Case Study : The Danube Region

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Key messages

- Drought is becoming one of the major challenges in water management in countries of the Danube region (more frequent, more intense, no longer only associated with the summer months, various sectors under drought impact). In the last decades, droughts had large negative impacts on the economy and welfare of the people in the Danube region. In recent years such as 2003, 2007, 2012, 2015, 2017, significant parts of the Danube River Basin (DRB) were affected by drought, impacting various water-dependent economic sectors, vegetation and the aquatic environment. Drought risk is expected to increase in the future, especially over DRB's south and east. Also, the frequency of drought events and low water levels in the region is expected to increase, especially in summer and in particular in the southeastern DRB.

- In practice, drought continues to be managed as a crisis situation by implementing emergency procedures and urgent measures. However, this approach usually fails to achieve the most sustainable solutions. In the existing legislation and policies, the roles and responsibilities of stakeholders including those of lead institutions are often unclear and/or overlapping with regard to the actions to be taken under specific drought conditions. The co-responsibility without a clear inter-institutional scheme of data, responsibility and communication flow results in neutralising the institutional response, especially before and during drought, instead of accelerating it. The existing crisis-oriented drought policies thus support the adoption of a crisis management (reactive) approach that activates institutions mostly when drought intensity is already alarming. In spite of this, there are some good practices existing in DRB that show how the state of inadequate drought policies can be changed by amending other existing policies that function well in practice, such as climate change or water management policies, with concrete drought-related topics.

- In the view of the changing nature of drought occurrence, also the far-reaching impacts of drought are very likely to increase across countries, communities, watersheds, economies and ecosystems in the Danube region. The water availability-demand ratio in a number of water-dependent sectors (such as hydropower generation, supply of water for domestic use, agriculture, industry, other economic uses, and for other activities such as fishing and winter tourism) is likely to become a serious problem in DRB in the future. This is likely to be further aggravated by interlocking a number of riparian countries relying on each other for their individual water security, while being politically, socially and economically very diverse and having high levels of socioeconomic disparities. While such negative effects can partly be reduced by water use efficiency gains (i.e. in the field of irrigation), these efficiency measures will not

- be sufficient to compensate for general increases in climate-induced water stress. In that view, the – often short – periods of water scarcity with competing demands of water from the various economic sectors together with ecological flow targets, will be the most challenging for water management in the Danube River Basin.

- In spite of this, there are some good practices and solutions existing in DRB for more proactively managing drought in DRB. There is a variety of ways at the national level that could be used to enhance the implementation of comprehensive drought management, among others the adoption of an Optimal Drought Management Model (ODMM), use of a monitoring and impact database & tools, strengthening the cooperation between stakeholders, sectoral experts and decision-makers, and enhancing drought topics in national legislation.

Short description of the physical and socio-economic characteristics of the case study

Coverage and Danube River tributaries.
The catchment area of the Danube River Basin (DRB) contains - at least a part of - the territory of 19 countries, which makes the Danube River the most international river in Europe and as a matter of fact in the world. However, most of the DRB is covered by parts of nine European Union (EU) countries, namely Germany, Austria, the Czech Republic, Hungary, Slovakia, Slovenia, Croatia, Bulgaria and Romania, and five non-EU countries, namely Serbia, Bosnia and Herzegovina, Montenegro, Ukraine and Moldova (ICPDR, 2011). The Danube River, which flows for 2 857 km, is one of the key corridors for transporting people and goods, and for connecting western and eastern Europe (EUSDR, 2016). The Danube connects 27 large and over 300 small tributaries on its way from the Black Forest to the Black Sea. There are also a large number of lakes in DRB. Based on its gradients, the Danube River Basin can be divided into three sub-regions: the Upper (UDRB), Middle (MDRB) and Lower (LDRB) Danube River Basins (the latter including the Danube Delta) (Figure 1). Before reaching the Black Sea, the river divides into three main branches, forming the Danube Delta, which covers an area of about 6 750 km² (ICPDR, 2011).

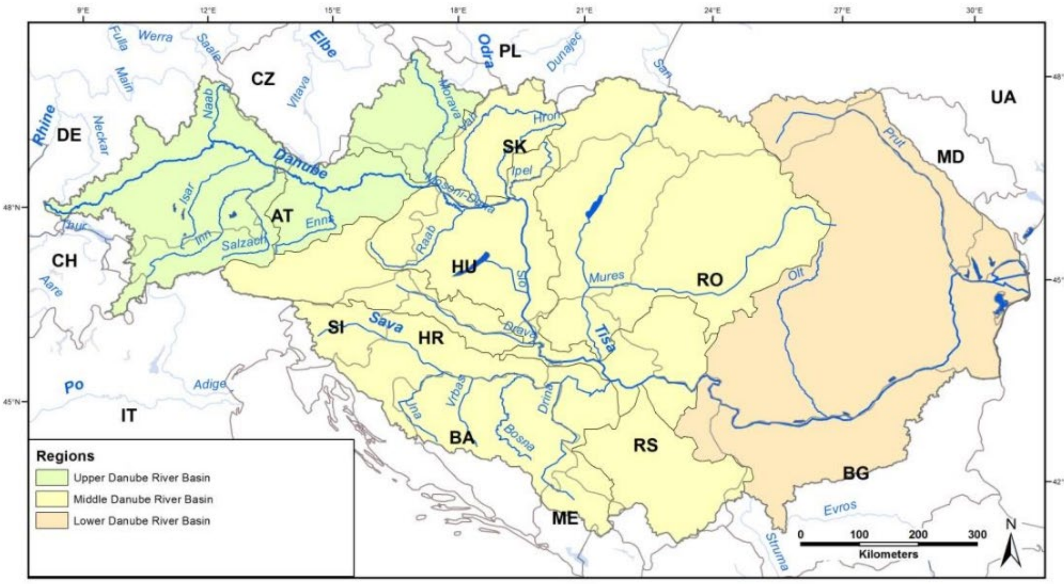

Figure 1: Main regions of the Danube River Basin. The separation between the UDRB and MDRB is defined by the gauge Bratislava, and between the MDRB and LDRB by the gauge Iron Gate at the border of Serbia and Romania (source: Ludwig-Maximilians-Universität Munich, 2018).

The main tributaries with the highest mean annual runoff are the rivers Inn within the UDRB, and Sava and Tisza within the MDRB, leading to a significant increase of the mean annual runoff of the Danube at their confluences (Figure 2). Many of the Danube tributaries have been considerably regulated with dams constructed to generate hydroelectricity and channels dredged to direct its flow. Nevertheless, natural habitats along the middle and lower reaches host unique assemblages of flora and fauna, as well as several endemic species (Ludwig-Maximilians-Universität Munich, 2018).

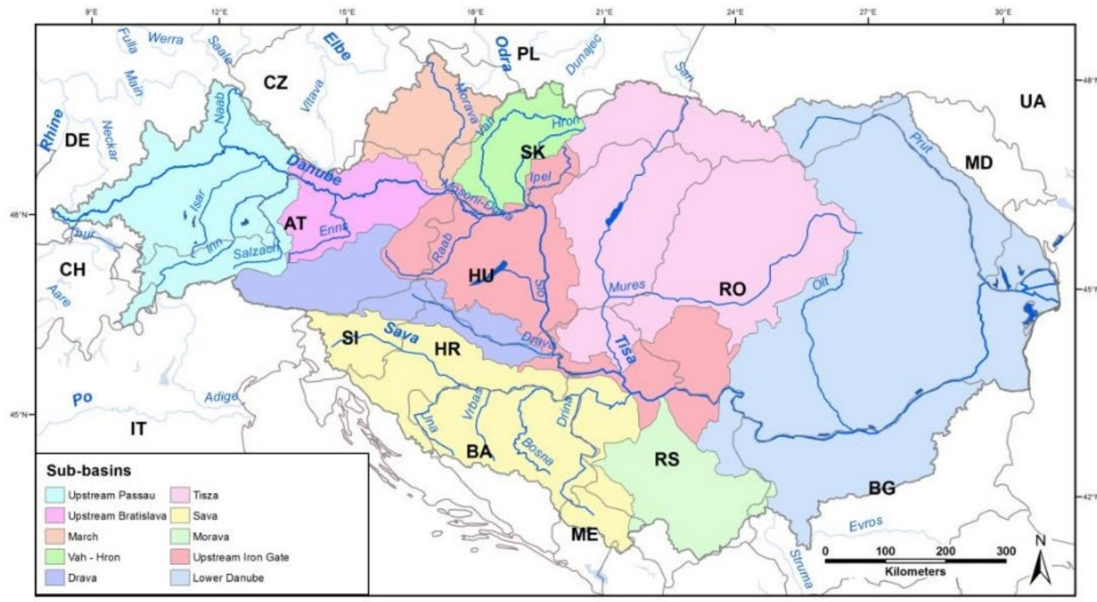

Figure 2: Main sub-basins of the Danube River Basin (source: Ludwig-Maximilians-Universität Munich, 2018).

Climate.

The geography of the Danube river basin is very diverse. It includes high mountain chains, large plains, sand dunes, large forested or marshy wetlands and, very specifically, the karst and the delta. The Alps in the west, the Dinaric-Balkan mountain chains in the south and the Carpathian mountain bow in the eastern centre of DRB are distinctive morphological and climatic regions and barriers. Generally, the Danube basin is dominated by a continental climate with hot summers and cold winters in its central and eastern parts. Only the western part of the UDRB in Germany is influenced by the Atlantic climate, while the southern and southwestern parts of DRB are influenced by Mediterranean climatic conditions with warm, dry summers.

Average temperature increases from west to east of the DRB. The coldest temperatures are present on the mountain peaks in the Alps and the Carpathians. Precipitation falls throughout the year and reaches a maximum in the summer months in almost all regions except the southwestern parts with long dry periods during summer. However, the amount of precipitation strongly varies in the basin: the mountain chains receive the highest annual precipitation (1000-3200 mm per year) while the inner and outer basins (Vienna basin, Pannonian basin, Romanian and Prut plains), the lowlands of the Czech Morava and the delta region are very dry (350-600 mm per year).

The runoff characteristics change along the way through the riparian countries, determined by the passages through plains and mountain regions, and the climatic conditions. Pluvial characteristics of the Danube River are under strong influence of ice- and snowmelt close to the source of its tributary rivers in UDRB, and of precipitations in Middle and Lower DRB (UNDP/GEF, a; Stolz et al., 2018). The different physical features of the river basin affect the amount of water runoff in its three sections. In the Upper DRB, the runoff corresponds to that of the Alpine tributaries, where the maximum occurs in June when melting of snow and ice is the most intensive. In the Middle DRB, the phases last up to four months, with two runoff peaks in June and April. The June peak stems from that of the upper course, while the April peak is local caused by melting snow in the plains and early spring precipitation of the lowland and the low mountains of the area. In the Lower DRB, all Alpine traits disappear completely from the river regime. The runoff maximum occurs in April, and the low point in LDRB extends to September and October. The period of low water in Middle DRB begins in October and reflects the dry spells of summer and autumn that are characteristic of the low plains, while in the Upper DRB, runoff drops to its lowest point during the winter months (Encyclopedia Britannica).

Biodiversity.
The Danube River Basin is characterised by an aquatic ecosystem with numerous important natural areas, including wetlands and floodplains. The river dynamics of the Danube provide the basis for a large range of unique habitats, from grassy plains, vast mountain ranges and gravel islands to significant areas of floodplain forests and extended wetlands. The DRB, including its tributaries, is home to numerous endangered or nearly extinct species, most of which are aquatic or water dependent. In addition, among the EU member states of DRB participating in the policy to protect these sanctuaries, Slovenia and Bulgaria have the highest terrestrial rate of Natura2000 sites coverage in the whole EU. Floodplain forests consist of a suite of plant species that tolerate weeks and even months of flooding. They provide excellent habitats, particularly for birds which use them as natural migratory corridors and

nesting sites (Danube Parks; ICPDR, 2011). One of the largest floodplain areas in DRB lies at the confluence of the Drava and the Danube rivers, across the territories of Hungary, Croatia and Serbia. They provide favourable living conditions for over 20 000 birds and 55 different species of fish in this area (ICPDR, 2011). Many mammals live along the shores of the Danube River and in the higher areas of the Danube Delta that cannot be reached by waters. They also present valuable drinking water reserves for millions of people. Poor land use and land management like the straightening of rivers, detachment of floodplains and fragmentation of habitats through dams and weirs increase the degradation of habitats and loss of species (Danube Parks).

Demography.

The Danube river basin is home to over 80 million people of different cultures and lifestyles, with many depending on the Danube River for drinking water, energy production, agriculture and transport (ICPDR, 2011). With exceptions of Germany and Ukraine, all other countries belong to the group of countries with small and medium total population numbers. From the demographic aspect, the Danube Region is one of the most endangered regions in Europe. In fact, it is the only macro region in the EU where the population is decreasing. Also, at the level of counties within DRB, most of them have begun to experience negative population growth rates. Demographic decline is followed by ageing of population, and the decrease has both natural and migratory reasons.

Beside migration inflow from outside Europe, there are also significant migration flows inside the continent and the Danube Region. A major part of DRB countries are so-called “sending countries”, while only a few are “receiving countries”. Highly qualified labour force from eastern DRB is looking for job opportunities in countries of western DRB, starting mostly during their education and studies. Consequently, the import-export ratio of internationally mobile students in the countries of the region is unfavourable. Only Austria, Germany, the Czech Republic and Hungary have a positive balance (Savić et al., 2016). As population in the DRB shrinks and ages, this will result in changing social and consumption patterns that may, in turn, lead to a change in environmental impacts (ICPDR, 2011).

Socioeconomic diversity, GDP.

The Danube river basin, covering mostly the parts of nine EU countries and five non-EU countries over the course of less than 3000 km, is as such characterized by significant disparities in countries’ economic development and their living standards. The region is challenged by several issues, among which are environmental threats (water pollution, impacts of climate change), lack of road and rail transport connections, insufficient energy connections, uneven socio-economic development, uncoordinated education, research and innovation systems, and shortcomings in safety and security. The socio-economic data show just how diverse the region is. The GDP per capita varies considerably between the most and the least developed countries in the region; it is more than 47 000 USD in Austria and Germany, while in Moldova and Ukraine it is less than 3 000 USD, with a wide gap between DRB’s northwestern countries and the rest of the DRB countries (Tominc et al., 2019). The standard of living measured by GDP per capita in the Danube Region is significantly lower than that of the EU-15, EU-28 or the OECD countries (Müller et al., 2015). These differences in economic development pose a challenge in developing a common development strategy on the one hand, but on the other also offer opportunities for cooperation that hold possibilities and advantages for all the partners involved (Löffler et al., 2019).

Main economic sectors in the region.

The Danube River and its tributaries are not only of a high environmental value but also its economic and social value is immense. They support drinking water supply, agriculture, industry, fishing, tourism and recreation, power generation, navigation, disposal of wastewater, and sustain biodiversity (UNDP/GEF, b). However, a look at the sectoral value-added structure also reveals differences in the region: in countries of northwestern DRB the agricultural sector plays a distinctly subordinate role, while in the other countries agriculture is an important part of the state economy: 9.8 % of Ukrainian, 12.4 % of Romanian and 21.8 % of Moldovan GDP is generated from agriculture, while this share is only 1.7 % for Austria, 2.4 % for Germany and 2.6 % for Czech Republic. The importance of the manufacturing sector also varies greatly among the countries surveyed. In Montenegro, for example, industrial production accounts for just under one fifth of economic added value, while in the Czech economy with its strong focus on the automotive industry in particular this share is just under 36 %; in the traditional „industrial state" of Baden-Württemberg in Germany it is around 40 %. At the level of the entire DRB, industry including energy generation and mining are economically very important since they account for 31-42 % of the GDP of the DRB countries, and 29-50 % of total employment. The sector uses 5.7 billion m³ of water from the Danube River System every year (ICPDR, 2011; Löffler et al., 2019). A large number of dams, reservoirs, dykes, navigation locks and other hydraulic structures have been built on the Danube River to facilitate many of these important water uses (ICPDR, a). Groundwater is of extraordinary importance in DRB as it is the major source of drinking water (about 72 % of drinking water in DRB is produced from groundwater). Apart from the drinking water aspect, it is also an important resource, i. a., for industry in cooling processes, food processing etc. (Liska, 2015). Historically, the Danube and some of its main tributaries, such as the Sava, have formed important trade routes across Europe for centuries. The channelization of the river's course has made it easier for ships to navigate 2411 km, or 87 % of the length of the Danube. As "Corridor VII" of the EU, the Danube connects the Black Sea with the industrial centres of western Europe. Recent years saw an increasing awareness of the need to balance economic and environmental needs in navigation management with special attention to the natural characteristics of the river (ICPDR, b).

3. Specific drought characteristics of the area.

a. Frequency and severity

Although drought in Europe as a natural phenomenon presented an issue already in the ancient and recent past, the observations show that the occurrence of drought has been changing over the last decades. Society is challenged by more frequent extreme weather events such as heat waves and droughts, which provokes extensive damages especially in vulnerable sectors of the economy such as agriculture, water supply, hydro energy, water transport. Climate of the recent past is characterised by more years with above average temperatures, resulting in increased evapotranspiration and an unfavourable distribution of rainfall – all of them increasing the occurrence of drought, which is thus becoming more frequent, more intense and no longer only associated with the summer months. Since the early 1980s, the number of drought-affected areas in Europe has been steadily increasing especially, i.a., in southern and southeastern Europe as well as in traditionally rainfall-rich Alpine countries where drought has not been an issue in the past. In recent years such as 2003, 2007, 2012, 2015, 2017, significant parts of DRB were affected by drought, impacting various water-dependent economic sectors, vegetation and the aquatic environment. Beside these, severe droughts occurred also on sub-regional scale also in certain years in between.

The frequency of drought events and low water levels in the region is expected to increase, especially in summer and in particular in the southeastern parts of the DRB (Gregorič et al., 2019). Weather extremes such as droughts and heat waves will increase with higher certainty (Ludwig-Maximilians-Universität Munich, 2018). In comparison to 1981-2010, drought frequency in near-future 2041-2070 is expected to increase, especially over the downstream half of DRB where an even higher occurrence of drought is expected. Also, the severity of drought and number of extreme drought events is projected to increase mostly over southern and eastern DRB. On a seasonal scale, a noticeable increase of summer and also spring droughts is expected, smaller increase also in autumn droughts. Similar projections apply also for the far future 2071-2100, however, under RCP8.5 drought and its seasonal pattern of occurrence are projected to become considerably more severe compared to 1981-2010, especially over the downstream half of DRB (Spinoni et al., 2017). Regarding low flows, the seasonal discharge of the DRB River is projected to decline progressively. General intensification of the drought and low flow situation is expected all over the DRB with its south and east stronger affected than the north. The decrease in summer discharge is more severe, as it aggravates existing low flow periods. The most affected rivers will be smaller tributary rivers in the southern and eastern DRB. At the same time, an increase of low flows is expected also over the Alpine region. Spatial distribution of drought-affected areas will extend from south-east to north-west (Ludwig-Maximilians-Universität Munich, 2018). In that view, adverse changes in the temperature and precipitation regime is likely to evoke far-reaching impacts of drought across countries, communities, watersheds, economies and ecosystems in the Danube region.

b. Recorded and expected direct and indirect socio-economic and environmental impacts.

Recorded:
The earlier time period prior to 1970 is only sparsely covered by reports on impacts of drought in DRB, in contrast with more recent times (Stahl et al., 2016). When classifying the impacts of drought in DRB that occurred from 1981-2016 into 5-year periods, the recent period from 2011-2015 is characterized by the greatest number of drought impacts (Jakubinsky et al., 2018). Besides those events, the number of annual reports generally appears to have increased since the 1990s (Stahl et al., 2016). In recent years such as 1992-93, 2003, 2007, 2012, 2015 and 2017, significant parts of the DRB were affected by drought, which had a negative impact on various water-dependent economic sectors, on vegetation and on the aquatic environment (Gregorič et al., 2019). Agriculture, and also livestock farming, is highly impacted by drought across the entire DRB due to the climate sensitive nature of the sector (Stahl et al., 2016). Other sectors also impacted in DRB include hydro energy and industry, public water supply, public health, freshwater ecosystem, wildfires, forestry and water quality, although they appear to be more country- or region-specific as well as event-specific,

e.g. dependent on whether an event is short and accompanied by a heat wave (such as 2003 drought in DRB) or characterized by a long multi-year deficit in surface water supplies (such as 2015-2019 drought in the Czech Republic). However, since drought often has wide spatial coverage and water-dependent sectors under drought impact are often closely interlinked directly or indirectly, the damages and losses are not easily measurable and may thus be underreported (ICPDR, 2015; FAO, 2018).

- **Drought 2003 (severe summer drought).**

Although regarded as the major drought in Europe and the DRB over the last 20 years, the exact impact on water-dependent sectors is often not available (FAO, 2018). In DRB, the reduced crop yields, shortages in green fodder supply, increased mortality in the livestock and poultry stocks caused major financial losses to farmers (Fink et al., 2004). In Montenegro, for example, 2003 has been observed as an agricultural drought which also affected its northern part up to 1,000 m above sea level. The overall water deficit was noticeable also in the hydrology sector (FAO, 2018). In Hungary, the dry season caused a significant decrease of water levels of the two biggest natural lakes, Lake Balaton and Lake Velence (Fink et al., 2004).
The annual Danube discharge in 2003 was 76.6 % of the average annual discharge, with an even lower discharge in the second half of the year (ICPDR, 2003). The extreme glacier melt in the Alps during summer months prevented the river flows of the Danube from attaining even lower values. At the end of the summer, the water level fell to the lowest level over the century, stranding ships and barges from southern Germany to the Romanian lowlands, which led to transport shortages for companies (Fink et al., 2004). Although groundwater levels dropped in many places and springs and wells dried up, water supply was not threatened. However, water withdrawal was restricted in some places (Erfurt et al., 2019). In southern parts of DRB, the severe drought of 2003 caused also an energy crisis as, for example, in Albania the average production of the Fierza hydroelectric power plant decreased by 33 % in November, and in Romania, the Cernavoda Nuclear Power plant, which draws cooling water from the Danube, was forced to shut down for nearly a month (The Guardian, 2011; FAO, 2018). A consequence of the increased water temperature and hydrological drought was also an increased number of polluting events in the channel network and small streams in Serbia and Montenegro, leading to the oxygen deficit (ICPDR, 2003).

- **Drought 2012 (severe summer drought after a dry winter 2011/12).**

Yield of agricultural crops across the countries of the middle and lower DRB was reduced between 40-60 % for certain crops, in some countries up to 90 %. Mostly affected were maize, soya beans, cereals, wheat crops, sunflowers, vegetable plantations, fruits and fodder production, including permanent pastures. The dryness of the natural environment resulted in severe wildfires across Croatia, Serbia, Bosnia and Herzegovina, North Macedonia and Montenegro, and left negative impacts also on ecosystems. The Palic Lake in northern Serbia, for example, needed to be artificially filled with thousands of gallons of water from a river to save its fish and ecological system. Water levels in lakes and rivers reached historical low values or dried up, also drinking water supply was nearly endangered in Bosnia and Herzegovina, Croatia, Montenegro, North Macedonia, Romania, Slovenia, and in Serbia which introduced water restrictions. Low water levels in rivers also caused low running electricity supply in Serbia, Bosnia and Herzegovina and North Macedonia (DMCSEE, 2012). Waterways were also affected. At times, it was impossible for ships to navigate the Danube. The dry and warm spring 2011/12 encouraged development of certain drought-loving pests (bark beetle, oak processionary) that pose risks to human and vegetation health (Bissoli et al., 2012). In Slovenia, for example, it caused drying of coniferous trees and resulted in heavily limited forestry seedling, reduced forest vitality and resulted in poor growth rates, altogether leaving a lasting negative impact on the forestry sector in the following years (Zavod za gozdove, 2012). In Slovenia, the combination of drought in early 2012 and strong bora wind resulted in topsoil erosion (Sušnik et al., 2013).

- **Drought 2015 (short but severe summer drought).**

During 2015, agriculture was by far the most impacted sector (ICPDR, 2017). Extremely hot and dry weather during the flowering and grain-filling period reduced grain quality and overall limited the summer crop growth in major agricultural areas (JRC, 2015). Austria, Bosnia and Herzegovina, Czech Republic, Croatia, Hungary, Serbia, the Slovak Republic and Moldova reported high impacts on agriculture, with most significant impact on corn production. In areas with periodical irrigation in Austria, water demand was significantly above the long-term average due to precipitation deficits during spring months. Other countries observed also lower yields at later harvested plants like soya, sugar beet or rapeseed (ICPDR, 2017). Navigation too suffered considerable impact from drought. Critical fairway depths were registered at several transport rivers across DRB, requiring an introduction of lower mean levels of capacity of ships, and interruption or even limitation of navigation during certain days were reported in countries in the upstream half of DRB (Schilling; ICPDR, 2017). Low impacts in relation to drinking water supply were reported in 8 DRB countries, with a particular issue in Bosnia and Herzegovina and Serbia where water-saving measures had to be introduced. In more than half of DRB countries, impacts were reported also in the hydro-energy sector, water quality (high water temperature), and also in relation to ecology (dried up streams, low water levels and eutrophication). Other impacts of drought 2015 in DRB were observed in regard to the forestry sector (Croatia), fish farming (Czech Republic), recreation (Bosnia and Herzegovina) and water quantity (Slovak Republic) (ICPDR, 2017).

- **Drought 2017 (severe spring and summer drought).**

A very warm and dry weather characterised spring months, consequently accelerating phenological development. By early summer, biomass accumulation was reduced and senescence of leaves was accelerated. The vegetation period was marked by heavily reduced yield and quality of major agricultural crops (JRC, 2017a; JRC, 2017b). Most affected were annual crops across all DRB, i.e. cereals and vegetables, while the yield of oilseed rape (Bulgaria 50 %), vine (Slovenia, Montenegro 50 %), olive trees (Slovenia 30-50 %) and fruit trees was also heavily reduced. In addition to reduced yield, fruit had poorer quality, meaning most of the production ended up in processing (Bosnia and Herzegovina). Damage was noted also on open-field areas with irrigation systems since hot weather conditions left effects of irrigation as “cooking” the products. Fodder production was heavily reduced as well: the second yield of hay was reduced by 50 % while there was practically no third yield on natural meadows and pastures. Heavily reduced hay yield resulted in not enough food for livestock, which forced farmers to use their winter supplies to feed them, sell them for low prices at fairs or send them to slaughter houses. At the same time, milk production dropped by about 25 % in Romania. (DMCSEE, 2017; Gregorič et al., 2019). The known overall damage in the agriculture sector due to drought 2017 was estimated at 65 million EUR (Slovenia), 120-140 million EUR (Austria, Bosnia and Herzegovina, Croatia, Czech

Republic) and up to 600 million EUR (Serbia) (Serbia Business, 2017; Gregorič et al., 2019). By mid-summer, drought conditions evolved into a hydrological drought. Even water levels of big rivers such as Tisa, Sava, Velika Morava and Danube were very low, while many small tributary rivers and lakes completely dried out. In some areas of Bosnia and Herzegovina, farmers even ran out of water for irrigation. Drastic drop in water levels had also an ecological impact as fish mortality occurred in Austria and Montenegro, and fish farming was endangered in Croatia and Serbia. By the end of the summer, Danube river flow at Galati city in Romania was reduced to 63 % of its normal levels, causing transportation problems - sand islands of the length of a stadium appeared on the river, forcing crossing ships to take a detour while also preventing barges from entering ports and loading cargo. Consequently, the cereal business was severely affected (DMCSEE, 2017; Gregorič et al., 2019). The hydrological drought was reflected also in severely affected groundwater reservoirs due to reduction of inflows. Consequently, several areas experienced drinking water supply problems, especially affected were towns over Karst and Dinaric terrain all along the western and southern part of DRB. In that sense, Croatian islands, which during summer time bear a high number of European tourists, suffered from local water supply shortages. Firefighter units had to be activated to supply several households with water (Bosnia and Herzegovina, Croatia, Slovenia) and strict water regimes had to be introduced (only certain towns remaining on the public water supply network, night-time interruptions, drinking water available only certain hours in a day (DMCSEE, 2017). Several hydro-power plants, as a preferable source of energy in DRB, experienced high losses in energy production, among others, HEP Bileca (Bosnia and Herzegovina) 40 % losses, HEP Perucica and HEP Piva (Montenegro) 42-50 % losses. In Romania, the reduced hydro energy production provoked the use of more expensive and environmentally harmful fossil fuels such as coal, while Serbia was forced to import electricity at expensive tariffs (DMCSEE, 2017; Blic, 2018).

Expected:
Climate change impacts will be of different magnitude in the DRB regions and almost all water related sectors are likely to be triggered by a north-west to south-eastern gradient of the temperature increase and the north-southern transition zone of precipitation changes. These changes are likely to cause a reduction in water availability with changes in glaciers coverage, reduced snow storage, soil water content and groundwater recharge. All these can be seen as hard facts (Ludwig-Maximilians-Universität Munich, 2018).

Due to a drier climate, an increased water demand by, and water withdrawal for agriculture, industry, energy and human consumption is very likely, especially in the southeastern DRB and in warmer months. This includes increased water use for some other purposes. In that view, the water availability-demand ratio is likely to become a serious problem in DRB in the future, leading to potential economic losses, water conflicts and water use restrictions. The increase in the number of extreme events, the impacts on agriculture and ecosystem can be seen as highly certain, whereas other impacts carry limited significance (ICPDR, 2019).
Tourism: A decrease in snow precipitation, and consequently in snow cover, together with an earlier snow melt, will cause a shorter snow season in all altitudes, decreasing the reliability of slopes dependent on natural snow. Due to its strong reliance on specific climate conditions, winter (snow) tourism will be directly impacted through shortened and more variable ski seasons, a contraction in the number of operating ski

areas, altered competitiveness among and within regional ski markets, and attendant implications for ski tourism employment and values of vacation property real estate values. In that sense, winter tourism is highly likely to be putting additional pressure on the environment upon increased water demand for artificial snow making (water abstraction) (Steiger et al., 2017; ICPDR, 2019).

Agriculture: Although the duration of the thermal growing season is projected to increase, the number of extreme events such as heat stress, drought and water stress is also projected to increase, especially during summer months. This will lead to a general increase in water demand for agricultural purposes (livestock, irrigation, also transport and processing of agricultural products, storage conditions) in the entire DRB in the future, more pronounced in the MDRB and the LDRB. Them being climatically dry regions, there will not be enough freshwater to meet the requirements. An increase of water pressure on the environment may deteriorate the ecological and chemical balance of freshwater bodies and could lead to an increase of contaminated surface and groundwater bodies after enhanced agricultural use. Unfavourable weather conditions will pose challenges for grazing livestock and harvesting grass, and cause the inter-annual variability of crop yields (quantity and quality), altogether putting farmers at higher economic risks and yield losses, especially in MDRB and LDRB (Ludwig-Maximilians-Universität Munich, 2018; ICPDR, 2019; EEA, 2019). Since in the southern and eastern part of DRB, employment is directly dependent on agriculture to a great proportion, the inter-annual variability of crop yields presents a great potential for socio economic issue (employment rate) (Ludwig-Maximilians-Universität Munich, 2018). On the other hand, it is a challenge also for food-importing countries worldwide, since most of the countries receive their agricultural imports from just a few dominant producing states (EEA, 2019).

Ecosystems: With the reduction in stream flow levels together with an expected increase in water temperature, good water quality is likely to be endangered. Changes in ecosystems and biodiversity with shifts of the aquatic and terrestrial flora and fauna are to be expected as a consequence. Higher stress in aquatic ecosystems, predominantly for littoral communities, may occur, especially in the MDRB and LDRB. Negative impacts are also expected on aquatic and wetland habitats, especially for fishing and fish farming through decline of fish breeding places and poor water quality impacting spawning. Some aquatic systems show a higher risk of algal blooms and eutrophication, indicating an endangerment of lakes and wetlands where in dry periods ecologically important minimum flow (the minimum flow necessary to preserve individual natural species in surface water bodies) might be endangered. Therefore, it is of greater importance to prevent water scarcity which can further enhance impacts of droughts - as to limit, or completely withdraw from, water abstraction such as water over-allocation, new water demands from agriculture, tourism etc. (WWF, 2013; ICPDR, 2019; EEA, 2019).

Navigation: There is no agreement about the significance of influences on the navigation for the near future, whereas for the far future there is in general an agreement in limited or impassable navigation due to more frequent low water levels and unstable conditions, especially on routes using free-flowing waterways and in bottlenecks as these areas can impact shipping on a long river stretch. Low water levels, also often in combination with a reduced flow velocity, lead to reduced cargo and limited navigability. This is expected to be particularly true for the UDRB and

MDRB countries and especially in summer for the hot lowlands with less precipitation in future. While navigation in DRB might benefit in winter due to ice and snow melting and higher runoff in the UDRB, shipping is expected to be more frequently restricted in summer due to more days with low water conditions. Due to expected intensification of drought severity, number of extreme drought events and low flow situations especially over southern and eastern DRB, navigation problems are not excluded also for LDRB. Drought-imposed disruptions in inland waterways activities are likely to further increase the number of vessels to compensate for reduced load factors, or increase travel times when vessels stop and wait for the water levels to rise again (Ludwig-Maximilians-Universität Munich, 2018; ICPDR, 2019; Christodoulou et al., 2019).

Hydropower: Hydropower is strongly related to changes in mean annual discharge as well as extreme low flow events throughout a year. In future decades, mean annual hydroelectric power generation is likely to decrease across DRB, and also inter-annual variability is highly expected due to strong influence of the low flow situation of dry years. At the same time, the seasonal pattern will significantly change. While mean hydroelectric power generation is likely to increase in winter because of more rainfall instead of snow precipitations and earlier ice- and snow melt, the latter are at the same time decreasing the natural water availability (runoff) for spring and summer months. Additionally, due to less precipitation projected for summer months, a decrease in energy production of hydro and thermal power in summer is highly expected, which may coincide with an increased energy demand for cooling in households. Moreover, a possible increase in sediment loading in dry periods would perturb the functioning of power-generating infrastructure. Considering regional differences, the decline in hydropower generation in the Alpine head watersheds will be lesser than in the Alpine forelands and the Danube lowlands because of the buffering factor of the snow and glacier storage and less low flow events. In general, extreme events may impair the whole energy production and transport infrastructure and may have further negative effects, i.e. on energy pricing, and can lead to energy shortages (Koch et al, 2010; Ludwig-Maximilians-Universität Munich, 2018).

Groundwater: Changes in runoff conditions are in turn assumed to cause a decline in groundwater storage and recharge, particularly in summer. Besides shortages in water availability, a decline in groundwater recharge could also lead to negative effects on groundwater quality. After long droughts, preferential flow paths are of particular relevance in groundwater protection zones given the fact that pollutants can pass rapidly along them and almost unimpeded into groundwater. To cope with drought in the face of increasing agricultural production and human needs, people will find ways to compensate for the water shortage, largely by extracting groundwater. Potential increasing water demand, especially in the southeastern parts of DRB, may intensify the groundwater decline and also deteriorate the ecological and chemical balance of freshwater bodies and could lead to an increase of contaminated surface and groundwater bodies (Stolz et al., 2018; ICPDR, 2019).

Water demand by other sectors: As expected, general increase in water demand for households, industry and agriculture, together with pronounced water scarcity during summer in the MDRB and LDRB and in some areas of the UDRB, is likely to lead to high water stress. Manufacturing industrial production losses are possible during droughts and hot summers due to scarce water supply, as well as increased difficulties in accessing water resources and higher costs for water resource use. Increasing GDP and GVA (gross value added) may lead to increases in industrial and cooling water demands. It is expected that the water supply cannot fulfil the water demands in coming decades (JRC, 2018; ICPDR, 2019).

Expected long-term impacts:

Forestry and soils: Forests, the terrestrial ecosystems with the highest water demand, will likely be the most influenced by the changing water regime. They share much of the climate change impact with agriculture, such as the shift and change in species to the north and to higher elevated areas, increased water stress and positive effects of a longer growing season only in areas with enough water. Drought stress on forests depends on root-zone water storage and soil absorption capacity, meaning scarce precipitation in the growing season and frequent summer droughts already present problems for forest water balance. The projected decline in summer precipitation and the increase in drought severity may easily trigger the loss of forest cover and vitality. Simultaneously, drying of forest soils present a direct cause for an increased risk of forest fires throughout the year. Nearly all regions of the DRB show a possible decrease of soil water content. Longer periods of dry soil are predicted, especially for the MDRB and LDRB regions during summer months. Therefore, soil degradation is also possible in these regions. Similarly, as for agriculture, the negative impacts of climate change on forestry exceed the positive impacts, which especially apply for some regions in the southeastern DRB where even desertification is expected (southern Romania, Bulgaria). Considerably a lower productivity and health status of forests is expected from 2040 onward, especially in the southeast of DRB, while more frequent occurrence of drought-loving pests and diseases would additionally weaken forest health status. Changes in the distribution, species composition, density and biodiversity of forests are also expected. In the LDRB, even a loss of native tree species may occur. Overall, projected drought impacts on forests are likely to disturb certain ecological services that forests provide (Csaba et al., 2014; Ludwig-Maximilians-Universität Munich, 2018; International Sava River Basin Commission, 2018; ICPDR, 2019).

Flora and fauna: As projected for forestry, also flora and fauna migration patterns are expected to expand north-eastward and to higher altitudes, whereby a rearrangement of biotic communities and food webs, and an earlier onset of life cycles could take place. Certain species will likely face extinction. The species expected to disappear are mainly native, whereas the presence of invasive species may increase (ICPDR, 2019).

c. Cascading and compound impacts, risk of systemic failures

Impacts can be both direct, such as affecting crops and reducing water supply and quality, and indirect such as knock-on effects on business production affecting the flow of goods and services. Listed below are the initial drivers of the upcoming change, and expected impacts from its early stage of occurrence, through several steps of indirect impacts to cascading, larger-scale impacts occurring as a consequence later on.

Driver of drought impacts: Drought stress has its origins in scarce precipitation, while it can be further aggravated by high evapotranspiration (especially relevant for summer half of the year) and by winter rain instead of snow precipitations (relevant in winter half of the year).

Step 1: Ice- and snow melting, drying of soils; drying of wetland; drying of surface waters (streams, lakes); heat stress on living organisms; cracking of soils.

Step 2: Increased wildfires risk; lack of suitable pasture land; difficulties in seed bed preparation and sowing campaign; unfavourable sprouting conditions; decreased reliability of slopes dependent on natural snow (ski resorts); poor water quality (increased algal blooms, chemical pollutants etc.); dried up streams and lakes; increased use of water for different activities (irrigation, wildfires, artificial snow-making etc.); disrupted public water supply upon released significant fluxes of sediments and chemicals (and pollutants into groundwater) after sudden wetting of the soils at the end of a drought (i.e. thunderstorms); local deformation of terrain (soil profile structure, surface soils in mountainous area; weakened rock fall stability in steep mountainous areas).

Step 3: Lower food and fodder quality; reduction in food stocks; decline in productivity of livestock (i.e. milk); increased prices to feed cattle felt by both farmers and by consumers; struggling to provide the necessary volume of fodder cereals to those farmers who traditionally rely on their supply (followed by shortages of certain products on the markets in following months); farmers forced to search for alternative markets and significantly more expensive supply channels; drinking water shortages and disrupted (restricted) supply; civil protection activation for water supply to mountainous areas (households, livestock); poor hygiene and sanitation (especially during summer tourism); health infections; reduced cargo ship bearing capacity; inability to use waterways for cruise and cargo transport ships (forced to make a detour, unable to land in ports to load cargo etc.); reduced or shut down production of hydro energy; increased water pressure on the environment by water-demanding/consuming sectors; endangered fish farming.

Step 4: Collapse of snow tourism and professional winter sports; farmers forced to reduce number of their livestock (selling for low prices at fairs, or sending to slaughter houses); affected entire food chain from the farm to the consumer: packers, processors, supermarkets and retailers; endangered food security of food-importing countries worldwide; fish mortality; need for electricity import or use of more expensive and environment-polluting resources such as coal; higher electricity prices; environmental pollution; poor radial growth of forest trees in post-drought year(s) as food stores are quickly used up; weakened forest vitality.

Step 5: General water scarcity; increased susceptibility of forests to be attacked by insect pests such as the bark beetle and other disease; shift of the market due to disrupted navigation services to more environmentally harmful transportation modes (in terms of carbon emissions per tonne of cargo, i.e. road); poor profitability of agricultural land; weakened incentives for young people to stay on farms, or in rural areas overall, and making it more critical for family members to obtain off-farm work to supplement on-farm income; cultivated fields no longer economically viable under existing land-use and socio-economic conditions.

Step 6: Public health at risk; change in species and wildlife (migration, extinction, disrupted ecosystem balance); land degradation (losing arable land due to drought); land abandonment, especially of agricultural sites, and shrinking of small towns in rural areas; loss of employment in agriculture, and flow-on effects to employment in rural communities and businesses in nearby towns which depend heavily on agriculture and lack economic diversity; human population migration into larger towns and cities (urbanisation); food insecurity of food-exporting and food-importing countries;

intensified transboundary water conflicts among riparian countries; reduced intake of (human-induced) carbon dioxide emissions from the atmosphere by forests.

Step 7: Poverty; loss of biodiversity; higher susceptibility to disturbances of the ecological balance; soil desertification; soil erosion.
(DMCSEE monthly bulletins; MaRIUS; Crossman et al., 2014; Ludwig-Maximilians-Universität Munich, 2018; Garrick et al., 2018)

d. Civil unrest and conflict

There are many pressures on the Danube river that reveal the fundamental and often conflicting interests of its riparian nations. The pressures mainly originate in high water demand for hydropower generation, supply of water for domestic use, agriculture, industry, other economic uses, and for other activities such as fishing and winter tourism. The background of water conflicts in DRB lies in interlocking of numerous countries that share this basin and rely on each other for their individual water security, while being politically, socially and economically very diverse and having high levels of socioeconomic disparities. Any conflicts that arise over transboundary water use are a specific challenge in DRB since problems of sharing transboundary waters are nonlinear and political, and are subject to perceptions and intentions of different actions reflected in their governance choices (Maggerson, 1997; Choundhury et al., 2018). Moreover, the costs and benefits associated with the various uses of the Danube are not evenly distributed among the various riparian states and highlight the power imbalances among them. There are many national actors with differing agendas, laws and resources with which to address their needs (Maggerson, 1997). Most of the existing treaties do not even mention water quantity and contain no detailed principles or rules on water allocations (Pistocchi et al., 2015). The history of cooperation and conflicts on the Danube River shaped the nature of bilateral and unilateral negotiation processes that led to the formation of the modern-day governing structures. The Danube is currently administered under the legal authority of the International Commission for the Protection of the Danube River Basin (ICPDR), a transnational body, which has been established to implement the Danube River Protection Convention. Although established with a legal structure as a coordinating platform to address multilateral and basin-wide issues, final decisions are still a matter of the riparian countries (Maggerson, 1997; Choundhury et al., 2018). In the future, the potential for conflict over finite fresh water resources like the Danube River and its tributaries is ever more likely with increasing populations, the growing demand for food, and the impact of industrialization, urbanization and agricultural practices. This is true even in non-arid regions within DRB where water scarcity is not an immediately pressing problem (Maggerson, 1997). Regions most likely to be affected by water scarcity may actually remain the same, but the water scarcity problem they experience is projected to intensify. A number of sectors requiring water, such as arable and irrigated agriculture and locally also the energy sector, will likely face longer periods with a substantial lack of water to carry on with their activities, which may lead to a loss of production. While there is a common consensus among DRB countries of ensuring drinking water supply as a priority water use, the expected drought impacts as discussed above are likely to intensify existing water conflicts across DRB. In times of water scarcity, it is almost inevitable that some people may feel that the government or districts are not managing water properly or that their needs are a lower priority (JRC, 2018). Importantly, while such negative effects can partly be reduced by water use efficiency gains (i.e. in the field of irrigation, public water supply), these efficiency measures will not be sufficient to compensate for general increases in climate-induced water stress (Baranyai, 2015). In that view, the – often short – periods of water scarcity with competing demands of water from the various economic sectors together with ecological flow targets, will be the most challenging for water management in the Danube River Basin Pistocchi et al., 2015).

4. Existing and/or potential management/mitigation and adaptation options.

a. Do drought policies and legislation and/or drought management plans exist?

DRB countries clearly recognise drought as a serious issue and show commitment to achieve drought-related goals by participating in many international political activities and programmes related to the drought issue, and by signing important international documents targeting drought that strive towards a sustainable future of the environment. A drought-policy review, carried out in the frame of DriDanube project for 10 DRB countries, reveals that these mainly include the UNCCD, the UNFCCC, the Danube River Protection Convention, the EU Water Framework Directive (WFD), EU Climate Change Programme, the EU Strategy for the Danube Region (EUSDR), the EU Adaptation Strategy, the Alpine Convention, the Framework Agreement on the Sava River Basin (FASRB), and the Carpathian Convention (Table 1 below). But even if the ratification of international policies demonstrates countries' will to achieve drought-related goals, only a few of those policies are binding.

Despite the commitment to a number of international policies, most DRB countries do not have a national umbrella document in place that would directly address the overall national drought management. Drought and its management are only partially and insufficiently considered in various strategic documents, laws, regulations, and programmes, mostly only in connection with emergency situations and natural disasters. In addition, terms like dryness, dry periods, heat waves, water scarcity and drought in these documents seem to be used interchangeably (Moderc, 2018; Gregorič et al., 2019). Systematic quantitative knowledge on the environmental and socioeconomic impacts of drought, however, is often the missing piece in drought planning and management (Stahl et al., 2016). Some key documents such as action plans and management plans in relation to drought have in recent years been prepared or are under development, while there is an evident lack of operational national drought management documents. Some DRB countries also have legal framework established on post-drought procedures for economic estimation of drought damage, however, it is usually also the main manner of dealing with drought (Moderc, 2018; Gregorič et al., 2019).

	AT	BA	CZ	HR	HU	ME	RO	RS	SI	SK
United Nations Convention to Combat Desertification (1996)	Signed	Signed	Signed	Signed	Signed	Signed	Signed	Signed	Signed	Signed
United Nations Framework Convention on Climate Change (1994); Kyoto Protocol (2005)	Signed	Signed	Signed	Signed	Signed	Signed	Signed	Signed	Signed	Signed
Danube River Protection Convention (1998)	Signed	Signed	Signed	Signed	Signed	Signed	Signed	Signed	Signed	Signed
EU Water Framework Directive (Directive 2000/60/EC) (2000)	Signed	In process	Signed	Signed	Signed	In process	Signed	In process	Signed	Signed
European Climate Change Programme (2000)	Signed	In process	Signed	Signed	Signed	In process	Signed	In process	Signed	Signed
EU Strategy for the Danube Region (2011)	Signed	In process	Signed	Signed	Signed	In process	Signed	In process	Signed	Signed
EU Adaptation Strategy (adopted in 2013); European Climate Adaptation Platform	Signed	In process	Signed	Signed	Signed	In process	Signed	In process	Signed	Signed
Alpine Convention (1995)	Signed	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Not relevant	Signed	Not relevant
Framework Agreement on the Sava River Basin (2004)	Not relevant	Signed	Not relevant	Signed	Not relevant	Not relevant	Not relevant	Signed	Signed	Not relevant
Carpathian Convention (2006)	Not relevant	Not relevant	Signed	Not relevant	Signed	Not relevant	Signed	Signed	Not relevant	Signed

Colour code legend:

Signed, transposed to national law | In process of being introduced | Not relevant

Table 1: International policy activities and programmes adopted by the DriDanube countries. Number in brackets indicates the year when a policy came into force. (Source: Gregorič et al., 2019)

b. If yes, have they been useful

In the existing legislation and policies, the roles and responsibilities of stakeholders including those of lead institutions are often unclear and/or overlapping with regard to the actions to be taken under specific drought conditions. The co-responsibility without a clear inter-institutional scheme of data, responsibility and communication flow results in neutralising the institutional response, especially before and during a drought, instead of accelerating it. The existing crisis-oriented drought policies thus support the adoption of a crisis management (reactive) approach that activates institutions mostly when drought intensity is already alarming. Consequently, the activities are focused on treatment of drought symptoms (impacts) rather than on a proactive approach which would include also preparedness and early response/actions. In practice, drought continues to be managed as a crisis situation by implementing emergency procedures and urgent measures. However, this approach usually fails to achieve the most sustainable solutions. Despite extensive drought damages on the economy and welfare of the people, drought is at the political level still not considered an issue of high priority although there is noted interest from the operational services in establishing a proactive approach in responding to drought, which is also slowly becoming a priority in DRB countries. Findings from a review of the current status of drought management, carried out in the frame of the DriDanube project for 10 DRB countries, are summarised in a Table 2 below (Moderc, 2018; Gregorič et al., 2019).

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Reviewed drought management aspects		Status of existing drought management			
		National *Unit: number of countries out of 10*			Regional
Strategic elements in nat. legislation	Drought recognized and/or declared as natural hazard	9	-	1	
	National drought management strategy or similar umbrella document on drought exists at governmental level	2	1	7	
	National drought management plans prepared, or in preparation	1	1	8	
Monitoring and early warning	Drought monitoring in place of public bodies with drought indices	7	3	-	
	Defined thresholds for different drought types	1	4	5	
	Regular, periodic and on-time informing of public about the level of severity of drought in place (early warning system)	4	4	2	
Communication on drought	Information about drought spreads spontaneously through media	10	-	-	
	Communication with stakeholders about drought risk, mitigation and damages	-	6	4	
	Communication within different level governmental bodies on drought risk, mitigation and damages	1	1	8	
Drought response	Systematic adoption of actions to prevent further drought damages	-	2	8	
	Regular drought impact collection and/or sectoral damage evaluation in place at public bodies	3	5	2	
	Established national drought damage compensation scheme	6	3	1	

Colour code legend:

	National status	Regional status
	Not in place	Poorly managed
	In place but not systematic	Partially managed
	In place and systematic	Well managed

Table 2: Colour-classification of the drought management status at regional level based on the existing national drought management status in DriDanube countries. (Source: Gregorič et al., 2019)

The way drought is managed in practice reveals that existing drought-related policies are very useful in parts that concretely address drought management or response actions, such as drought monitoring obligations, response to natural disasters, compensation scheme procedures etc. While on the other hand, aspects of drought management that are not concretely addressed in these policies are usually not as successfully carried out or their implementation relies on individuals' self-initiative. No clear inter-institutional scheme of responsibility- and information flow, especially before and during drought development, is considered one of the main shortcomings of existing drought-related policies. The lack of their definition in legal documents is reflected in poor cooperation between relevant national institutions and across different vulnerable sectors in practice, especially in times of no-drought conditions when preparation and/or improvement of development strategies and policies could take place, and during drought early development when potential drought impacts could still be proactively mitigated (Moderc, 2018; Gregorič et al., 2019).

In spite of this, there are some good practices existing in DRB of how the state of inadequate drought policies can be changed by amending other existing policies that function well in practice, such as climate change or water management policies, with concrete drought-related topics. One such example can be observed in Austria where measures introduced in the water supply sector as a result of the 2003 drought proved their effectiveness in regions vulnerable to resource limitations during the 2015 drought, thus illustrating that amending water management with drought-concerned topics can to some degree improve also drought management. Better knowledge on drought risk areas by outlining regions with limited (own) water supply and thus potential shortages expected during longer drought periods, have also proved effective (Schilling).

c. Which steps have been taken to mitigate droughts in case of an event?

The manner of mitigating drought is similar across DRB countries, however, it is disproportional throughout the drought event life-cycle (drought onset, development, and disaster). Its general characteristic is to be reactive to severe drought impacts once already in place, thus response steps taken during crisis-level drought outweighs a preventive response. Usually, some action plans are adopted in the form of relief operations which initially focused on drinking water supply and livestock.

During drought development, most focus is on regular drought monitoring and various means of informing the public about the current state of dry conditions. It is usually accompanied with only general recommendations given, such as rational use of water, irrigation, applying soil mulching and other general technological recommendations, while concrete steps of mitigation during this phase of drought are not defined officially. Other, more concrete advice tailored to a specific drought event is spoken to the public through self-initiative, although their reach is bound to be sporadic. In recent decades, a lot of progress has been made in improving monitoring of drought and its early detection via remote sensing and modelled indices, but detection of drought through its monitoring is not integrated into formal procedures, and thus no official response takes place until drought has almost reached the level of natural disaster. Then, mitigation response is typically ad-hoc oriented.

When it comes to drought being declared as a natural disaster, DRB countries usually have a clear response procedure defined, that comes into force through Acts. Official procedures are clear in terms of steps to be taken, responsible institutions and workflow between them. In several countries, official procedures consist also of a state preliminary assessment of the damage in current agricultural production, which is the base for post-drought compensation aid by the state.

The increased number and severity of drought events in recent years along with the ineffective nature of reactive-based response triggered countries to search for better and long-term solutions outside their national domain, especially in the field of preventive response and early actions. It is reflected through networking with neighbour countries into application for drought-related projects, active involvement and engagement with regional initiatives and bodies (such as i.e. the Drought Management Centre for Southeastern Europe - DMCSEE, the Global Water

Partnership Central and Eastern Europe - GWP CEE, the Integrated Drought Management Programme - IDMP, ICPDR, World Meteorological Organisation - WMO) and active bonding with experts from other DRB countries, knowledge and good practices sharing and expert training. This is especially important in the light of transboundary shared sub-basins of Danube tributary rivers (Moderc, 2018).

d. Possible options/pathways to increase the resilience and minimize the risk from droughts

Option 1: Optimal Drought Management Model (ODMM)

An alternative to crisis-oriented management of drought can be found in adopting a proactive approach, which is slowly becoming one of the main concerns of strategic regional bodies. Through focusing on the preventive and early response, it helps building country resilience to drought and better preparedness for a potential next drought. To start tackling the aforementioned weaknesses at their core, and with a noted interest in 10 DRB countries in adopting an alternative to crisis management, an optimal drought management model was developed in the frame of DriDanube project for the practical implementation of a proactive approach.

The main aim of ODMM is to provide an operational model for collaborative and proactive management of drought at the national level, thus enabling building drought resilience through proactive response. The concept of ODMM has been developed in a way that allows its adoption by any country regardless of its internal organisation of national authorities. The model organises the existing legislation, institutions and their roles in the country in such a way so that they can jointly implement drought-related policies according to the specified protocol of actions (Figure 3). Therefore, the model has 3 main components:

i. *Drought policy framework,* which represents the legislative basis for drought management (documentation);
ii. *Institutional cooperation scheme,* through which the drought policy is implemented (setting);
iii. *Protocol of actions,* which provides a basis for timely response of involved institutions (implementation).

Its purpose is to clearly indicate the necessary actions and the responsible institutions that should take those actions in each respective stage of drought – as to determine who is doing what and when. In the model, the outcomes of national drought monitoring are connected with a cooperative national response, thus corresponding to changing drought conditions: it encourages preventive actions during no-drought conditions, early response upon the occurrence of first signals of a drought and its further development, mitigating the effects when drought is present, and drought recovery afterwards. In this way, the model serves as a tool for strengthened institutional cooperation and support in the decision-making process (Gregorič et al., 2019).

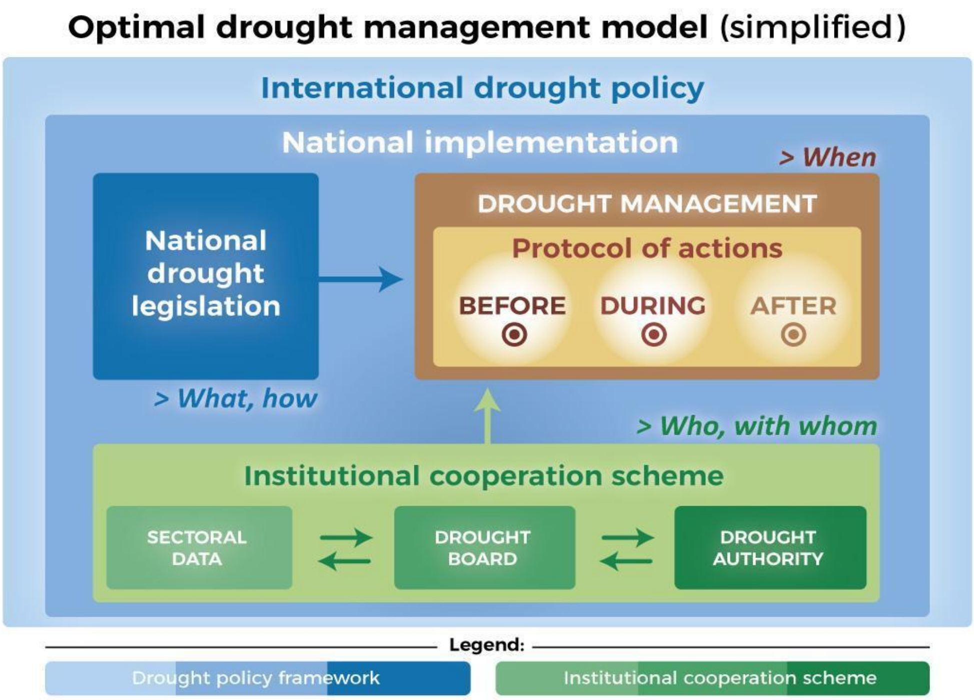

Figure 3: Simplified scheme of the optimal drought management model (ODMM). The drought-policy component is presented in shades of blue while the institutional-setting component is presented in shades of green. The protocol of actions, presented in shades of yellow, acts as the driving force of the model (Source: Gregorič et al., 2019).

Option 2: Use of monitoring and impact database & tools

It should be kept in mind that early warning systems designed to help protect life, property and livelihoods are the most important one of all the services provided by national hydrometeorological services. Drought monitoring outcomes therefore act as a direct support to sectoral experts for planning their activities or adjusting to changing drought conditions, and to national authorities for recognizing the optimal time to trigger restrictive measures. Recent technological and methodological improvements in the field of drought monitoring have enabled the development of some tools that support the implementation of proactive drought management in the countries of the Danube region.

Drought Watch is an open interactive web application for near-real-time drought monitoring as it offers an insight into the development of drought conditions across the entire Danube region. It was designed for national authorities and drought experts, but also for other end-users such as farmers or water managers, to help them make appropriate decisions that lead to the application of relevant short-term measures. It displays various drought indices (drought-related datasets from different sources: satellite, modelled and reported) through colour-classified values which can be interpreted as triggers for early warning. Its additional added value lies in a unified cross-border view of drought situation across DRB on a fine scale rather than a point-value display. It combines information on drought risk areas based on climatological and yield loss perspectives, regular monitoring through drought indices, and weekly information on drought impacts detected on the field, all in one place (*https://www.droughtwatch.eu/*).

Information on drought impacts, available in Drought Watch, is collected through National Reporting Networks (NRNs). NRN is an operational way of drought impact assessment which helps to deliver early awareness of drought damage in place. They consist of engaged individuals on the field, mostly farmers and technicians with knowledge in agriculture and forestry, who weekly report their observations on the state of soil, vegetation or even loss of yield on their specific location, throughout the season or the year.

Information on drought risk areas, available in Drought Watch, has been mapped based on a unified drought risk assessment. Informative drought risk maps were prepared through a harmonized approach for 10 Danube countries to enable comparative information on the level of risk for drought occurrence. One set of drought risk maps considers the climatological aspect of drought occurrence, thus allowing to recognize the areas prone to rainfall deficit. The other complementary set of maps considers drought risk in terms of occurrence of impacts due to drought, thus allowing to recognize the areas where the risk for crop yield loss for four main agricultural crops (maize, wheat, rape and barley) can be considered as high, medium or low (Gregorič et al., 2019).

Option 3: Strengthening the cooperation between stakeholders, sectoral experts and decision-makers

Here are some brief recommendations on how to enhance the capability of the society to better cope with droughts on the long run:

1. Encourage internal collaboration. Strengthen existing partnership between policy makers and stakeholders by laying down a schedule of regular meetings between relevant national institutions for briefings, updates, potential improvements of short- and long-term work etc. In parallel, creating a single web portal where the general public can get as accurate as possible information on the state of drought directly from national expert institutions. It would at the same time help to increase general awareness of the drought issue among the public.

2. Encourage international partnerships in order to be continuously tuned with the latest developments. On one hand, country's obligations that derive from existing international drought-related commitments call for active involvement since drought policies are live initiatives or documents even after being put into force. Regular updates are taking place at international meetings and conferences, new strategic frameworks are being formed, and helpful toolboxes and platforms developed for their implementation at the national level. In addition to being continuously tuned with the latest on-goings, a country's active international involvement presents an opportunity also for addressing transboundary water management issues jointly. On the other hand, extra skills for an increased drought management capacity come from nurturing existing networks and building new initiatives (projects, follow-ups, expert teams). It is thus recommended to connect with other institutions and regional initiatives to exchange knowledge and good practices for improving drought management activities, with emphasis on the learning process and the prevention. One such successful regional networking occurred in 2006 when 13 countries established a Drought Management Centre for Southeastern Europe (DMCSEE) to better monitor the occurrence, frequency and impacts of drought. Situated in Slovenia, it also coordinates and facilitates the development and application of drought risk-based tools and practices in countries of southeastern Europe.

3. Search for resourcing to invest in data, products, tools and human capacities to support improvement of drought monitoring practices and its long-term continuity of operation. It is crucial for ensuring stability of national operational processes, which further on can help build ground for their placing in drought-related legislation.

4. Establish water-related learning curriculums at all levels, especially in elementary education. Learning methods, such as i.e. study books, excursions, summer schools and documentaries, are best to be prepared by water experts and didactic persons working together (Gregorič et al., 2019).

Option 4: Enhance drought topics in national legislation

Generally, national drought management consists of two major parts: monitoring of drought development and its impacts, and corresponding institutional legal-based reaction, which both need to be strongly inter-connected at all times: during the periods of preparedness, response and recovery from drought. It should be flexible and able to adapt to the constantly progressing outcomes of drought research: continuous efforts of governmental bodies are required to upgrade drought monitoring (use of new data, tools, drought characterisation method (indices) or others), and to further seek good response practices. There are a variety of ways at the national level that could be used to enhance the implementation of comprehensive drought management.

1. Initiate political will and call for a coordinated legal approach. Policy coherence related to drought on the national level is one of the guiding principles of implementation of a proactive drought management. For achieving this, countries are encouraged to acknowledge drought as a significant water issue and thus include it among national priorities.

2. Develop a national strategic document on drought management and apply a legal Act. It shall cover strategic views on the drought issue, set long-term goals and a manner of achieving them, and define a matrix of the drought timeline and corresponding course of institutional actions. A result-oriented proactive drought management requires clear assignment of responsibilities and roles, including their integration into the operational process and action plans. Support for its preparation can be found in the Danube Drought Strategy. A country can transpose this comprehensive drought management document in existing national policies, i.e. under water acts, environment protection acts or under climate change adaptation, while some other recommended legislative framework options with its base in international commitments are listed in Table 3.

3. WMO recommends national regulations to follow a "single authoritative voice" on weather warnings within the countries in order to avoid public confusion. Other providers of weather-related information are discouraged to style their products in the shape of warnings. Early warning on extreme weather events is essential for national emergency responses or mitigation activities, which shall therefore be directly tied to extreme weather alerts, further completed within a drought plan (Gregorič et al., 2019; IDMP, 2019).

4. Search for additional short- and long-term measures to strengthen the level of resilience of vulnerable communities. The basic prerequisite for this is to review and evaluate existing drought-related measures and plans, and identify conflicts among water users. It is then of great importance to define concrete sector-based measures for each stage of drought development. However, early identification of research needs in each vulnerable sector can also help activate the science community in advance for

exploring solutions for bridging the gaps in sectoral drought topics. Having science at the table when decisions are being made would ensure launching "clever" sector-oriented measures. The joint work of the science-policy-decision making community will hand in hand support policy and practice.

Legislative framework at regional level	Existing implementation mechanism at national level	Implementation period	Associated obligations of the countries	Additional information on implementation
United Nations Convention to Combat Desertification (UNCCD)	National Action Programme (NAP)[44]	UNCCD 2018-2030 Strategic Framework for implementing the Convention	PRAIS UNCCD reporting proces[45] (started in 2018)	Drought Initiative & Drought Toolbox
EU Water Framework Directive (Directive 2000/60/EC)	River Basin Management Plan (RBMP)[46]	Ongoing WFD 2nd cycle (2016–2021), WFD 3rd cycle (2021-2027)	Reporting & evaluations	Water Information System for Europe (WISE)[47]
EU Strategy on Adaptation to Climate Change (EUSACC); **European Climate Change Program** (ECCP)	National Adaptation Strategy with National Adaptation Plan[48]	2020	Reporting & evaluations	European Climate Adaptation Platform (Climate-ADAPT) – reference information system[49]
Sustainable Development Goals (SDGs) & **The 2030 Agenda for sustainable development**	Aligning national priorities with the 2030 Agenda & SDGs[50]	2030	National targets (i.e. SDG 15.3)	SDGs HelpDesk[51]
EU Common Agriculture Policy (EU CAP)	Rural Development Programmes (RDPs)	Post-2020	Implementation of RDPs actions	EC information on national RDPs[52]

Table 3: Some policy options for the implementation of drought policy with auxiliary information. (Source: Gregorič et al., 2019).

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