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WATER PLANNING AND MANAGEMENT IN SPAIN IN A CLIMATE CHANGE CONTEXT: FACTS AND PROPOSALS

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ABSTRACT. Water planning and management in Spain is being affected by the recorded effects of the current climate change process. The traditional paradigm based on a policy of continuous water supply no longer fits with the forecasts of decreasing water flows identified by climate and hydrological modelling. The guarantee of water security, a guiding principle of planning, as indicated by Spanish Climate Change Law (2021), requires the incorporation of new water resources that allow water management to be less dependent on rainfall. Effective demand management, the incorporation of regenerated water with a high level of purification, the inclusion of rainwater for urban and leisure uses and the use of desalinated water in coastal areas to be used mainly for urban water supply are presented as viable alternatives to the development of large public hydraulic works that prove ineffective in drought conditions. This paper presents an updated balance of water resources and demands and analyses the increasing difficulty of hydrological planning in our country within a complex political context that requires cooperation and governance actions in water matters. A series of recommendations are proposed, from a geographical perspective, for the necessary adaptation of hydrological planning to the effects of climate change in Spain.

Planificación y gestión del agua en España en el contexto del cambio climático. Realidades y propuestas

RESUMEN. La planificación y gestión del agua en España se está viendo afectada por los efectos registrados del proceso actual de cambio climático. El paradigma tradicional basado en una política de continua oferta de agua ya no se ajusta a las previsiones de disminución de caudales que señalan la modelización climática e hidrológica. La garantía de la seguridad hídrica, principio rector de la planificación, como señala la Ley de Cambio Climático de 2021, requiere de la incorporación de nuevos recursos hídricos que permitan hacer menos dependiente la propia gestión del agua de las precipitaciones. La eficaz gestión de la demanda, la incorporación de aguas regeneradas con alto nivel de depuración, la inclusión de las aguas pluviales para usos urbanos y de ocio y el uso de aguas desaladas en zonas de litoral con finalidad principal de abastecimiento se presentan como alternativas viables frente al desarrollo de grandes obras públicas hidráulicas que se demuestran ineficaces en condiciones de sequía. El trabajo muestra un balance actualizado de recursos y demandas de agua y analiza la creciente dificultad de la planificación hidrológica en nuestro país en un contexto político complejo que requiere acciones de cooperación y gobernanza en materia hídrica. Se presentan una serie de recomendaciones, desde la geografía, para la necesaria adaptación de la planificación hidrológica a los efectos del cambio climático en España.

Keywords: hydrological planning, climate change, water security, governance, demand management.

Palabras clave: Planificación hidrológica, cambio climático, seguridad hídrica, gobernanza, gestión de la demanda.

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1. Introduction

Water is one of the elements of the natural environment that is most sensitive to the effects of the current global warming process. The changes in rainfall patterns recorded over the last few decades in many regions of the world (including Spain) are conditioning the future of the planning and management of this resource, which should adapt to the alterations in the climate elements indicated by modelling (Caretta *et al.,* 2022).

Water is an essential element for the development of societies. If water is not controlled, civilising work cannot take place. This has been the case throughout the history of humankind to the present day. Water is the cause of development but it also gives rise to conflicts between societies. The pressure on water resources has been increasing in recent decades (Karamidehkordi *et al.,* 2024). Populated countries and regions around the world with growing economic activity require an increasing supply of water. Sometimes, these resources do not exist and generate disputes between territories (Fernández-Jáuregui *et al.,* 2017; Angelakis *et al.,* 2021). The future perspectives in terms of water resource management on a global level indicate a greater complexity in the planning of water uses. Fortunately, in Spain there are no intense conflicts related to water resources, although there is territorial tension with regard to the use of water. This situation requires decisions to be made in order to guarantee a water supply in a difficult climate context (Martínez-Fernández *et al.* 2020).

There are many studies that analyse the impact of the current climate changes on precipitations, the volume of water available on the Earth's surface and the differences in each climate region. On a global level, we can observe an increase in precipitations in the inter-equatorial region, a decrease in the areas affected by subtropical subsidence, due to the polar expansion of the Hadley cells, and an increase in mid and high latitudes, due to the greater intensity of the atmospheric readjustment processes with an increase in meridian circulations. (Muñoz *et al.,* 2020; Cresswell-Clay *et al.,* 2022)

Climate change affects four principal plans in modern society. That is, it obliges specific mitigation and adaptation actions to be designed to guarantee well-being. The measures to implement affect the planning processes of economic activities, particularly those most exposed to the consequences of the change in the climate elements (temperatures and precipitations), such as agriculture and tourism. Furthermore, the guidelines for territorial planning also need to be adapted. In other words, the assignment of new uses to the land has, until now, been carried out within a context in which the climate was unalterable but this is no longer the case. Water planning requires special attention and should be focused on the management of demand and not so much on a resource supply policy in view of the irregularity in precipitations. Finally, emergency planning should be adapted due to the increase in extreme weather events, the increasing prominence of certain climate hazards and the emergence of new risks within the framework of climate modelling. In short, fundamental planning changes are required to guarantee the future functioning of a society, driven by the modifications recorded in climate conditions (Olcina Cantos, 2024).

The twenty-first century is, or should be, the century of the commitment to sustainability in territorial and economic processes and of the adaptation to climate change. It should be the guiding principle steering the actions of governments and individuals. The definition of sustainable development is complex, hence it is preferable to sideline theoretical aspects and address its practical embodiment, which should be governed by rationality, common sense, ethics, prudence and the acknowledgement of its transversal and multidisciplinary nature. Sustainable development, understood in this way as a guideline for action, is a development that is implemented according to the features of the natural environment in which it takes place; a process that does not seek to surpass the limits imposed by nature or, in any case, which contemplates actions that contribute, where possible, to overcoming these limits (Elorrieta-Sanz and Olcina-Campos, 2021).

In the European context, these principles are set out in two documents that have helped to guide policies over the last two decades. The European Territorial Strategy (1999) and the Water Framework Directive (2000). Both of them contain the objectives that territorial planning and water planning should fulfil, which should be oriented towards the respect for the territory, the reduction of risks and the search for a social well-being that does not irreversibly alter the features of the environment (Farinós-Dasí, 2021; Navarro-Sousa, 2022). The incorporation of the effects of climate change in territorial and water policies is a principal action for the European Union (EEA, 2024 a). Moreover, addressing hydrological extremes is the main focus of policies and promotes the research in the territory of the Union in the search for adaptation strategies (EEA, 2024 b).

In Spain, we have struggled to incorporate these action guidelines in the sustainable planning of territories and water; but the evident effects of the current global warming process have fuelled the implementation of initiatives consisting in public actions aimed at managing natural resources (land, air, water, coasts) under the principles of protecting them against the unstoppable human desire for a transforming and continuous economic growth of the environment (Solorzano-Chamorro *et al.,* 2022). This concept of development based on the continued use of resources, including water, has begun to experience changes in Spanish society and even in economic sectors, which are perceiving an exhaustion of these resources and their shortage due to a global climate change process whose effects are visible in Iberian latitudes (Fundación BBVA, 2022; CEOE, 2023).

In Spain, traditional water planning has been governed by supply policy (Figure 1). That is, in response to an existing demand, the State, responsible for large-scale water planning, should cover this use with its own resources from the river basin or from other basins when its own resources are insufficient. It is a planning model that is based on the principle that the water existing in Spain is abundant and sufficient to supply all of the existing demand. And this is true, although with an important geographical nuance: the unequal regional distribution of precipitations and the uneven distribution of water resources in the country as a whole. Therefore, the concepts of surpluses and deficits of water resources arise in the territories (Morote Seguido, 2014; Sotelo Pérez *et al.* 2021).

Law 7/2021 on climate change proposes an interesting concept as a guiding principle for water planning within the current context of climate change: water security (art.19). We must understand this expression from science not politics, given that it runs the risk of being interpreted as the objective that should be fulfilled with some kind of action, that is, reinforcing the continued water supply policy. Water security refers to the guarantee of the supply of the demands existing in a territory (prioritised according to the Water Law). A supply designed from a demand management perspective that respects the environmental values of the water resources (surface and ground) and avoids conflicts between territories to achieve this security. This process should be under constant review in relation to climate evolution at all times (López Gum and Vargas Amelín, 2020).

This study analyses the state of the question of water planning in Spain. It presents an updated balance of resources and uses and proposes measures for the efficient management of situations of circumstantial water deficit (droughts) and structural water deficit (aridity) that have an impact that differs in terms of its diversity and intensity across the Spain territory. It addresses the relationship between natural limits and political-administrative limits in water planning and management in Spain which makes this task even more complex, sometimes generating territorial disputes and conflicts. It calls for a necessary change in the paradigm of water planning in Spain to adapt it to the European policy determinations on water and, particularly, the effects of current climate change that are generating a greater irregularity in precipitations, with evident decreasing trends in some of its territories.

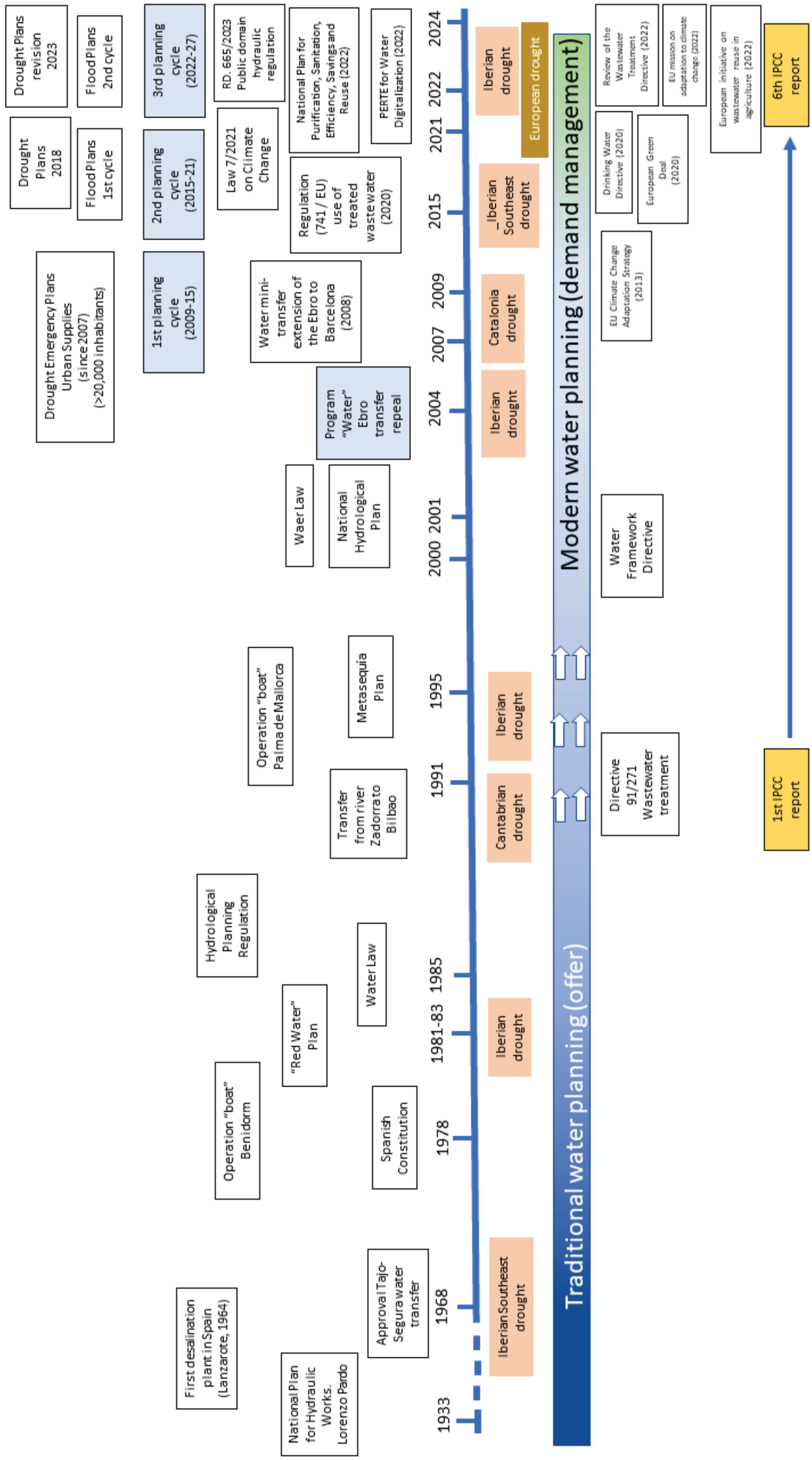


Figure 1. Evolution of the water policy in Spain 1933-2024.

2. Method and sources

This study uses data, reports and official documents of government departments (state and regional) related to water management and planning. Furthermore, in order to analyse local cases, company reports on the distribution of drinking water and reports of the Spanish Association of Water Supply and Wastewater (AEAS) have been consulted. Moreover, it also uses the projects applying for European economic subsidies (Next Generation Funds) processed by the Spanish Government and projects related to water management, particularly with the promotion of the reuse of treated water.

For references of a climate nature, the most recent publications on the relationship between rain, climate change and the effects on water resources in Spain published by Spanish research groups have been used. All of the sources consulted are free to access online, except the local scale projects, which have been obtained by the author (Table 1).

Table 1. Sources used relating to the planning and management of water in Spain (2024).

Scale of study	Sources consulted
Europe	- European Water Framework Directive - European Directive on urban wastewater treatment. Reports on the status of the compliance with the Directive (European Commission). - European Floods Directive - European Drought Observatory (EDO) - Reports on the status of water in Europe (European Environment Agency, 2024)
Spain	- River Basin Plans (1st, 2nd and 3rd planning cycle) - Drought Management Plans - Law of the National Hydrological Plan 2001 - Water Law of 2001 - Water Programme 2005 - Portal of the Spanish National Recovery, Transformation and Resilience Plan (Next Generation Funds). Water Section. - Meteorological drought monitor - Reports on the State of the Climate in Spain (AEMET) - Reports and research articles - Reports of AEAS, FEDEA, AEDyR, CEOE, Instituto Elcano.
Autonomous regions	-Wastewater treatment plans -Plans for the reuse of treated water
Local scale	- Annual reports on drinking water management - Local experiences in the management of droughts and floods (Barcelona, Alicante, Madrid, Seville)

One of the most noteworthy aspects in the study of water is the lack of transparency in the information related to water data; in some cases because no precise calculations are made (agricultural uses) as there are no water measurement systems on the plots of land; in others because there is no record of the unregistered resources in the urban environment (losses in the supply network); and, in general, because, traditionally, the consultation of these data has not been facilitated for professionals and experts of official bodies or private companies in the sector (PWC, 2018). The European Directive on the right to information on the environment (2003/4/EC) has not been effective in the public dissemination of water data (Razquín Lizárraga, 2018). The implementation of the so-called PERTE for the digitalisation of the water cycle in 2022 as part of the Spain's National Recovery, Transformation and Resilience Plan (Government of Spain, 2022), which includes, among other actions, the creation of a Water Management Observatory in order to improve the governance and management of the digital infrastructure, could become the great public water databank.

The work method used is the hypothetical-deductive method. It responds to the objectives stated in the research through the analysis of the data consulted and readings. It is based on the precept that the guiding principle of water planning in Spain (continuous supply of water) is incorrect within the current context of climate change and proposals are presented to implement a change in this paradigm within the principles of sustainability and adaptation. All of this is backed with data and own analyses and those of researchers who have studied this topic in recent years.

3. Results

3.1. A climate context of uncertainty: Effects on dry sequences

Water planning based on long-term climate scenarios no longer makes sense in Spain. The current climate context, which clearly reveals the effects of global warming in the principal climate elements (temperatures and precipitations), obliges us to periodically review the forecasts and their effects on the available water resources. In Iberian latitudes, the current climate change is manifested in an increase in temperatures and an overall loss of thermal comfort, with a more irregular behaviour of precipitations and the alteration of seasonal rainfall patterns (Cramer *et al.,* 2018; Meseguer-Ruiz and Olcina Cantos, 2023). In addition, there is a greater intensity and frequency of extreme weather events, related to temperature and precipitation. The latter is related to the intensification of the global energy readjustment processes and the warming of the seas that surround the mainland territory, particularly the Mediterranean sea basin (Olcina Cantos*,* 2024).

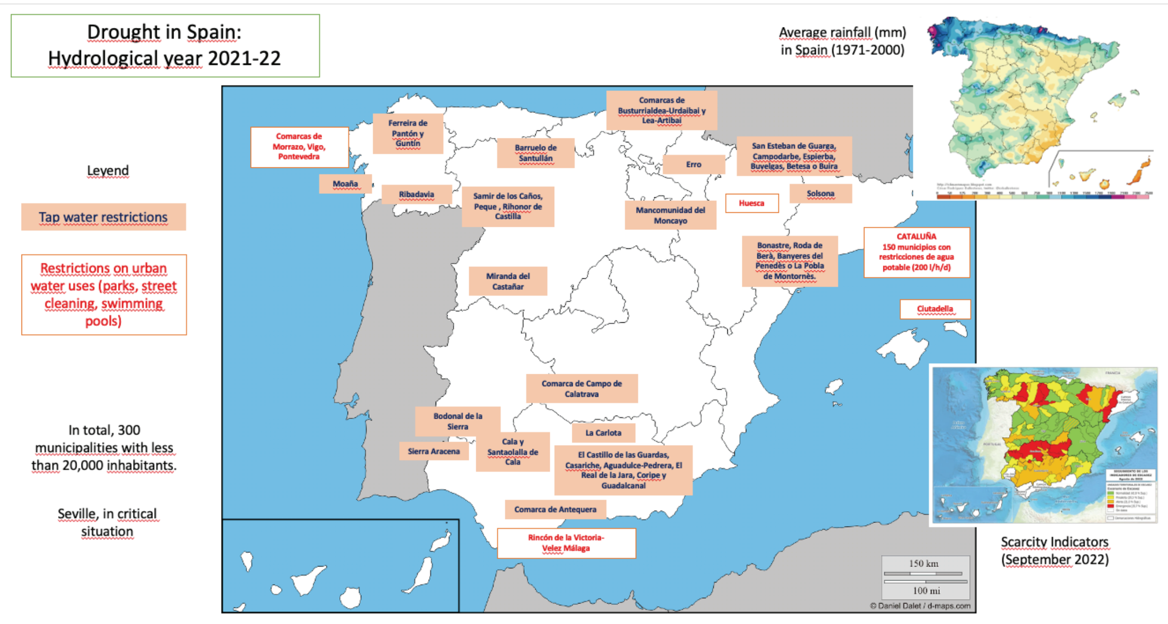
Different studies have analysed the change in the seasonal precipitation patterns in Spain (Ruiz-Sinoga *et al.,* 2011; Acero *et al.,* 2012; Serrano-Notivoli, 2017; CEDEX, 2021; Senent-Aparicio *et al.,* 2023), highlighting the "Mediterraneanisation" process of the maximum precipitations towards the west of the peninsula (Cordillera Ibérica sector) with a main peak in autumn (González-Hidalgo *et al.,* 2010). Recently, González-Hidalgo *et al.* (2023, 2024) have shown the recent trend in rainfall in the Iberian peninsula with an increase in the amounts in autumn and a reduction in spring (Paredes *et al.,* 2006). This is particularly important for the planning and management of water resources, given that the volumes of water that can accumulate in spring are fundamental for guaranteeing the demands of the summer season, which increase considerably due to the increase in agricultural and tourist uses and the increase in the real evaporation due to the higher temperature. This trend of a reduction in spring rains is significant in the southern sector of the Cordillera Ibérica, where the sources of two important rivers are located (Júcar and Tajo), which serve demand systems (agricultural and urban-tourist) that are highly valuable to the Spanish economy (Miró *et al.,* 2021, 2023).

Drought has become an important study topic for water planning in Spain (Vicente-Serrano, 2021). There is uncertainty as to the duration of droughts which have been occurring since the beginning of the current century. Contrary to the long sequences that occurred in the second half of the twentieth century that generated droughts in the Iberian Peninsula (Iberian droughts), with a duration of between 3 and 5 years (calendar year), the droughts occurring in the twenty-first century are more intense, but with a shorter duration (one or two calendar years) (González *et al.,* 2020; Torelló-Sentelles *et al.,* 2022; Trullenque-Blanco *et al.,* 2024). Similarly, the drought sequences display diverse regional manifestations (droughts in the north-east of the peninsula, south-eastern droughts, Cantabrian droughts) (Olcina, 2001; Lana *et al.,* 2021), with their own calendars of development and repercussion on the percentage reduction in precipitation recorded with respect to the annual averages.

The occurrence of shorter and more intense droughts would correspond to the changes in the overall atmospheric circulation in mid latitudes, with an expansion of the Hadley cell towards the pole (Xian *et al.,* 2021; Cresswell-Clay *et al.,* 2022), which generates a greater probability of anticyclonic days each year, with energy readjustment days with the installation of cold air masses in mid and hight layers of the troposphere, which generate unstable configurations (cold drops) and the possibility of the occurrence of occasional intense rain events, which, in general, cannot be used to satisfy agricultural demand (Olcina Cantos, 2024).

In any case, the shortage of water for agricultural and particularly urban use generated by a drought situation reveals a failure in water planning and management on a water basin, regional or local scale. In the dry sequence recorded in Spain during the hydrological years 2021/22 and 2022/23, it is interesting to observe that the population nuclei that suffered from a shortage of supply and in which emergency measures had to be applied are small areas in the interior or north of the peninsula, with no alternative supply sources and which have not optimised their drinking water systems so as to guarantee the storage of volumes of water for a supply of three months (Fig. 2 a and b).

a)



b)

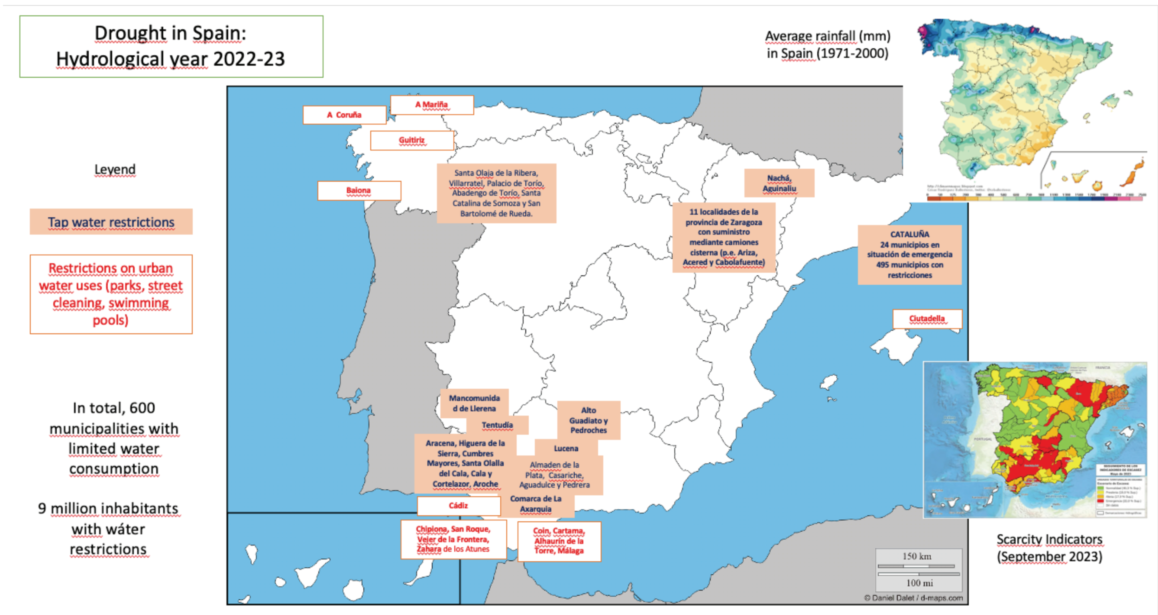


Figure 2. Map of towns affected by an urban water supply shortage. Hydrological year 2021/22(a) of towns affected by an urban water supply shortage. Hydrological year 2022/23(b). Source: Own elaboration based on monthly drought reports (Spanish Ministry of Ecological transition and Demographic Challenge) and regional press news reports.

In Spain, the risk map, with its integral components (hazard, vulnerability and exposure) reveals significant regional differences (Fig. 3). Based on the analysis of the effects of the latest droughts recorded in Spain over the last three decades on water security, it is possible to represent a map of the hazard, vulnerability and exposure to drought, which shows the need to activate water management mechanisms for supplying areas with a greater volume of annual precipitation, given that their excessive dependence on this climate element generates conditions of shortages in supply at times of less rainfall.

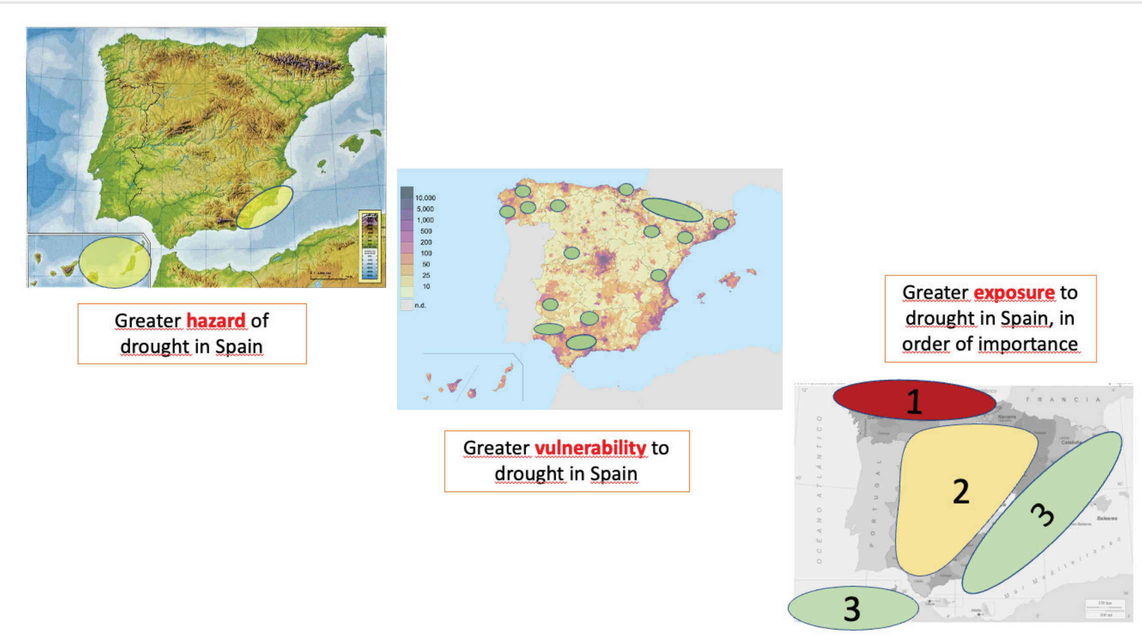


Figure 3. Drought in Spain in terms of risk analysis.

3.2. In a complex political context: Water, State and Autonomous Regions

As a general rule, the local scale of the planning and management of natural resources is the work unit closest to the citizens. However, the general interests can (usually) clash with individual (local) interests. Hence, there is a need to establish a hierarchy for the planning and management of natural resources. The hierarchy of natural resource planning and management in Spain integrates the global sustainable development goals (SDGs) established by the international bodies to which the Spanish government belongs; the European scale, which is decisive due to the obligation of member countries of the European Union to comply with the environmental directive; the State scale, which, in terms of the environment, is limited to the enactment of general regulations (water, coasts, natural and protected spaces, climate change) and fundamentally planning and managing the public domain (water, coast); and the Regional Governments, which are the key actors in environmental management because this competence has been transferred to them by constitutional mandate.

In recent years, legal disputes have arisen between the regional and state levels due to the interest of the autonomous regions to control the planning and, most of all, the management of two basic resources whose public domain belongs to the state (water and coast). Finally, land uses are planned on a local scale, including the natural environment and its resources; some autonomous regions have been given the power to establish and manage natural spaces that are protected on a local or supralocal level with the final approval by the regional government.

The conflicts between administrations, depending on their working scale are resolved by higher legal entities: regional, state or European. This is because the resources found in the natural environment are a potential source of revenue, which is desired by the management level closest to the resource (local and regional). In Spain, the planning and management of the natural environment and its resources is regulated in Articles 148 and 149 of the Constitution, which refer to the competencies assumed by the autonomous regions and those that are the exclusive competence of the State (Romero, 2009, 2017). The autonomous regions are responsible for territorial and urban planning, housing, the mountains and forest uses, the management and protection of the environment and construction and exploitation projects related to water use. The State has the exclusive competence for the legislation, the planning and concession of resources and water uses and the basic legislation regarding the protection of the environment (mountains, forest uses and livestock trails), together with the management of the coast with respect to the Public Domain (Fig. 4).

On paper, the competences of the state and regional governments regarding the environment and its resources are clear. However, there are misalignments in their planning and management, particularly when the political party in power is different in the regional and state governments and when there is no willingness to compromise because a resource is considered as being strategic for a state or a region. On the contrary, in general, there are no misalignments when the political party in power in the state and regional governments is the same (or there is a similar ideology) and when the willingness to compromise of the governments involved is clear (Romero, 2017). In the first scenario, there is a political utilisation of the natural environment, with actions taken that lead to legal disputes and, in short, an inefficient planning and management of the natural environment. In the second scenario, planning is ordered, the governance is effective and the benefit of the government action is collective.

The elements of the natural environment that generate the most conflicts between territories and between different levels of governments are coasts and water. Article 132.3 of the Spanish Constitution indicates that they are elements of the state public domain by law, but it states that “the maritime-land area, beaches, territorial sea and natural resources of the economic area and continental platform” belong to the state. Therefore, the coast is a public domain because it is indicated as such in the constitutional text. The waters also belong to the State, but in this case this is determined by a state law. In this case (water), the State also has the power to elaborate a national hydrological plan and manages the river basin districts, which are the territorial representation of the state in a water basin. Meanwhile, one of the competences of the autonomous regions is becoming increasing more prominent in the current context of climate change: the treatment and reuse of wastewaters. Finally, the local governments are obliged to guarantee the supply of water in the municipality.

In terms of planning and management, water is a matter of the State. However, there are different interpretations of this precept. It may be understood that water, as a public domain asset is the property of all Spaniards. In a situation of conjunctural or structural shortage, it becomes a liquid element able to be displaced form its natural territory in order to satisfy human demands; in short, water is basically understood as a resource at the service of economic development and the maintenance of the well-being of a population. On the other hand, the public domain can understand water as a resource owned by the territory, as a liquid element that favours the creation of ecosystems, therefore, as a resource that should first satisfy the needs of the natural environment before the demands of human beings. From this perspective, water is a resource at the service of the environment. In Spain, the “economic” discourse has prevailed over the “environmental” discourse when contemplating water planning and management proposals. It has only been since the enactment of the Water Framework Directive (60/2000) that the environmental view of water has gained prominence in water planning actions in Spain.

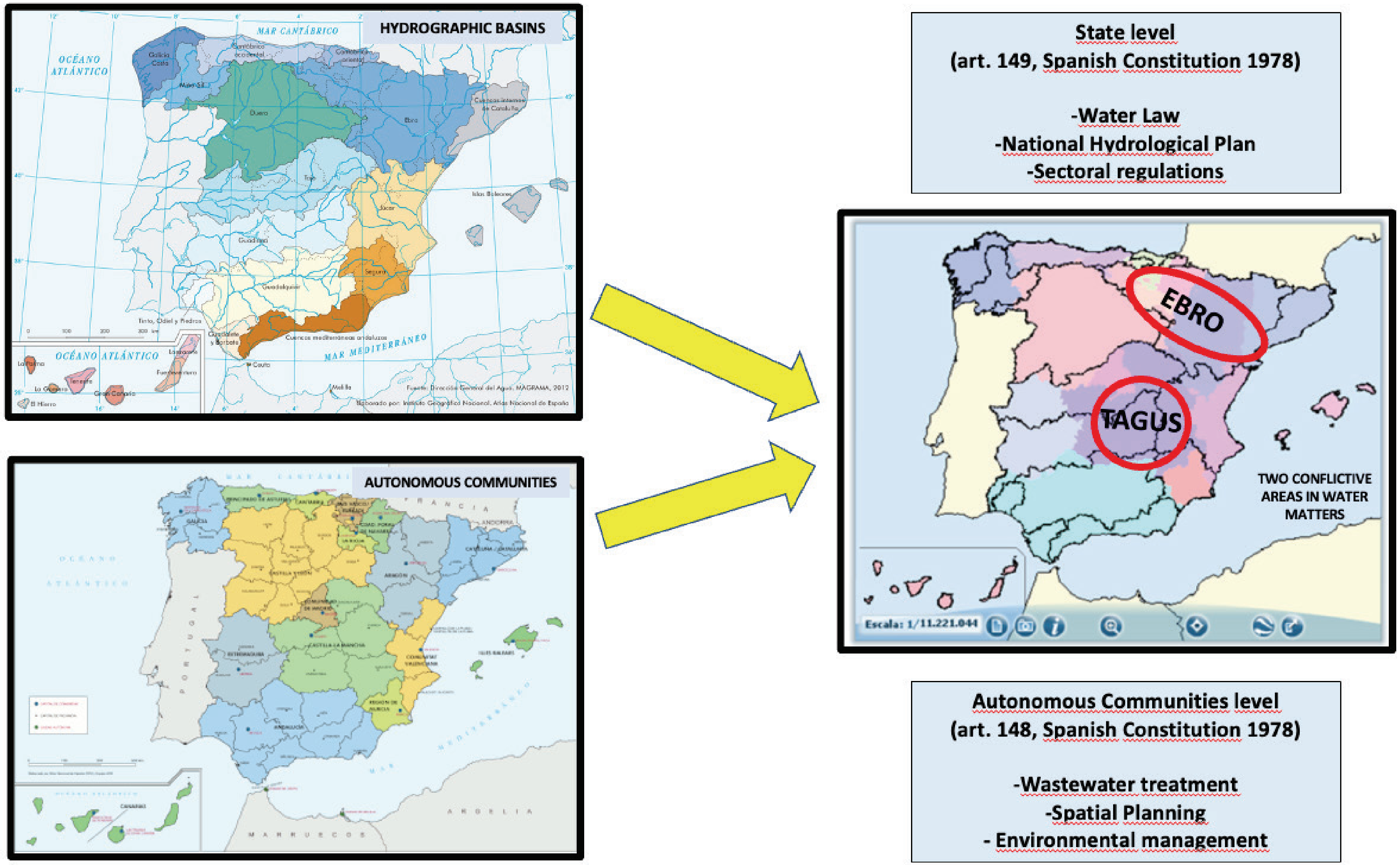


Figure 4. Natural limits (river basins) and political limits (autonomous regions) in the planning and management of water in Spain. Source: Own elaboration. Cartographic base. IGN. España en mapas. https://www.ign.es/resources/acercaDe/libDigPub/EspanaenMapas.pdf

In Spain, there are two river basins whose water planning and management, for different reasons, are the focus of territorial disputes over water: The Ebro and the Tajo. The Ebro river basin is a large Iberian river whose whole length runs through Spanish territory. This water basin has been strongly altered by the needs of urban supply and, particularly, that of agriculture and the defence against situations of the extraordinary swelling of the river. The prominence given to the River Ebro in the water transfer proposal to the Mediterranean coast included in the Hydrological Plan of 2001 has generated debate and controversy from the beginning. First, due to its approval and, on paper, the start of the works; then, due to the repeal of Article 13 of the Law of the National Hydrological Plan, which rendered this proposal for an annual macro-transfer of water ineffective. And, since then, due to the repeated attempts to restart the project by the autonomous regions of Valencia and Murcia under right-wing governments. The last link, resulting from the drought situation suffered in Catalonia between 2022 and the spring of 2024, has been the attempt to restart the project to extend the transfer from Tarragona to Barcelona, which was attempted during the previous drought of 2008. Both then and now, this proposal was strongly rejected by the population of Les Terres del Ebre.

The Tajo basin has a unique feature in its current water planning and management process. It has a water transfer infrastructure (Tajo-Segura Transfer) which was built during the final years of the Franco dictatorship and began operating in 1979 when the first waters arrived in the Segura basin. It has an international regulation agreement (Albufeira Agreement, 1998), in the review phase in 2024, which establishes the amount of water that should circulate in Portuguese territory (De Stefano and Hernández Mora, 2019). The first has been a cause of conflict between territories since its implementation, because the territories of Castilla-La Mancha have demanded water resources from the upper Tajo basin in order to satisfy different demands (agriculture, urban and environmental). These demands have been met unsatisfactorily according to the users, who demand more resources for the territories belonging to the Tajo basin. These demands imply the rejection of the water transfer to the south-east of the peninsula established by law, although the transfer amounts stipulated in the regulation have never been covered, nor the annual petitions of the farmers benefiting from the Tajo waters. The main problem in the management of the resources of the upper Tajo basin is, therefore, related to the existence of this infrastructure approved in 1968 and in the democratic period, with the delimitation of the regional limits, whose interests do not coincide with the territory of the river basin. The effects of climate change on the precipitations in the headwaters of the Tajo have given rise to an uncertain future for this water transfer, as in recent decades there has been a decreasing trend in the volumes of potentially transferable water. Furthermore, political decisions have led to the establishment of minimums in the headwater reservoirs below which transfers are not permitted (Escudero Gómez and Martin Trigo, 2020; Olcina Cantos, 2024).

3.3. Water data in Spain

The real data corresponding to water resources and demands in Spain are unknown. In order to estimate the resources, annual average precipitation is analysed, together with the calculation of groundwater volumes with the purpose of calculate the total available resources for hydrological planning. In Spain, total resources are estimated at 112,000 hm^3/year, of which 82,000 are surface waters and 30,000 groundwaters. The reservoir capacity, in work project conditions, is calculated at 56,069 hm^3, although different studies indicate that this theoretical capacity would be lower, in fact 15-20% lower due to the accumulation of sediments dragged by the regulated rivers since their implementation. This aspect has had particular attention in the Ebro river, due to the expectations created for using "excess" water retained in its reservoirs for the development of water transfers (Ibáñez *et al.,* 1996; Vericat and Batalla, 2006; Horacio *et al.,* 2018; Vázquez-Tarrío *et al.,* 2023; Goroztiza *et al.,* 2023).

These natural resources are not directly usable by humans, given that the rivers have to fulfil their ecological function and, most of all, due to the evaporation recorded in Spain, with its regional differences, and which is very intense in the summer months. This means that the balance between precipitation and the evapotranspiration of water in Spain only generates positive values in the Cantabrian regions, while from the Duero basin to the south of the peninsula the deficit of this indicator increases until it reaches values of over -600 mm/year in a large part of the south of the peninsula and -900 mm/year in the south-east of the Iberian peninsula (Martí Ezpeleta *et al,* 2019). For the economic uses of water, Spain has 27,400 hm^3/year in conventional resources (20,600 of surface water + 6,800 of groundwater) to which “non-conventional” resources are added (treated water + desalinated water + rainwater), representing around 1,000 hm^3/year more (between 350-500 hm^3/year of reused water + 600 hm^3/year of desalinated water + 10 hm^3/year of rainwater collected in urban nuclei).

Meanwhile, the demands are also estimates, due to the lack of a real calculation of agriculture consumption. It is estimated that agriculture consumes around 22,500 hm^3/year. This figure is basically obtained from calculating the water needs of the different irrigated crops grown in Spain, given that there is no effective control of the water used or recording systems (meters), except in certain forms of irrigation with a high degree of technification (crops grown under plastic, crops with a high commercial value), which represent only 20% of the volume of water used for irrigation in Spain (Gómez Espín, 2019; Albiac Murillo *et al.,* 2023). Sixty-eight per cent of crops are irrigated with surface water; the rest with groundwater. And 902,163 use gravity irrigation (24% of the total). The belief that localised irrigation reduces the cost of water used in irrigation is incorrect. Irrigation with localised irrigation systems (53% of the total in Spain) is more efficient and favours the productivity of the plant, but it does not lead to a reduction in the volume of water used (Sanchis-Ibor *et al.,* 2016; Berbel and Espinosa-Tasón, 2020).

Urban demand is calculated at 4,236 hm^3/year, of which 3,180 hm^3/year is water that has been invoiced and the rest is an estimate. Meanwhile, industrial water is estimated at 1,264 hm^3/year. Urban and industrial water is the volume of water in Spain whose calculation is the closest to reality. Although the percentage of losses in the supply network recorded for all Spanish cities should be taken into account and calculated at 15% (AEAS, 2022) (Table 2).

Table 2. Water resources and demands in Spain (2024).

RESOURCES	TOTAL RESOURCES	**112,000 hm^3/year** (82,000 surface water+ 30,000 groundwater)
	Reservoir capacity	**56,069hm^3/year**

DEMANDS	AGRICULTURA USE	**22,500 hm^3/year**
	URBAN USE	**4,236 hm^3/year** (3,180 invoiced+1048 estimated)
	INDUSTRIAL USE	**1,264 hm^3/year**

CONVENTIONAL RESOURCES	SURFACE AND GROUND RESOURCES	**27,400 hm^3/year** (20,600 surface water +6,800 groundwater)
NON-CONVENTIONAL RESOURCES	TREATED WATER	**4,200 hm^3/year**
	REUSED WATER	**350-350 hm^3/year**
	DESALINATED WATER	**600 hm^3/year**

Therefore, a priori, in the general accounting of water in Spain, the demands can be met by the existing resources (conventional and non-conventional) under normal climate conditions. The problem is the uneven territorial distribution of resources and demands throughout the territory of Spain, which includes river basins with sufficient resources to guarantee water security (North, Duero, Ebro) and others where the level of demand notably exceeds that of the conventional resources (Segura, Júcar, Andalusian Mediterranean, Canarias, Ibiza).

However, the guarantee of supply is questioned at times of drought, which constitute a defining feature of the climate conditions in all Spanish climate regions. As previously indicated, up to five types of drought can be distinguished according to the territory affected in Spain (Olcina Cantos, 2001), being more frequent in the south-east of the peninsula (south-eastern droughts), which have a structural nature in the climate features of this geographical space.

The development of a dry sequence leads to the gradual reduction in the volumes of surface and groundwater due to the insufficient replenishment of the supply systems by rainfall (Fig. 5). In these cases, the sequence of effects of a drought cause the reduction in water resources, effects on rain-fed crops and non-stabled livestock farming, the reduction in resources for irrigation and in the most intense periods, there are effects on the urban supply systems, which can lead to the supply being cut off at extreme moments of a drought. Long-lasting and intense droughts call into question, therefore, the management of water if it is exclusively designed for moments of normality or rainfall abundance and if the supply system does not have non-conventional resources to make up the deficit of rainfall-based resources.

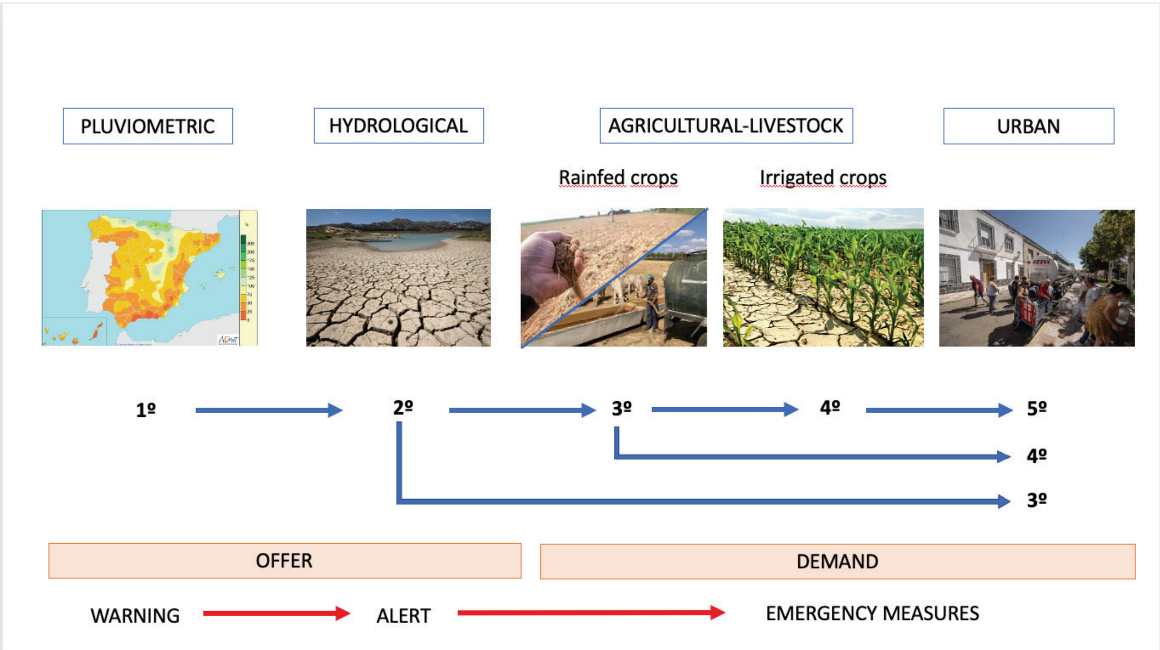


Figure 5. Phases of a drought sequence and sectors affected.

Within the context of climate change, with more irregular precipitations, the solution of the water transfers as a mechanism for supplying water in territories affected by conjunctural drought or structural shortage is not ideal due to environmental, economic and political reasons. We should remember that in Spain there are forty water transfer pipes for agricultural use and urban supply; of these, sixteen are large-scale transfers including those of the Tajo-Segura, Tajo-Guadiana, Pas-Besaya, Alto de Tornos, Zadorra-Arratia, Cerneja-Ordunte, Carol-Ariége, Alzania-Oria, Siurana-Riudecañas, Ebro-Tarragona, Guadiario-Majaceite, Negratín-Almanzora, Del Condado, Júcar-Turia, Júcar-Vinalopó and Ter-Llobregat transfers (Molina Giménez, 2010). Together, these large water transfers move an annual volume (variable depending on rainfall) of 800 hm^3/year.

Traditionally, Spain’s water policy has promoted the development of these water transfers from areas of the country acting as “assignors” as they had volumes of water above their demands and could transfer their surplus towards “recipients” with conjunctural or structural water deficits. In addition to the Tajo-Segura transfer, which was considered during the Franco dictatorship, during the democratic era several interconnections have been developed between nearby river basins or with the same basin.

Furthermore, hydrological planning has considered water transfers as the principal solution to the water shortage in territories mainly in the east and south of Spain. Therefore, the proposal of the Hydrological Plan of 1993 (Plan Borrell, never approved) proposed the interconnection of basins through annual transfers of 4,000 hm^3; meanwhile, the National Hydrological Plan of 2001 considered a single large transfer from the Ebro of 1,000 hm^3 to the internal basins of Catalonia, Júcar, Segura and Mediterranean Andalusia (Almería). The transfer was abolished in 2004 and the volume of water that would have theoretically been transferred from the final section of the Ebro to the afore-mentioned territories on the Mediterranean coast were replaced with non-conventional resources (basically desalination) within the so-called "AGUA Programme" (Rico Amorós, 2010; Morote Seguido, 2014; Albiac Murillo *et al.,* 2023).

Water transfers are not useful for resolving Iberian drought sequences, given that at times of scarce rainfall the volumes of water reduce considerably in all of the river basins, so surpluses that could be moved between river basins are not recorded. The Tajo-Segura transfer has mainly been used to resolve situations of structural scarcity, however, the decrease in precipitations and available volumes of water recorded in the headwaters of the Tajo have led to a gradual decrease in the flows transferred since 2000 to the present. In fact, the average flow transferred since 1979 to the present is 330 hm^3. We should remember that this transfer considered a first phase with an annual transferred volume from the Tajo to the Segura of 600 hm^3/year, extendible to 1,000 hm^3/year in a second phase. Over the last two decades, there has been a significant reduction in precipitations in the southern sector of the Cordillera Ibérica, where the sources of the Tajo and Júcar are located. If we compare the contributions in the headwaters of the Tajo between 1940-79 and 1980-2018, the reduction is 275 hm^3/year (Miró *et al.,* 2021). This reduction could also have been affected by the increase in the forest area in this mountainous sector, which would generate a greater natural demand for water by the vegetation. For all practical purposes, the reality is that the headwaters of the Tajo have less available water to transfer than when the transfer began to operate (Olcina Cantos, 2024).

3.4. The need to incorporate non-conventional resources into the system

Guaranteeing water security in Spain within the context of climate change should involve increasing the prominence of non-conventional resources. In order of prominence, these are treated water, rainwater and desalinated water. This requires the provision and improvement of the necessary infrastructures for generating water resources that would allow a supply that would guarantee the satisfaction of the existing demands in terms of quantity and quality. In the case of treated water, a modernisation plan should be elaborated that includes the connection of the treatment stations with the potential reuse areas; and, for the use of rainwater, the installation of large-capacity tanks that harvest the waters of the river valley derived from intense rains with the dual objective of reducing the flood risk and using the collected waters for urban uses. In the case of the desalinated water, the cost of the water produced will decrease in the coming years if changes are made in the energy supply required by the desalination plants with the installation of solar energy.

The widespread treatment of water in Spain began after the passing of European Directive 91/271, at the beginning of the 1990s (Rico Amorós et al., 1998). Since then, and in compliance with the determinations of the afore-mentioned directive, which was subsequently modified, a large number of treatment stations (EDARs) began to operate in the Spanish regions, although with very diverse paces: with a more accelerated rhythm in the eastern regions of the peninsula and a very slow pace in the Cantabrian regions. This directive represented a significant change in urban water management, given that it made it compulsory to treat the flows used in the city and by industry and to potentially reuse them. It is true that the objectives of the Directive of 1991 did not include the direct reuse of purified water for economic uses. The water treatment technology installed in the majority of the EDARs implemented in Spain over the last three decades limit the potential use of the treated flows as their level of purification is not high (basically, secondary treatment). The reuse possibilities increase in relation to the type of treatment. The European Union has recently made a new commitment to wastewater treatment and, as a novelty, the reuse of treated waters (Directive 2024 of the European Parliament and Council on the treatment of urban wastewater, recast version; González, 2024). In 2021, the Ministry of Ecological Transition approved the National Sanitation and Treatment, Efficiency, Savings and Reuse Plan - the DSEAR Plan - to promote this water resource in different uses, particularly agriculture (Miterd, 2021). Meanwhile, the Spanish Ministry of Agriculture has launched a sustainable water management in Spanish irrigation that contemplates the increase in the volume of treated water as an important resource for agriculture after the updating of the regulations on the reuse of treated water (Royal Decree 1085/2024).

The reality of water treatment and reuse in Spain provides an important lesson for future water planning. In Spain, the level of treatment is very high compared to other European countries, particularly those in the Mediterranean region. But the level of reuse with economic ends (agricultural, urban-tourist uses) could be vastly improved. Barely 10% of the total volume of treated water is used in urban and industrial environments in Spain (Fig. 6).

This means that there is a wide margin of water reuse that can mitigate occasional severe droughts or enable "first use" waters (rivers or aquifers) to be replaced with treated waters in order to reduce the final consumption of water of urban and agricultural uses. In this way, water management adapts to the circular economy model, sharing the principles established by Raworth (2012, 2017) in a proposal for the sustainable management of resources and activities to constitute a principle of action of the economy.

The promotion of water reuse should include the improvement of wastewater treatment stations to extend and enhance the purification systems and the development of treated water piping infrastructures so that it is possible to use these flows in the urban environment and the fields. In this respect, and within the framework of the European economic recovery policies after the Covid-19 pandemic, Spain is the country that has presented the most projects for treated water reuse in recent years (Bluefield Research, 2023) (Fig. 7).

There are examples of good practices in the promotion of the use of treated waters in Spain, such as the implementation of a wastewater network in the city of Alicante for the irrigation of gardens (public and private) that distributes 1.5 hm^3 per year for this use. This has involved the installation of a specific treated water distribution network through the urban fabric that enables the treated flows to reach the parks or private gardened areas (Aguas de Alicante, 2023). Meanwhile, the government of the Region of Valencia is developing a project for transferring treated wastewater for agricultural use from the municipality of Alicante (28 hm^3/year of treated waters in its two treatment stations) to the Bajo Vinalopó (Campo de Elche). This frees up other resources from the River Segura and the wells that can be used for irrigating the fields of the Bajo Segura. The "Vertido Cero" (Zero Waste) project will be the first treated water transfer within the same large scale river basin in Spain (Fig. 8).

However, it is necessary to indicate that the reuse of treated waters should be planned in detail. Direct reuse (agricultural use, urban-tourism use) should be compulsory in those territories with a natural shortage of water and with mostly dry rivers that do not require an ecological status based on the existence of a continuous run-of river in its courses. However, in river environments with a continuous circulation and rich aquatic ecosystems, the treated waters with a high level of treatment should be used primarily for environmental use to maintain these environments. In the case of the River Tajo, a high percentage of the flow circulating through Toledo is derived from the treated wastewater of Madrid (Martin *et al.,* 2024). Therefore, the promotion of reuse should be a principal objective of the water policy in Spain, but taking into account the needs that these waters could cover in each territory.

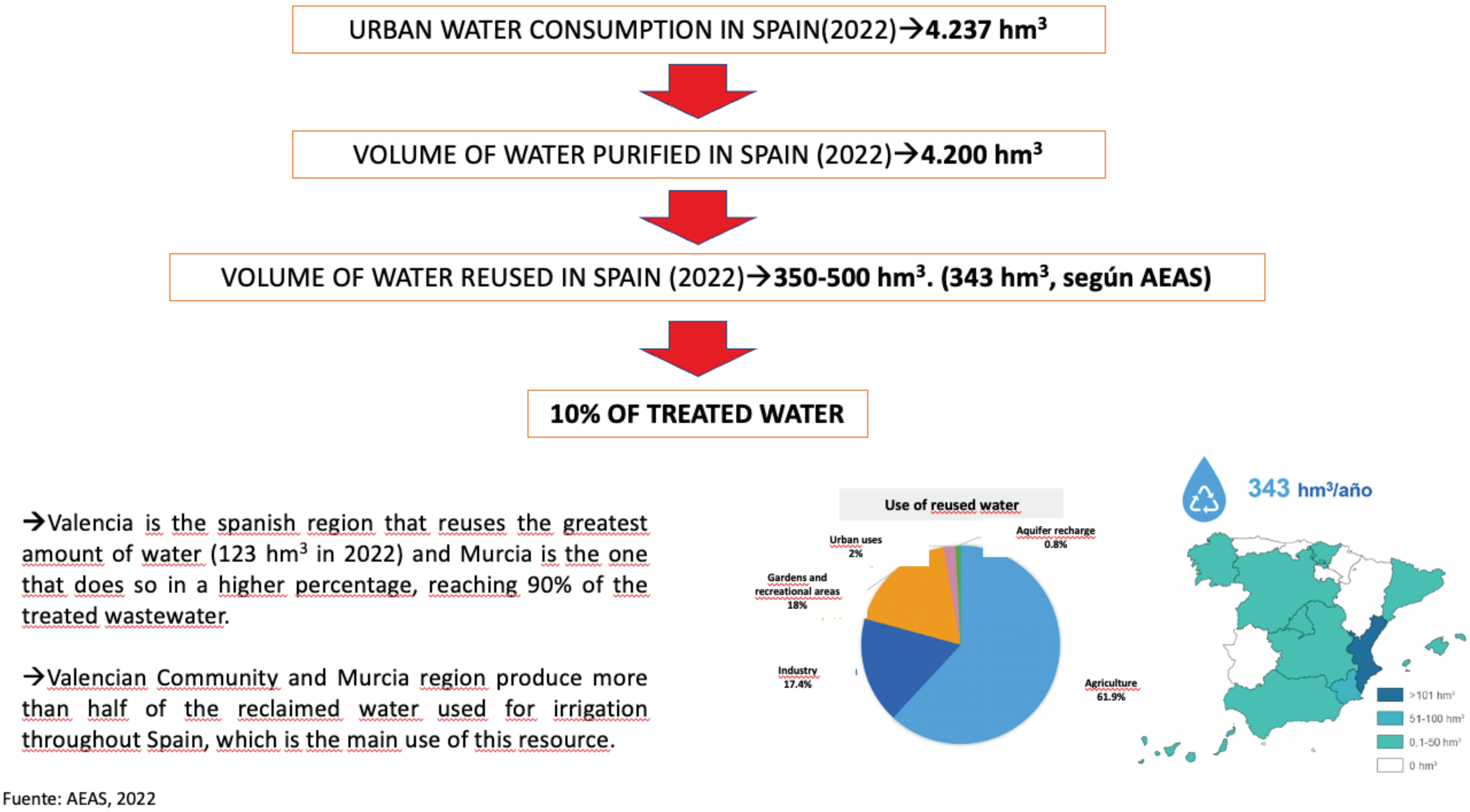


Figure 6. State of wastewater treatment in Spain (2023). Source: Own elaboration based on the reports of regional urban wastewater treatment bodies.

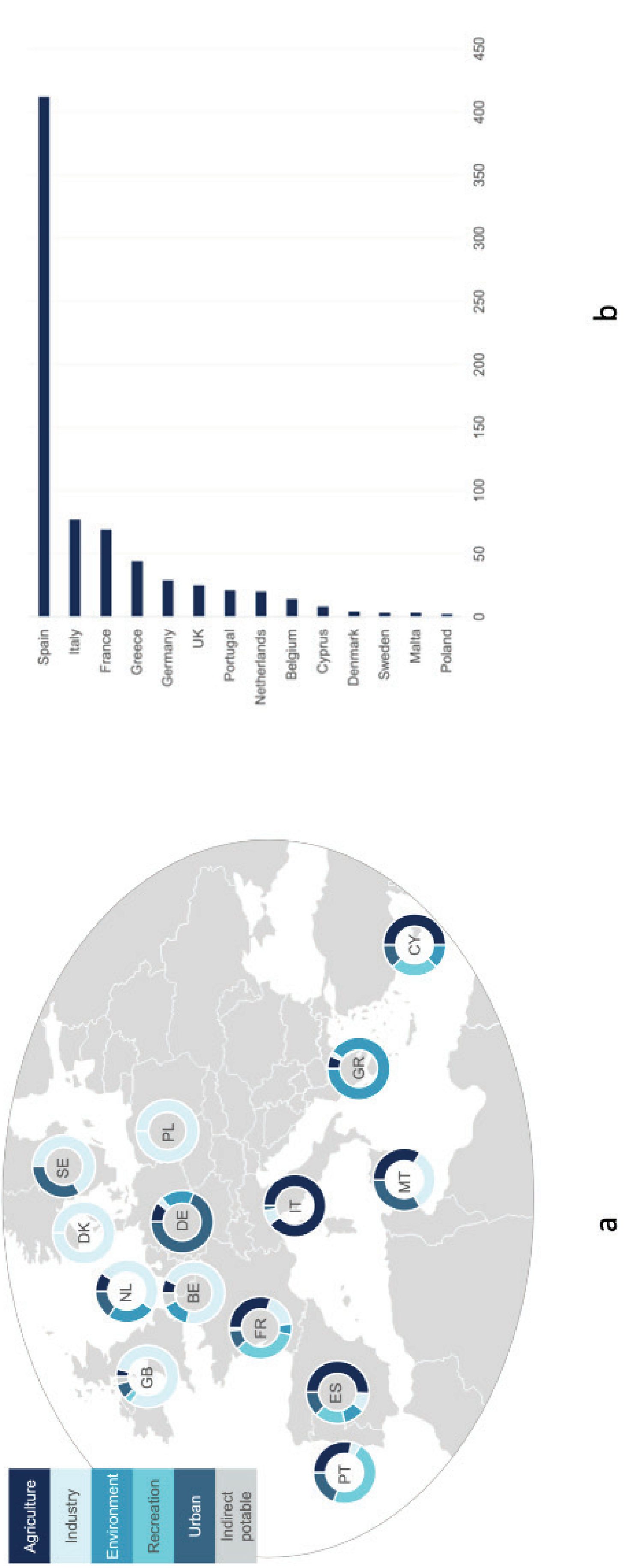


Figure 7. New projects for the reuse of treated water in Europe, financed with Next Generation funds. a) Share of reuse projects in Europe by sector; b) Number of reuse projects by country. Source: Water Reuse Europe. Bluefield Research.

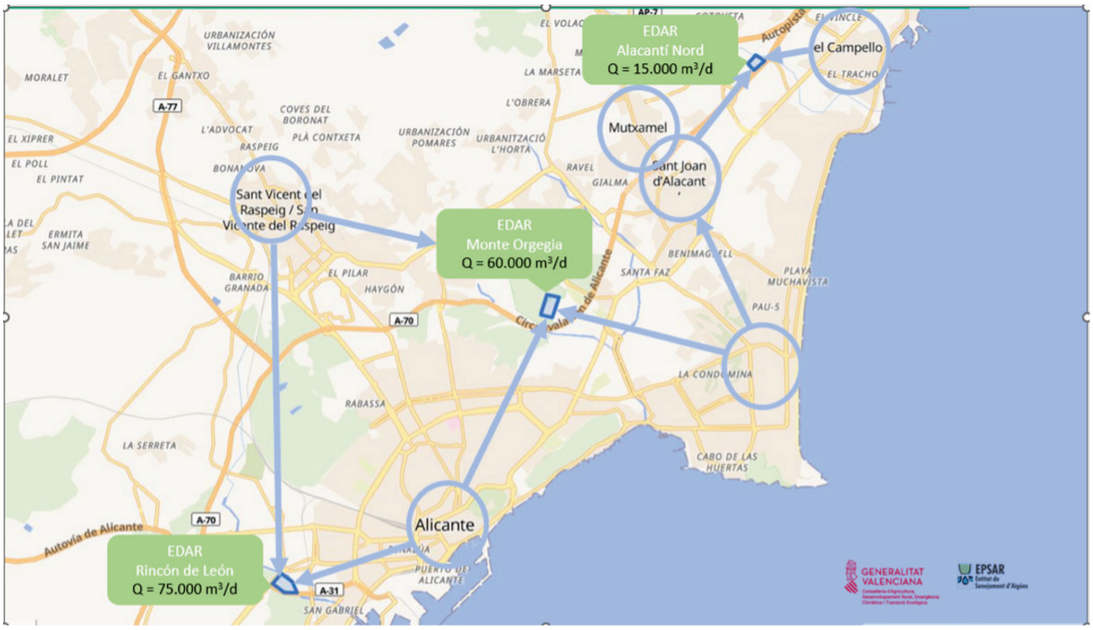


Figure 8. "Vertido Cero" water project for the comprehensive reuse of treated waters of the city of Alicante for agricultural purposes. Its development will give rise to the implementation of the first "transfer" of wastewater between districts of the same province in Spain. Source: Generalitat Valenciana. EPSAR.

Desalination provides an "inexhaustible" source of water in coastal areas and large volumes in the areas far from the coast with saline groundwater resources. Desalinised water enables the state of emergency to be modified in situations of drought as it provides water that does not depend on the rain and guarantees supply, particularly in urban nuclei. Spain is the European leader and one of the global powers in terms of the production capacity of desalinated water (5.6 hm^3/day). Since the first desalination plant was opened in Lanzarote in 1964 until the present day, the desalination capacity, the type of plants and the production costs have improved continuously. In 2024, the volume of water from the desalination of marine water and continental brackish water is 600 hm^3/year. The principal use of desalinated water is urban. The cost of the water produced (€0.70/m^3) is high for its use in irrigation, except in the avant-garde agricultural crops. This is the case even though the cost has decreased considerably over the last three decades due to the improvement in the productivity of the membranes (inverse osmosis) and the lower energy cost (Swyngedouw and Williams, 2016). Voutchkov (2016) indicates that the cost of desalinated seawater will continue to decrease over the coming years from €1.1/m^3 at the end of the 2020s to €0.3-0.8 €/m^3 at the end of the 2030s. However, currently, the public administrations (state and regional) are required to promote support measures in order to reinforce the use of desalinated water in agriculture. In recent years, within the framework of the Iberian drought 2021-23 and applicable until 2026, the Ministry of Ecological Transition issued a series of economic grants to subsidise the cost of desalinated water production in the provinces of Alicante, Murcia and Almería, establishing a maximum price of €0.40/m^3 for the waters produced in the desalination plants in these territories. These subsides were extended with regional funds in the Region of Valencia, resulting in a final price of desalinated water (Torrevieja plant) of € 0.24/m^3 (plus VAT), an amount that is highly competitive with the price established for the use of the water of the Tajo-Segura transfer (€ 0.18/m^3, exempt from VAT).

To the treated wastewater resources we should add the rainwater collected in the urban environment. This volume of water is small but the implementation of rainwater harvest systems represents a commitment of the cities to the recovery of a resource that would otherwise cause damage (intense rains) in the urban fabric and would be lost if a direct human use were not made of them through the sewer network or collectors in the urban nuclei. Rainwater harvesting recovers the historical tradition dating back to Roman times, widely disseminated throughout urban nuclei and rural dwellings in the south-east of the peninsula, which used the rainwater for their drinking water supply in daily life. These systems fell into disuse with the implementation of a widespread domestic water supply with the mapping and consolidation of the suburbs and the contemporary evolution of Spanish cities. At the end of the last century, some cities on the Mediterranean coast designed modern rainwater harvesting systems in order to reduce the risk of floods in urban environments. They are municipally managed sustainable urban drainage systems (SUDS), designed to harvest torrential rainwater and the principal aim is to reduce the risk generated by the circulation of water in the streets and floods. Barcelona was the first city (1999) to develop a harvesting system in the suburbs seeking to reduce the water circulating in the streets. This reduces the risk to human life in the city during intense rain episodes, which are becoming more frequent in Spain, particularly in the territories of the Mediterranean coast (Arahuetes and Olcina Cantos, 2019). In addition to tanks, floodable parks have also been designed that capture water in a gardened area and with a recreational everyday use, while acting as a rainwater storage facility on days of abundant rainfall. The water remains in this tank for a few days and can be returned to the natural environment (river) or sent to a nearby treatment station to be reused after treatment. In this respect, we can refer to the floodable parks of Alicante (La Marjal) (Morote Seguido and Hernández Hernández, 2017) and those constructed since 2021 in the Vega Baja del Segura as an effect of the development of the Vega Renhace Plan after the flood of September 2019 (Generalitat Valenciana, 2020).

As a whole, the rainwater harvesting systems installed in different Spanish cities with a capacity to be incorporated into the municipal water supply network represent 1% of the volume of urban water resources. However, it is important to promote their implementation as an example of good practices for the management of flood risk and the urban commitment to the circular economy of water. The rainwater tanks or floodable parks do not resolve the problem of a large impact flood; but they enable the risk in intense rain episodes of between 50 and 100 mm/h to be reduced.

All of these “non-conventional” resources, together with the traditional water sources, should be managed efficiently; that is, a precise accounting of the expenditure should be made in both the agricultural and urban environments and water should be supplied avoiding as much as possible losses associated with the distribution of a liquid in continuous use. In the agricultural environment, the PERTE of water, approved in 2022, considers the installation of meters on the plots of land in order to practice a real accounting of the agricultural expenditure. In the cities, 650 hm^3/year are lost in the distribution networks, which indicates an inadequate accounting of the urban consumption of water (approx. 4,000 hm^3/year) (Fig. 9). To this volume we must add the losses to obtain the real figure of water distributed in the municipal supply networks and that did not reach the meters in the homes (due to direct losses in the network or non-invoiced water in the households). The existence of a transparency portal in water management in Spain is one of the most important tasks that should be undertaken by the State in the coming years. Its development constitutes a basic piece of water planning in the current context of climate change.

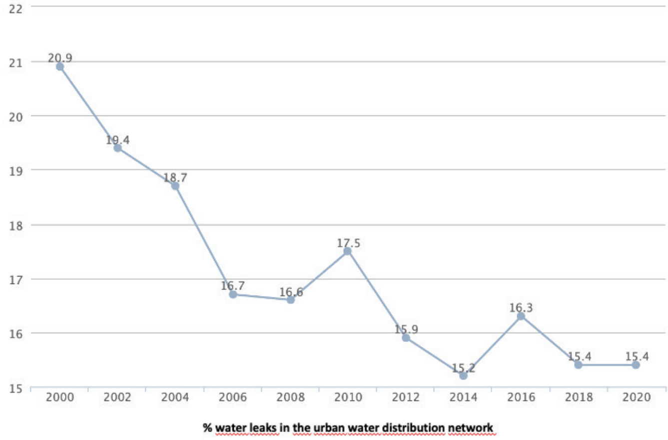


Figure 9. Losses of water distributed in the drinking water network in Spanish municipalities Source: AEAS.

4. Discussion and conclusions: water planning in Spain, future agenda

The planning and management of water in Spain within the context of climate change should be based on clear principles of action: quality instead of quantity, the improvement of the management of demand as opposed to a continued resource supply policy and the circular management of water with the incorporation of all the available resources in a territory in water planning. Hence, according to scientific-technical criteria, Spain needs a medium-term planning scheme that should be approved in the next hydrological cycle (4th cycle 2028-33) to be able to integrate a precise modelling of the effects of climate change on the temperatures and precipitations of our country and, in short, on the volumes of water available until 2050, updating the report elaborated in 2017 by the Cedex (Cedex, 2017).

The firm commitment to the mobilisation of new water resources that guarantees Spain's water security should be based on the reuse of treated waters, which should have a percentage share in the water resources mix of over 50% for the whole of the country and 80% in the regions and areas with a higher precariousness of conventional resources (Murcia, Region of Valencia, Balearic Islands, Canary Islands, Eastern Andalusia). Large population nuclei (>100,000 inhabit.) should become spaces for the production of regenerated water for its use in nearby agricultural areas and for urban supply (irrigation of parks and gardens, street cleaning and the irrigation of private green spaces) (Bernabé-Crespo *et al.,* 2023). Within this urban context, rainwater should be incorporated into the circular water cycle of the city.

Desalination will become a commonly used source of water resources on the Mediterranean coast. The volumes contributed should replace flows of conventional resources used in the urban nuclei that can be partly or wholly used for the agricultural activity. The use of desalinated water by agriculture for irrigation should receive public subsidies to adjust the final price to the income statement of the agricultural production in each case. The technological improvements will enable the price of desalinated water to be reduced over the next two decades.

The existing water transfers in Spain will be able to continue operating, although in some cases they will experience the alterations forecast in precipitations within the context of climate change. The contemplation of new transfers between water basins does not seem to be feasible due to climate and political reasons. However, transfers within the same river basin would be possible, particularly when they are located within the borders of the same autonomous region, provided that there is an agreement between the users (assignors and recipients). On the contrary, the future is uncertain for the transfers between different river basins that have their origin in rivers whose headwaters are currently experiencing a decrease in rainfall contributions and available volumes (Tajo-Segura). In this case, it is necessary to plan alternative solutions to the volumes transferred each year through other non-conventional resources if we wish to maintain the current level of agricultural and urban-tourism development in the receiving territories (Oliva *et al.,* 2022). There is no unanimity with respect to this option in the scientific-technical community. The continuity of the hydraulic engineering works for the retention and transfer of water is still a focus of economic (Melgarejo and López Ortiz, 2015) and engineering (Cabezas, 2002, 2013) studies. Although other studies defend an integrated management of the basins, in which the structural works (dams, canals) should constitute just one more piece in an overall plan for a river basin (Grindlay *et al.*, 2007, Magdaleno Mas, 2020).

It will be necessary to activate economic "compensation" systems in terms of water between the city and the countryside for the use of treated waters in the rural environment; and also between the coast and the inland territory for the use of desalinated waters in conditions of economic profitability for agriculture. The agricultural activity should begin to work on adapting to climate change, with the installation of meters on farms that enable us to determine the real cost of water. Over the coming decades, there will be improvements in irrigation systems, in crop varieties and changes in cropping calendars, which will facilitate the adaptation to the new climate conditions being recorded, with higher temperatures and a greater irregularity of precipitations. Agronomic research will play a prominent role in restraining the agricultural use of water in Spain. And the hydrological plans of the basin should constitute an element of containment and reduction in the aspirations of new agricultural changes, particularly in regions with a natural shortage of conventional resources.

In any case, water planning, with its different figures (river basin plans, drought plans, flood risk plans) should take into account regular review calendars in their estimates in accordance with the improvements that are taking place in climate modelling.

Water planning in Spain should harmonise water resources and demands with territorial planning, both for agriculture and urban uses of water. From the next hydrological cycle plan (2027), the implementation of new irrigation techniques should adapt to the rainfall reality in the river basins. Future hydrological plans for river basins should only approve new irrigation techniques if they use treated waters or groundwater from aquifers that are not at risk of overexploitation in the medium term (horizon 2050). An identical procedure should be applied for golf course projects, which, from now on should only be permitted if they can be maintained with regenerated water. The example of the golf course law of the Balearic Islands should serve as an example for the rest of the Spanish territories with these kinds of project, particularly in the Mediterranean coast regions. Urban planning should establish growth indicators in the housing stock that ensures its future supply with the currently existing resources; and compact city models should be imposed on dispersed cities that incur a greater urban consumption of water (150 litres/inhabitant/day in the former as opposed to 350-400 litres/inhabitant/day in the latter) and greater losses in the distribution network. The case of Benidorm, with a drinking water network efficiency of 95% (one of the greatest in Europe) can serve as an example for the whole of Spain (Rico *et al.,* 2019).

In short, the planning and management of water in Spain should seek to become more transparent in terms of the data for research purposes. This planning should be based exclusively on scientific-technical criteria, which means the exclusion of ideological interferences in the elaboration of water-related action programmes in Spain. In this respect, the geography discipline will play a prominent role in the future of water in this country due to its comprehensive knowledge in physical and human aspects in the territory. Hence the importance of the training of geography professionals in order to prepare them for participating in water planning and management.

Author's note

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