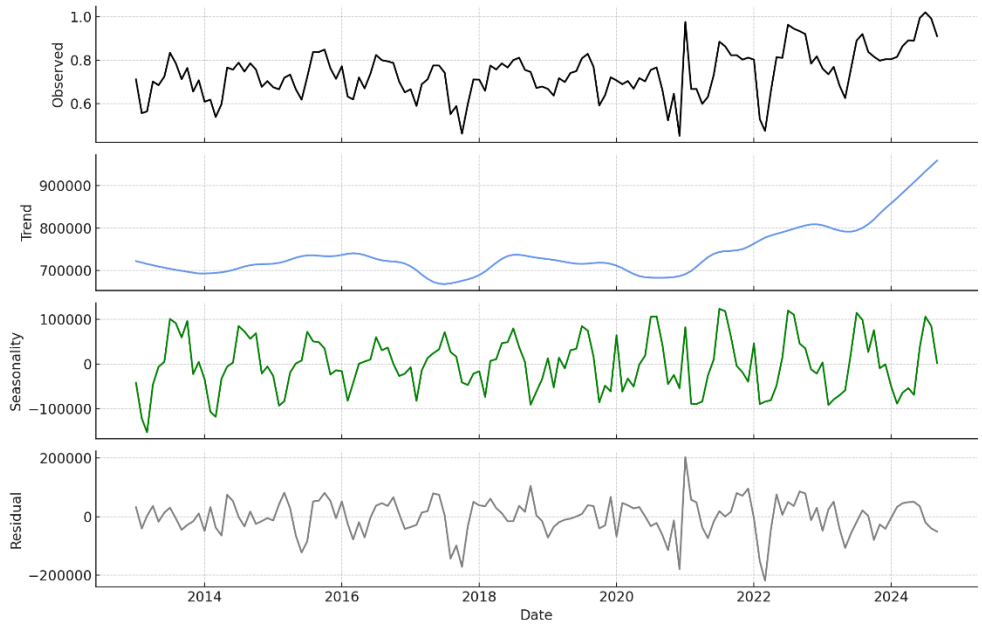


Figure 20: TL Decomposition – Oil Industry Consumption

4.4 Tourism

This section analyses the temporal and spatial distribution of water consumption associated with the tourism sector across the Attica region. The analysis relies on tourism-related data from multiple sources, including the Hotel Chamber of Greece and regional tourism statistics from INSETE (see Section 3.3 for details). Precise measurements or data of touristic water consumption were not publicly available. Therefore, total yearly water use was estimated using the following formula:

$$Q = q \times \Pi \tag{6}$$

where:

q = specific water consumption per person per day, derived from the Koutsoyiannis and Efstratiadis (2015) [28]

Π = population. In this case, instead of actual population, the number of overnight stays based on available data was used as a proxy for the temporary touristic population.

4.4.1 Water consumption

Estimated yearly touristic water consumption for the entire region of Attica was calculated using available data on overnight stays. The year 2019 is used as a reference period, representing pre-pandemic tourism activity. Data from 2020 were not included, as the COVID-19 pandemic severely disrupted the tourism sector, leading to atypical tourism activity and thus consumption patterns. Year 2023 was also included as the most recent year for which data are available.

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The total number of overnight stays in Attica was 10,260,847 in 2019, and 12,380,957 in 2023. Using the above-mentioned range for q the total yearly touristic water consumption was estimated as follows:

Estimated Touristic Water Consumption – 2019

- Lower estimate ($q = 250L/day$): $Q = 250 \times 10{,}260{,}847 = 2{,}565{,}212\ m^3$
- Upper estimate ($q = 350L/day$): $Q = 350 \times 10{,}260{,}847 = 3{,}591{,}296\ m^3$

Estimated Touristic Water Consumption – 2023

- Lower estimate ($q = 250L/day$): $Q = 250 \times 12{,}380{,}957 = 3{,}095{,}239\ m^3$
- Upper estimate ($q = 350L/day$): $Q = 350 \times 12{,}380{,}957 = 4{,}333{,}335\ m^3$

These values represent the total yearly demand associated with the tourism sector. The range reflects the uncertainty in total consumption depending on accommodation type, service level and facilities level. For example, it is not known which specific hotels or campsites contributed to the overnight stays, what their exact location is within the region, or how much green space or water-intensive infrastructure (e.g., gardens, pools) they maintain.

4.4.2 Spatial and temporal variability

To explore the temporal distribution of tourism-related water consumption, the monthly breakdown of overnight stays in Attica was examined for the years 2019 and 2023 (see Table 19)

Table 19: Monthly distribution of overnight stays

Month	Overnight stays - 2019	Overnight stays - 2023
January	477,406	562,815
February	535,439	614,124
March	714,576	821,070
April	879,257	913,027
May	974,771	1,150,755

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June	1,097,421	1,404,912
July	1,218,510	1,573,502
August	1,192,392	1,604,876
September	1,120,841	1,395,601
October	925,074	1,056,041
November	626,473	631,245
December	498,687	652,989
Total	**10,260,847**	**12,380,957**

Below in Figure 21 the plot showing the monthly estimated touristic water demand for 2019 and 2023 is presented, with both lower and upper bounds based on the specific consumption range of 250-350 L/day per overnight stay.

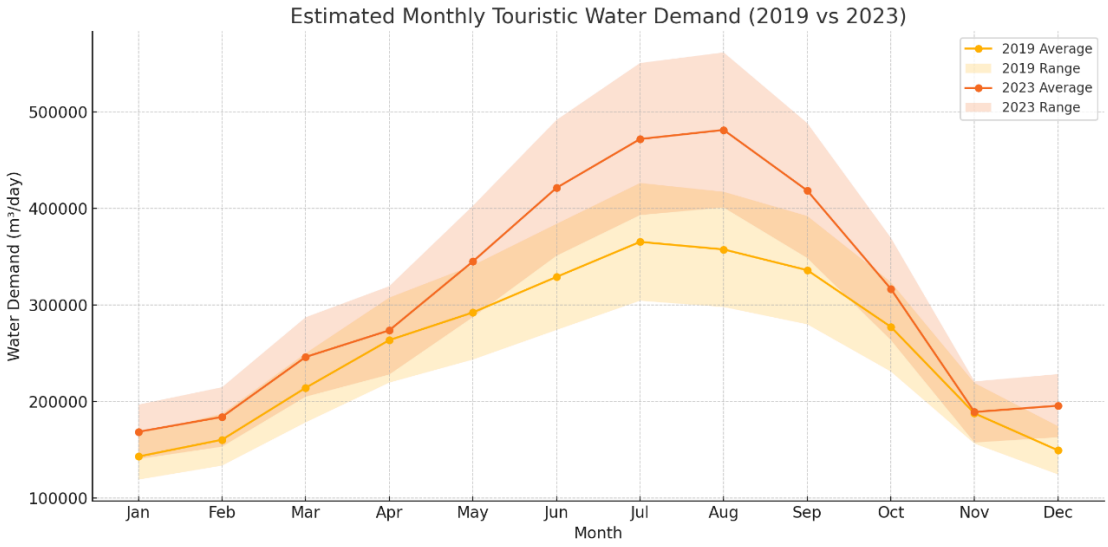


Figure 21: Estimated monthly touristic water consumption for the years2019 and 2023.

The estimated touristic water consumption exhibits substantial monthly variability, with peak demand occurring during the summer months (June-August), significantly exceeding winter consumption (December-February). On average, summer consumption is 3-4 times higher than in winter. Specifically, in July and August, average daily water demand reaches approximately 425,000–500,000 m^3/day, whereas in

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January and February it ranges between 140,000–190,000 m^3/day. Consumption gradually increases from March to June, followed by an extended peak lasting until September.

For spatial disaggregation, touristic water consumption, was estimated using overnight stays data per regional unit of Attica.
Table 20 presents the spatial distribution across the eight regional units of Attica, highlighting areas with the highest tourism-related water demand.

Table 20: Spatial distribution to regions of Attica of overnight stays for years 2019 and 2023

Regional unit	Overnight stays -2019	Overnight stays - 2023
Regional Unit of Central Athens	6,534,335	7,791,583
Regional Unit of Northern Athens	274,577	385,985
Regional Unit of Western Athens	23,168	15,911
Regional Unit of Southern Athens	828,129	834,013
Regional Unit of Eastern Attica	1,543,193	1,581,177
Regional Unit of Western Attica	160,492	164,220
Regional Unit of Piraeus	480,435	592,681
Regional Unit of Islands	416,518	1,015,387
Total	**10,260,847**	**12,380,957**

Based on the spatial distribution to regional units of Attica the following Figure 22 presents the estimated water consumption per regional unit, based on the assumption of 250-350 L per overnight stay.

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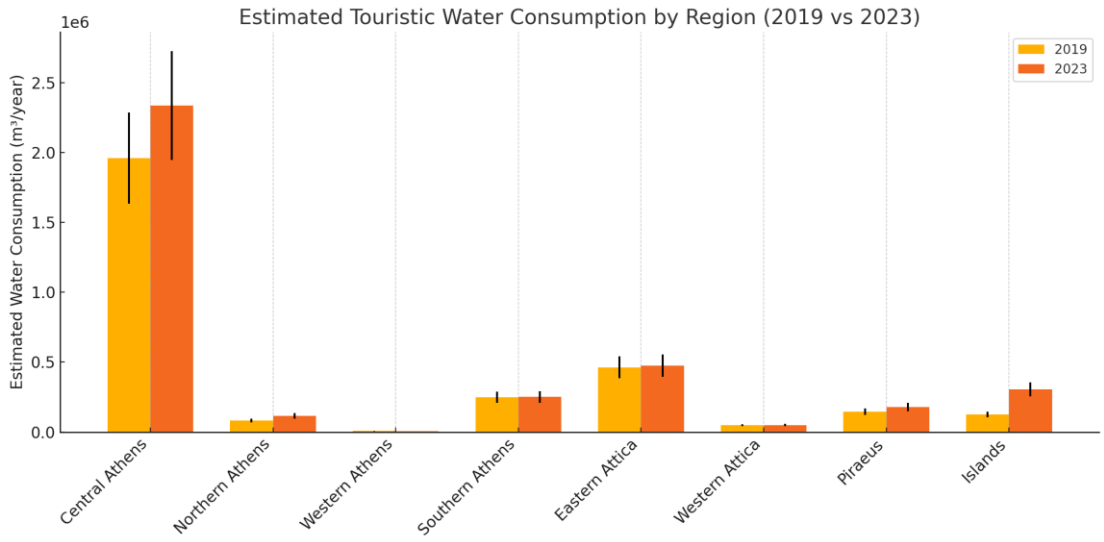


Figure 22: Average estimated water consumption for all regions of Attica for 2019 and 2023 with uncertainty bounds

As observed, Central Athens exhibits by far the highest water demand, reflecting its large number of overnight stays. Eastern Attica and Southern Athens follow, showing comparatively higher consumption than other regional units. Notably, the Islands regional unit experienced a significant increase in water consumption in 2023 compared to 2019, suggesting ongoing growth in the tourism sector.

Overall, the analysis underscores the strong temporal and spatial variability of tourism-related water use in the Attica region. Seasonal peaks during the summer months are markedly higher than in winter, while spatial patterns reveal that Central Athens and Easter Attica are the principal contributors to the region's total touristic water consumption.

4.5 Urban green

This section analyses the temporal and spatial distribution of water consumption for urban green irrigation across the municipalities of Attica, using monthly billed consumption data provided by EYDAP (See 3.3 for these data sources and pre-processing analysis for monthly disaggregation). The dataset covers the period 2010-2024 and includes 66 municipalities, specifically for irrigation under tariff type 'K2', which is attributed to urban green irrigation use. This section focuses on analysing the specific dataset and extracting insights on urban green consumption.

No alternative sources or studies were found that provided consisted comparable information or data for urban green consumption. Some municipalities may use groundwater sources, but these are not reflected in the available datasets.

4.5.1 Water consumption

An overview of the billed water consumption for urban green irrigation across the region of Attica is provided in this section.
Table 21 presents the annual total consumption volumes from 2018 onwards, and averages for the entire

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study period (2011-2024). Reference period 2020 is selected to be comparative with other sections' (e.g., Industry, tourism, agriculture), for which available consumption data from alternative sources also cover this timeframe. These values are expressed in cubic meters.

Table 21: Annual total urban green consumption based on EYDAP data for the whole region of Attica for recent years and reference period. Source: EYDAP billing data, K2 type

	2018	2019	2020	2021	2022	2023	Avg. 2011-2023
Total Volume (hm^3)	3.915	4.262	4.342	4.627	4.565	4.350	4.567

Annual urban green water consumption in Attica ranges between 3.9 and 4.6 million m^3 during the post 2018 period (Table 21). The reference period 2020 recorded 4.342 hm^3, slightly below the 2011-2023 average, indicating a gradual increase in irrigation demand in more recent years. However, as shown from 2018 until 2022 there was a slight increase.

Similarly, Figure 23 presents a bar chart with total annual urban green consumption for all years based on EYDAP data. 2010 and 2024 have been excluded from the chart as missing values in some of their months were identified.

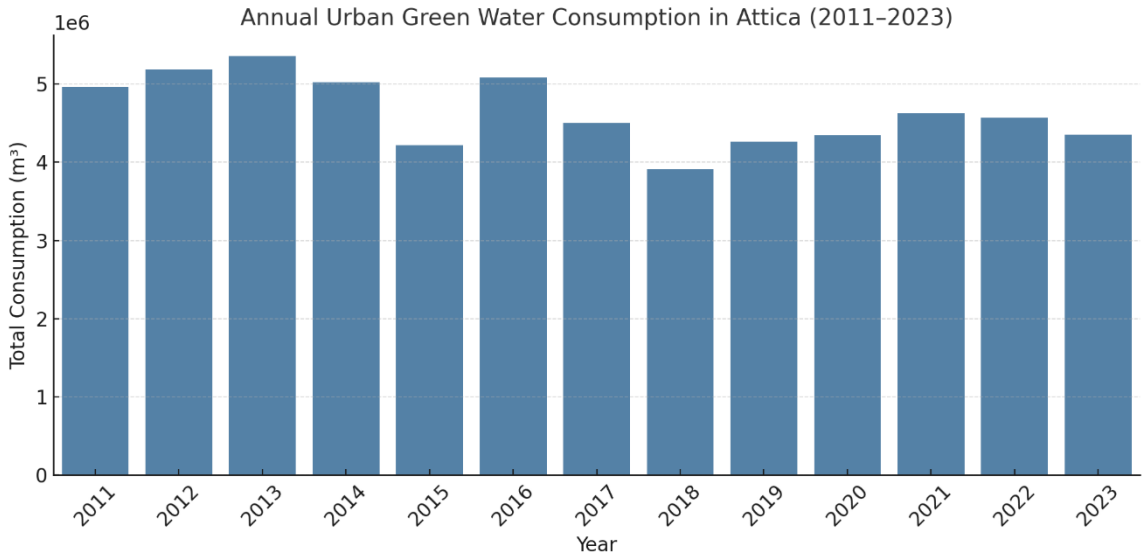


Figure 23: Bar chart of annual total urban green consumption based on EYDAP data for the whole region of Attica for all years. Source: EYDAP billing data, K2 type

Figure 24 shows the monthly time series of total urban green consumption for the years 2010-2024. Again, from this figure, there was a gradual increase from 2010 to 2018 and a slight increase from 2018 to 2024.

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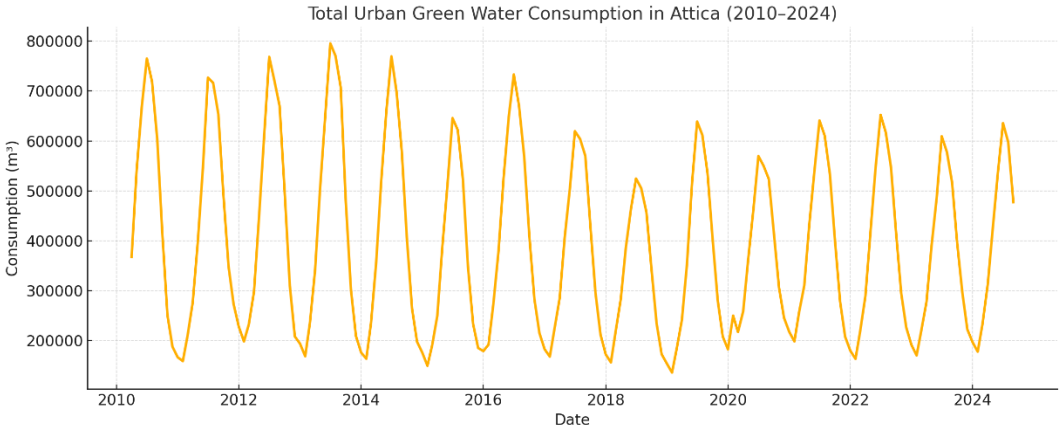


Figure 24: Total Urban Green Water Consumption in Attica (2010–2024) in monthly values. Source: EYDAP billing data, K2 type

Table 22 presents the three highest and lowest monthly urban green water consumption values in the period 04/2010-09/2024.

Table 22: Three highest and lowest monthly urban green water consumption. Source: EYDAP billing data, K2 type

Highest Consumption (m^3)	July 2013	795,532
	August 2013	770,367
	July 2014	769,667
Lowest Consumption (m^3)	February 2019	135,510
	February 2015	149,111
	January 2019	153,638

This seasonal pattern illustrated in the above table is further quantified and visualized in Section 4.5.2.

4.5.2 Spatial and temporal variability

This section examines urban green water consumption across the Attica region, considering both spatial and temporal dimensions.

For the analysis of spatial variability, EYDAP data were aggregated at both the municipal and regional levels. The regional level corresponds to the administrative divisions of Attica, including North Athens, South Athens, West Athens, Central Athens, West Attica, South Attica, and Piraeus.

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Table 23presents the spatial variability at the regional level, derived from the aggregation of municipal-level billing data, highlighting differences in water consumption patterns across the region.

Table 23: Regional spatial variability of summed urban green water consumption for period 2010-2024. Source: EYDAP billing data, K2 type

Region	Sum of consumption (2010-2024) (m^3)	Percentage
Central Athens	22,994,590	33.6%
South Athens	11,865,892	17.3%
West Athens	11,316,002	16.5%
Piraeus	8,361,778	12.2%
North Athens	6,714,876	9.8%
East Attica	5,260,621	7.7%
West Attica	1,678,293	2.4%
Islands	326,458	0.5%
Total	**68,518,508**	**100%**

The results indicate notable spatial disparities in urban green water demand. Central Athens leads with the highest consumption, totaling approximately 23 hm^3 for the period 2010-2024. This is followed by South Athens and West Athens, with totals of 11.87 and 11.32 hm^3, respectively, indicating moderately high irrigation levels. Piraeus and North Athens exhibit lower total consumption, around 8.36 and 6.71 hm^3 and lastly East Attica and West Attica record the lowest urban green water use at 5.26 and 1.67 hm^3, respectively.

It should be noted that these figures are derived solely from EYDAP billing data. In some municipalities, water for urban green irrigation may come from private sources, or a single hydrometer may cover the entire municipal network, preventing separation of water use by tariff type. Consequently, urban green consumption in such cases could not be precisely determined. Municipalities with a single hydrometer are primarily located in East Attica; therefore, consumption values for this area should be considered rough estimates.

Table 24 presents comparable results for the reference years 2020 and 2023, with 2023 being the most recent year with complete data.

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Table 24: Regional spatial variability of urban green water consumption for reference period 2020 and 2023. Source: EYDAP billing data, K2 type

Region	Total 2020	Percentage	Total 2023	Percentage
Central Athens	1,342,013	30.9%	1,519,720	35%
South Athens	788,021	18.1%	635,371	15%
West Athens	726,125	16.7%	703,820	16%
Piraeus	542,668	12.5%	510,982	12%
North Athens	481,272	11.1%	477,516	11%
East Attica	302,949	7.0%	325,568	7%
West Attica	130,336	3.0%	145,762	3%
Islands	29,530	0.7%	31,619	1%
Total	4,342,913	100%	4,350,359	100%

As shown, the percentage distribution of urban green water consumption remains relatively consistent across the years 2019 to 2023, indicating low regional variability. Central Athens exhibits the highest consumption (30.9%–35%), followed by South Athens and West Athens. In contrast, the Islands show the lowest consumption, reflecting limited green spaces due to the arid environment.

The spatial patterns from Table 24 are visualized in Figure 25 and Figure 26 for the years 2020 and 2023, respectively. These maps clearly highlight that the majority of urban green water use is concentrated in Central Athens and South Athens.

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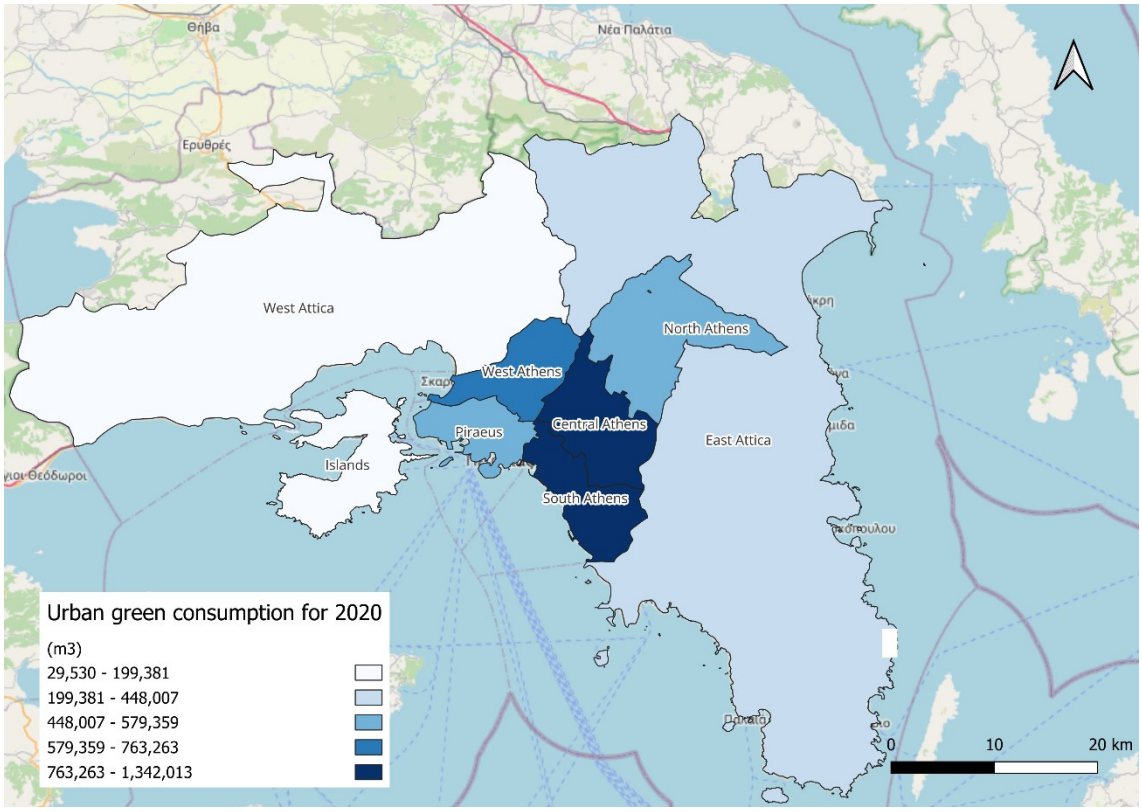


Figure 25: Spatial distribution of urban green consumption in regions of Attica for 2020. Source: EYDAP billing data, K2 type

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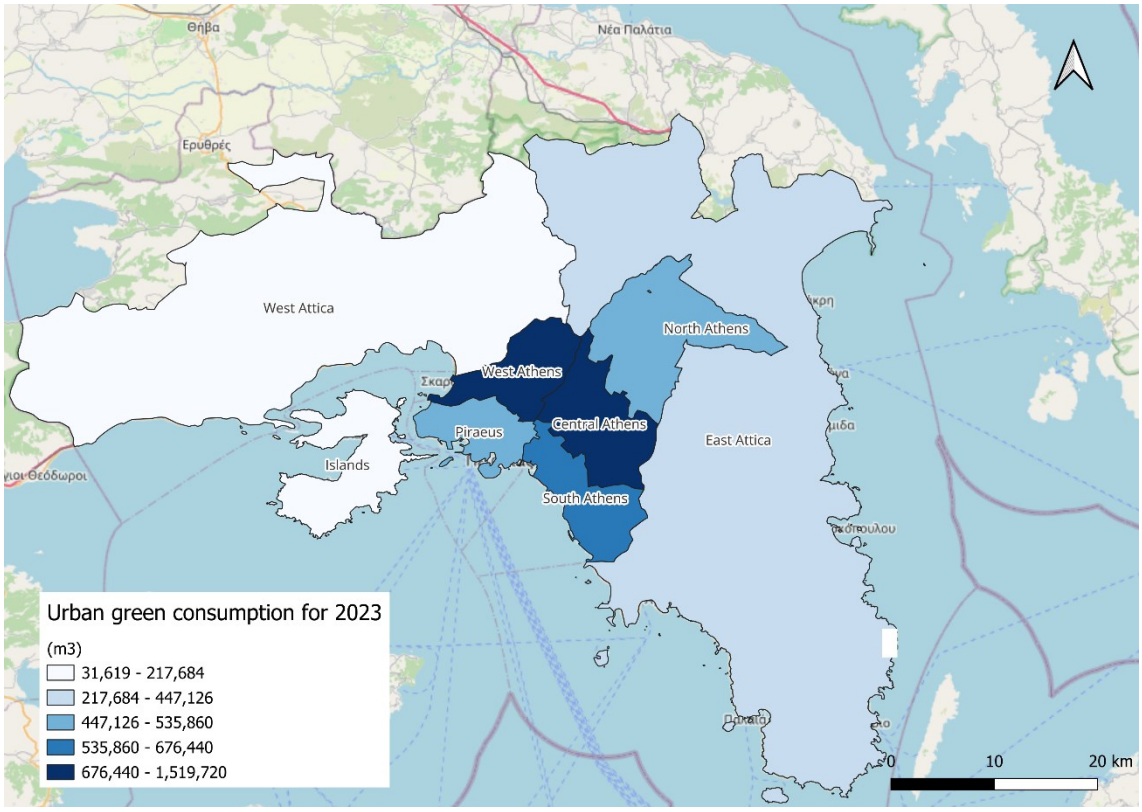


Figure 26: Spatial distribution of urban green consumption in regions of Attica for 2023. Source: EYDAP billing data, K2 type

At the municipal level, Table 25 presents the top five municipalities in urban green water consumption for the periods 2010-2024 (total period), 2018-2019 (reference period) and 2023 (latest year). The municipality of Athens consistently shows the highest consumption, followed by Glyfada, Ilioupoli and Peristeri, which maintain high levels across all periods. Notably, Keratsini appears among the top consumers in 2023, reflecting increased urban green irrigation in that year.

Table 25: Top Municipalities by Consumption for different periods. Source: EYDAP billing data, K2 type

Top 2010-2024	Volume 2010-2024	Top 2020	Volume 2020	Top 2023	Volume 2023
Athens	15,678,130	Athens	940,712	Athens	1,112,223
Glyfada	4,011,757	Glyfada	319,099	Peristeri	251,414
Ilioupoli	3,994,011:	Peristeri	236,736	Ilioupoli	212,119

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Top 2010-2024	Volume 2010-2024	Top 2020	Volume 2020	Top 2023	Volume 2023
Peristeri	3,107,684	Ilioupoli	201,724	Keratsini	179,152
Egaleo	2,776,195	Palaio Faliro	152,050	Glyfada	147,719

In addition to spatial distribution, urban green water consumption in Attica exhibits significant temporal fluctuations, mainly driven by seasonal climatic patterns. As illustrated in Figure 27, a distinct intra-annual cycle is observed, corresponding to the irrigation season.

On average, consumption reaches its lowest levels during winter (December-February), corresponding to the cooler and wetter conditions when irrigation demand is minimal. Demand begins to rise in March and April, reaching a peak in consumption during the summer months of June through August. The highest average monthly consumption occurs in July, at approximately 6,800,000 m^3, while January records the lowest levels, below 1,800,000 m^3. Seasonal fluctuations are relatively consistent across years, as indicated by the narrow standard deviation confidence intervals. It is noteworthy that confidence intervals widen during the summer months, suggesting that consumption during this period is more influenced by external factors, whereas winter demand remains relatively stable.

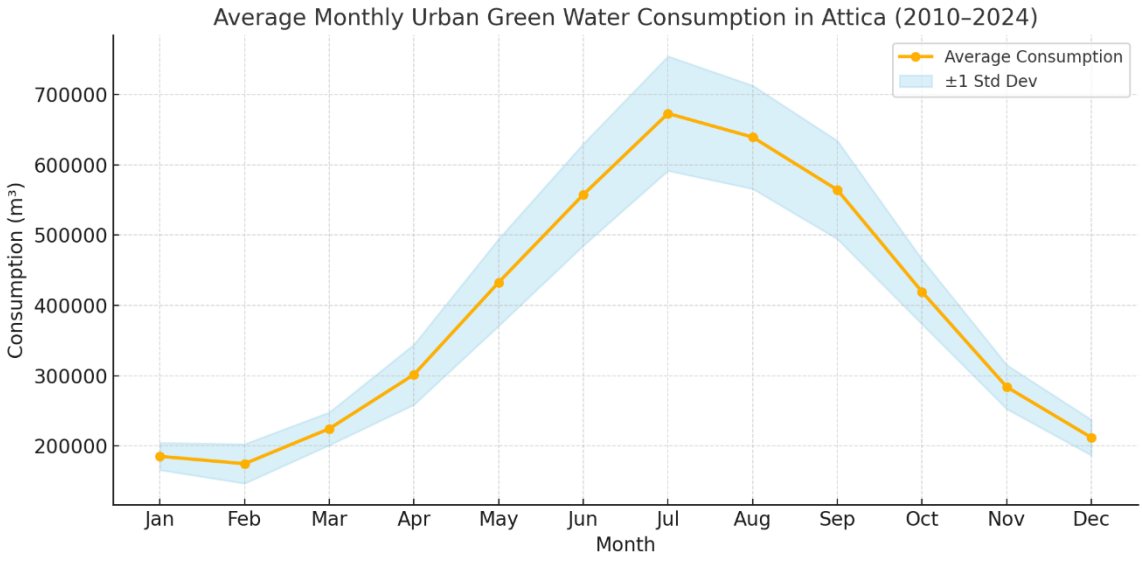


Figure 27: Average monthly urban green water consumption in Attica for period 2010-2024. Source: EYDAP billing data, K2 type

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To further analyse and interpret the temporal patterns of urban green water demand, an additive time series decomposition was performed. Figure 28 presents the result of this decomposition, using the classical seasonal model with monthly frequency.

The trend component indicates the gradual increase in overall urban green consumption from 2010 to approximately 2019, followed by signs of stabilization in recent years. This observation aligns with earlier observations based on annual totals. The seasonal component displays a regular yearly cycle, highlighting the strong influence of climate-driven irrigation needs. Finally, the residual component captures short-term anomalies that may be attributed to weather extremes, administrative changes, or occasional data irregularities.

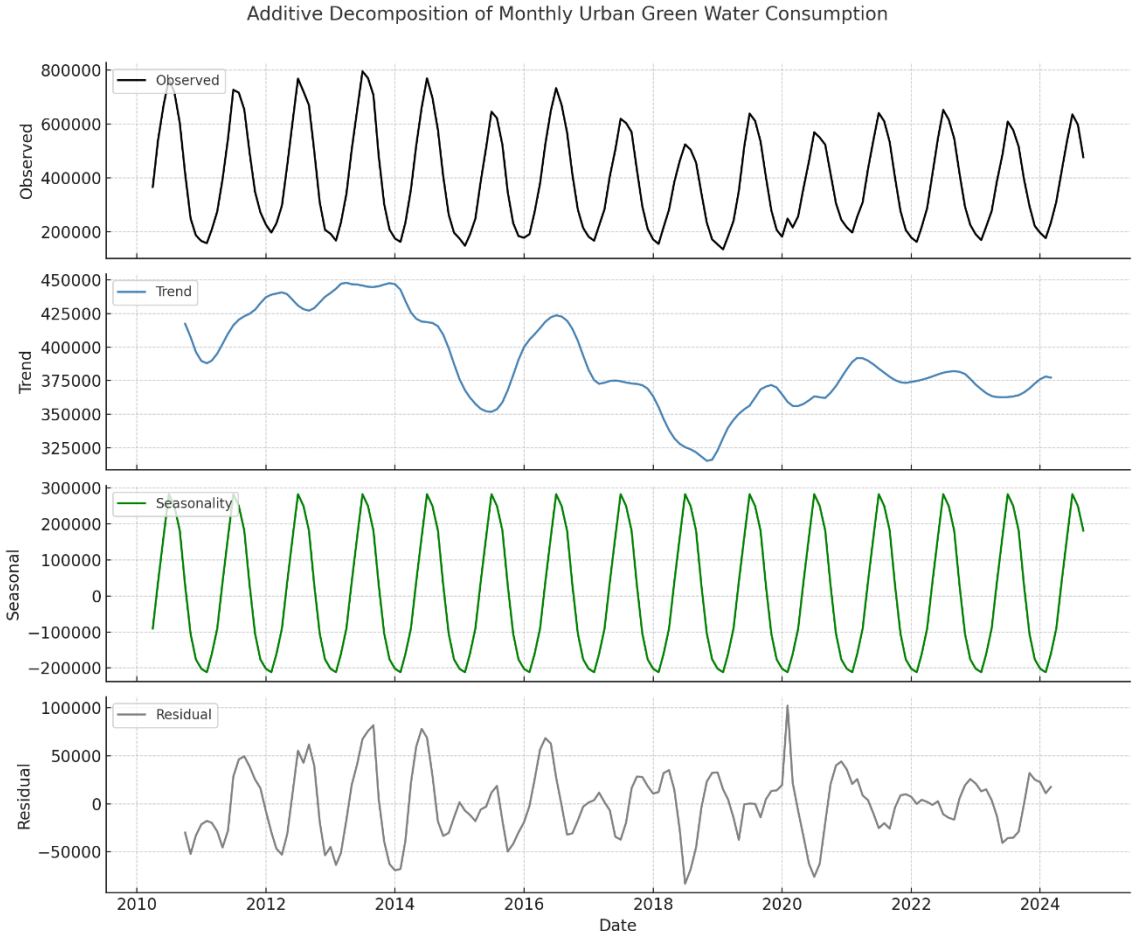


Figure 28: Decomposition (trend, seasonality, residual) of monthly urban green water consumption. Source: EYDAP billing data, K2 type

4.6 Factors influencing water demand

Water demand for agricultural purposes is influenced by a combination of climatic and socioeconomic factors. Rising temperatures combined with reduced precipitation increase crop evapotranspiration rates,

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thereby elevating irrigation requirements. Extreme weather events, such as droughts and floods, along with population growth and urbanization, further affect water demand. [29]. In the case of livestock farming, critical drivers include the type of animal and its dietary needs, with ruminants requiring significantly more water than monogastric animals [30]. Tourism-related water demand is shaped by visitor numbers, seasonal fluctuations, as well as the types of services offered [31], which can cause great strain in water resources, given the fact that most of tourist destinations have few water reserves. Lastly, industrial water demand is primarily driven by the scale of production, with the sector type also playing a role; water-intensive industries, such as chemical manufacturing, consume considerably more water than less intensive sectors [32].

4.7 Total consumption for all sectors

Table 26 presents the total water consumption volumes per sector, based on the analysis described in the previous sections. The results suggest that the combined water demand in agriculture, livestock, industry, tourism, and urban green sectors amounts to approximately 102.04 hm^3. Agriculture represents the largest share accounting for 63.95% of total consumption, followed by industrial use at 27.7%.

Table 26 Total consumption for all sectors examined

	Reference period	Total consumption (hm^3)	(%) of consumption	Primary source
Agriculture	2020	65.25	63.9%	Groundwater
Livestock	2020	1.13	1.1%	Groundwater
Industry	2020	28.24	27.7%	Surface water (outside of Attica)
Tourism	2019	3.08	3.0%	Surface water (outside of Attica)
Urban green	2020	4.34	4.3%	Surface water (outside of Attica)
Total		102.04	100%	

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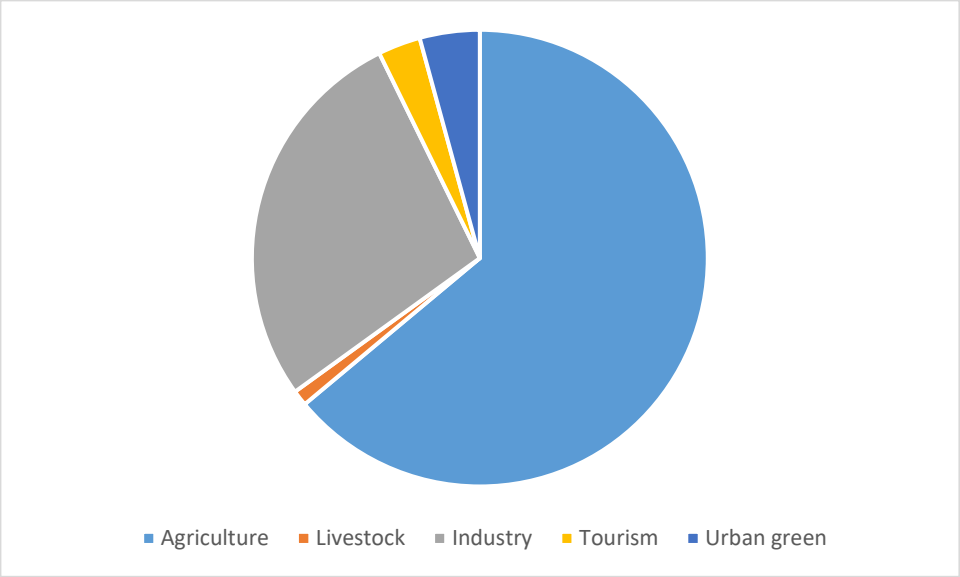


Figure 29 Water consumption volumes per sector

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5. Water Quality Considerations

5.1 Sector Specific Water Quality Requirements

In the Attica region, water needs across various sectors are primarily met through the use of potable water or abstraction from local aquifers. However, in many cases, the quality of potable water exceeds the minimum physicochemical requirements for specific uses. Moreover, the increasing frequency of droughts and rising temperatures are intensifying pressure on conventional renewable water resources, leading to the intrusion of sea water in the aquifers disrupting the underground water and soil quality in the region. It is therefore essential to assess the actual quality requirements of each sector to enable the substitution of conventional resources with alternative water resources, such as adequate treated reclaimed wastewater from WWTPs, rainwater and stormwater. Since quality requirements vary by sector, some alternative sources may be unsuitable for certain applications unless advanced, costly treatment is applied. The establishment of pollutant limits aligned with the requirements of each specific reuse activity is a critical prerequisite for advancing the adoption of alternative water sources. This chapter outlines the water quality standards that reclaimed water must achieve in each sector, thereby supporting its safe, efficient, and sustainable valorisation within the Attica region.

Joint Ministerial Decision (JMD) 145116/2011 [33] establishes Greece's national legal framework for the reuse of treated wastewater. It goes beyond the scope of EU Directive 91/271/EEC [34], transposed into Greek law through JMD 5673/400/1997 [35], by addressing reuse categories and methods, water quality parameters, monitoring requirements, and variance provisions within an integrated framework. Figure 30 illustrates the sectors and the potential reuses.

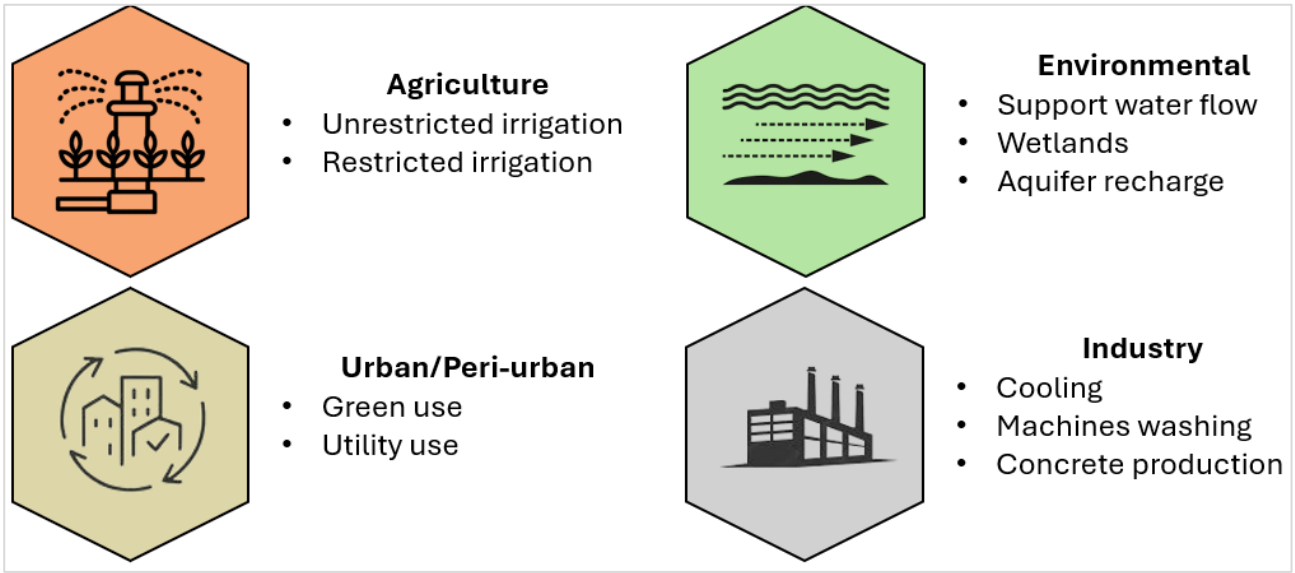


Figure 30 Categorisation of treated wastewater reuse applications according to JMD 145116/2011, grouped into four main sectors: agriculture, urban/municipal, environmental, and industrial.

Specifically, the JMD defines eight potential reuse categories, summarized in Table 27. These eight categories represent a structured and tiered framework that considers both the intended use and the

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potential health and environmental risks associated with each reuse application. The agricultural sector is divided into unrestricted and restricted irrigation, depending on whether the reclaimed water comes into direct contact with edible parts of the crop. Urban and peri-urban application are grouped into green use (such as park or roadside irrigation) and utility use, which includes non-potable operations like street cleaning or toilet flushing. The industrial sector allows reuse in processes like equipment washing or cooling, where specific physicochemical characteristics are prioritized. Environmental reuse focuses on supporting ecological flows or wetlands, while aquifer recharge is split into indirect (through soil infiltration) and direct (via injection wells), each requiring advanced treatment and risk control measures.

Table 27 Overview of the treated wastewater reuses defined in JMD 145116/2011, including the main application areas across agricultural, urban, industrial, environmental, and groundwater recharge uses.

Category	Description
Agricultural Reuse – Unrestricted Irrigation	Irrigation of edible crops consumed raw (e.g., lettuce, fruits).
Agricultural Reuse – Restricted Irrigation	Irrigation of non-food or processed crops (e.g., cotton, cereals), or using subsurface/drip methods.
Urban and peri-urban Green Use	Irrigation of parks, road medians, cemeteries, and recreational areas.
Urban Utility Use	Uses such as street cleaning, toilet flushing, firefighting, and dust suppression.
Industrial Use	Water for cooling systems, equipment washing, and concrete production.
Environmental Reuse	Wetland support, streamflow enhancement, or habitat restoration.
Indirect Aquifer Recharge	Infiltration of water through soil (e.g., via basins or trenches) to replenish aquifers.
Direct Aquifer Recharge	Direct injection into aquifers via wells.

5.1.1 Reclaimed water quality for Agriculture use

Agriculture is one of the most critical sectors addressed by JMD 145116/2011 due to its high water demand and direct connection to food safety. The regulation distinguishes between two main reuse scenarios within agriculture: unrestricted irrigation and restricted irrigation, each associated with specific crop types, irrigation methods, and risk exposure levels.

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Unrestricted irrigation refers to the reuse of treated wastewater for crops whose products are consumed raw or have direct contact with the reclaimed water, such as vegetables (e.g., lettuce, spinach), fresh herbs (e.g., parsley, basil), fruits with exposed surfaces (e.g., strawberries, tomatoes), vineyards, and ornamental or flower crops. In this category, all irrigation methods are permitted, including sprinkler systems, and there are no access restrictions for the general public in irrigated areas. Due to the higher risk of human exposure, this use requires the strictest treatment and water quality standards. According to JMD 145116/2011, wastewater intended for unrestricted irrigation must undergo, at a minimum, secondary biological treatment, followed by a tertiary filtration process, such as sand or membrane filtration and final disinfection, typically via chlorination or ultraviolet methods. This multistep treatment ensures sufficient removal of solids, organic matter, and pathogens, enabling safe use on edible crops.

Restricted irrigation, in contrast, applies to crops not consumed raw, crops intended for animal feed or industrial processing (e.g., cotton, cereals, alfalfa), and trees not bearing edible fruits, as well as situations where irrigation avoids direct contact with the edible portion of the crop, such as through subsurface or drip systems. In this category, the use of sprinkler irrigation is prohibited, and access to the irrigated fields must be limited. If the area is accessible to people or animals beyond trained personnel, additional protective measures must be implemented, such as fencing or temporal grazing restrictions. The minimum required treatment for this category consists of secondary biological treatment followed by disinfection, without the mandatory inclusion of a filtration step.

The microbial and physicochemical parameters defined for unrestricted and restricted irrigation are summarized in

Table 28 The microbiological and physicochemical quality requirements for reclaimed water intended for agricultural reuse are differentiated based on the type of irrigation application. For unrestricted irrigation, the concentration of Escherichia coli must not exceed 5 EC/100 mL in at least 80% of the samples and 50 EC/100 mL in 95% of the samples. This category also requires turbidity ≤ 2 NTU (median value), biochemical oxygen demand (BOD_5) ≤ 10 mg/L, and suspended solids (SS) ≤ 10 mg/L. Nutrient concentrations are also regulated, with total nitrogen (TN) ≤ 10 mg/L and total phosphorus (TP) ≤ 1 mg/L. These thresholds are aligned with the provisions of JMD 5673/400/1997 and specifically apply to wastewater treatment plants (WWTPs) that discharge into recipients serving more than 100000 population equivalents (PE). For WWTPs discharging into recipients serving fewer than 100000 PE, the allowable concentrations are higher, TN ≤ 15 mg/L and TP ≤ 2 mg/L. In the case of irrigation in areas designated as nitrate vulnerable zones, nitrogen removal through nitrification–denitrification is required, such that ammonium nitrogen (NH_4^+-N) concentrations do not exceed 2 mg/L and total nitrogen (TN) concentrations remain below 15 mg/L.

In the context of restricted irrigation, the regulatory thresholds are comparatively more lenient. E. coli concentrations are permitted up to 200 EC/100 mL, while BOD_5 and SS limits are set at 25 mg/L and 35 mg/L, respectively. The same nutrient thresholds apply as in unrestricted irrigation, subject to the population-based differentiation noted above. The maximum permissible concentrations of heavy metals and trace elements are uniformly applied to both irrigation categories to safeguard soil integrity, crop quality, and food safety. These include, among others, cadmium (0.01 mg/L), arsenic (0.1 mg/L), copper (0.2 mg/L), zinc (2.0 mg/L), and mercury (0.002 mg/L), as detailed in Table 29.

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Table 28 Physicochemical and microbial parameters of reclaimed water intended for unrestricted and restricted irrigation

Parameter	Unrestricted Irrigation	Restricted Irrigation
E. coli (EC/100 mL)	≤ 5* & ≤ 50*	≤ 200
Turbidity (NTU)	≤ 2 (median)	-
BOD_5 (mg/L)	≤ 10*	≤ 25
SS (mg/L)	≤ 10*	≤ 35
TN (mg/L)	≤ 10	≤ 10
TP (mg/L)	≤ 1- 2	≤ 1

**80% of samples*
*** 95% of samples*

Table 29 Maximum permissible concentrations of metals and element

Metal / Element	Maximum Concentration (mg/L)
Al (Aluminum)	5.0
As (Arsenic)	0.1
Be (Beryllium)	0.1
Cd (Cadmium)	0.01
Co (Cobalt)	0.05
Cr (Chromium)	0.1
Cu (Copper)	0.2
F (Fluoride)	1.0

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Metal / Element	Maximum Concentration (mg/L)
Fe (Iron)	3.0
Li (Lithium)	2.5
Mn (Manganese)	0.2
Mo (Molybdenum)	0.01
Ni (Nickel)	0.2
Pb (Lead)	0.1
Se (Selenium)	0.02
V (Vanadium)	0.1
Zn (Zinc)	2.0
Hg (Mercury)	0.002
B (Boron)	2.0

At the EU level, the European Commission, through Regulation (EU) 2020/741 [36], has established a harmonized framework for the safe reuse of treated urban wastewater in agricultural irrigation. In effect since June 2023, the regulation aims to support water reuse as a strategic measure to address increasing water scarcity and climate change, while ensuring a high level of protection for public health and the environment. It sets out minimum quality requirements for reclaimed water used in agriculture, structured into four quality classes (A to D), which are defined according to the type of crops being irrigated and the irrigation method applied. Class A, intended for high-exposure scenarios such as the irrigation of food crops consumed raw, imposes the most stringent treatment and monitoring requirements, including advanced filtration, disinfection, and validation for microbiological contaminants. Classes B to D apply to scenarios with progressively lower exposure risks, such as the irrigation of processed food crops or non-food crops, and are associated with correspondingly tailored treatment and monitoring obligations.

Regulation (EU) 2020/741 and Greek JMD 145116/2011 both establish regulatory frameworks for the safe reuse of treated wastewater in agriculture; however, they differ significantly in scope, structure, and regulatory focus. The Greek JMD, adopted in 2011, was one of the most comprehensive national regulations of its time, addressing not only agricultural reuse but also urban applications, industrial processes, and environmental uses such as groundwater recharge. In contrast, Regulation (EU) 2020/741 introduces minimum requirements specifically for agricultural reuse and adopts a more risk-based, performance-oriented model. Its four water quality classes (A to D) are directly linked to the level of human

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exposure associated with different crop types and irrigation methods. Unlike the Greek legislation, the EU regulation does not set limits for nutrients, focusing instead on microbiological safety indicators such as E. coli and turbidity, and incorporating validation monitoring for pathogens such as viruses and protozoa in high-risk scenarios. A key innovation of the EU framework is the mandatory development of a Risk Management Plan (RMP) for each reuse scheme, requiring operators to identify hazards, implement mitigation measures, and define monitoring responsibilities throughout the entire reuse system, from treatment to end use. This introduces a more holistic and dynamic approach to managing health risks and achieving regulatory compliance across Member States.

As can be seen in Table 30 when comparing the water quality requirements of Regulation (EU) 2020/741 with those of Greek JMD 145116/2011, it is evident that the Greek framework is stricter and more comprehensive in several key areas. For instance, JMD 145116/2011 sets a limit of ≤ 5 EC/100 mL for unrestricted irrigation (with ≤ 50 EC/100 mL as a maximum single sample), whereas the EU regulation allows ≤ 10 EC/100 mL under its most stringent Class A category. The turbidity median value requirement in the Greek law is ≤ 2 NTU for unrestricted irrigation, compared to ≤ 5 NTU in the EU regulation for Class A. Furthermore, the Greek law includes clear thresholds for BOD_5 (≤ 10 mg/L), suspended solids (≤ 10 mg/L), and nutrients such as total nitrogen (≤ 10 - 15 mg/L) and total phosphorus (≤ 1 - 2 mg/L), while the EU regulation only prescribes BOD_5 ≤ 10 mg/L for Class A and does not regulate TN or TP. This difference reflects a fundamental divergence in regulatory philosophy. Specifically, the EU regulation considers nutrients like nitrogen and phosphorus potentially beneficial in certain reuse scenarios, as they may substitute conventional fertilizers through fertigation practices. In contrast, the Greek JMD regulates nutrients based on wastewater discharge standards, prioritizing uniform environmental protection and preventing nutrient accumulation in soil or adjacent water bodies. For restricted irrigation, the Greek limits for EC (≤ 200 EC/100 mL), BOD_5 (≤ 25 mg/L), and TSS (≤ 35 mg/L) are also more prescriptive than the broader Class B–D ranges in the EU table, where E. coli thresholds are ≤ 100, ≤ 1,000, and ≤ 10,000 EC/100 mL, respectively, and no explicit limits are provided for nutrients or turbidity (except Class A). Additionally, while the EU regulation includes monitoring for Legionella spp. when aerosolization risk exists, the Greek JMD does not specify Legionella but compensates with stricter general microbial and nutrient limits.

Table 30 Comparison of water quality requirements for agricultural reuse between Greek JMD 145116/2011 and EU Regulation 2020/741, focusing on key microbiological, physicochemical, and nutrient parameters under different reuse categories

Parameter	Greek JMD 145116/2011 – Unrestricted	Greek JMD 145116/2011 – Restricted	EU Regulation 2020/741 – Class A	EU Regulation 2020/741 – Classes B to D
E. coli (EC/100 mL)	≤ 5* & ≤ 50**	≤ 200	≤ 10***	≤ 100 (B), ≤ 1000 (C), ≤ 10,000 (D)
Turbidity (NTU)	≤ 2	–	≤ 5	–

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Parameter	Greek JMD 145116/2011 – Unrestricted	Greek JMD 145116/2011 – Restricted	EU Regulation 2020/741 – Class A	EU Regulation 2020/741 – Classes B to D
BOD_5 (mg/L)	≤ 10*	≤ 25	≤ 10	Secondary treatment standard (BOD_5 ≤ 25 or COD ≤ 125)
SS (mg/L)	≤ 10*	≤ 35	≤ 10	Secondary treatment standard
TN (mg/L)	≤ 10 – 15	≤ 10 – 15	Not regulated	Not regulated
TP (mg/L)	≤ 1 – 2	≤ 1 – 2	Not regulated	Not regulated
Legionella spp. (CFU/L)	Not specified	Not specified	< 1000 (only if aerosolization risk exists)	Not specified

**80% of samples*
*** 95% of samples*
**** 90% of samples*

5.1.2 Reclaimed water quality for Industrial uses

In the Attica region, industries represent a notable share of total water consumption, with applications ranging from machinery cleaning and cooling tower operation to the production of both edible goods, such as food and beverages, and non-edible products, including construction materials and marble. This diversity of water uses creates opportunities to reduce reliance on potable water and underground water sources through the integration of alternative water sources, particularly reclaimed water. Greek JMD 145116/2011 establishes the legal and technical framework for such substitution in the industrial sector, identifying specific reuse applications and prescribing quality requirements that ensure operational compatibility, protection of public health, and prevention of environmental degradation. However, industrial reuse is not permitted in facilities producing goods intended for human consumption where only water meeting potable water quality requirements is used for processes directly or indirectly associated with the production line.

The regulation distinguishes between two main categories of industrial reuse, based on the type of water application and the associated exposure risk. The first category, (i) industrial use – single-pass cooling water, applies to applications where reclaimed water is used once for cooling and then discharged, with minimal or no human contact during the process. The second category, (ii) industrial use excluding single-pass cooling water, covers reclaimed water used in recirculating cooling systems, boiler feedwater, and process water. For process water in particular, the regulation requires the implementing industry to apply

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any necessary advanced treatment systems, such as ion removal or other specialized processes to eliminate dissolved compounds or elements, ensuring the reclaimed water meets the technical and safety requirements of the specific industrial operation. For industrial use excluding single-pass cooling water, JMD 145116/2011 requires that reclaimed water undergo secondary biological treatment, followed by tertiary treatment and disinfection, ensuring high microbiological and physicochemical quality suitable for higher-exposure applications. In contrast, for single-pass cooling water, the regulation mandates secondary biological treatment and disinfection only, reflecting the lower exposure risk and less stringent quality requirements of this category.

The specific water quality limits for the reuse of reclaimed water in the industrial environment are presented in Table 31. For the first category, industrial use – single-pass cooling water, according to JMD 145116/2011, E. coli concentrations must not exceed 200 EC/100 mL. Most of water quality limits correspond to secondary treatment requirements by EU Directive 91/271/EEC. There is no turbidity requirement for this category, reflecting the lower relevance of suspended particle clarity in single-pass systems. BOD_5 is limited to 25 mg/L, while SS must remain at or below 35 mg/L to prevent scaling, fouling, or clogging in cooling system components. Nutrient concentrations are also regulated, with TN capped at 10 - 15 mg/L and TP at 1 - 2mg/L, helping to minimize the risk of biofilm growth and other operational issues in cooling infrastructure. For the second category, industrial use excluding single-pass cooling water, which includes applications such as recirculating cooling systems, boiler feedwater, and process water, the regulation prescribes stricter quality limits that require tertiary treatment, due to the higher potential for human exposure and the more sensitive nature of the associated equipment and processes. In this category, E. coli concentrations must average no more than 5 EC/100 mL, with a maximum allowable value of 50 EC/100 mL in any single sample, ensuring a high level of microbial safety. Turbidity must not exceed 2 NTU. BOD_5 and TSS are both limited to 10 mg/L, minimizing the risk of organic fouling, scaling, and particulate deposition. Nutrient concentrations remain regulated, with TN restricted to 10–15 mg/L and TP to 1–2 mg/L, in order to reduce the likelihood of biofilm formation and other nutrient-related operational issues. Nutrient limits follow the population-equivalent differentiation outlined in Section 5.1.1. Finally, the limits of metals and other elements presented in Table 29 also apply to this category.

Table 31 Water quality limits for reclaimed water intended for industrial reuse under Greek JMD 145116/2011, distinguishing between industrial use excluding single-pass cooling water and industrial use as single-pass cooling water

Parameter	industrial use excluding single-pass	Industrial use – single-pass cooling water
E. coli (EC/100 mL)	≤ 5* & ≤ 50*	≤ 200
Turbidity (NTU)	≤ 2	–
BOD_5 (mg/L)	≤ 10	≤ 25

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SS (mg/L)	≤ 10	≤ 35
TN (mg/L)	≤ 10 – 15	≤ 10 - 15
TP (mg/L)	≤ 1 – 2	≤ 1 - 2

**80% of samples*
*** 95% of samples*

5.1.3 Reclaimed water quality for urban and peri urban uses

Water is routinely required for a wide range of public and municipal services, including the irrigation of public parks, roadside vegetation, and recreational lawns; the cleaning of streets, pavements, and public squares; the operation of ornamental fountains and water features; the supply of water for fire-fighting systems; and dust suppression in construction zones or heavily trafficked areas. These activities, although not intended for direct human consumption, are carried out in spaces where people are often present or in close proximity to treated water. As such, the potential for direct or indirect human contact varies significantly across applications, influencing the stringency of the applicable reclaimed water quality requirements. Greek JMD 145116/2011 provides the legal and technical framework for the safe integration of reclaimed water into these uses, ensuring that water quality is appropriate for the specific type of activity and associated exposure risk. In this context, the regulation distinguishes between (i) Urban use and (ii) peri-urban green, both of which can utilise reclaimed water but are subject to quality limits aligned with public health protection, infrastructure performance, and environmental safety. Urban use covers a broad set of activities within densely populated areas, including Irrigation of public green spaces (parks, botanical gardens, and sports fields), cleaning of streets, pedestrian walkways, and public squares, water supply for ornamental fountains and decorative water features, fire-fighting networks and hydrants and dust suppression in construction sites or urban industrial zones. Peri-urban green refers to irrigation of landscaped areas, public parks, and recreational zones located outside dense urban cores. Examples include suburban sports facilities, landscaped road medians in peri-urban areas, and reforestation or environmental restoration projects adjacent to urban settlements.

The water quality requirements for urban and peri-urban uses under Greek JMD 145116/2011 (Table 32) are among the most stringent within the national reuse framework, reflecting the high potential for public exposure in these applications. For microbiological safety, the regulation imposes very strict E. coli limits an average of ≤ 2 EC/100 mL for 80% of samples and a maximum of ≤ 20 EC/100 mL for 95% of samples ensuring that reclaimed water poses minimal risk in environments where human contact is likely, such as street cleaning, irrigation of public parks, schoolyards, and sports fields. Turbidity is limited to ≤ 2 NTU, a critical requirement to ensure effective disinfection, as low turbidity improves UV penetration and reduces the likelihood of microbial survival. From a physicochemical perspective, BOD_5 must not exceed 10 mg/L, and SS is capped at a notably low ≤ 2 mg/L, further minimizing the risk of biofilm formation, surface fouling, and aesthetic issues in public spaces. Nutrient limits follow the population-equivalent differentiation outlined in Section 5.1.1. While nutrients can be beneficial in some irrigation contexts, in urban and peri-urban applications their levels must be tightly controlled to prevent excessive plant growth, odour development, and eutrophication in receiving water bodies. The required treatment sequence for

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reclaimed water in these uses includes secondary biological treatment, followed by tertiary treatment (e.g., sand filtration, membrane filtration, or equivalent clarification processes) and final disinfection (commonly via chlorination or UV). The tertiary stage is essential for achieving the low turbidity threshold, while disinfection targets microbial pathogens. In situations with high public exposure, such as spray irrigation in urban parks, robust disinfection with residual monitoring is necessary to ensure pathogen control up to the point of use. Finally, the limits of metals and other elements presented in Table 29 also apply to this category.

Table 32 Water quality limits for reclaimed water intended for urban and peri-urban uses under Greek JMD 145116/2011

Parameter	Urban use – Peri urban use
E. coli (EC/100 mL)	≤ 2* & ≤ 20*
Turbidity (NTU)	≤ 2
BOD_5 (mg/L)	≤ 10*
TSS (mg/L)	≤ 2
TN (mg/L)	≤ 10 - 15
TP (mg/L)	≤ 1 - 2

5.1.4 Reclaimed water quality for ecological uses

In the Attica region, reclaimed water can also be applied for environmental protection and resource management purposes, notably through aquifer recharge. This practice involves the intentional introduction of high-quality treated effluent into groundwater systems via subsurface infiltration through a soil layer. Direct injection of reclaimed wastewater is permitted only to aquifers not used for potable water. The objective is to restore or enhance groundwater reserves that are, or may in the future be, utilised for potable water supply. Given the direct link between these systems and drinking water resources, the applicable reclaimed water quality requirements are among the most stringent within the national framework, ensuring the preservation of groundwater status and the protection of public health.

Aquifer recharge is permissible only when reclaimed water meets the quality requirements of Table 33. The water quality limits for aquifer recharge reflect the dual objective of maintaining groundwater quality suitable for potable use and preventing adverse environmental impacts. For microbiological quality, E. coli concentrations must be ≤ 2 EC/100 mL for 80 % of samples and ≤ 20 EC/100 mL for 95 % of samples. Turbidity must not exceed 2 NTU, a critical parameter for both effective disinfection and protection of aquifer infiltration capacity. Organic matter and solids are strictly controlled, with BOD_5 ≤ 10 mg/L and SS ≤

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2 mg/L. Nutrient limits follow the population-equivalent differentiation outlined in Section 5.1.1. Finally, the limits of metals and other elements presented in Table 29 also apply to this category.

Table 33 Water quality limits for reclaimed water intended for ecological uses (aquifer recharge) under Greek JMD 145116/2011

Parameter	Ecological use – Aquifer recharge
E. coli (EC/100 mL)	≤ 2* & ≤ 20*
Turbidity (NTU)	≤ 2
BOD_5 (mg/L)	≤ 10
TSS (mg/L)	≤ 2
TN (mg/L)	≤ 10 – 15
TP (mg/L)	≤ 1 – 2

5.2 Policy gaps and legal limitations in the use of alternative water resources

The regulatory framework governing water reuse in Greece is primarily defined by Joint Ministerial Decision (JMD) 145116/2011, which sets the conditions for the planned reuse of treated wastewater, and by JMD 5673/400/1997, which establishes discharge standards for wastewater from municipal WWTPs and certain industrial sectors. Together, these instruments provide the backbone for national water reuse governance. However, despite this formal structure, there are significant legal and policy gaps that limit the full potential of alternative water sources and hinder the broader uptake of reuse practices.

Exclusion of Internal Industrial Reuse: JMD 145116/2011 does not apply to the internal reuse of treated wastewater within the same industrial facility. As defined in the decision, "recycling of industrial wastewater", the recovery and reuse of wastewater generated by an industrial installation in its own production processes, is excluded from its scope. This means that the quality standards, treatment requirements, and monitoring obligations prescribed by the 2011 framework apply only when treated water is supplied to third parties. Internal reuse remains governed only by the environmental permit of the facility, which can result in inconsistencies in water quality management, variability in monitoring frequency, and lack of national benchmarks. While this exclusion avoids over-regulation of closed-loop industrial systems, it also necessary to have a uniform framework.

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Absence of Provisions for Other Alternative Water Sources and fit for purpose practises: The scope of JMD 145116/2011 is limited to treated wastewater from municipal WWTPs and certain industrial sources. Other potential non-conventional water sources are entirely absent from the national framework. These include (i) Rainwater harvesting, which could supply irrigation, cooling, or street cleaning needs but currently lacks national quality standards or monitoring requirements, (ii) Stormwater capture and treatment and (iii) Greywater. In addition, although several potential reuse practices have been incorporated into the current legislative framework, the overall range of applications remains limited. The absence of a comprehensive, fit-for-purpose approach that systematically identifies further potential uses and establishes corresponding water quality standards continues to restrict the broader adoption of water reuse.

Omission of Fertigation Practices in National Reuse Law: Another notable gap in the current Greek reuse legislation is the absence of provisions addressing fertigation, the combined application of irrigation water and nutrients through reclaimed water. Although treated wastewater often contains residual nitrogen, phosphorus, and potassium that could benefit agricultural production, JMD 145116/2011 frames irrigation strictly as a water supply activity, without reference to its potential nutrient contribution. This omission contrasts with evolving EU and international approaches that promote resource recovery and circular agriculture.

Gaps in Public Transparency and Data Availability: While JMD 145116/2011 sets out monitoring requirements for water quality in reuse applications, it does not impose explicit obligations for the public disclosure of monitoring results. This lack of transparency can undermine public confidence and limit opportunities for informed dialogue between regulators, stakeholders, and end-users. In contrast, Regulation (EU) 2020/741 explicitly requires Member States to ensure that key information, such as water quality performance, compliance results, and monitoring data is made publicly available. This approach has proven instrumental in countries with advanced reuse schemes, where transparency not only enhances public trust but also strengthens regulatory accountability and facilitates knowledge exchange across sectors.

Given the identified gaps, it is essential to upgrade the national water reuse framework to ensure alignment with evolving EU policies, particularly Regulation (EU) 2020/741 on minimum requirements for water reuse and the Urban Wastewater Treatment Directive (UWWTD, Directive 2024/3019). The revised UWWTD, which entered into force on 1 January 2025, introduces stricter treatment standards, extended coverage to smaller communities, mandatory nutrient and micropollutant removal (including pharmaceuticals and microplastics), and a legally binding target for energy neutrality in WWTPs by 2045. Crucially, it also requires Member States to promote the reuse of treated wastewater, especially in water-scarce areas. To remain robust and future-proof, Greek reuse legislation should integrate these advancements, expanding its provisions to support wastewater reuse from smaller plants, incorporating emerging contaminant treatment requirements, and strengthening resource-efficiency goals. This means enriching the framework not merely with EU goals but tailoring them to Greece's specific environmental and water-security context, thereby enabling broader, safer, and more sustainable reuse applications.

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6 Conclusions and recommendations

This report provides a systematic assessment of non-domestic water demands in the Attica region, covering agriculture, livestock, industry, tourism, and urban green sectors. By integrating multiple datasets—from EYDAP, River Basin Management Plans, climate adaptation studies, and national statistics—and applying advanced methods of data disaggregation and analysis, the study offers a detailed understanding of both spatial and temporal variations in water demand.

The analysis shows that agricultural water consumption in Attica, while relatively modest compared to other Greek regions, relies heavily on private boreholes, highlighting potential sustainability and monitoring challenges. Livestock water use is limited at the regional scale but is concentrated in specific municipalities, making local management crucial. Industrial water consumption represents a significant portion of total abstractions, with the oil industry emerging as a high-volume consumer and general industrial demand exhibiting pronounced seasonal peaks in summer. Tourism contributes to strong seasonal pressures, particularly in Central Athens and the Saronic islands, while urban green irrigation adds an additional layer of demand, especially during peak summer months.

Key cross-cutting observations include:

- **Strong seasonal variations** across all sectors, with clear summer peaks.
- **High dependence on groundwater resources**, especially private abstractions, complicating monitoring and sustainable management.
- **Data gaps** in industrial and livestock water use, as well as incomplete information on groundwater withdrawals.
- **Growing variability in water quality requirements**, highlighting opportunities for a fit-for-purpose approach (e.g., reclaimed wastewater for irrigation or industrial use). The analysis indicates potential efficiency gains by aligning sectoral demands with appropriate water quality standards without compromising safety. It also underscores challenges in fully implementing European and national regulatory frameworks (e.g., EU Regulation 2020/741, WFD 2000/60/EC, JMD 145116/2011), emphasizing the need for closer alignment of local practice with legislation.

Based on these findings, several recommendations are proposed:

- **Enhance data recording and integration:** Systematically monitor private groundwater abstractions, livestock, and industrial water use to improve the reliability of future demand forecasts.
- **Promote reuse of reclaimed wastewater:** Encourage non-potable applications in agriculture, industry, and urban green irrigation to reduce freshwater demand.
- **Implement seasonal demand management:** Apply adaptive measures, such as flexible tariffs, scheduled irrigation, and awareness campaigns, to mitigate peak summer pressures from tourism, industry, and urban green irrigation.
- **Engage stakeholders effectively:** Conduct surveys, interviews, and participatory sessions with municipalities, industry, and sectoral associations to foster bottom-up planning and implementation.

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- **Incorporate findings into regional circular water strategies:** Strengthen the link between local initiatives and EU directives (e.g., Water Framework Directive, Water Reuse Regulation, Water Resilience Strategy) to ensure resilience and sustainable growth under climate change.

In conclusion, this report provides critical analytical insights to support the development of water symbiotic flows in Attica. By addressing data gaps, promoting water reuse, and advocating integrated management approaches, it demonstrates how the operationalization of the fit-for-purpose concept and compliance with regulatory frameworks can transform reclaimed water into a strategic resource, enhancing resilience, sustainability, and circularity in the region's water future.

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Annexes

Annex 1 Theseus Questionnaire Task 7.1

Analysis of water needs by use in the Attica Region

This questionnaire aims to collect data, knowledge and experiences regarding the main users of water resources in the Attica Region, in order to conduct a comprehensive analysis of water flows for all uses except domestic.

In this case, the analysis will examine the water needs for each category of users , while at the same time incorporating the qualitative dimension , so that the calculated quantities of water demand can be correlated with the appropriate use of water for each purpose, in accordance with the respective European and National Legislation.

Your responses will contribute to the development of an upgraded water demand management plan for the Attica Region, aiming to achieve reduced water flows from all users. Furthermore, this process will strengthen cooperation with competent bodies at regional and local level, as well as with representatives from industry, academia and local communities.

The editing and drafting of this questionnaire was carried out by the following laboratories of the School of Civil Engineering of the National Technical University of Athens:

- Urban Water Management and Hydroinformatics Group
- Sanitary Engineering Laboratory

For any questions or clarifications, you can contact the researchers:

- Dr. Klio Monokrousou - ✉ kmonokrousou@gmail.com
- Dr. Argyro Plevri - ✉ plargyro@gmail.com

Which of the following categories do you belong to?

Attica Region
Municipality
Industry
Agricultural Sector
Tourism Sector

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Section A: Quantitative data on water demand (Municipalities)

1. How are water uses distributed in percentage in your Municipality?

	0-20%	21-40%	41-60%	61-80%	81-100%
Watter supply					
Irrigation					
Livestock					
Industry					
Other uses					

2. What is the monthly amount of water required for the irrigation of urban green spaces in your Municipality?

3. What is the amount of water required for irrigation of rural areas in your Municipality?

(Data from recorded boreholes or from network water or from another alternative source)

4. What is the quantity of water for the needs of industry in your Municipality?

(Data from mains water or another alternative source)

5. What is the demand for water for other uses in your Municipality (e.g. tourism, livestock farming, etc.)?

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6. What is the seasonal variation in water demand per use in your Municipality?

Please clarify for each use of water that you know (Water uses: Water supply, Irrigation, Livestock, Industry, Other uses).

7. What are the projected trends in water demand per use in your Municipality?

(Select each item from 1 – Decreases a lot to 5 – Increases a lot)

	1	2	3	4	5
Watter supply					
Irrigation					
Livestock					
Industry					
Other uses					

8. Which of the following factors most affect water demand in your Municipality?

(Rate each item from 1 – Does not affect to 5 – Affects a lot)

	1	2	3	4	5
Water consumption					
Urbanization					
Leaks in the water supply network					
Lack of decentralized water collection/treatment systems					
Irrigation practices					
Over-pumping of groundwater/ illegal water abstractions					
Lack of institutional framework					
Lack of awareness in society					

9. Which of the following adaptation measures do you consider most important for addressing water adequacy issues in your Municipality?

(Rate each item from 1 – Not at all Appropriate to 5 – Very Appropriate)

	1	2	3	4	5

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Improving water infrastructure					
Implementation of water saving technologies					
Recycling and reuse if treated water					
Rainwater collection and reuse					
Strengthening water storage infrastructure					
Artificial recharge of groundwater systems					
Implementation of controlled environmental agriculture practices					
Development and implementation of policies for sustainable management and efficient use					
Understanding the importance of saving water					
Creating natural water retention and storage solutions					
Reduction of impervious surfaces					
Installation of desalination units					

Section B: Water demand quality data (Municipalities)

1. What are the water sources you use to meet your needs?

(You can select more than one option)

- Water supply network
- Wells
- Recycled water
- Rain Water
- Another

2. For each of the water sources you mentioned in the previous question, please specify the uses for which you utilize it.

(e.g. Recycled water: Operation of fire extinguishing systems, Water supply network: irrigation of urban greenery)

_____

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3. Is there a Wastewater Treatment Plant (WWTP) within your Municipality?

- YES
- NO

If so, is the reclaimed water used for any of the uses?

- YES
- NO

If you answered "YES", please specify what use it is put to.

_____

If you answered "NO", what is the main reason it is not being utilized? Do you think it could be used in the future? If so, for what use?

A prerequisite for its utilization is the coverage of the quality limits set by Regulation (EU) 2020/741 for the reuse of water.

_____

4. Have you noticed any quality problems in the water sources you use?

- YES
- NO

If you answered "YES", please specify the water source and the type of problems identified.

(e.g. Source: Drilling, Problem: Water Pollution)

_____

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5. Have you implemented measures to improve water quality?

- YES
- NO

If you answered "YES", please specify the water source and the measures you implemented.

(e.g. Source: Drilling, Measure applied: Water filter)

_____

6. Do you observe seasonal variations in water quality?

- YES
- NO

If you answered "YES", please specify the water source and its seasonal variations.

(e.g. Source: Surface Water, Seasonal variation: Better water quality was observed in the winter months)

_____

7. How do you evaluate the quality of the water from the source that covers the largest percentage of your needs, based on the following criteria?

(Rate each item from 1 – Not at all Appropriate to 5 – Very Appropriate)

	1	2	3	4	5
Hardness					
Smell/Taste					
Clarity					
Temperature					

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8. How do you ensure that the water you use meets the required quality standards for consumption or use, and how often is the relevant testing carried out?

(Open question)

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9. Do you test for micropollutants and microplastics in any of the sources you use?

- YES
- NO

If "YES", please specify which water source and the frequency of checks.

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10. Do you believe that the quality of the water from each source you use:

- A It is proportional to the needs of each use
- B It is often of higher quality than required (e.g. drinking water from the network for irrigation of green spaces)

If you chose option "B", have you taken measures to reduce the use of higher quality water than required or do you plan to do so in the future? If so, what measures are you considering?

(Open question)

Section C: Participant details

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Name (optional):

_____

Carrier:

_____

Consent to data collection and processing for the Theseus project

The purpose of this research is related to the objectives of the Horizon Europe Theseus project, funded by the EU under grant No. 101178059. Personal data will be processed in accordance with the General Data Protection Regulation of the European Union (Regulation (EU) 2016/679) (GDPR). The data will be stored on the project's internal network for the duration of the project. The information will only be used for the purposes of the project. Further details will be described in the D1.1 Theseus Ethics and D1.6 Data Management Plan, to be delivered in May 2025. I am aware that I can ask the researchers questions at any time if something is unclear and to take the necessary time to decide whether I want to participate. I am aware that I can discontinue my participation at any time by contacting the project's Data Protection Officer: Charalambos Manousiadis, c.manousiadis@iccs.gr, +30-210-772-2280. I agree to provide the requested data and information and confirm that my participation is voluntary. I agree to the processing of my personal data in accordance with the procedures mentioned.

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