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Current status of water-related planning for climate change adaptation in the Spree river basin, Germany

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Abstract. Fuelled by climate change, low flows, heavy rain and flooding will likely intensify in the future, adding to the pressures experienced by rivers in western and central Europe in recent decades. To meet these challenges, comprehensive water-related adaptation to climate change is indispensable. Based on the case study of the Spree river basin in Germany, this study analysed legally defined plans for water management, spatial planning and landscape planning for their current status of integrated climate change adaptation. To pre-structure the document analysis, eight water management fields of action for adaptation to climate change were identified using official recommendations for action. A total of 39 % of the 28 plans analysed specify objectives and measures for adapting to climate change. Of these, 55 % address the diverse impacts of climate change in a more comprehensive way, including prevention and mitigation of droughts and floods, as well as protection of water ecosystems and groundwater resources. Filling these planning gaps may include more frequent updating of plans, a greater focus on evidence from informal plans, multifunctional measures, and the adaptation of best-practice examples for the systematic integration of climate change impacts and adaptation. Planning and implementing comprehensive climate change adaptation will strengthen the resilience of ecosystems and secure human livelihoods.

1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC, 2022), climate change is already affecting rivers in western and central Europe with high confidence, and impacts are expected to accelerate. Precipitation in recent decades has significantly increased river flooding in western and central Europe and is estimated to further exacerbate it in the future, as are the intensity and frequency of heavy rainfall events and related pluvial flooding (Ranasinghe et al., 2021). Furthermore, low flows are likely to become more frequent and severe, leading to streamflow droughts and water scarcity (Ranasinghe et al., 2021). Over the last century, an increase in water temperature of about 1–3 °C has been observed in European rivers, with an upward trend in the future, which may lead to significant changes in species composition and aquatic ecosystem functioning (EEA, 2017; Garack et al., 2022).

In recent years, Germany has repeatedly experienced extreme weather events with deadly consequences, demonstrating the diverse threats associated with climate change. For example, heavy rainfall and flooding along the Ahr river in July 2021 caused deaths and damage to homes, businesses and critical infrastructure (Tradowsky et al., 2023), summing up to an estimated EUR 40.5 billion in direct and indirect costs (Trenczek et al., 2022). Another widely regarded example is the Oder river: low water levels and higher water temperatures have made the river more sensitive to sewage disposal and pollutants, causing the collapse of the ecosystem in August 2022 with a fish kill of about 360 t over a length of 500 km (Free et al., 2023).

The Spree river basin is located in the largest driest and warmest region of Germany, where climate change is expected to lead to a strong increase in heat days and tropical nights with resulting droughts and low water levels as well as an increase in heavy rainfall events (Kahlenborn et al., 2021). Preventing and mitigating these and other effects of water-related hazards require appropriate planning that fully addresses the impacts of climate change. Using the Spree river basin and its challenges posed by climate change, this study examines the current status of climate change adaptation in water-related planning. To this end, a document analysis of legally defined plans for water management, spatial planning and landscape planning was carried out. The results serve as a first systematic overview of the current state of climate change adaptation planning in the formal framework of water governance in the Spree river basin, and they help to identify opportunities for improvement.

2 Study area and scope

2.1 Spree river basin and its water management challenges

The Spree river basin (Fig. 1) is part of the German Elbe river basin (FGG Elbe, 2021b) and covers a river length of approximately 382 km (Uhlmann et al., 2023). It springs in south-eastern Saxony and flows northwards through Brandenburg and into the Havel in Berlin. It is therefore located in an area with one of the lowest precipitations in Germany, with average precipitation amounts of 500–700 mm in the Berlin–Brandenburg region for the years 1991–2020 (Umweltatlas Berlin, 2024). The middle section of the Spree, on the border between Saxony and Brandenburg, is part of the Lusatia region (Uhlmann et al., 2023). Here, large areas of the Spree river basin are characterized by around 150 years of active open-cast lignite mining and the resulting post-mining landscapes with many artificial lakes. To the north of the Lusatia region, the Spree flows through the Spree Forest, a lowland with extensive floodplains, moors and swamps with a large water-related tourism industry (MLUR, 2000). The last part of the Spree river is heavily influenced by the capital region of Berlin with large sealed areas and a high population density (SenStadtUm, 2016).

Despite the environmental heterogeneity of the Spree river basin, Kahlenborn et al. (2021) estimate similar climatic changes across the entire river basin: the number of heat days, tropical nights and heavy rainfall events are expected to increase. The area will be particularly affected by droughts and low water levels, as well as flash floods and pluvial flooding. Overall, the Spree river basin is likely to remain one of the driest and warmest regions in Germany in the future (Kahlenborn et al., 2021).

The coal phase-out by 2038 for climate change mitigation is putting further pressure on water management in the Spree river basin (Uhlmann et al., 2023). Due to lignite mining, the groundwater level is kept artificially low and sump water is pumped into the Spree river. This, together with the construction of dams, has led to artificial discharge conditions and a water surplus in the Spree, benefitting the water balance in the subsequent Spree Forest and the Spree-dependent water supply to the capital region of Berlin. As part of the coal phase-out, the remaining open-cast mines in the Lusatia region must be redeveloped. Under the given environmental conditions, water resources of the Spree river basin without pumped water will not be sufficient to fill all dams and open-cast mining holes located in the Spree region for efficient water storage, as was originally intended. The coal phase-out will consequently lead to a higher risk of water shortages in the Spree, negatively affecting the protected ecosystems and regionally significant tourism in the Spree Forest and the metropolitan water supply (Uhlmann et al., 2023). Regarding the latter, around 70 % of Berlin's water supply is currently obtained from bank filtration along the rivers Spree and Havel (BWB, 2022), illustrating the high water supply as a strong pressure on the Spree's water balance. Climate change is expected to exacerbate the impending challenges to water management through rising temperatures, evaporation and water demand (Uhlmann et al., 2023). Therefore, the case study of the Spree river basin exemplifies the complexity of future water management, providing a study area with diverse demands on water for the following analysis.

2.2 Water-related planning

In Germany, water issues are regulated by a variety of laws for water management (WHG[1]), spatial planning (ROG[2]), land-use planning (BauGB[3]) and landscape planning (BNatSchG[4]). Addressed are inter alia flood protection (§2 ROG, Sect. 6 WHG), rainwater management (§55 WHG, §9 BauGB), protection of groundwater resources (§1 BNatSchG, §2 ROG) and protection of water(-dependent) ecosystems (§1 BNatSchG, §6 WHG).

Water management in accordance with the Floods Directive (FD) and the Water Framework Directive (WFD) refers to plans for cross-administrative river basins. The "Flood Risk Management Plan", the "River Basin Management Plan" and the "Programme of Measures of the German Elbe River Basin" are usually legally binding for the federal state authorities (§2 BWG, §24 BbgWG, §87 SächsWG). River basin management plans and programmes of measures can be concretized by river development plans on the sub-basin level (Article 13 WFD). Their preparation is not required by law, and the objectives described do not impose binding obligations on public authorities. As such, they do not constitute formal planning. Nevertheless, they are useful, if not necessary, for the spatially specific implementation of the overarching river basin management plans and programmes of measures and thus for achieving the objectives of the WFD (Garack et al., 2022). Given that Germany is signif-

[1] *Wasserhaushaltsgesetz* (Federal Water Act of July 2009), incorporates the WFD in Germany.

[2] *Raumordnungsgesetz* (Federal Spatial Planning Act of December 2008).

[3] *Baugesetzbuch* (Federal Building Code in the version of the announcement of November 2017).

[4] *Bundesnaturschutzgesetz* (Federal Nature Conservation Act of July 2009).

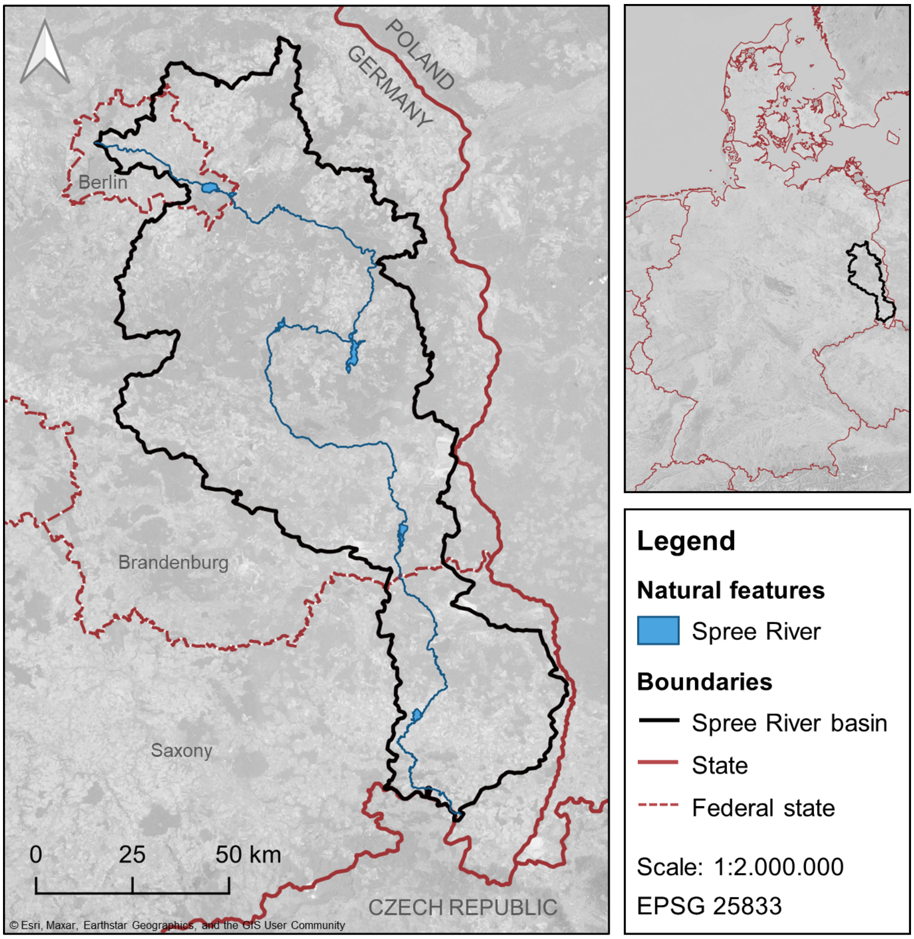

Figure 1. Spree river basin. Map data acquired from Esri, Maxar, Earthstar Geographics, and the GIS User Community (2024), BKG (2009), LfU (2024), WasserBLIcK/BfG & Zuständige Behörden der Länder (2016), LfULG (2021) and EC/ESTAT/GISCO (2020).

icantly lagging behind in meeting the WFD targets (BMUV and UBA, 2022), their preparations are arguably even more important.

Spatial, land-use and landscape plans usually exist at the administrative levels of the federal states, regions and municipalities (§13 ROG, §5 to 10 BauGB, §10 to 11 BNatSchG). Spatial plans deal with the overall spatial development and are legally binding for public authorities (§3 ROG). Landscape plans concentrate on the sustainable development of natural assets (biodiversity, soil, water, air, climate, landscape) and open-space recreation (§1 and 9 BNatSchG) and usually have to be integrated into spatial or land-use plans to become legally binding (§10 and 11 BNatSchG). However, even without such integration, their content must be considered (but not strictly followed) in all plans and projects that may affect nature and landscape (§9 BNatSchG).

3 Methodology

To analyse and assess the current status of water-related climate change adaptation planning in the Spree river basin, the study scope covers relevant plans for water management, spatial planning and landscape planning. The study focuses on formal plans that have a legal basis and need to be prepared and updated, with the exception of the river development plans, which have a legal basis in the WFD but are not required to be prepared or updated. Selection criteria for the plans included a spatial reference to the Spree river basin, a preparation by or on behalf of a public authority, and digital availability. In the case of the "Flood Risk Management Plan", the "River Basin Management Plan" and the "Programme of Measures of the German Elbe River Basin", the study scope includes measures limited to a smaller part of the Elbe river basin, the so-called coordination area "Havel" (see Fig. S1 in the Supplement). For plans requiring mandatory updating, the most recently published version or the current draft (if already publicly available and participation procedures completed) was analysed. Land-use and landscape plans on the municipal level were not investigated due to their large number, which exceeded working capacities. Berlin is an exception, as it is a city-state with only two formal administrative levels (city-state and districts).

A document analysis (Bowen, 2009) allowed the evaluation of the current status of water-related climate change adaptation in the mentioned plans. Firstly, a general analysis examined the consideration of climate change aspects in the plans using three predefined categories (Table 1).

Secondly, a more detailed analysis investigated the comprehensiveness of climate change adaptation within the plans. Here, the pre-structuring of the data largely corresponds to the updated "Climate Change Report" of 2020 by the German Working Group on Water Issues of the Federal States and the Federal Government (Bund/Länder-Arbeitsgemeinschaft Wasser; LAWA) (LAWA, 2020). The report contains 15 nationwide fields of action for water management with an extensive list of measures and (subordinated) actions to adapt to climate change for each field of action. For the Spree river basin and with regard to the selected plans, eight fields of action are relevant for our analysis:

a. low-water management
b. groundwater protection and use
c. public water supply
d. agricultural irrigation
e. water ecosystem protection
f. flood protection during heavy rain
g. inland flood protection
h. urban drainage and wastewater treatment.

These eight fields of action contain a list of 71 climate change adaptation measures. Nine of them were excluded as they do not fall within the remit of the plans analysed, are of little relevance to the study area or strongly overlap with other measures in the same field of action.

The final selection of the fields of action and associated climate change adaptation measures and actions provides an overview of possibilities to implement climate change adaptation in the Spree river basin (see Tables S1–S8 in the Supplement) and serves as the basis for the analysis of the current state of climate change adaptation in formal planning.

A statement in the plan was included in the analysis if it met all of the following requirements:

- The statement contains an objective/measure/action that is generally described as appropriate for adapting to climate change or that is specifically aimed at minimizing an impact of climate change (e.g. increasing heavy rainfall or drought due to climate change).
- The statement is linked to at least one of the water management fields of action suggested by the LAWA.
- The statement corresponds to a proposed climate change adaptation measure and/or action by the LAWA.
- The statement refers explicitly to (parts of) the Spree river basin or to water management in general (see Discussion, Sect. 5).

It should be emphasized that the analysis excluded statements that are relevant to climate change adaptation but do not explicitly refer to it. This decision was made to focus our research on the intentional consideration of climate change adaptation in planning rather than on the potential of objectives and measures that primarily serve other purposes (see Discussion, Sect. 5).

4 Results

The document analysis includes a total of 28 plans (Arndt, 2024), consisting of 19 water management plans, 5 spatial plans and 4 landscape plans (Table 2). The location of the respective planning areas is shown in Figs. S1–S4. Not all regional and landscape master plans falling within the Spree river basin could be analysed, as they only exist in analogue form or only parts of the plans are available. A total of 17 river development plans constitute the largest share. The plans' publication dates range from 2021 back to 2000. In the following, we do not intend to rank the different types of plans in comparison to each other, as they have different legally defined aims and tasks.

4.1 Consideration of climate change

Regarding the analysis category "CC" (Table 1), 16 plans examined (57 %) mention climate change. A total of 9 out of 21 plans published before 2019 address climate change, and from 2019 onwards all plans do (see Fig. S5). Of the 11 formal plans (marked with * in Table 2), 9 plans (82 %) consider climate change, their publication dates ranging from 2007 to 2021. Among the 17 river development plans published between 2009 and 2020 (preparation and updating is not legally required), 7 plans (41 %) mention climate change.

4.2 Consideration of climate change impacts

Concerning the analysis category "CCI" (Table 1), 14 plans (50 %) recognize climate change as an issue for the water balance in the planning area and describe (potential) impacts of climate change. The thematic focus lies on increasing low-water situations and decreasing water supply due to climate change (described in 12 plans) (see Table S9). Seven plans refer to increasing heavy rainfall events and flooding as (potential) climate change impacts. Five plans address the deterioration of the water status in the context of climate change.

Table 1. Analysis categories.

Category	Description
CC	Climate change or a closely related term (e.g. global warming) is mentioned in the plan.
CCI	(Potential) climate change impacts concerning the planning area are described in the plan.
CCA	Climate change adaptation is considered in the context of water management in the plan.

Table 2. Overview of the plans examined and their allocation to the analysis categories ($N = 28$, $1 =$ applies). Plan abbreviations are composed of plan acronym, area allocation and publication date. Plan acronyms are FRMP (flood risk management plan), RBMP (river basin management plan), PoM (programme of measures), RDP (river development plan), SDPro (state development programme), SDP (state development plan), RP (regional plan), LUP (land-use plan), LaPro (landscape programme) and LaMaP (landscape master plan). Area allocations for water management plans are the German Elbe river basin (Elbe) and Spree river sub-basins (divers) with federal state affiliation (BB for Brandenburg, BE for Berlin, SN for Saxony). Area allocations for spatial and landscape plans refer to their respective administrative levels, labelled with either the federal state or the region/county with federal state affiliation.

Scope	Plan abbreviations (plan acronym, area allocation, publication date)	Citation	Analysis categories CC	CCI	CCA
Water management (according to the WFD and FD)	FRMP_Elbe_2021*	FGG Elbe (2021a)	1	1	1
	RBMP+PoM_Elbe_2021*	FGG Elbe (2021b, c)	1	1	1
	RDP_Berste_BB_2013	LUGV (2013a)	1		
	RDP_Cottbuser_Spree_BB_2011	LUGV (2011a)			
	RDP_Erpe_BB_2011	LUGV (2011b)			
	RDP_Erpe_BE_2013	SenStadtUm (2013)			
	RDP_Greifenhainer_Fließ_BB_2011	LUGV (2011c)	1	1	1
	RDP_Großes_Fließ_BB_2011	LUGV (2011d)	1	1	
	RDP_Kleine_Spree_SN_2011	LfULG (2011)	1	1	
	RDP_Krumme_Spree_BB_2013	MLUV (2013)	1	1	1
	RDP_Löcknitz_BB_2013	LUGV (2013b)			
	RDP_Mügelspree-see_BE_2015	SenStadtUm (2015)			
	RDP_Panke_BB_2009	MLUV (2009)			
	RDP_Panke_BE_2009	SenGUV (2009)			
	RDP_Pretschener_Spree_BB_2013	LUGV (2013c)			
	RDP_Schwielochsee-Dammühlenfließ_BB_2016	LUGV (2016)			
	RDP_Spree-2_SN_2020	LfULG (2020)	1	1	1
	RDP_Unterer_Spreewald_BB_2012	LUGV (2012)	1	1	
	RDP_Wuhle_BE_2014	SenStadtUm (2014)			
Spatial planning	SDPro_BE-BB_2007*	GL (2007)	1		
	SDP_BE-BB_2019*	GL (2019)	1	1	1
	SDP+LaPro_SN_2013*	SMI (2013a, b)	1	1	1
	RP+LaMaP_Oberlausitz-Niederschlesien_SN_2019*	RPV Oberlausitz-Niederschlesien (2019)	1	1	1
	LUP_BE_2020*	SenSW (2020)	1	1	1
Landscape planning	LaPro_BB_2000*	MLUR (2000)			
	LaPro_BE_2016*	SenStadtUm (2016)	1	1	1
	LaMaP_Oder-Spree_BB_2021*	Landkreis Oder-Spree (2021a, b)	1	1	1
	LaMaP_Spree-Neiße_BB_2009*	Landkreis Spree-Neiße (2009)			
			16	14	11

* Formal plans (preparation and updating are legally required).

Overall, 4 out of the 14 plans with climate change impacts (29 %) cover the full range of potential impacts (increasing low water, heavy rainfall and flooding events as well as deterioration of the water status) in their respective planning area.

4.3 Consideration of climate change adaptation

With regard to the analysis category "CCA" (Table 1), 11 plans (39 %) contain planning statements on adaptation to climate change, all of them also considering climate change

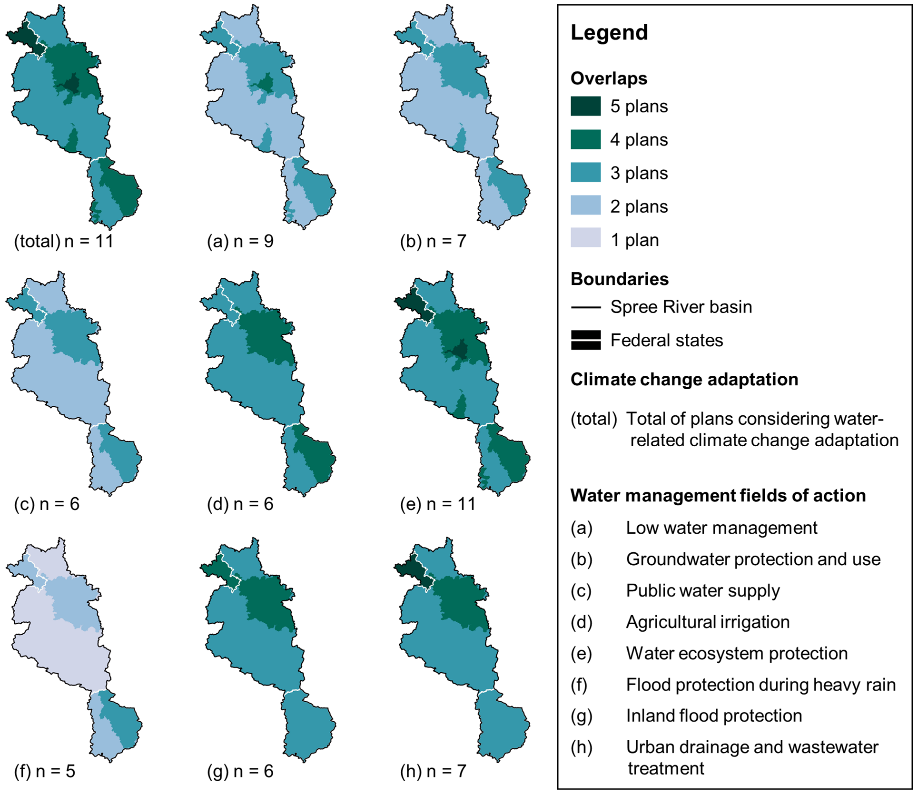

Figure 2. Spatial overlaps of plans with proposed climate change adaptation measures corresponding to water management fields of action of the Spree river basin. Plan overlaps may be compared with the planning areas in Figs. S1–S4. Map data acquired from WasserBLIcK-/BfG & Zuständige Behörden der Länder (2016), BKG (2009), LfU (2014) and LfULG (2021).

impacts. Of nine formal plans that consider climate change, all plans except the oldest one (from 2007) address climate change adaptation. Of the seven river development plans recognizing climate change, three address climate change adaptation.

Figure 2 panel "(total)" provides an overview of the spatial overlaps of the 11 plans considering climate change adaptation. Figure 2a–h show the consideration and spatial distribution of the plans in relation to each water management field of action. Whereas all 11 plans consider the field "water ecosystem protection", only five take into account "flood protection during heavy rain". Regarding the latter, relevant measures such as "water retention in urban areas" or "exploiting infiltration potentials" are assigned to the action field "urban drainage and wastewater treatment" and must therefore also be considered (see also Table 3). All other fields of action are dealt with by six to nine plans.

Regarding the consideration of the action fields per plan, four plans refer to all eight or seven action fields; another three plans consider six or five action fields; and the remaining four plans, including the three river development plans, address two or three (see Table S10).

The water management fields of action most comprehensively addressed by the plans are "groundwater protection and use", "agricultural irrigation" and "inland flood protection". Here, more than half of the plans considering the respective field of action refer to more than two measures (see Tables S12, S14 and S17). For the remaining five action fields more than half of the plans only refer to one or two measures (see Tables S11, S13, S15, S16 and S18).

Table 3 gives an overview of the climate change adaptation measures proposed by the LAWA (2020) and the number of plans with corresponding statements. For a better understanding of the single measures, see Tables S1–S8 or Appendix II of the "Climate Change Report" by the LAWA (2020).

5 Discussion

The analysis reveals some considerable gaps in the comprehensiveness of climate change adaptation in water-related planning. Merely half of the plans we examined refer to (potential) climate change impacts within their designated planning areas, and less than half also make planning statements about adapting to these changes. Only about one-third of the plans mentioning climate change adaptation refer to all eight or seven water management fields of action. Gaps become particularly evident in the limited extent of measures (only

Table 3. Water management fields of action with climate change adaptation measures adopted from the "Climate Change Report" by the LAWA (2020) and number of plans with corresponding statements in the context of climate change adaptation.

	Water management fields of action (total no. of plans)	Climate change adaptation measures according to the "Climate Change Report" by the LAWA (2020)	Number of plans with corresponding statements
(a)	Low-water management ($n = 9$)	Low-water and temperature forecasting	0
		Water-use restrictions	5
		Ensuring water quality	5
		Oxygen management through aeration	0
		Artificial raising of low water levels	3
		Creating artificial water reservoirs	1
		Promoting natural water retention	7
(b)	Groundwater protection land use ($n = 7$)	Climate-specific evaluation and adaptation of groundwater monitoring	0
		Promoting groundwater-friendly agriculture (quality and quantity)	4
		Land-use changes	5
		Protecting groundwater-dependent terrestrial ecosystems (peatlands)	7
		Promoting groundwater recharge	7
		Increasing groundwater supply	1
		Sustainable groundwater management	3
(c)	Public water supply ($n = 6$)	Redundant water harvesting systems	1
		Adapting water supply infrastructure	3
		Rainwater harvesting	1
		Reducing water demand	3
		Improving water quality in the pipeline network	0
		Advanced drinking water treatment	0
		Comprehensive water supply management	3
(d)	Agricultural irrigation ($n = 6$)	Soil and erosion protection	6
		Conservation tillage	4
		Humus accumulation	4
		Adaptations in cultivation	1
		Efficient irrigation	1
		Groundwater substitution	0
(e)	Water ecosystem protection ($n = 11$)	Improving continuity of flowing water	1
		Variation in hydromorphological structures	8
		Protecting and developing riparian strips	3
		Installing sedimentation barriers	4
		Nature-conserving watercourse maintenance	2
		Conservation and expansion of protected areas and biotope networks	6
		Reducing diffuse pollutant entry and nutrient inputs	4
		Adapting abstraction and discharge threshold values	4
		Water quality warning service	0
		Climate-specific adaptation and evaluation of water monitoring	1
(f)	Flood protection during heavy rain ($n = 5$)	Retention through changes in forest management	3
		Establishing and securing emergency waterways	0
		Object protection in case of flood risk	1
		Organized measures in case of extreme rainfall and flash flooding events	1
		Behavioural precautions and training in the event of extreme rainfall and flash flooding	3
		Regular maintenance and inspection of the drainage systems	1
		Flood risk assessment (e.g. heavy rain hazard and risk maps)	1
(g)	Inland flood protection ($n = 6$)	Technical flood protection	5
		Recovery of flood plains and renaturation of floodplains	5
		Activating additional and optimizing existing retention areas	5
		Land-use regulations in flood plains/areas at risk of flooding	4

Table 3. Continued.

Water management fields of action (total no. of plans)		Climate change adaptation measures according to the "Climate Change Report" by the LAWA (2020)	Number of plans with corresponding statements
(g)	Inland flood protection ($n = 6$)	Designation of *Vorranggebiet*[1] and *Vorbehaltsgebieten*[2]	1
		Flood hazard and risk maps	4
		Identifying and mapping areas at risk of waterlogging (groundwater)	0
		Property protection in the event of damaging high groundwater levels	2
		Flood partnerships	2
		Organized measures in case of an extreme inland flooding event	2
		Behavioural precautions and training in the event of extreme inland flooding	4
(h)	Urban drainage and wastewater treatment ($n = 7$)	Optimizing the construction and operation of existing sewer systems	3
		Adapting wastewater treatment operations	1
		Installations for precipitation water treatment	1
		Water retention in urban areas	4
		Exploiting infiltration potentials	7
		Incentives for rainwater management	0
		Protecting wastewater facilities from floods	1

[1] *Vorranggebiet* is a designated area in spatial plans in which certain functions or land uses (here: preventive flood protection) have priority over conflicting uses (Scholich, 2018). [2] *Vorbehaltsgebiet* is a designated area in spatial plans in which certain functions or land uses (here: preventive flood protection) must be given spatial weight when balancing different competing land uses and giving priority to one of them (Scholich, 2018).

one or two) for "low-water management", "public water supply", "water ecosystem protection", "flood protection during heavy rain", and "urban drainage and wastewater treatment" that most plans refer to. Therefore, the subsequent sections elaborate on opportunities to improve the integration of climate change adaptation into planning instruments that treat water management issues.

5.1 Updating plans more frequently

The analysis shows that the publication date has a significant impact on the extent to which climate change is addressed in the plans. The year 2019 draws the line from which all plans address climate change, its impacts and adaptation measures (seven out of seven plans). The plans published before 2019 show lower consideration rates. Here, only one-third of the plans describe climate change impacts (7 out of 21 plans) and only 19 % climate change adaptation measures (4 out of 21) (see Fig. S5).

Schliep et al. (2017) examined landscape programmes and landscape master plans in Germany concerning their consideration of climate change and associated objectives and measures in the context of biodiversity conservation. The study shows similar results: the more recent the plan, the higher the rate of climate change consideration. According to §10 of the BNatSchG, landscape master plans have to be updated at least every 10 years. Taiber (2023) indicates a high need for action regarding the updating and digital provision of landscape master plans in Germany, with the majority exceeding a 10-year planning horizon.

5.2 Including insights from informal planning

Regular updating of plans allows for the inclusion of ongoing environmental changes and new policy priorities. For example, the Berlin Senate faced (potential) impacts of climate change, the coal phase-out and a growing population in the informal "Master Plan Water" from 2022 (SenUMVK, 2022). The plan includes a variety of measures in the areas of low-water management, rainwater management, wastewater infrastructure and public water supply, where the analysed formal plans for Berlin show gaps. In Brandenburg, the informal federal low-water concept was introduced in 2021 (MLUK, 2021). Among other things, it addresses the introduction of a water quality warning service focused on low water, which was not envisaged in the water management field of action "water ecosystem protection" by any of the preceding plans. Such informal plans are not legally formalized, standardized or directly legally binding but are characterized by a high degree of flexibility and adaptability, allowing pressing issues to be addressed in a timely manner (Danielzyk and Sondermann, 2018). Incorporating their respective findings and suggestions into formal plans offers opportunities for a more comprehensive integration of climate change adaptation, achievable if formal plans are regularly updated.

5.3 Promoting multifunctional measures to address various climate change impacts

A total of 4 out of 14 plans describing the potential impacts of climate change on water management address the variety of impacts (increasing low water, heavy rain and flood events and deterioration of water status) for their respective planning area (see Table S9). Only 2 out of 11 plans address climate change adaptation measures for all 8 water management fields of action, another 2 plans do so for 7 action fields, another 2 do so for 6, 1 does so for 5, and the remaining 4 plans mention measures for 2 or 3 action fields. Here, the river development plans in particular show a very narrow planning approach, as they do not formulate climate adaptation measures for the water management fields of action "public water supply", "agricultural irrigation", "flood protection during heavy rain", "inland flood protection", or "urban drainage and wastewater treatment". However, according to Article 1 of the WFD, inland surface waters should also be developed and protected in the most natural way possible for sustainable and equitable water use and to minimize flooding. Furthermore, the majority of plans that mention climate change adaptation for the water management fields of action "low-water management", "water ecosystem protection", "flood protection during heavy rain", and "urban drainage and wastewater treatment" refer to only one or two measures.

Such planning gaps could be filled by focusing more on the multifunctionality of measures. Planning approaches like the sponge landscape concept (BBSR, 2023a), sponge city concept (BBSR, 2023b) or nature-based solutions (EU, 2015) already include integrative planning for both periods of water abundance and water scarcity.

Many potential climate change adaptation measures are multifunctional and serve multiple water management fields of action. They contribute to improving the functioning of ecosystems and the quality of human life, also in the absence of climate change impacts, and can therefore be defined as no-regret measures (cf. FGG Elbe, 2021b). Measures promoting natural water retention and groundwater recharge, improving water quality, and protecting biodiversity include peatland protection, floodplain restoration, establishing riparian strips and riverbank planting, soil-conserving agriculture, forest protection and afforestation, forest restructuring from pure pine to mixed broadleaved forests, and unsealing. For comprehensive and efficient climate change adaptation in water-related planning, planned measures should be multifunctional and address multiple potential climate change impacts.

5.4 Adopting best-practice examples for systematic integration of climate change impacts and adaptation

The analysis shows considerable variation in the way climate change impacts and adaptation are addressed. Out of 14 plans that refer to (potential) climate change impacts, only 5 do so by a separate section or extensive references. The remaining nine plans include only sporadic references to (potential) climate change impacts.

Given that climate change is already having an impact on the natural environment and is expected to further do so, plans should systematically include (potential) climate change impacts. Climate scenarios and models can be used to assess climate-change-related hazards for the planning area. The DWD (2021) provides guidance on the possible interpretations of climate models. Linke (2023) specifically helps with the interpretation of regional climate model data, which may be helpful for German planners.

Of the 11 plans that refer to climate change adaptation, 8 do so systematically or through extensive references. The remaining three plans only sporadically mention climate change adaptation. The systematic and extensive consideration of climate change adaptation in eight plans is in contrast to the five plans that comprehensively address climate change impacts, meaning that at least three plans consider adaptation measures without having thoroughly addressed climate change impacts. This discrepancy might be attributed to (one of) the following reasons: high level of uncertainty in predicting and interpreting climate change impacts at the regional/local level and insufficient databases and resources in terms of time, money, staff and expertise. However, this discrepancy shows that adaptation to climate change and precautionary measures (e.g. no-regret measures) can be taken into account in planning even under conditions of uncertainty.

A best-practice example for the systematic integration of climate change adaptation is the review of a plan's catalogue of measures for its potential for adaptation to climate change, as demonstrated in the "Flood Risk Management Plan", the "River Basin Management Plan" and the "Programme of Measures of the German Elbe River Basin" (FGG Elbe, 2021a, b, c). In these plans, all planned measures are assessed from two perspectives: firstly their suitability for adaptation to climate change and secondly their vulnerability to progressive climate change. Table 4 illustrates an example from the "Programme of Measures of the German Elbe River Basin".

The adoption of best-practice examples can help to facilitate and systematize the integration of climate change adaptation into planning and can also be beneficial when prioritizing measures for implementation.

5.5 Addressing climate change explicitly in the WFD and its planning instruments

All 18 water management plans according to the WFD included in the analysis address measures to improve water status. This is based on the objective in Article 4 of the WFD to achieve "good surface water status" by ensuring at least good ecological and chemical status in surface waters. Eight water management plans mention climate change, of which seven also refer to climate change impacts. However, only two of the latter make a specific link between climate change and the deterioration of water status (see Table S9), thus ad-

Table 4. Best-practice example of a systematic integration of climate change adaptation of the catalogue of measures, adopted from the "Programme of Measures of the German Elbe River Basin" (FGG Elbe, 2021c, Appendix M1; translation by the authors).

Measure	Potential actions	Does the measure support adaptation to climate change?	Does climate change affect the effectiveness of the measure?
Improving habitats in the riparian zone	Creation of riparian strips with native trees and shrubs, replacement of technical structures with bioengineering constructions	Yes, because near-natural water bodies are more resilient to climate-related changes in the hydrological regime	No, because it supports adaptation to climate change
Establishing linear continuity at dams and retention basins	Construction of passable structures such as bypass channels or fish ladders	Possible, because improved river continuity allows aquatic organisms to avoid adverse climate-related changes in the waterbody	Possible, because climate change may change the assessment bases for low and high water levels in waterbodies and facilities
Reducing the impact of leisure and recreational activities	Regulation of recreational use and visitor guidance, prohibition of travelling on water, camping and/or making fire	Possible, if the adverse effects in the waterbody are due to activities caused by climate-related changes (e.g. heatwaves)	Yes negatively, because longer periods of drought and heat increase the demand for activities in and around water

dressing a potentially more challenging achievement of good ecological and chemical status.

The WFD does not explicitly mention climate change. This has already been addressed and criticized in the literature (Hendry, 2017; Lamon et al., 2009; Reese et al., 2016). However, the 2019 evaluation of the WFD concludes that the directive is generally fit for purpose but that implementation needs to be accelerated (DG ENV, 2019). Nevertheless, specifically mentioning climate change as an aggravating factor in achieving the WFD targets and emphasizing its consideration in the planning of measures may strengthen the integration of climate change adaptation into water-related planning. In this respect, Garack et al. (2022) propose integrating special climate impact monitoring into the WFD monitoring and ensuring that the measures defined in the programmes of measures for the river basins contribute to the adaptation to climate change and not only serve the medium-term objectives of the WFD but also remain effective with regard to long-term climatic changes (no-regret measures).

6 Limitations

There are mainly four limitations to our study. Firstly, not all statements made in the 11 plans covering an area larger than the Spree river basin can be clearly assigned to a specific (sub-)area of the respective planning area. Although we tried to exclude all statements referring to areas outside the Spree river basin, this was not always possible with certainty. This may lead to slightly skewed analysis results for these 11 plans. Secondly, climate change adaptation measures in these 11 plans, which refer solely to other river basins, were not included in the analysis. This leads to a distorted picture regarding the single plans and their consideration of climate change adaptation in water management. Thirdly, the plans analysed mention measures relevant to climate change adaptation without explicitly addressing the measure's particular importance for it. These measures were excluded from the analysis, as our research interest was to determine the extent to which existing plans consciously and explicitly consider the climate–water nexus. This leads to a partly biased estimation of the actual potential of the plans for climate change adaptation. However, establishing and clearly showing and considering the links between already-existing measures that primarily serve other goals and climate change adaptation are necessary to consciously take precautions against climate change impacts. Moreover, it is deliberating on and therefore fully using any measure that could promote climate change adaptation and ensuring awareness of potential conflicts between adaptation to climate change and other objectives, with the aim of reducing such conflicts. It may also help to facilitate the prioritization of actions and to promote multifunctional measures. Lastly, due to the overview character of this study, we cannot provide a detailed analysis of the different environmental situation and the status quo of climate change adaptation in water-related planning in the sub-regions of the Spree river basin. For this purpose, a more detailed inventory had to be carried out, including an analysis of spatial and landscape plans at local level. This remains a future task.

7 Conclusions

This study analysed the current consideration of climate change, its impacts and adaptation in water-related planning as a governance instrument in the case study of the Spree river basin. We analysed 28 plans for water management, spatial planning and landscape planning. A total of 16 (57 %) explicitly refer to climate change, 14 (50 %) also address (potential) impacts of climate change, and 11 plans (39 %) also mention climate change adaptation measures. The majority of the latter addresses water ecosystem protection, low-water management, groundwater protection, urban drainage and wastewater treatment, public water supply, agricultural irrigation, and inland flooding. Flood protection during heavy rainfall is considered by less than half of the 11 plans. The findings indicate gaps in a comprehensive planning approach to the different impacts of climate change, particularly evident in the limited number of measures mentioned in the water management fields of action “low-water management”, “public water supply”, “water ecosystem protection”, “flood protection during heavy rain”, and “urban drainage and wastewater treatment”. Shortcomings might be caused by an insufficient update of the plans and therefore a lack of appropriate consideration of climate change. In particular, the river development plans, which are an essential contribution to the implementation of the WFD at the subbasin level, lack references to climate change.

The results also show a need for updating plans, especially for many river development plans and to some degree for landscape plans in Brandenburg. Also, recognizing and addressing climate change in the WFD and its planning instruments as a threat to the achievement of the WFD objectives may strengthen the integration of climate change adaptation into water-related planning. To enable comprehensive and effective water management in times of climate change, more attention should be paid to the findings from current informal plans, to the multifunctionality of measures, and to a consistently structured integration of climate change impacts and adaptation into plans. This work aims to encourage authorities, planning agencies and water management practitioners to comprehensively consider climate change adaptation to enhance the resilience of the Spree river ecosystem and to ensure a liveable future in the Spree river basin.

Data availability. The research data underlying this paper refers to 28 formal plans for water management, spatial planning and landscape planning in the Spree river basin that were prepared by or on behalf of a public authority. All plans are cited in the article and can be accessed via the URLs given in the references. Plans cited without a URL have been personally requested by the authors from the responsible authority, as they are not publicly available. In these cases, please contact the named authority directly. Please also be aware that the URLs provided may become outdated as plans are updated over time. The research data underlying this work may be accessed at https://doi.org/10.5281/zenodo.14242954 (Arndt, 2024).

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