Aquifer Vulnerability to Climate Change

Recommendations and best practices for the management of groundwater resources

Document prepared for COST Action CA19120: WATer isotopeS in the critical zONe from groundwater recharge to plant transpiration (WATSON)

https://watson-cost.eu/

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Introduction

Groundwater is a precious natural resource and plays an important role in meeting water needs for domestic, industrial, and agricultural use, as well as sustaining the needs of groundwater-dependent terrestrial ecosystems. Groundwater is especially important in countries characterized by a lack of rainfall during the dry season. Globally, groundwater provides approximately 26% of the potable water supply, 42% of water used for irrigated agriculture, and 24% of the water for direct industrial needs (IAH, 2016). The main aquifer systems in Europe are developed in sands, gravels, sandstones, conglomerates (porous aquifers), limestones, dolomitic limestones, and marbles (karst aquifers).

Groundwater is under many pressures, which are exacerbated by land use changes, including urbanization, increased demands for food production, water quality deterioration, mismanagement, and the climate crisis. These pressures create a regime characterized by over-exploitation of groundwater (due to natural scarcity of other resources during the dry season and/or inadequate exploitation of surface and spring water) and a decline in groundwater levels, combined with a reduction in reserves (negative/deficit water balances). Figures 1 and 2 show two characteristic maps of the decline in groundwater levels and of the pollution of groundwater bodies by agriculture in Europe, respectively (data from European Environmental Agency, https://www.eea.europa.eu). They show that many aquifers are affected by quality degradation, mainly salinization due to seawater intrusion as a direct result of over-abstraction, which will potentially be exacerbated due to sea-level rise, and pollution by nitrate, pesticides, and other contaminants due to the use of fertilizers and agrochemicals. Another threat to groundwater pollution is the uncontrolled discharge of untreated domestic and industrial wastewater into surface waters, and/or septic tanks, as well as leakages from municipal sewers. Contaminated groundwater is common in densely populated areas and in areas of intensive agricultural and industrial activity (WWDR 2022). In addition, prolonged over-pumping will contribute to the spread of land subsidence by significantly lowering the water table in alluvial aquifers, causing damage to water supply networks and surface infrastructure, including roads and other services.

Although groundwater is more resilient to climate change than many surface water resources (Amobichukwu et al, 2020), it remains vulnerable, because climate change will affect the recharge of aquifer systems. It has been pointed out that the climate crisis (floods, droughts, reduced rainfall) and the ensuing prevalence of extreme climatological events will affect the water cycle and consequently the natural recharge of groundwater resources. Vulnerability is often used to describe climate change's potential (adverse) impacts on groundwater. Nistor (2020) suggests that areas with high and very high groundwater vulnerability classes to climate change are distributed in central and north-western Europe, south of the British Isles, and in agricultural areas and large plains (North European Plain, Po Plain, Romanian Plain), while medium, low and very low vulnerability classes were identified for mountainous and hilly areas (Figure 3). These results also suggests that Europe's groundwater quality and quantity status are under pressure from climate change (e.g., reduced water availability) and human activities (e.g., landfills, agriculture, and irrigation practices).

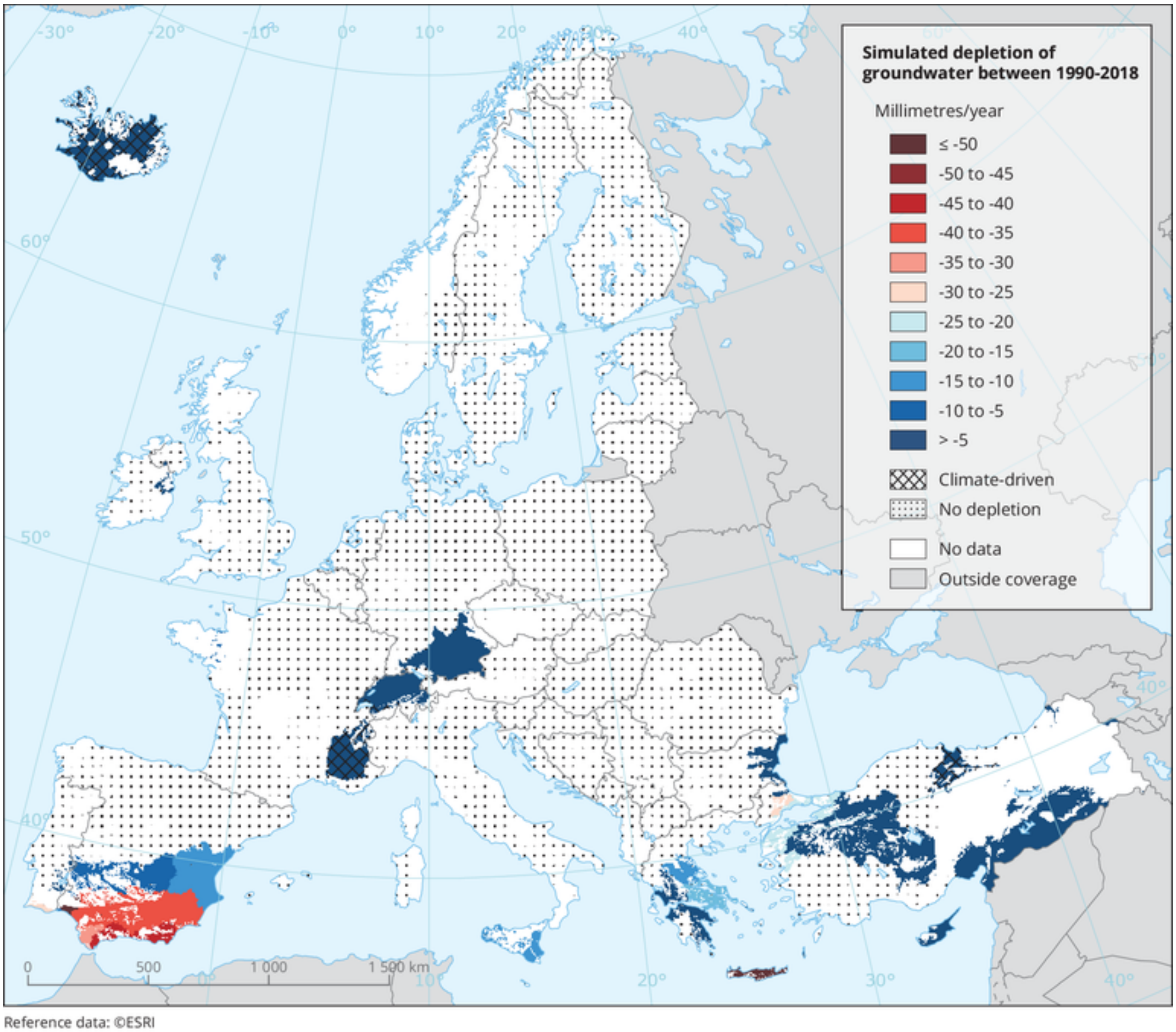
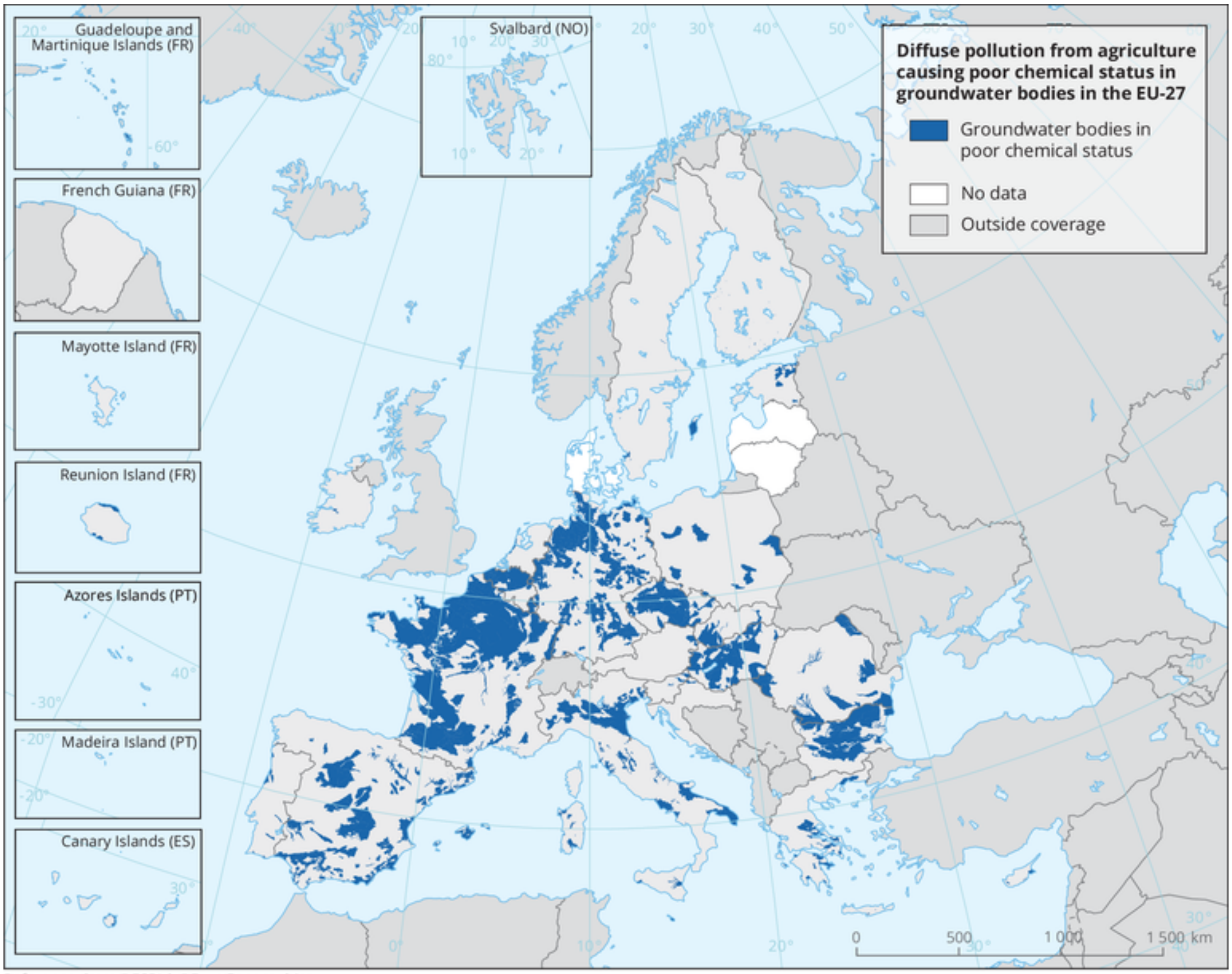


Figure 1: Groundwater level decline between 1990-2018 in Europe (Source: EEA, https://www.eea.europa.eu).



Reference data: ©ESRI | ©EuroGeographics

Figure 2: Pollution from agriculture in groundwater bodies in Europe (Source: EEA, https://www.eea.europa.eu).

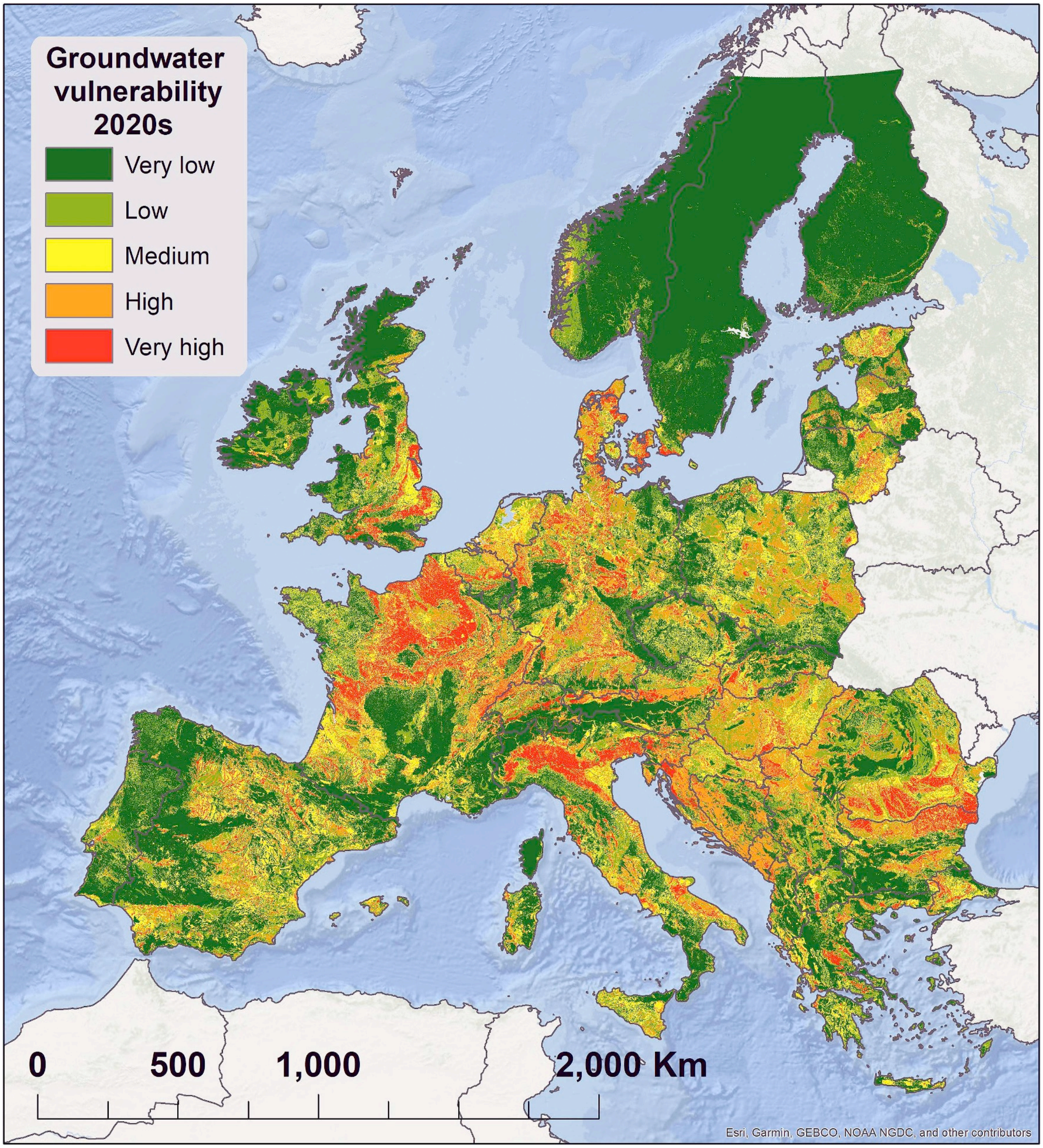


Figure 3: Groundwater vulnerability map of Europe for the present period (2020s).

(Source: Nistor, 2020).

Recommendations and best practices

Groundwater can help us adapt to the climate crisis and protect ecosystems. It must therefore be exploited rationally and managed sustainably. Water is at the heart of the circular economy. The focus should be on the circular economy, starting with wastewater reuse. The restoration of aquifer systems through solutions such as Managed Aquifer Recharge - balancing the impact of extreme events and thus guaranteeing the sustainability of groundwater systems has an equally important role. Also, the interaction between land use and groundwater recharge, as well as protection, plays a significant role in the management of groundwater resources. For instance, the European Project PROLINE-CE (https://programme2014-20.interreg-central.eu/Content.Node/PROLINE-CE.html) identified land use management practices that can be implemented with a focus on drinking water protection. Moreover, considering the framework of integrated water resources management, also flood and drought management practices can be designed with consideration of their implication for groundwater. Finally, an adaptation of policy guidelines is also needed to allow an effective implementation of the required actions needed for an improved management of groundwater resources.

Improved water efficiency and groundwater sustainability through the application of the 5R principles (reduce, reuse, recover, recycle, replenish) can be achieved through the following recommendations (Findidakis and Sato, 2011; Voudouris, 2024), as shown in Table 1:

1. Simultaneous use of surface water and groundwater would maximize water use efficiency and meet the growing demand for irrigation water (demand management). It is noted that effective groundwater protection can be achieved by not considering groundwater in isolation but within an integrated water resources management framework that includes surface water and other alternative (non-conventional) water resources.
2. Emphasis on representative monitoring networks to gather reliable and real-time data and develop the capacity to interpret monitoring data. Effective stakeholder engagement - disseminating information, promoting stakeholder awareness and participation - and ensuring that information is presented in a way that stakeholders can understand. Data on groundwater recharge studies, maps, and water-stable isotope sampling sites can be found at the WATSON website (https://watson-cost.eu).
3. Construction of small interception dams in the main torrents to delay torrential flows and increase groundwater recharge (supply management), following an ecological impact assessment and taking into account the local conditions.
4. Reduce irrigation water by using water-saving techniques. In any case, irrigation methods must be adapted to the climate, crop, and soil type. Isotope data can help determine the source of water used by vegetation (WATSON WG2).
5. Reuse treated wastewater in the frame of circular economy to reduce the amount of water entering the sea and the environment and provide water for irrigation, especially in water-scarce areas.

6. Adopt pricing policies that ensure a level of cost recovery (including resource and environmental costs) sufficient to encourage efficient use of water resources, combined with economic incentives to promote the restoration and efficient use of natural freshwater resources. Prevent overexploitation of aquifers by setting limits on abstraction.
7. Applying best agricultural practices to reduce the use of fertilizers and agrochemicals. This means using the right type and dose of fertilizer in the right soil for a particular crop at the right time. As part of the WATSON COST Action, a review paper on the use of nitrate isotope data has been published (Matiatos et al., 2023).
8. Adopt an appropriate set of management strategies at a river basin level, that considers groundwater within a comprehensive management framework, including water conservation measures, regulation of existing development, improvement of existing legislation, public education, and awareness raising.
9. Management of floods and droughts within integrated river basin management plans through the construction of appropriate infrastructure, e.g., flood control dams, small interception dams in the torrents of the mountainous areas, water storage tanks, etc.
10. Assess the vulnerability of groundwater to external pollution and delineate protection zones around boreholes and springs for safe drinking water (sufficient quantity and acceptable quality).
11. The sustainable management of groundwater is an issue of national and international water security, as some aquifers are transboundary. This implies the need for cooperation between the countries concerned to resolve conflicts.
12. Ensure sustainable and efficient water management through "digital water" with positive impacts on quality and quantity, particularly through developing smart devices and sensors, smart networks, and advanced data analytics (Water Europe, 2020).

Table 1: Correspondence of the 12 recommendations with the model of the 5R principles.

No Rec.	**Reduce**	**Reuse**	**Recover**	**Recycle**	**Replenish**
1	+		+		
2	+			+	
3			+		+
4	+				
5		+			
6			+		
7	+				
8			+		+
9					+
10					
11					
12					

Concluding words

Groundwater is a reliable source of water, but managing and governing groundwater resources is very complex. Finally, human intelligence and the spectacular development of hydro-technology (drones, GIS, remote sensing, satellites, Internet of Things (IoT), citizen science, digital water, and modeling-groundwater flow simulation) are the appropriate guarantees for humanity's ability to adapt to the climate crisis in the future. That is why greater efforts are needed by governments, scientists, and society at large to protect groundwater resources for the well-being of the planet and the dignity of human life.

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