PBL Netherlands Environmental Assessment Agency

WATER-RELATED CONFLICT AND MIGRATION: RISKS AND AMBITION PATHWAYS

Background report for the *Future Water Challenges – Bending the Trend* report

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Water-related conflict and migration: risks and ambition pathways. Background report for the *Future Water Challenges – Bending the Trend* report

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Contents

Summary

This background report concerns water-related conflict and water-related migration. The results are published in *Geography of future water challenges – Bending the trend (GFWC – Bending the trend)* (Ligtvoet W. et al., 2023). GFWC – Bending the trend gives an overview of what could be achieved with concrete measures in four hotspot landscapes: river basins, deltas and coasts, dryland regions, and cities. Measures are explored in High, Moderate, and Low ambition pathways. These pathways are compared to the Business-as-usual scenario characterised by the SSP2 pathway in combination with the RCP6.0 climate change scenario. The SSP2 pathway reflects a middle-of-the-road socioeconomic and mitigation development. Under the SSP2 pathway, the population growth from 7 billion people today to around 9 billion people by 2070, and the projected further economic development, will strongly increase the use of and pressure on water resources and aquatic ecosystems. The RCP6.0 climate change scenario projects a temperature increase of close to 3 °C by 2070 and 3.7 °C by 2100. While the Low and Moderate ambition pathways are dominated by sectoral approaches in management and technical measures, the High ambition pathway is based on an integrated systems approach and a high level of efforts. The ambition pathways show that we can bend the trend of increasing water- and climate-related stresses.

Although in the absence of full consensus upon the drivers of conflict and migration it is not possible to accurately predict conflict and migration in the long-term, this background report on water-related conflict and water-related migration does show that under a high ambition pathway local water-related conflict risk will decrease (Figure 8). It also shows that as institutional resilience will increase, the risk of transboundary conflict is projected to decrease (Figure 17).

The key issues for the four chapters about water-related conflict, migration, and displacement are summarised point by point below. The first bullet always refers to the pages in GFWC –Bending the trend where the results are listed.

Water-related conflict

- Results in GFWC – Bending the trend p. 136 – 139.
- Water and climatic hazards unequally affect societies; especially vulnerable populations that depend on their natural environment for their livelihoods bear the brunt of adverse impacts. Vulnerability to water and climatic hazards is affected by poverty, low education, social and economic inequalities, and limited institutional capacity.
- Armed conflict has devastating consequences for socioeconomic development and political stability, thereby further increasing vulnerability to future water and climatic hazards. Conflict-affected countries may become trapped in a vicious circle of violence and vulnerability that is further exacerbated by climate change.
- Multi-year droughts multiply the effects of long-term water stress in agriculture. These droughts can, however, both increase and decrease conflict risk.
- In the business-as-usual scenario, the most vulnerable regions to future water and climatic hazards are projected to be the Horn of Africa (especially Eritrea and Somalia), the Sahel (Niger, Mauritania, and Mali), parts of central/southern Africa (Angola, Zambia), and parts of central and south Asia (Afghanistan, Yemen, Pakistan) (Figure 8).
- Under a high ambition pathway, by 2070, about 21 million people are projected to live in water stress-related conflict risk areas, which is a tremendous decrease compared with the number of over 2 billion people today. Only parts of Pakistan and Afghanistan, Angola, and a part of Yemen and Somalia – with a population of 167 million – are projected to be at

moderate risk by 2070. Solutions to water stress-related conflict are rooted in both water management and reducing the socioeconomic vulnerability of populations at risk (Figure 8).

Water stress-related migration

- Results in GFWC – Bending the trend p. 122 – 123, p. 136 – 137, p. 140 - 141.
- Rural people depending on agriculture in low-income countries are most likely to be affected by water stress, which may lead to temporary or definite out-migration depending on the livelihood conditions and dynamics.
- However, some of these people – the poorest, oldest, sickest, least educated – may also become trapped; not everyone has the financial or physical capacity to migrate.
- In a business-as-usual scenario by 2070, especially the Sahel and the Horn of Africa are projected to face relatively high out-migration related to water stress (figure 11).
- Under a high ambition pathway, by 2070, around 24 million people are projected to live in water stress-related migration risk areas, which is significantly less than under the business-as-usual scenario (102 million).
- Historically, water stress-related migration has mostly been driven by the impact of water stress on livelihoods, demographic dynamics, and economic conditions. However, on top of high water yield gaps, some regions may become too hot to sustain (small-scale) agriculture. Particularly the Sahel and parts of central Africa are at risk (Sudan and South Sudan). But also parts of Brazil, Saudi Arabia, South Asia, and parts of southeast Asia might become too hot to sustain (figure 12).

Transboundary conflict

- Results in GFWC – Bending the trend p.76 – 77.
- Historically, cooperation between countries over shared rivers is more likely to occur than conflict, and when it does come to conflict, it is mostly non-violent.
- Pressures are increasing in basins, due to new hydropower dams, climate change, consumption growth, and lagging governance structures.
- A stringent issue resulting from conflict in transboundary river basins is the lack of cooperation over environmental, economic, or social issues, such as the increasing water.
- Increasing water variability or water scarcity can affect cooperation between states, although the existing relations between riparian countries are decisive, as is the institutional capacity in a basin to deal with change. Low governance and internal conflict directly affect the capacity within states to anticipate and deal with political unrest or unexpected events.
- Demand and pollution, and ecological degradation, as well as the impacts of climate change.
- Failing to cooperate on these issues will impact millions of livelihoods, ranging from decreasing incomes and health issues, to casualties due to flooding that could have been avoided.
- By 2070, under a business-as-usual scenario, almost 900 million people are projected to live in parts of transboundary river basins with high to very high conflict risk.
- Combining all the risk factors, river basins with particularly high risks are Lake Turkana, the Nile, the Juba-Shibeli, the Congo (all Africa), the Orinoco (South America), and the Ganges-Brahmaputra, the Indus, the Irrawaddy, the Helmand, and the Rann of Kutch (Asia) (Figure 19).

- When solely assessing the exacerbating factors (hydrology and socioeconomic conditions), various other river basins – mostly in central Asia and across Africa – face risks as well.
- A rising ambition level regarding transboundary collaboration implies improved water management (water reuse, water use efficiency, changing operation of dams) and improved overall governance and institutional resilience in terms of water treaties and river basin organisations. Under the low ambition pathway, by 2070, fewer people are projected to live in high or very high risk areas than under the business-as-usual scenario – about 400 million. This number further decreases to about 90 million under the high ambition pathway.

Sea level rise and displacement

- Results in GFWC – Bending the trend p. 84 – 85, p. 112 – 115.
- There is a distinction between 'displacement' and 'migration' because of sea level rise. For displacement, flood risk is a dominant push factor but for migration, flood risk is one of many causal factors. The number of people exposed to coastal flooding, therefore, is an indicator of the potential number of people displaced out of flood-prone coastal zones because of increasing flood risk – or sea level rise.
- In the scientific literature, three definitions of population exposed to potential flooding are used: population impacted by specific levels of sea level rise; population impacted by flood events with a specific return period; and population living in low-elevation coastal zones. The numbers according to these definitions vary, and population exposed to flooding, therefore, can only broadly be used to express the link between sea level rise and potential displacement.
- The number of people exposed to coastal flooding because of sea level rise varies from about a hundred million people at 1 metre sea level rise to about half a billion people under extreme scenarios of 5 to 6 metres sea level rise.
- The number of people exposed to a once-in-a-hundred years flood level, neglecting (investments in) flood protection, is about 100-200 million people today, and continues to increase up to several hundreds of millions by 2100 (Figure 22).
- The number of people living in low-elevation coastal zones – mostly defined as the coastal land area less than 10 metres above sea level – is about 600-700 million for the current situation and could reach 1.4 billion people by as early as 2060 (figure 23).
- East, Southeast, and South Asia face the greatest overall exposure to coastal flooding both now and throughout this century. In addition, sub-Saharan Africa is projected to become a hotspot of populations vulnerable to coastal flooding as well.
- The increasing flood risk mainly affects the poor and exacerbates inequalities between low- and high-income countries.
- The increase of the number of people living in flood-prone deltas and coastal zones in Asia and sub-Saharan Africa will probably concentrate in cities (Figure 24). This development may reduce the pressure on future displacement because of sea level rise as it is relatively cost-effective to protect urban areas against flooding.

1 Introduction

In the absence of effective climate mitigation and adaptation measures, alongside continuing human-induced ecological degradation, water-related pressures on livelihoods are expected to worsen in several regions around the world. Contested impacts of water-related pressures are the potentially increased risk of local up to transboundary conflict as well as risks of displacements and migration (Abel et al. 2019; Mach et al. 2019; von Uexkull and Buhaug 2021). Figures 1 and 2 provide a conceptual overview of the potential linkages between water issues and migration/displacement as well as between water and conflict risk.

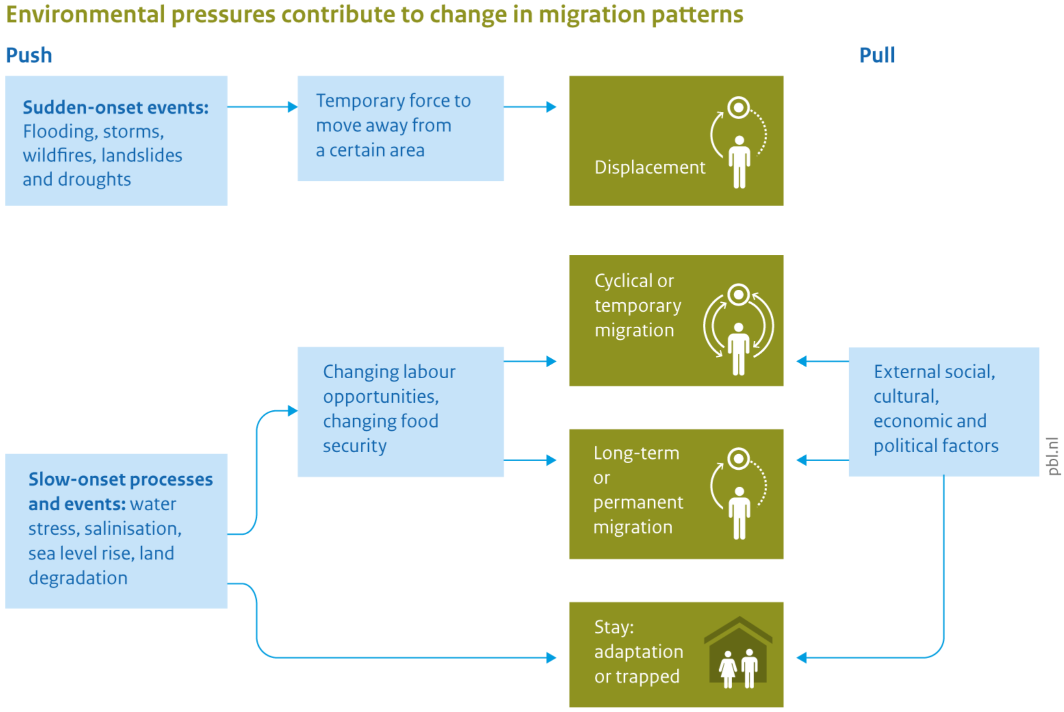
Due to the potential widespread impacts of water-related issues on conflict and migration, political concern, along with scientific and security interests, have increased over the last few decades. This has resulted in a maturing body of academic literature, feeding decision-making processes of intergovernmental institutions (de Bruin 2022). Although research on water and conflict/migration has been increasing and the knowledge base has expanded in the past 20 years, full consensus on the mechanisms linking climate, water, and (armed) conflict risk and migration remains limited (Ide 2017; Koubi 2019). Recent conclusions differ due to, *inter alia*, the use of different data proxies, different timescales and geographical scales, and different definitions of conflict and data uncertainties (Buhaug et al. 2014; Visser et al. 2020). Yet they also differ because relations between conflict drivers can change over time and per context; driver interactions are not stable (Bowlsby et al. 2019).

In the absence of a full consensus on the drivers of conflict and migration in the context of water issues, it is not possible to accurately predict conflict and migration in the long term (de Bruin et al. 2022a). What is possible, however, is identifying regions where risks compound as the result of the interaction between environmental and socioeconomic risk conditions. Several conditions — including low socioeconomic development and socioeconomic shocks, the strength of governments, inequalities in societies, and the recent history of violent conflict — are generally accepted as contextual risk factors (Hoch et al. 2021; Mach et al. 2019). It is under these conditions that climatic and environmental drivers can become risk factors for different types of conflict and migration (Koubi 2019; Mach et al. 2019).

In *The Geography of Future Water Challenges* (FWC-1) report, we explored the potential influence of too much or too little water on migration and conflict by 2050 (de Bruin et al. 2018b; Ligtvoet et al. 2018). Two types of water-related conflict (local conflict and transboundary conflict) and two types of migration (local water-stress related migration and displacement by sea level rise) were distinguished. In *The Geography of Future Water Challenges – Bending the Trend* (FWC-2) report (Ligtvoet et al., 2023), we build on the insights developed in FWC-1. We improve the existing region-at-risk analysis and extend these with the low, medium, and high ambition pathways. This document presents:

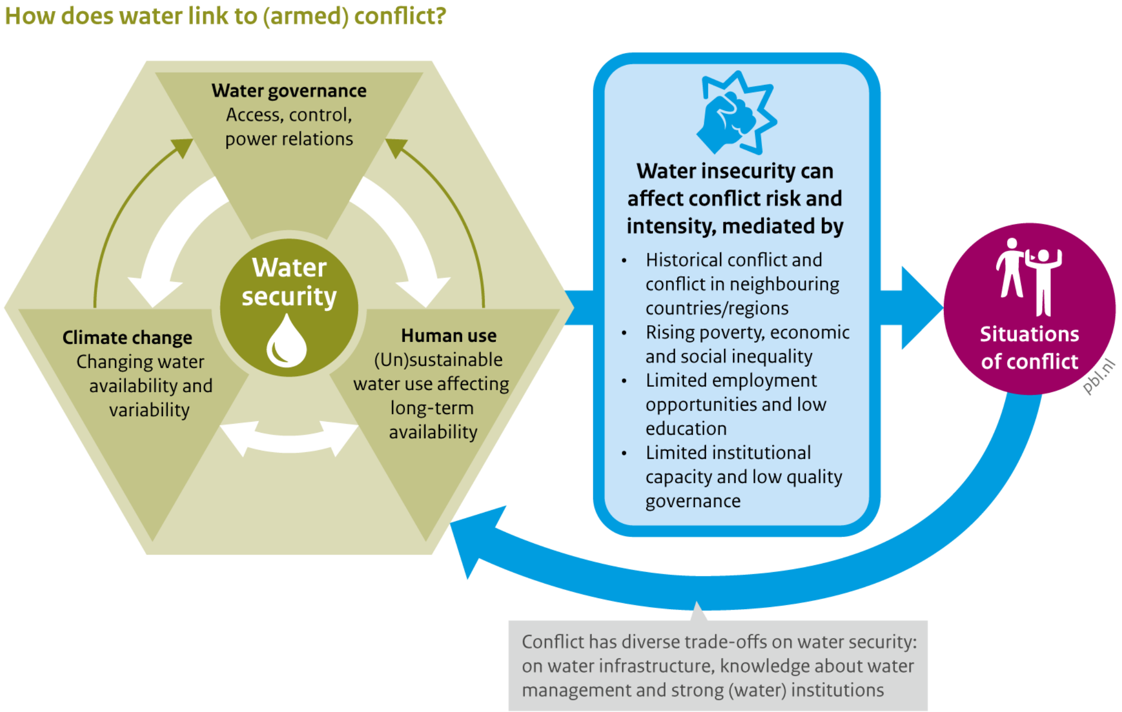
- A summary of the scientific progress in the field of local and transboundary conflict, migration, and displacement affected by environmental degradation in general and water stress and flood risk in particular;
- The indicators per topic and how these are combined for the different ambition pathways;
- Solutions per storyline.

Figure 1
Conceptual figure on migration and displacement (as developed for Ligtvoet et al. 2018)



Source: PBL

Figure 2
Conceptual figure linking water security to conflict



Source: PBL

2 Local water-related conflict risk

2.1 Background

The field of local conflict related to environmental degradation and climate change has matured in recent years, although discussion about potential future developments of conflict risks in an era of climate change and unequal distribution of resources remains (Mach et al. 2019; von Uexkull and Buhaug 2021). The complex interactions between social, political, economic, environmental, and historical factors make future explorations of conflict risks highly uncertain. Yet, initiatives to address security implications of climate change are developing in key international fora, including the UN Security Council, the European Union, and the African Union (Fetzek and van Schaik 2018). Such initiatives play a vital role in raising risk awareness and identifying common grounds for developing sustainable solutions to reduce future conflict risks. These efforts will only be successful, however, if scientific insights improve further. With this FWC-2 report, we aim to contribute to these insights by accounting for and examining such conflict risks.

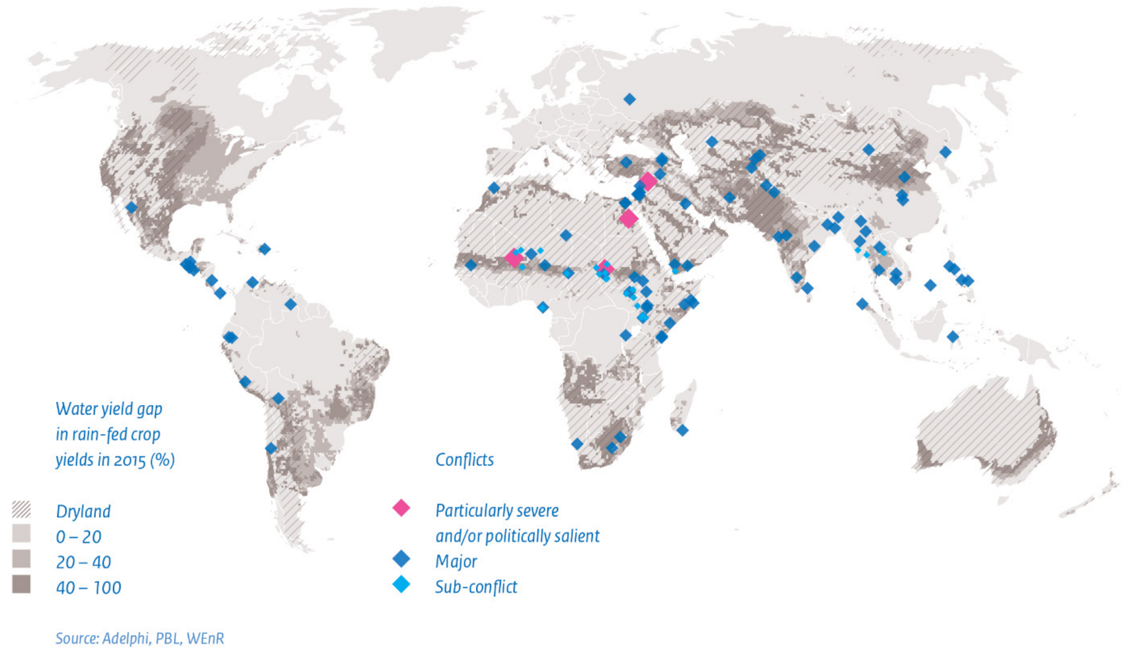
Evidence on water stress and local conflict

Local or regional water stress can lead to a wide range of issues, such as decreasing agricultural yields leading to a decreased income from agriculture, affecting food insecurity and poverty. Water stress does not cause armed conflict in isolation but is, rather, a compound risk in already vulnerable regions. Figure 3 presents historical water-related conflicts and water stressed areas, indicating an overlap between the two. In areas where livelihood dependencies on natural resources are high, both slow-onset processes such as increasing water stress and land degradation, and sudden-onset disasters such as drought, can affect social and political conflict. Especially in regions that depend on rain-fed agriculture, sensitivity to civil conflict following droughts is higher than in regions where irrigation is available (Scheffran et al. 2019).

Several studies have been conducted on the impacts of water stress on local conflict risk. This has yielded various insights into the contextual dependencies (de Bruin et al. 2018a). The overall loss of natural resource-dependent livelihoods due to limited water and land availability, is found to increase the number of people joining rebel or terrorist groups in some situations (Beardsley and McQuinn 2009; Hendrix and Salehyan 2012). When water stress occurs in combination with widespread poverty (SDG 1), economic or ethnic inequality (SDG 10), high dependency on agriculture (SDG 2), marginalisation and grievances, and especially weak governance structures (SDG 16), water stress can reinforce conflict in rural areas (Fjelde and von Uexkull 2012; Robins and Fergusson 2014; von Uexkull 2014). Such local conflict can occur between farmers and pastoralists, between groups of pastoralists, or between groups of farmers (Butler and Gates 2012; Campbell et al. 2000). These conflicts are often also linked to limited access or decreasing availability of fertile land, as well as to corruption and distrust in governments.

In some situations, water stress has a countervailing effect on conflict, leading to pacification or even reconciliation and cooperation between different societal groups (Theisen et al. 2012). For example, a study by Salehyan and Hendrix (2014) found that the 2010-2011 droughts in Somalia weakened the terrorist organisation al-Shabaab al-Mujahideen, the major armed opposition to the national government. This reduced terrorist attacks and improved overall societal security. On the other hand, Raleigh and Kniveton (2012) found that small-scale conflict can, in fact, increase under conditions of extreme rainfall variability, both too much and too little. Anomalously dry years are related to higher rates of rebels violently protesting against government policies, while anomalous wet conditions are found to trigger conflict between communities. Moreover, not only precipitation rates can be correlated with conflict. Döring (2020) has shown that lacking access to groundwater is associated with a higher risk of communal violence, which is conditioned by precipitation levels as well as population density. However, the effect of groundwater on violence is smaller in areas with a higher state presence.

Figure 3
Overview of water-stressed regions and water conflicts reported between 1944 – 2016



Vicious circles of vulnerability

Vulnerability to internal armed conflict and climate change are largely determined by similar factors, such as weak governance, low socioeconomic development, and a high dependence on natural resources for economic activities (Buhaug and Uexkull 2021). Table 1 provides an overview of the top 20 countries in the ND-Gain Index and the Fragile States Index. The ND-Gain Index summarises a country's vulnerability to climate change in combination with its readiness to improve resilience (University of Notre Dame 2021). The Fragile States Index provides information on a country's overall vulnerability to conflict (The Fund for Peace 2021). 13 countries can be found in the top 20 of both the ND-Gain Index 2019[1] as well as the Fragile States Index 2020, totalling a combined population of 328 million. The number of people living in these 13 countries is projected to increase to almost 570 million by 2050. it is important to note that vulnerabilities and conflict risk can always change with time, however.

The compounded vulnerabilities to climate hazards and conflict often result in a vicious circle of increasing risk of armed conflict and decreasing resilience and adaptive capacity to climate change

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[1] The ND-Gain index 2020 was not yet available during the time of writing.

hazards, including water stress. Meanwhile, potential synergies between climate adaptation and conflict prevention and/or peacebuilding efforts could break this vicious circle (Mach et al. 2019). Greater levels of adaptive capacity and, more specifically, access to water infrastructure, have been found to result in a lower likelihood of armed conflict in the context of water stress (Detges 2016; Regan et al. 2019). Additionally, Uexkull et al. (2020) found that, in the Democratic Republic of the Congo, less resilient individuals who experience drought and its associated losses are more likely to be supportive of the use of political violence.

Table 1
Top twenty countries listed in the ND-Gain Index 2019 and the Fragile States Index 2020. Country names in ***bold italic*** feature on both lists. The population given is for the country in the Fragile States Index

ND-Gain Index 2019	Fragile States Index 2020	Population 2020 (millions)	Projected population 2050 (millions)
Chad	***Yemen***	30.5	37.1
Central African Republic	***Somalia***	16.1	30.0
Eritrea	South Sudan[a]		
Guinea-Bissau	Syria		
Congo DR	***Congo DR***	88.4	162.5
Sudan	***Central African Republic***	5.0	6.9
Niger	***Chad***	16.2	29.6
Afghanistan	***Sudan***	43.1	67.2
Liberia	***Afghanistan***	39.0	77.4
Somalia	***Zimbabwe***	17.6	25.0
Yemen	Cameroon		
Zimbabwe	***Burundi***	11.5	17.1
Mali	***Haiti***	11.4	13.4
Haiti	Nigeria		
Burundi	Guinea		
Uganda	***Mali***	20.1	36.5
Congo	Iraq		
Madagascar	***Eritrea***	5.4	8.3
Bangladesh	***Niger***	23.8	58.6
Malawi	Libya		
Total population of countries listed in both the ND-Gain and Fragile States Index		**328.1**	**569.6**

a) South Sudan is not included in the ND-Gain Index.
Sources: University of Notre Dame (2021) for the ND Gain Index and The Fund for Peace (2021) for the Fragile States Index.

From a policy perspective, these studies mentioned above suggest that enhancing adaptive capacity under conditions of water stress, including improved access to water, can reduce security risks. Nowadays, conflict prevention and peacebuilding efforts are nonetheless mostly focused on improving governance and socioeconomic conditions (de Bruin 2022). Integrally including water and climate adaptation measures, as well as climate mitigation and adaptation, in peacebuilding and conflict prevention, remains limited. A more broadly recognised practice is *environmental peacebuilding*, which refers to efforts aimed at building more peaceful relations between countries or communities through cooperation over natural resource management and disaster risk reduction.

The UN Environment Programme (UNEP) has been a forerunner in this field. UNEP has stimulated and supported the integration of environmental issues into peacebuilding efforts in over 20 post-conflict societies, most recently in Colombia (2017), Iraq (2019), and Sudan (2018) (Ide 2020).

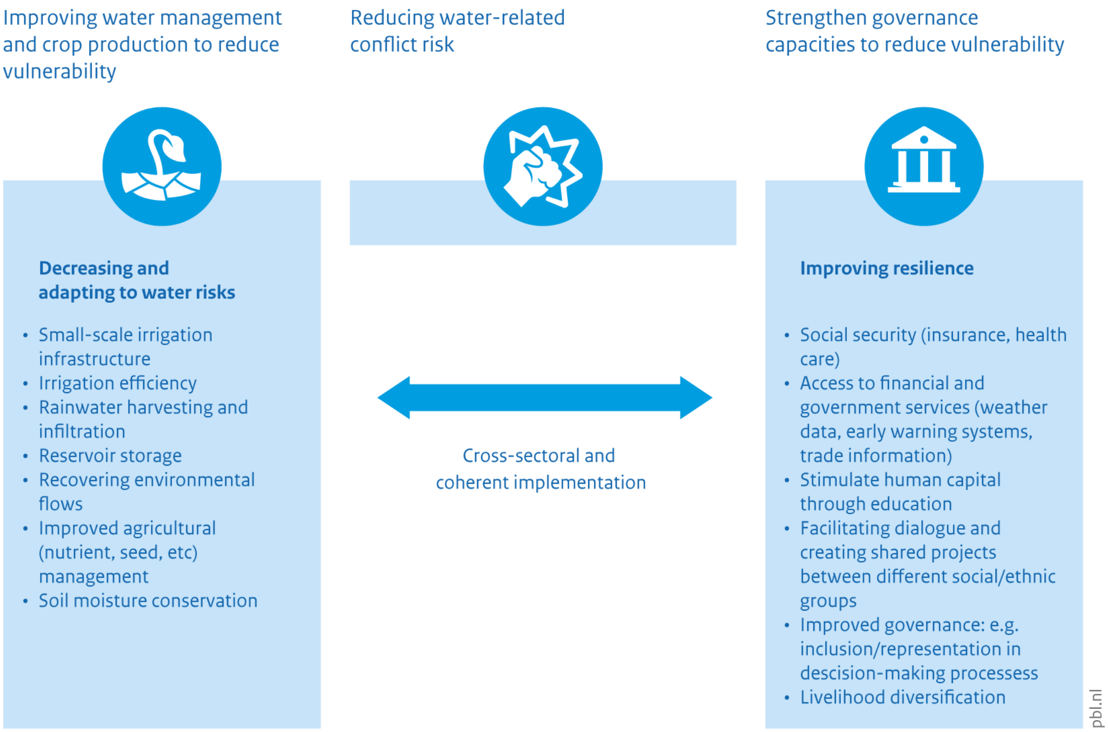
2.2 Solutions

Reducing water stress, adapting to climate change, and improving livelihood resilience

To reduce water stress-related conflict risks, both adaptive water measures and broader social and economic resilience measures need to be combined to sustain resource-dependent livelihoods and break the conflict trap. Investments in resilience can have a lasting impact on vulnerable populations who face increasingly severe and increasingly frequent levels of water stress. There is overlap between adaptive water management and factors that promote resilience to sustain peace and sustainable development. This means that addressing conflict prevention can contribute to reducing water- and climate-related risks as well, and vice versa (see also Box 1). Breaking the conflict trap is a prioritised entry point for development assistance and climate change adaptation in conflict-prone communities (Buhaug and Uexkull 2021). To stimulate an integrated approach, access to funding for adaptation projects and for reducing water stress in conflict prevention and peacebuilding should be made possible. This implies strengthening cooperation between the global adaptation/water and security communities. Being sensitive to conflict and doing no harm are important prerequisites for good adaptation and water programming.

More efficient and equitable water management can improve the situation in water-stressed regions but should not be implemented in isolation. Simultaneously, social security dimensions should be improved to increase resilience, such as insurances for multi-year droughts and access to proper education. Figure 4 provides an overview of such possible measures.

Figure 4
Solutions to reduce water stress-related conflict must be aligned between the water sector and broader social and governance measures



Source: PBL

Box 1: Climate adaptation and conflict risk
The implementation of measures to adapt to climate change comes with its own security challenges since power balances can shift, creating or reinforcing existing tensions between local stakeholders, or between countries. Although these dynamics are increasingly acknowledged by intergovernmental and military organisations, including in some National Adaptation Plans of Action (NAPAs), there are, at the time of writing, no designated international legal governance mechanisms which address the potential risks that can come with climate adaptation (de Bruin 2022). The relation between climate adaptation and conflict is two-directional, since, on the one hand, the outbreak of armed conflict can set back progress in climate adaptation and mitigation efforts. On the other hand, however, climate adaptation could increasingly play a role in conflict prevention and peacebuilding efforts, since conflict and climate vulnerability often overlap. Increased cooperation between the climate adaptation communities and security communities in these conflict-prone regions can, therefore, be an important future step (de Bruin 2022).

2.3 Approach and methods

To develop local conflict risk maps, we use various important indicators for conflict related to water issues. By combining these indicators, we identify regions where conflict associated with water stress may be relatively more likely compared to other regions. There are different types of water-related conflict, as reviewed by de Bruin et al. (2018a). In the following section, we particularly focus on rural water stress-related conflict within countries. Several existing studies have identified and analysed the major risk factors for conflict in general, which are low socioeconomic development and governance, including institutional capacity and a high level of horizontal or vertical inequality (Mach et al. 2019).

We follow the FWC-1 approach and assess the hotspot regions for local conflict largely by using the same indicators (see Table 2). To account for water stress, the *water yield gap* indicator is used to examine the impact of water stress on rural livelihoods. To account for resilience, *governance* and GDP *per capita* are used, which are also the most important drivers of conflict risk (Visser et al. 2019). To account for sustained droughts, the *Standardised Precipitation Index* (SPI, McKee et al. 1993) is used. Regions projected to face prolonged droughts (> 12 months) are indicated in several of the figures below with hatched lines (see Annex 1 for more details on the SPI). As spatial aggregation level we made use of water provinces: a balanced subnational representation of topographic, hydroclimatic, and administrative properties, with a minimal size of 20,000 km² (Straatsma et al. 2020).

In FWC-2, we developed different ambition pathways. Ambition, here, is defined by governance quality and water management. The first improvement is overall governance, as a crude proxy for resilience. The second improvement is the impact of potential water-saving measures to reduce water stress and improve crop production (as developed in the storyline for water and food production). We follow the thresholds as substantiated in FWC-1 (de Bruin et al. 2018b).

GDP per capita PPP: GDP projections (converted to 2005 USD in PPP) for 2015, 2050, and 2065 were derived from the SSP2 scenario developed by the International Institute for Applied Systems Analysis (IIASA) (Dellink et al. 2017). For our analysis, the IIASA GDP projection data is aggregated to a water province level based on the 0.5x0.5 grid dataset from Murakami and Yamagata (2019). Afterwards, the total GDP per water province is divided by the total population per water province. The dataset for the population per water province is based on SSP2 calculations from 2UP (Huijstee et al. 2018). Both datasets have values per 10 years. For the different ambition levels, the values for GDP/person stayed the same.

Table 2
The scoring system of the approach to indicate the risk for local conflict as a consequence of water stress

Indicator	Scenario indicators	Source	Threshold value	
			2	**1**
Water yield gap (rain-fed)	2050 - 2065 BAU Low ambition Med ambition High ambition	Gülpen et al. (2023)	> 40%	> 20%
GDP per capita PPP	All: 2050 -2065 SSP 2	Gridded GDP PPP data per water province (Murakami and Yamagata 2019): http://www.cger.nies.go.jp/gcp/population-and-gdp.html, divided by population per water province (2UP, see Huijstee et al. (2018))	< $10,000 per cap PPP	< $20,000 per cap PPP
Governance	BAU: 2020 values Low ambition Medium ambition High ambition	Worldwide governance index: https://info.worldbank.org/governance/wgi/	< 2.20	< 5.25

Governance: Governance data was derived from the worldwide governance index project (Kaufman and Kraay 2021). This composite indicator consists of sub-indicators accounting for Voice and Accountability; Political Stability; Absence of Violence/Terrorism; Government Effectiveness; Regulatory Quality; Rule of Law; and Control of Corruption. The governance index was scaled between 0 to 10. The 2020 values were taken for the Middle-of-the-Road projection for both 2050 as well as 2065. Although governance projections do exist according to the SSP scenario narratives (Andrijevic et al. 2020), we did not apply these projections since these are overly optimistic. In the low, moderate, and high ambition scenario, the governance quality per country is logarithmically increased. Countries with low 2020 governance values face a stronger increase than countries with high values. The formula below describes the governance value (G_t) based on the governance of five years ago (G_{t-5}) and has two criteria: i) the high ambition scenario has a stronger increase than the low ambition scenario, therefore the C, a constant value, is 1.5 for the high and 0.8 for the low ambition scenario; and ii) countries cannot exceed a governance value of 10.

$$G_t = C * (1 - log\,(G_{t-5}) + G_{t-5})$$

Water yield gap: The water yield gap is defined in percentages as the gap between the actual crop yield and the potential crop yield, which can be achieved if there are no water constraints. Data for the water yield gap is generated by the LPJmL model from 1980 until 2070 for different scenarios in Gülpen et al. (2023) for RCP6.0 and SSP2. Actual crop yields were calculated by forcing the model with gridded precipitation, temperature, and radiation data (CRU), whereas potential yields were calculated by supplying supplemental irrigation water in case of soil moisture deficits. These numbers, available at the level of 30 arc minutes, were aggregated to the water province level by calculating the average value for all cells containing data; hence cells with no data (mostly desert areas) were excluded. Data for Middle-of-the-Road up to the high ambition scenario are derived from model runs made for the FWC-2 project.

Per water province the values are multiplied, with 8 = high risk; 4 = intermediate risk; 2/1 = low risk; 0 = lowest risk. The score that each water province has is following the approach as defined in Table 2. For every indicator there are two different thresholds. The higher the threshold value, the higher the risk for conflict. An additional separate layer is included to indicate regions vulnerable for sustained droughts. See Annex 1 for more information on the methodology. Regions with a standard deviation of +1 are understood as (very) dry and are therefore considered regions with an additional risk.

2.4 Results

The results are presented in Table 3, Figure 7, and Figure 8. In the baseline, the number of people living in areas of high risk are projected to increase from 63 million in 2015 to 138 million in 2050. Areas most at risk are Afghanistan, parts of the Middle East (especially Yemen), and large parts of the Horn of Africa (Somalia, Eritrea, Sudan). The numbers for 2020 and 2070 in Table 3 are used in FWC-2; the key messages in the introduction and summary to this report are also based on these numbers.

Table 3
Number of people (urban + rural) living in areas at no, low, medium, or high risk of water stress-related conflict risk (in millions of people)

Year	Scenario	No risk	Low risk	Mod risk	High risk	Total
2015	baseline	4,393	1,396	860	63	7,242
2020			2,319[a]			
2050	BaU	6,304	1,519	534	138	9,166
2050	low ambition	7,591	462	442	-	9,166
2050	moderate ambition	7,764	332	399	-	9,166
2050	high ambition	8,010	305	167	-	9,166
2065	BaU	6,985	1,168	469	66	9,409
2065	low ambition	7,957	411	320	-	9,409
2065	moderate ambition	8,437	197	54	-	9,409
2065	high ambition	8,643	11	10	-	9,409
2070	BaU		1,703[a]			
2070	low		731[a]			
2070	moderate		251[a]			
2070	high		21[a]			

a) Combined population figure for low, medium, and high risk

The higher ambition pathways – in terms of improved water use and management, as well as improved governance levels – reduce risk globally by 2050; the projections reveal no people living in areas at high risk. But even under the high ambition pathway, large regions, including the Horn of Africa and Angola, as well as parts of Pakistan, Afghanistan, and Iraq, remain vulnerable to conflict related to water stress.

Towards 2065, conflict risk is projected to decrease due to high GDP growth under the SSP2 scenario. This high GDP growth in SSP2, however, has been widely criticised for being overly optimistic (Buhaug and Vestby 2019), which would imply that the projections provided in this study are equally too optimistic. On the other hand, the water yield gap is projected to increase in most places towards 2065 (Figure 5 and Figure 6), increasing stresses on agricultural livelihoods.

Figure 5
Rain-fed water yield gap in 2065 (time slice 2061 - 2070) for rain-fed crops (BaU scenario), indicating the difference between the actual yield and potential yield in the absence of water limitations

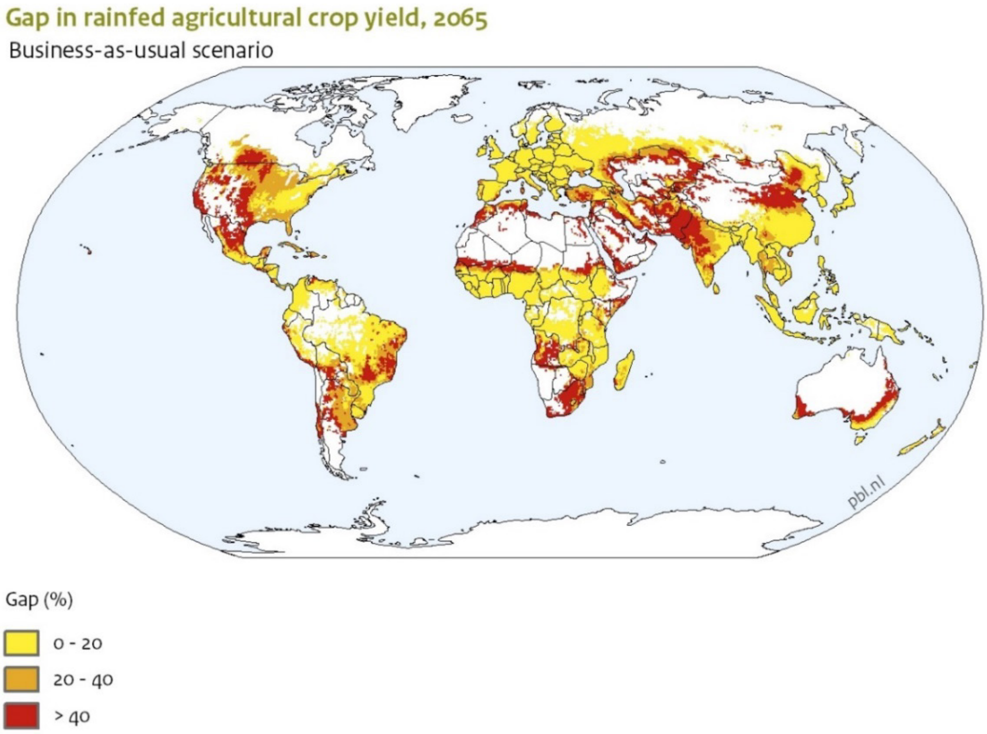
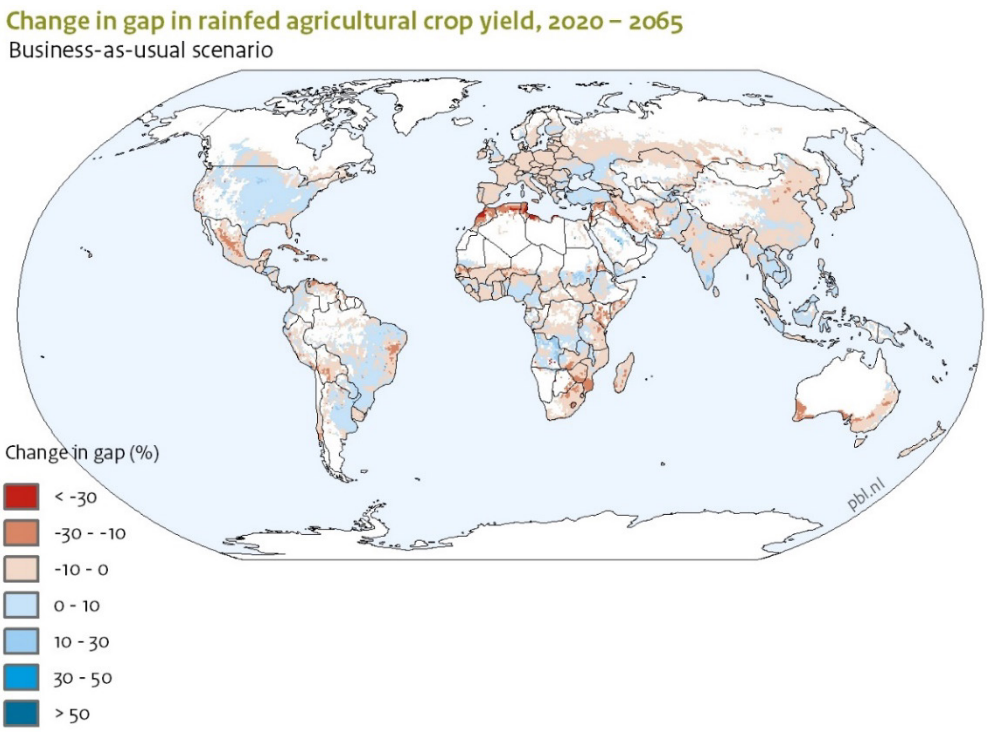
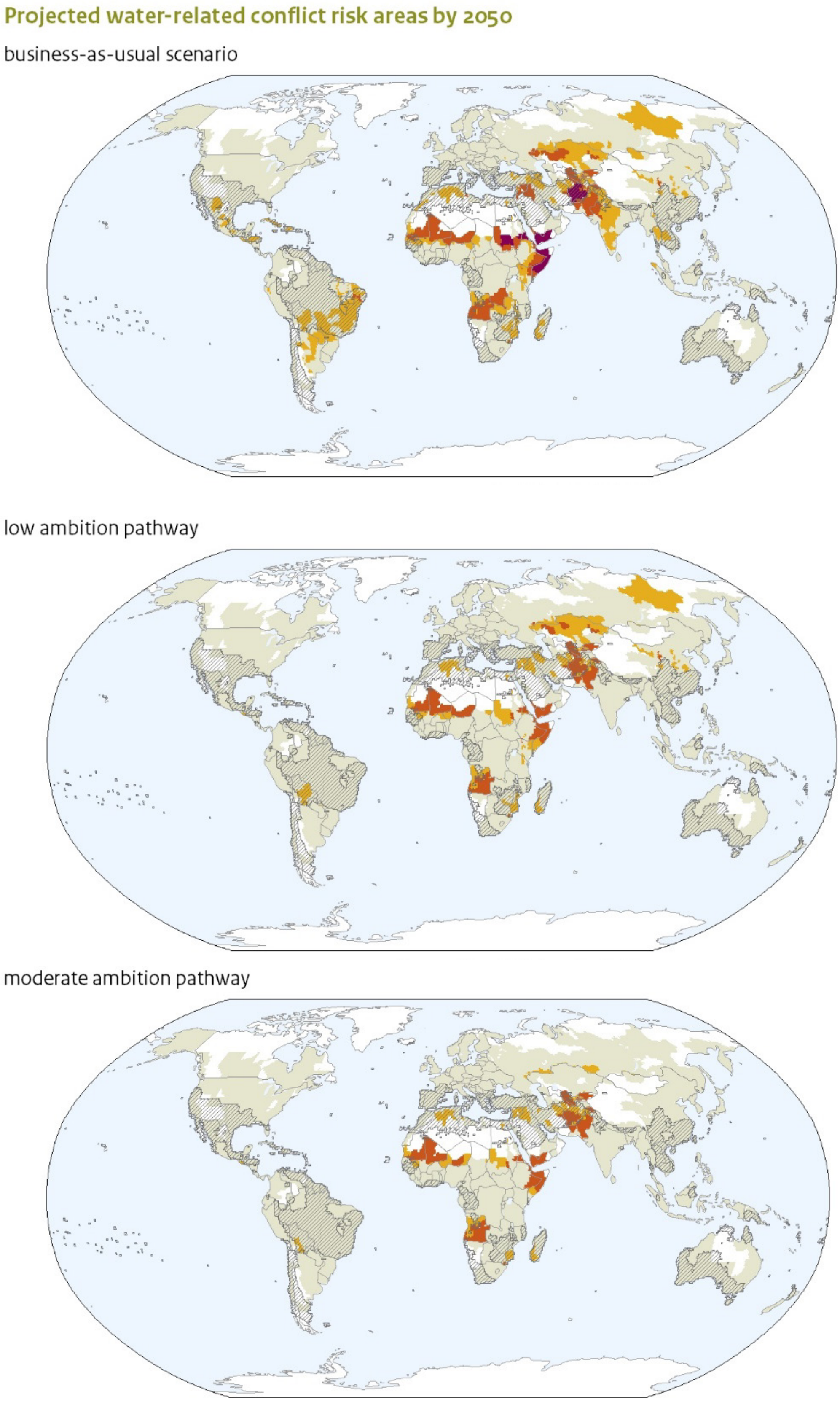


Figure 6
Relative change in yield gap between 2015 (time slice 2011-2020) and 2065 (time slice 2061-2070)

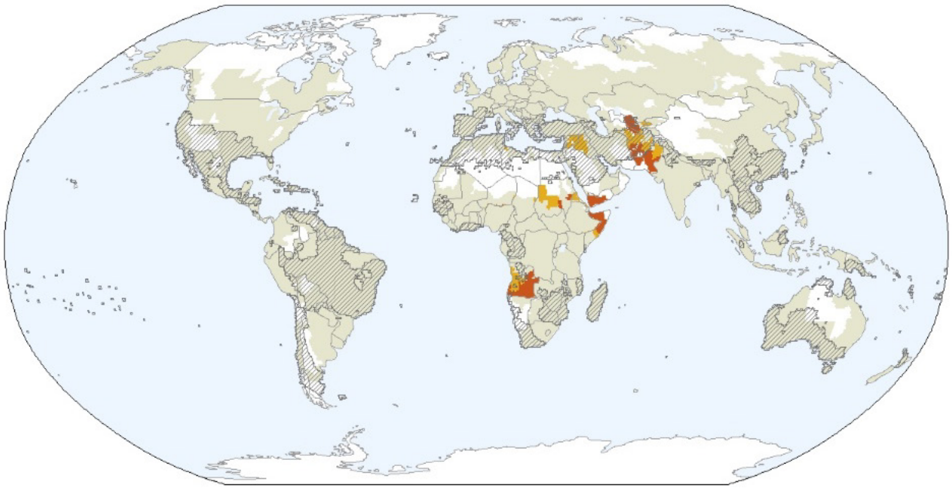


Source: Gülpen et al. (2023)

Figure 7
Local water-related conflict risk by 2050 following the BaU, low, moderate, and high ambition pathways. Shaded areas indicate regions with a high drought risk



high ambition pathway



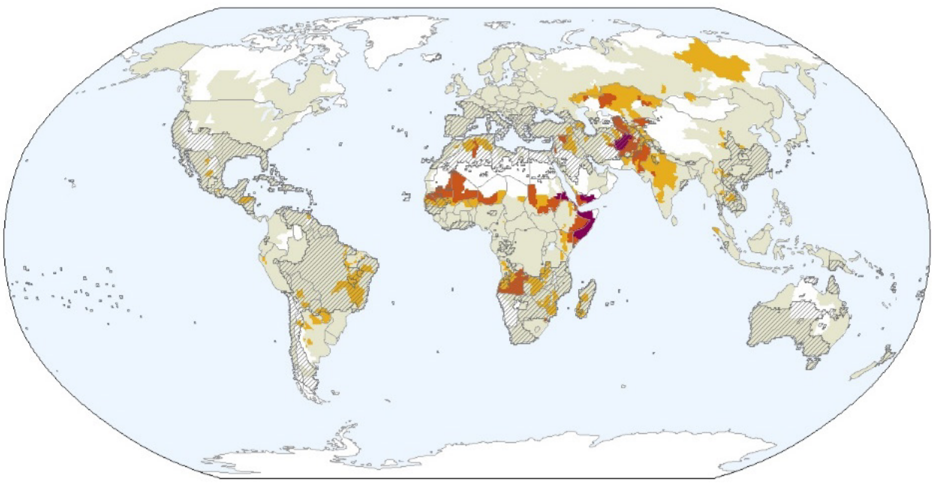
Source: Utrecht University & PBL

- increased drought risk 2050
- lowest/no conflict risk
- low conflict risk
- medium conflict risk
- high conflict risk

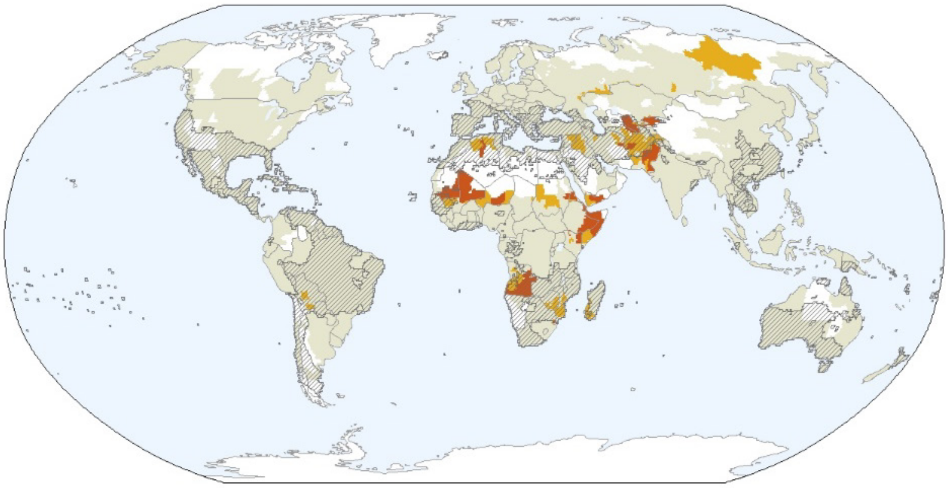
Figure 8
Local water-related conflict risk by 2065 following the BaU, low, moderate, and high ambition pathways. Shaded areas indicate regions with a high drought risk

Projected water-related conflict risk areas by 2065

business-as-usual scenario

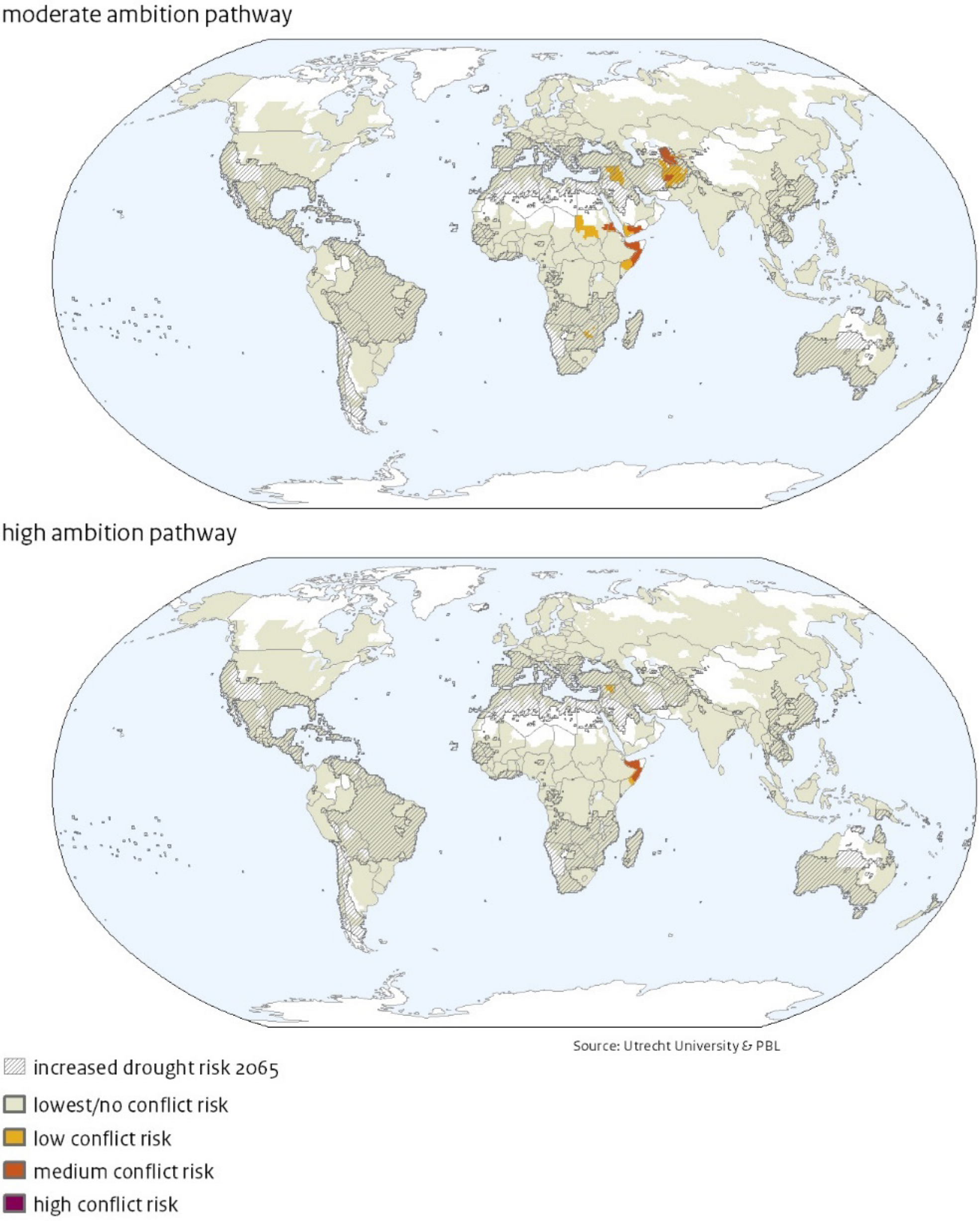


low ambition pathway



moderate ambition pathway

high ambition pathway



3 Water stress-related migration

3.1 Background

The impact of environmental change on migration dynamics has been receiving increased attention in academia and beyond, since slow-onset processes, such as increasing water stress and land degradation, are increasingly affecting the mobility of people (IOM 2021). Following the exacerbation of climate change impacts and the continuing unsustainable human resources use, futures of 'environmental migration' are discussed more and more in international scientific and policy discussions as a cross-cutting and complex issue (de Bruin et al. 2022b). As with conflict, the processes that determine migration decisions are diverse and depend on the place where people live, their gender, their age, and their perceived opportunities (Neumann and Hermans 2017). Therefore the identification of a causal link between environmental change related to water stress and migration is complex; there are many interconnected drivers of migration, including political, social, economic, and environmental causes (Black et al. 2011a). In addition to having a direct impact via fast-onset events (e.g. droughts and flooding), environmental change can have indirect slow-onset effects on migration decisions, as it also affects economic drivers in terms of income levels and stability (Afifi et al. 2016; Cattaneo et al. 2019).

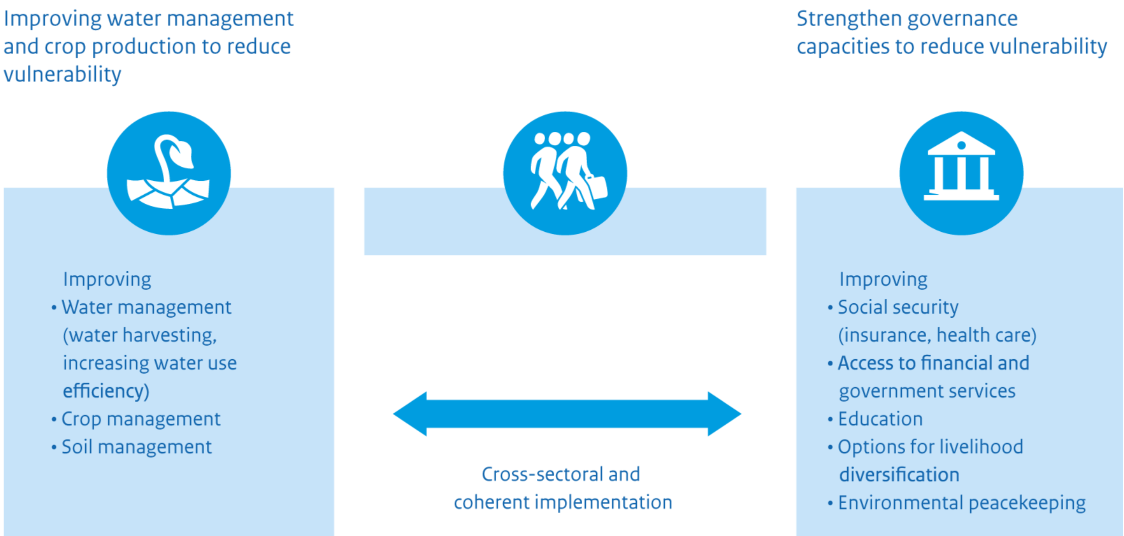
Opportunities and willingness to migrate differ per person and per community. Simultaneously, the balance between push and pull factors differs. 'Environmental' migration can primarily be seen as the result of a push factor (Black et al. 2011a), although chosen destinations are defined by pull factors (e.g. employment opportunities). International migration is generally the result of push and pull mechanisms, although a strict division is often impossible to make (Neumann and Hermans 2017). International migration is highest in upper-middle income countries, and slightly lower in the higher income countries (Clemens 2014; de Haas 2010). Migration associated with slow-onset environmental degradation is mostly local and regional, and is primarily observed in rural regions of low-income countries where a major share of the population depends on their natural environment for their livelihoods (Mortreux et al. 2018). For people depending on natural resources for their livelihoods, economic factors are the main mechanism through which environmental factors affect migration (Afifi 2011; Neumann and Hermans 2017). Temporary, cyclical, or permanent migration can be a strategy to improve individual or household security, to spread economic risks, or to avoid livelihood degradation when *in situ* adaptation to water stress or land degradation is not possible (Black et al. 2011a; Scheffran et al. 2012). In those cases, migration is mostly taking place within countries since people have limited resources to move abroad.

3.2 Solutions

In order to reduce water stress-related migration, overall vulnerability to water-related issues and socioeconomic problems need to be decreased, while simultaneously increasing economic and social opportunities. It is, however, important to note that the measures proposed here are in no way aimed to immobilise people. Indeed, migration, mostly from rural regions to growing urban centres, will play an important role in the sustainable development of many regions which primarily depend on agriculture (de Brauw et al. 2014). People migrate as a result of marriage, education, health care, better or new employment, adventure, and so forth. If people move due to deteriorating environmental conditions and limited resilience to cope with these issues, their decision may have been different if these local environmental conditions had been in better a state.

To reduce water stress-related migration, integrated approaches across multiple policy sectors and levels of governance are needed (Stojanov et al. 2021). These measures are summarised in Figure 9. They include water-related measures and measures that improve the resilience of rural communities.

Figure 9
Solutions to reduce (impacts of) water stress-related migration (solutions inspired by Clement et al. (2021) and Stojanov et al. (2021))



Source: PBL

Improving water management and measures
Improved water management measures can reduce vulnerability to water stress. The measures are similar to those proposed in section 2.2 (Figure 4) and derived from Gülpen et al. (2023). These include small-scale irrigation, rainwater harvesting and infiltration, improving reservoir storage, recovering environmental flows, and improving agricultural (nutrient, seed, etc.) management.

Improving social and economic resilience
Several measures can improve social and economic security, enabling people to better deal with water-stress. Social protection measures can stimulate agricultural productivity and reduce (rural) poverty and food insecurity by improving incomes and enabling farmers to cope with risks (Croppenstedt et al. 2018; Tirivayi et al. 2016). Low social protection often leads to risk-avoiding livelihood strategies, reducing income potential due to low use of agricultural inputs. Improving structural social protection measures, such as insurances and cash transfers, enables farmers to raise productivity and incomes alike (Hidrobo et al. 2018; Jones et al. 2017). These measures relate to access to other government and financial services, including weather data, early warning systems, and trade information, and can therefore play a role in reducing risks for rural communities (Kosec and Resnick 2019; Pingali et al. 2019).

Two other important measures to increase resilience are education and training, and land tenure security. Education and training can decrease vulnerability to natural disasters and climate risks by improving risk awareness, as well as by providing skills and knowledge to deal with risks, thereby improving resilience (Muttarak and Lutz 2014). Societies with (highly) educated citizens are better in responding to, preparing for, and recovering from disasters. Land tenure security, moreover, is a key element of improved governance. Enhanced land tenure security stimulates landowners and renters to make durable and sustainable investments in their land and shared water infrastructure, contributing to their resilience (Benjamin 2020; Sulieman 2015).

Box 2: Reducing inequality and inequity to increase resilience
High levels of economic and gender inequality hamper economic growth, food security, and health security, and potentially contribute to environmental degradation (Doyle and Stiglitz 2014; Kolawole et al. 2015). The poorest farming households are generally have fewer chances to benefit from measures to improve resilience (Franke et al. 2014; Ritzema et al. 2017), making development efforts and investments less effective under high levels of inequality. Therefore, reducing inequalities and inequities in terms of education, access to public services, income, and employment, requires continuous consideration in policies, development projects, and investments. However, inequality has been rising in recent years and may continue to rise in large parts of sub-Saharan Africa and, to a lesser extent, in South Asia (Alvaredo et al. 2018; Rao and Min 2018). The economic impacts of Covid-19 are exacerbating inequalities within countries, especially between high-income groups and lower-income groups (Egger et al. 2021). Without specific emphasis on inequality on both the macro and micro scale, the measures discussed in this report will only serve a specific group of rural actors, namely those who have the means to act upon the resulting opportunities.

Connectivity to cities
Connectivity between rural and urban regions diminishes the vulnerability of rural regions, as it provides access to finance, inputs, information, services, and off-farm employment (de Bruin and Dengerink 2020). The spatial patterns of urbanisation, in combination with the quality of infrastructure, shape rural-urban connectivity and rural access to urban markets. A dispersed pattern of urbanisation implies that more smallholder farmers have physical access to food markets, input, and knowledge, as well as to off-farm employment (Christiaensen et al. 2013; Henderson 2010). The growth of smaller cities rather than the primary cities is correlated with higher levels of poverty reduction by displaying more inclusive growth patterns (Christiaensen and Todo 2014; Gibson et al. 2017; Imai et al. 2018). National governments in sub-Saharan African and South Asian countries tend to invest less in smaller cities and instead favour the capital region and urban deltas, with a variety of advantages, including better access to financial assets, import-export licenses, and better provision of public services (Henderson 2010; Sahoo 2016). This limits the potential development of smaller cities, which can serve rural livelihoods in offering health care, education and training, access to finances, and access to market knowledge (de Bruin et al. 2021).

Measures in receiving areas
Measures should not exclusively be taken in the water-stressed rural areas. As migration is a key part of life on Earth, not all migration related to climate or water issues can be avoided in the future; some regions may become too hot or too water-stressed to remain liveable. Supporting destination areas in receiving incoming migrants is crucial to minimise any conflict or tensions

about housing, employment, or (natural) resources in these areas, which is a reality in almost all countries in the context of rising nationalism and xenophobia (Brzoska and Fröhlich 2016; Stojanov et al. 2021).

3.3 Approach and methods

To assess future geographical clusters of potential migration associated with water stress, four indicators have been determined that are of importance to identify regions vulnerable to emigration due to water stress. We have slightly adapted the methodology as developed in de Bruin et al. (2022b); we ascertain a longer time horizon than de Bruin et al. The four risk indicators are multiplied (based on their threshold value) and the following risk scores are provided: 16 = high risk; 8 = medium risk; 4 = low risk; and 0/1/2 = lowest/no risk.

As spatial aggregation level we made use of water provinces: a balanced subnational representation of topographic, hydroclimatic, and administrative properties, with a minimal size of 20,000 km² (Straatsma et al. 2020). An additional, separate layer is included to indicate regions vulnerable to sustained droughts. See Annex 1 for more information on the methodology. Regions with a standard deviation of +1 are understood as (very) dry and are therefore considered regions with an additional risk.

Table 4
Indicators for water stress-related migration analysis and threshold values for risk categorisation

Indicator	Scenario indicators	Source	Threshold value	
			2	1
Water yield gap (rain-fed crops)	2050 - 2065 BAU Low ambition Med ambition High ambition	Gülpen et al. (2023)	> 40%	> 20%
GDP per capita PPP	All ambition scenarios: SSP2 2050 -2065	Gridded GDP PPP data per water province (Murakami and Yamagata 2019): Global dataset of gridded population and GDP scenarios | GCP Tsukuba International Office (nies.go.jp) divided by population per water province (2UP, see Huijstee et al. (2018))	< $10.000 per cap PPP	< $20.000 per cap PPP
Share of young people 15-29	All ambition scenarios: SSP2 2050 – 2065	Lutz et al. (2018)	> 26% of the population	< 20% of the population
Population growth	All ambition scenarios: SSP2 2050 – 2065	Lutz et al. (2018)	> 2% growth/year	> 1% growth/year

3.4 Results

Taking the indicators which are considered risk factors today as the basis for future projections, the number of people migrating affected by water stress will drop substantially. The number of rural people living in areas at risk decreases from 217 million to 32 million in a scenario without additional water measures (Table 5). This is not because water stress itself will decrease, but because both population growth and youth share will decrease, while GDP grows considerably. Water yield gaps will actually increase towards 2065 (Gülpen et al. 2023). Figures 10 and 11 provide the spatial details. Table 6 presents the total number of people living in water-stressed migration risk areas for 2020 and 2070. These numbers are used in FWC-2; the key messages at the beginning of this report are also based on these numbers.

Taking the optimistic demographic and economic projections into account, risk will decrease substantially. However, economic growth projections have been widely criticised for being too optimistic and not taking geopolitical events into account (Buhaug and Vestby 2019). Moreover, other environmental factors may become more important; especially heat is becoming a risk in the long run (Xu et al. 2020). To give an indication, Figure 12 provides an overview of regions that are projected to have a mean annual temperature of above 29 degrees. These regions are mostly located in Africa, but also in South Asia, Southeast Asia, and parts of South America.

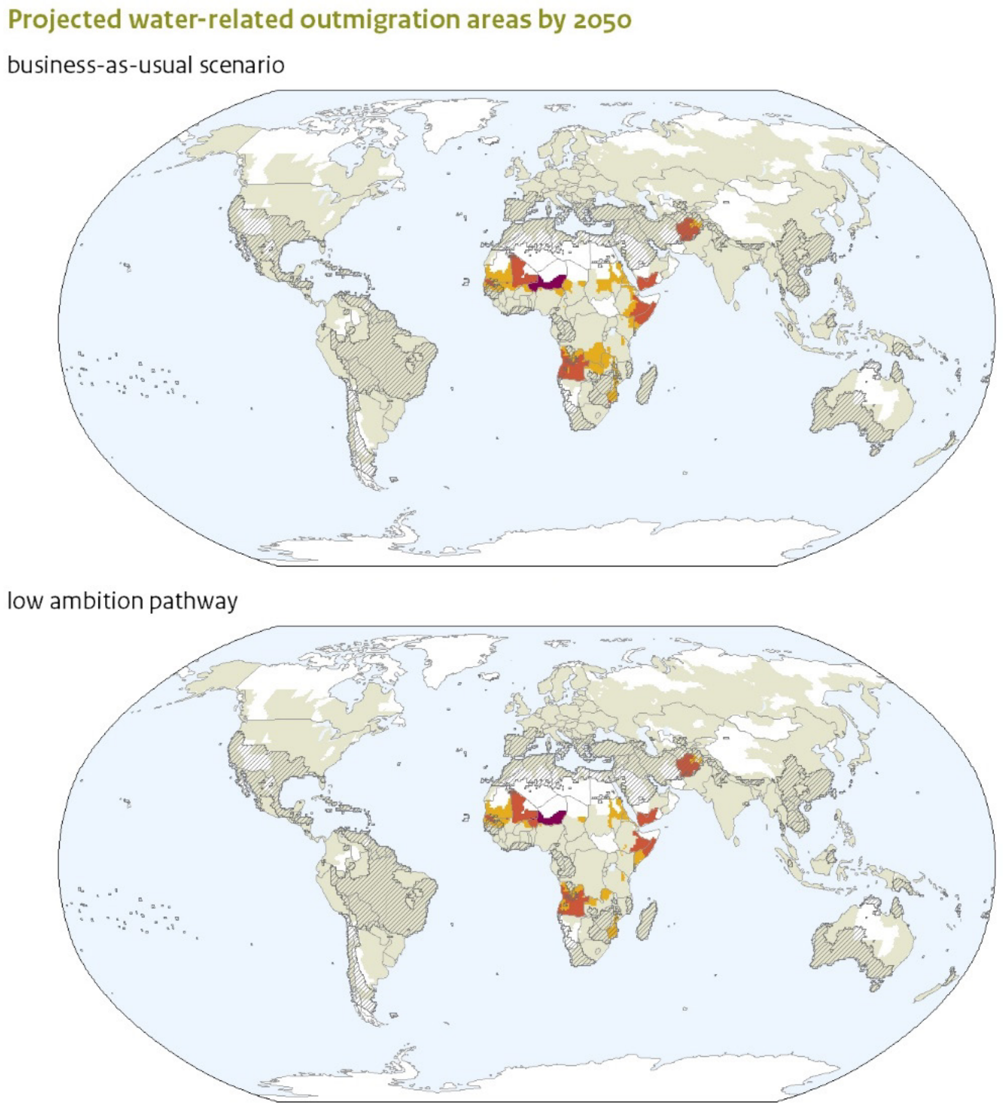
Table 5
Number of rural people living in areas at no, low, medium, or high risk of water stress-related conflict risk (in millions of people)

Year	Scenario	No risk	Low risk	Mod risk	High risk	Total
2015	baseline	3,489	394	386	214	4,793
2050	baseline	4,562	197	125	32	5,241
2050	low ambition	4,670	98	125	23	5,241
2050	moderate ambition	4,690	99	111	16	5,241
2050	high ambition	4,713	94	83	16	5,241
2065	baseline	4,646	73	53	-	5,100
2065	low ambition	4,666	81	25	-	5,100
2065	moderate ambition	4,667	79	25	-	5,100
2065	high ambition	4,667	84	11	-	5,100

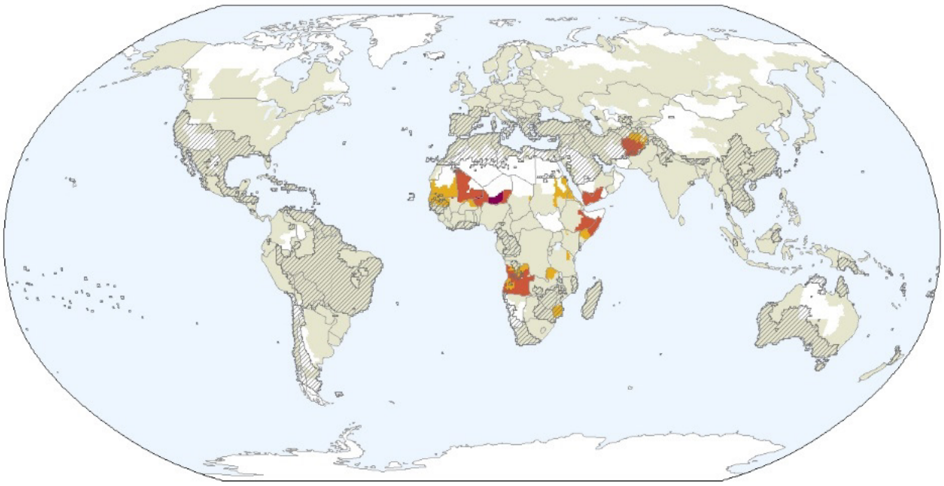
Table 6
Number of people living in water-stressed migration risk areas (in millions of people)

Year	Scenario	People (million)
2020		852
2070	Business as usual	102
2070	low ambition	45
2070	moderate ambition	45
2070	high ambition	24

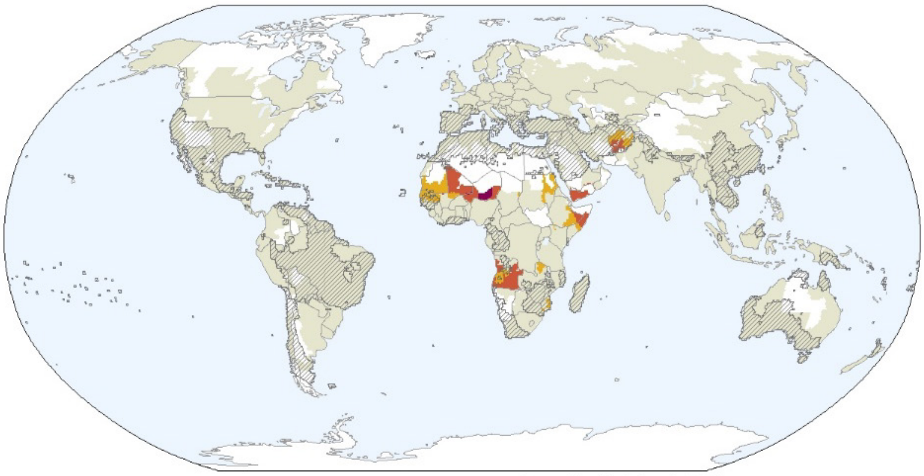
Figure 10
Water-related outmigration risk areas by 2050 following the BaU, low, moderate, and high ambition pathways. Shaded areas indicate regions with a high drought risk



moderate ambition pathway



high ambition pathway



Source: Utrecht University & PBL

increased drought risk 2050

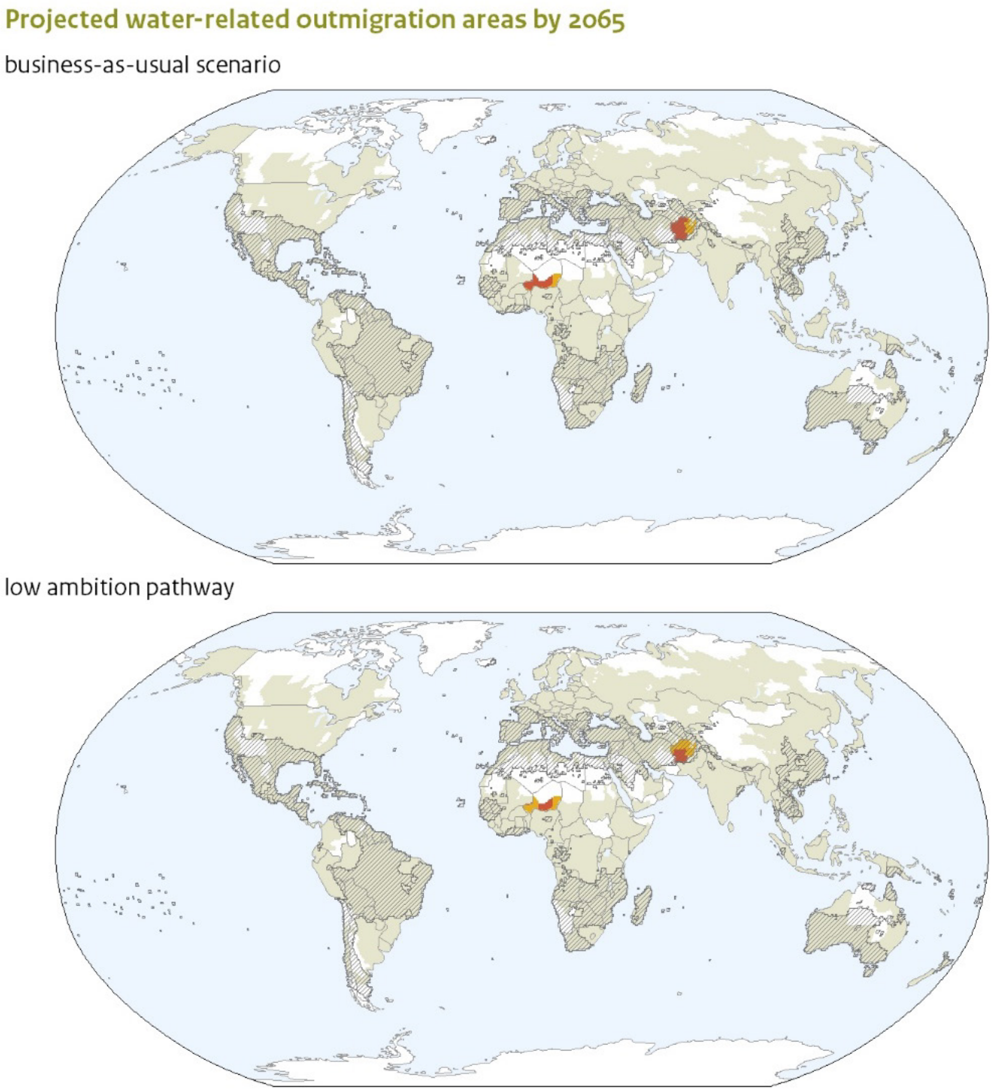
lowest/no migration risk

low migration risk

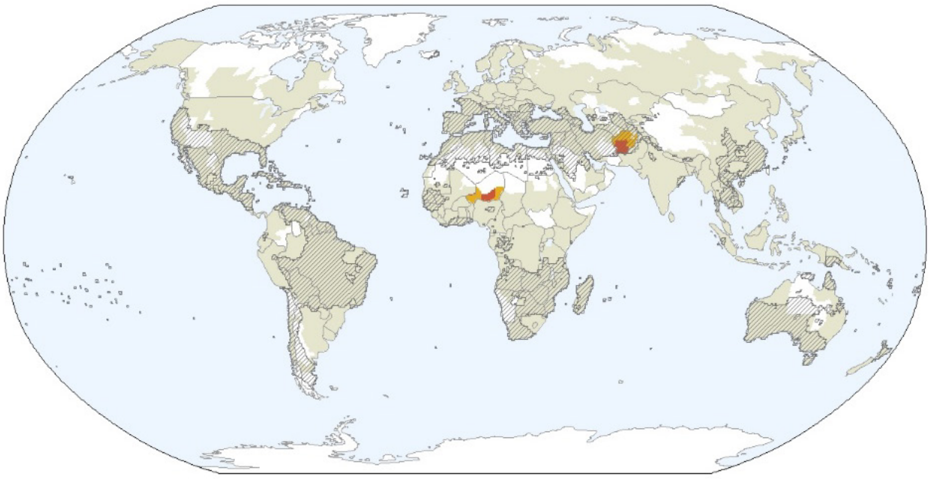
medium migration risk

high migration risk

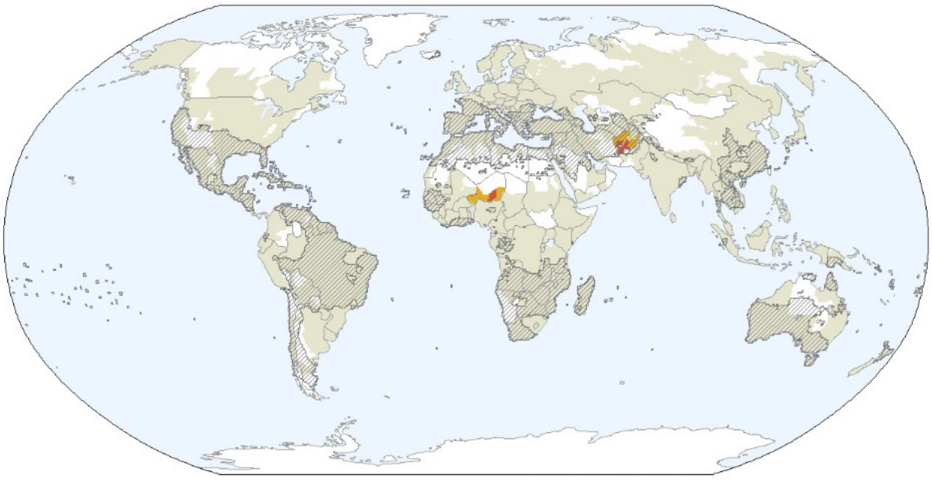
Figure 11
Water-related outmigration risk areas by 2065 following the BaU, low, moderate, and high ambition pathways. Shaded areas indicate regions with a high drought risk



moderate ambition pathway



high ambition pathway



Source: Utrecht University & PBL

increased drought risk 2065

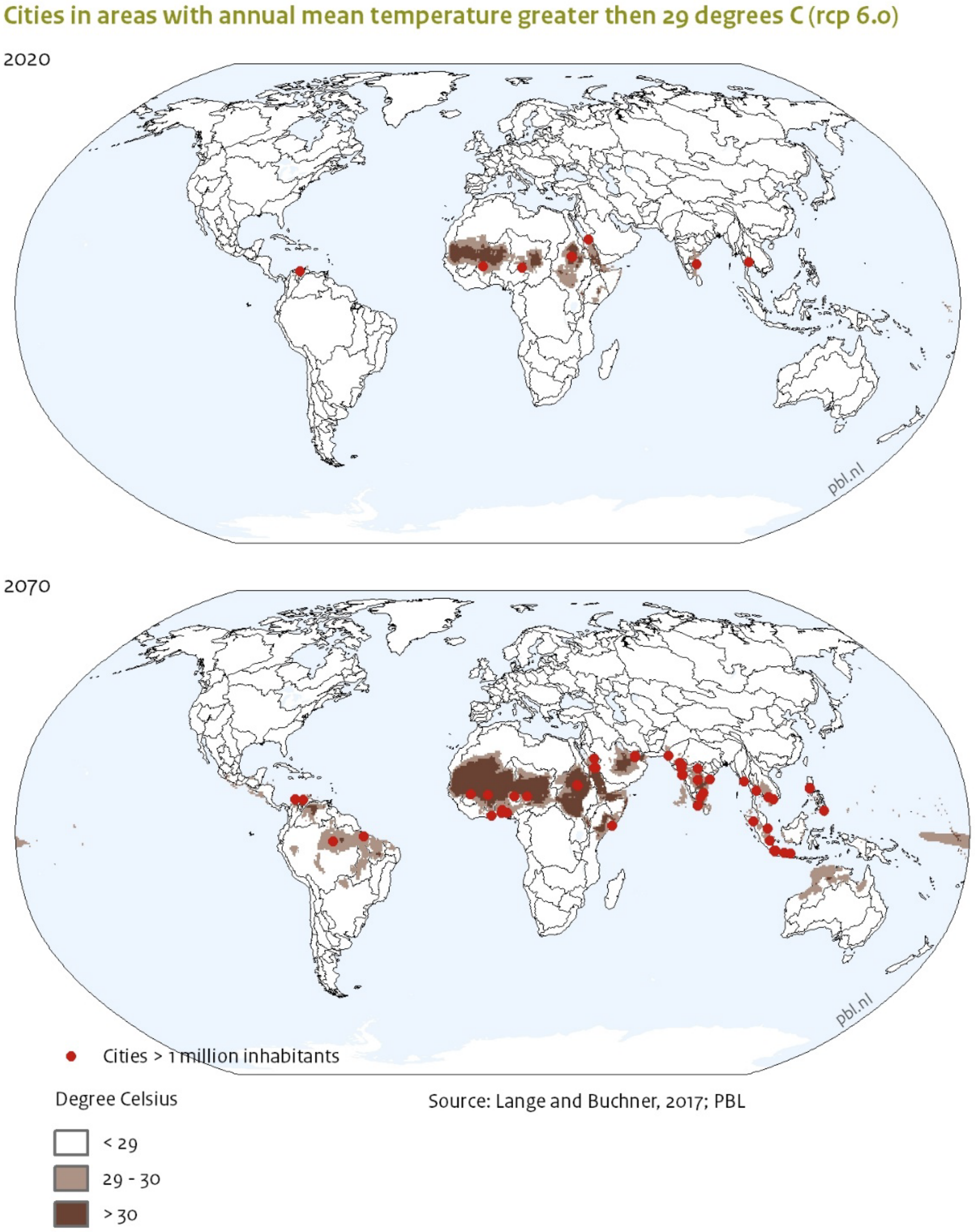
lowest/no migration risk

low migration risk

medium migration risk

high migration risk

Figure 12
Regions in areas with an annual mean temperature above 29 degrees (RCP 6.0). Red dots indicate cities with over 1 million people. Total population potentially facing annual mean temperatures above 29 degrees is estimated at 200 million in 2020 and 1.4 billion by 2070



4 Conflict risk in transboundary river basins

4.1 Background

Hundreds of rivers worldwide are shared by two or more countries. There are around 310 transboundary river basins, shared by 150 countries and territories. Together they cover 47.1% of the Earth's land surface and 52% of the world's population resides within their boundaries (McCracken and Wolf 2019). The use of these shared rivers can be a challenging socio-political issue for riparian countries, although cooperation over these rivers appears to prevail (Bernauer and Böhmelt 2020). Recent examples of conflicting interactions include tensions in the Indus basin (Pakistan, India); the Euphrates-Tigris (Turkey, Syria, Iraq); the Amu Darya (Central Asia); and the Mekong Basin (Laos, Thailand, Cambodia, China). The eminent non-violent but highly political conflict in the Nile basin between Egypt, Sudan, and Ethiopia concerning the Grand Ethiopian Renaissance Dam has been worsening in recent years, potentially destabilising the wider region (Heggy et al. 2021). So far, however, there has been no large-scale international violent conflict over shared waters (Petersen-Perlman and Wolf 2015).

In FWC-1, we provided a map with potential hydro-political tensions in the coming 5-10 years following the method of de Stefano et al. (2017). For FWC-2, we adapt the methodology as developed by de Stefano et al. to develop long-term scenario projections of conflict risk in transboundary river basins. Additionally, we provide an overview of water measures and institutional solutions to lower the projected risks.

Many dynamics and conditions can affect how transboundary conflict and cooperation interactions evolve, which has been studied by a wide range of scholars (Dinar et al. 2019; Link et al. 2016; Petersen-Perlman and Wolf 2015; Schmeier 2013). The findings of these various studies suggest a large number of drivers explaining the complex dynamics of conflict and cooperation, with different, sometimes opposing findings (Bernauer and Böhmelt 2020). While much has been published about historical events, hardly any research has been done on projections of potential future conflict risk and cooperation in shared river basins in the long term. While various scenario projections are available of conditions important to conflict and cooperation, long-term scenario projections of transboundary conflict or tensions do not exist. De Stefano et al. (2012) did perform a 2050 scenario projection study, but this study did not include the development of new large dams, while this is regarded as a major risk factor in transboundary river basins.

Providing conflict risk projections for transboundary river basins is relevant due to the rising hydroclimatic and socioeconomic pressures on shared river basins. In the coming decades, the hydrological impacts of climate change and the rising water demand are expected to intensify the water problems in many shared river basins (Munia et al. 2020). Since downstream water availability is highly dependent on upstream precipitation and water use patterns, countries towards the downstream ends of transboundary rivers can become dependent on the water use policies of their upstream counterparts (Munia et al. 2018). While climate change is projected to intensify hydrological pressures on basins, many large dams are planned to be constructed, especially in South America, the Balkans, Asia, and Africa (Gernaat et al. 2017; Zarfl et al. 2015). The construction of large-scale dams can exacerbate existing tensions or even create new ones (Link et al. 2016; Zeitoun and Mirumachi 2008), although this strongly depends on the way these dams will be constructed (de Stefano et al. 2017). Earlier research has suggested that one of the most indicative variables for conflict in shared river basins is the rapid or extreme change to physical water infrastructure in the absence of transboundary institutional mechanisms to manage the effects of that change (Wolf et al. 2003). In addition to the construction of dams, planned and operating inter-basin water transfers might add to future tensions between countries or states in different river basins (Purvis and Dinar, 2020), although little research has been done on the potential long-term impacts of these transfers.

While changes in water infrastructure (e.g. dams) have shown to matter greatly in the evolution of transboundary water interactions, these interactions are essentially inherently political processes determined by their broader political context. Indeed, the degree of cooperation or conflict very much depends on this broader historical and political context (Zeitoun and Mirumachi 2008). Research has shown that today, many countries in transboundary river basins hardly cooperate while historically, cooperation prevailed over conflict (Petersen-Perlman and Wolf 2015). Formal agreements governing transboundary basins, including international treaties and river basin organisations (RBOs), provide a framework for communication and negotiation with the intent to prevent potential disputes (de Stefano et al. 2017). However, treaties are essentially just formal documents and the presence of a treaty does not by definition mean the absence of conflict (Dinar et al. 2019). Even when treaties are in place, national institutions in various river basins may not be prepared for the increasing pressures coming from climate change, socioeconomic developments, and the construction of new dams (de Stefano et al. 2017). Although these increasing pressures and responses are not expected to directly cause interstate conflict, tensions can rise and cooperation can decrease, thereby potentially affecting the livelihoods of millions of people (Link et al. 2016).

In this study, we aim to provide insight into which shared river basins may face future conflict risk because of climate change impacts, socioeconomic developments, the construction of dams, and institutional resilience. We have identified that there is a research gap in exploring which transboundary river basins might be at risk of tension or conflict. This research gap results in a knowledge gap for decision-makers. Transboundary conflict risk projections can highlight which basins might be at risk under various scenarios, what can increase awareness concerning the need for conflict-sensitive transboundary climate adaptation strategies and measures, and identify potential conflict prevention efforts between states sharing water resources. Additionally, these scenarios can spur discussion between different actors, thereby stimulating a shared understanding of short- and long-term risks (de Bruin et al. 2022a).

4.2 Solutions

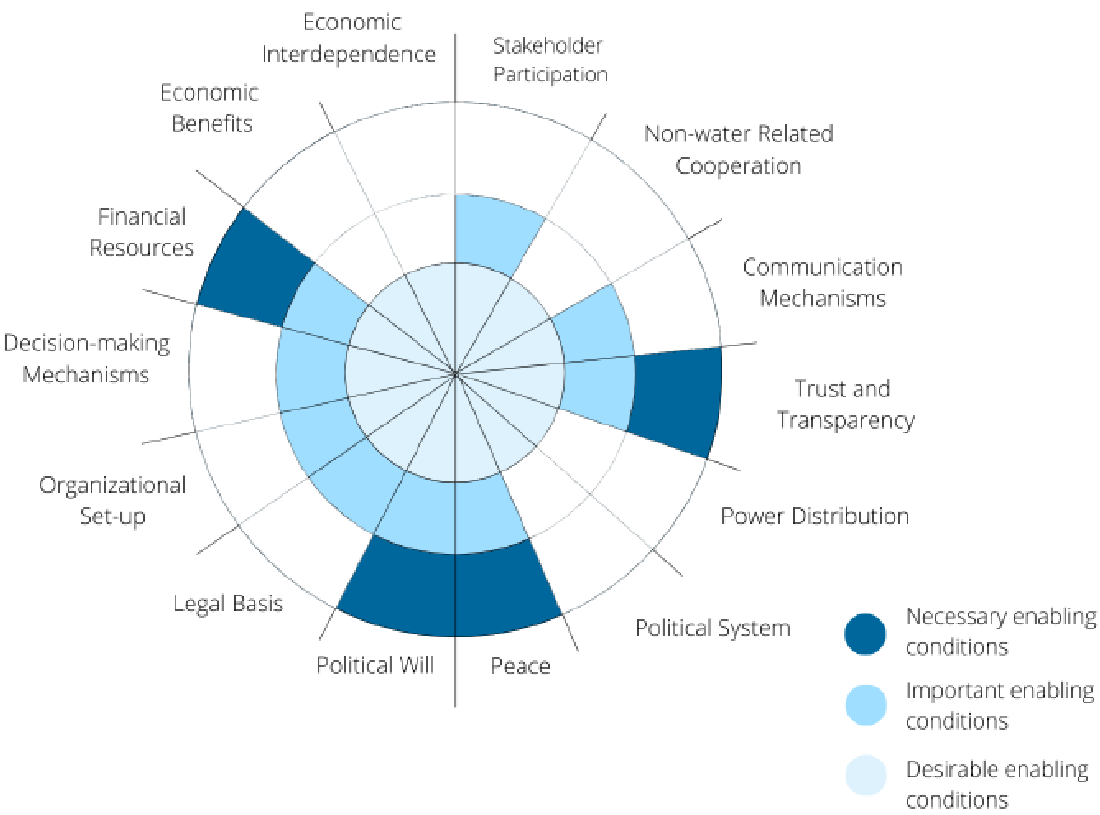
To reduce political tensions and conflict risks in transboundary river basins, a range of integrated technical and governance solutions can be implemented. These solutions focus on water management and strengthening transboundary cooperation in science and governance, thereby improving the institutional resilience of basins.

Transboundary adaptation plans

State-based climate adaptation in transboundary river basins can have adverse impacts on riparian countries. For instance, flood adaptation control upstream can affect flood control downstream, potentially damaging diplomatic relations. Meanwhile, diplomatic relations can also be improved by the joint development of resilience and adaptation strategies, as observed in the Hindu-Kush Himalayan river basins (Molden et al. 2017). A Guidance on Water and Climate Adaptation has been developed under the United Nations Economic Commission for Europe (UNECE) Water Convention, with the objective to support cooperation and decision-making in transboundary basins, and so addressing adaptation to climate change impacts on water resources. The Guidance acknowledges the international dimension of climate adaptation as a potential threat to international security by signalling a growing potential for conflict. This conflict is the result of the rising competition over water and the risk that countries might take unilateral measures with trade-offs for downstream countries (UNECE, 2009).

Water management measures include increasing efficiency for new irrigated areas, improving efficiency for domestic and industrial water demand, increasing groundwater pumping capacity, limiting extraction to renewable groundwater only, and changing the way dams are operationalised to sustain run-off.

Figure 13
Different types of conditions that enable River Basin Organisations to function efficiently and inclusively. Taken from Lengkeek (2022)

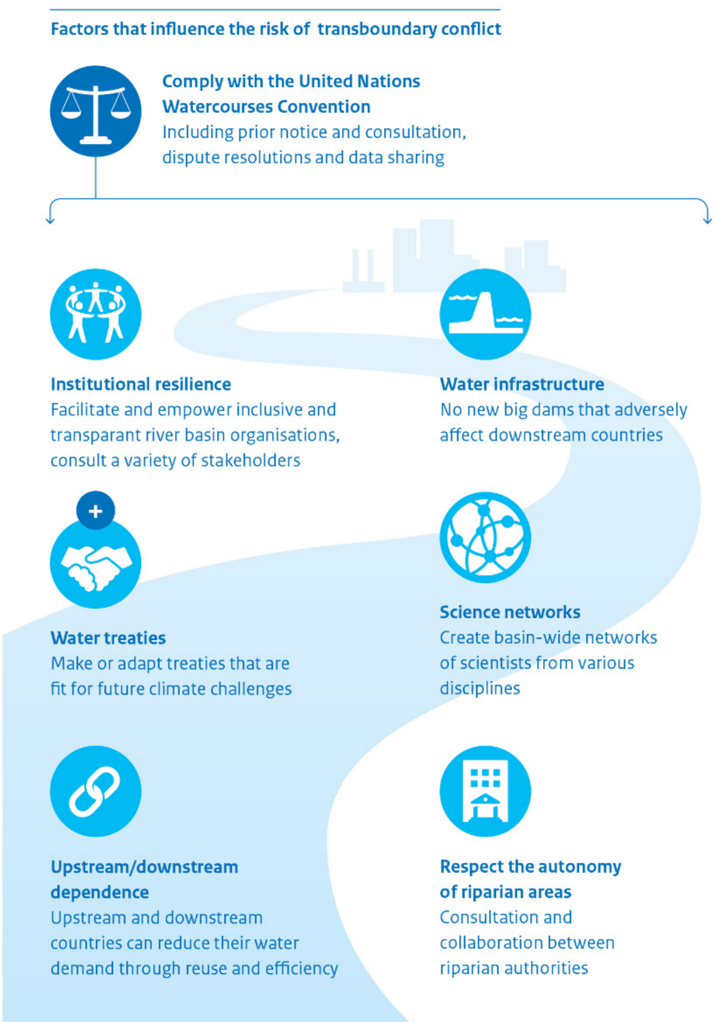


Improving institutional resilience in transboundary river basins

Treaties and River Basin Organisations (RBOs) are of great importance to deal with climate change and infrastructural change in basins. They boost the capacity of transboundary water institutions, thereby increasing the likelihood of long-term, stable cooperation between states (Brochmann 2012; Dinar et al. 2019; Schmeier 2013). RBOs are institutions that provide a set of institutionalised principles, norms, rules, and river basin mechanisms around which actors' expectations converge in the issue area of water resources governance (Schmeier et al. 2016). Existing treaties are, however, no guarantee for cooperation over climate change impacts and infrastructural change. Cooperation depends on both the intentions of the states involved and their capacity to implement treaty provisions (Karreth and Tir 2018), which is projected to be lacking in several Asian and African basins. Strengthening the adaptative capacity of treaties and RBOs and enhancing the resilience of institutionalised cooperation is therefore a crucial requirement for reducing conflict risk in the future.

Conditions that enable RBOs to govern transboundary river basins effectively, efficiently, and inclusively, can be social-cultural, political, institutional, and economic. 14 conditions with various levels of importance are summarised in Figure 13. RBOs should include climate change threats to the already substantial natural and anthropogenic pressures while governing transboundary river basins, since RBOs play an important role in adapting transboundary river basins to future water challenges.

Figure 14
Integrated solutions to reduce risks in transboundary river basins



4.3 Approach and methods

In this study, as mentioned above, we adapt the framework as developed by de Stefano et al. (2017) to make projections that span a longer time horizon (2050/2065).This multicriteria assessment combines (proxies for) the construction of mega dams, institutional capacity in terms of treaty characteristics, and the existence of river basin organisations, as well as exacerbating hydroclimatic and socioeconomic factors. It does so by predominantly making use of existing scenario projections following the shared socioeconomic pathways (SSPs) (O'Neill et al. 2014). In the absence of a full consensus on the drivers of conflict in transboundary river basins, it is not possible nor desirable to accurately predict conflict in the long term. What can be done, however, is identifying basins where various risks are projected to compound.

So, to develop the scenario projections, three dimensions are included, as listed above:

1. The construction of new dams,
2. Exacerbating socioeconomic and hydrological factors,
3. The institutional resilience of basins.

The analysis will be conducted at the oBasin Country Unit (BCU) level. A BCU is defined as the portion of a riparian country's land area that is within a certain transboundary river basin. For instance, the Tagus River Basin has two BCUs: the land area in Spain that is within the Tagus River drainage, and the land area in Portugal.

4.3.1 Dams

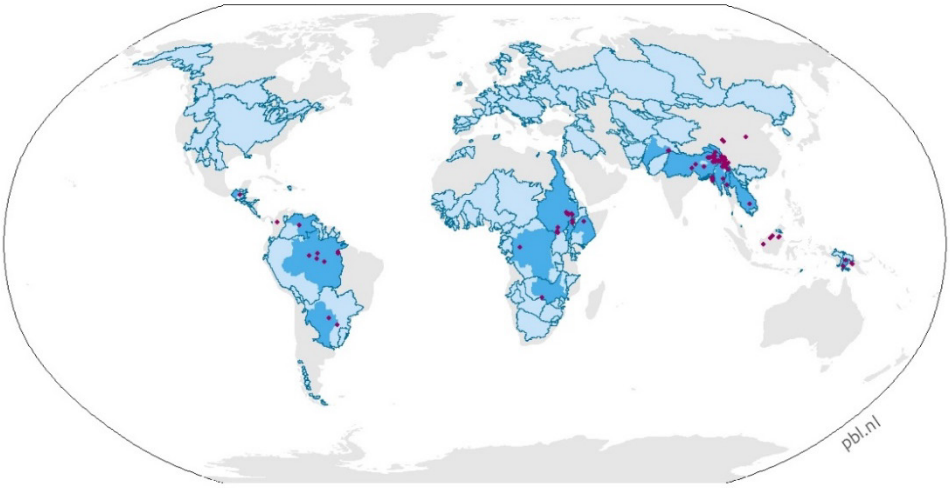
For this study, we make use of projections of new dams in the SSP2-RCP6.0 scenario following the method as developed by Gernaat et al. (2017). This dam construction scenario is based on physical feasibility, energy yield, and construction costs, and is restricted by several conditions. Dam construction is particularly restricted because it has to avoid large reservoirs in urban areas due to high displacement costs; it has to exclude the first 200 km upstream of basin outlets of rivers to allow for shipping and other uses; and it has to exclude protected nature areas and areas in the vicinity of large bodies of water (e.g. lakes and wide rivers). To avoid overlap between reservoirs, Gernaat et al. used an optimisation method to prioritise dam sites with the lowest cost per kilowatt-hour and reject upstream sites inundated by these dams. Economic potential was defined as net production costs lower than 0.1 $/kWh. The projected new dams come on top of the existing dams from the GRAND (Lehner et al. 2011) and the GOODD (Mulligan et al. 2020) databases. The GRAND database was already included in Gernaat et al. (2017); the GOODD database was not.

We adapted the threshold for including large dams as proposed by de Stefano et al. (2017). They defined dams as large if they divert quantities exceeding 100,000 $m^3\ yr^{-1}$ and if these dams have over 10 megawatt (MW) in capacity. In our study, we solely assessed large hydropower dams since primarily large infrastructural changes in shared rivers affect conflict risk. Although there is not one shared definition of how to define dam sizes - and we acknowledge that 'large' can have different meanings in different basins depending on hydrological and ecological characteristics - 400 MW was defined as large in several studies (García et al. 2021; Iannelli et al. 2017). For all ambition scenarios, the same scenario projection was used in terms of when and where dams are constructed, but the operation of the dams differed per scenario. If there are no new dams in the BCU or upstream of it, a score of 1 (low) was given to that BCU. If there are one or more new large dams projected in the BCU or upstream of it, a score of 3 (high) was given (Table 7). Figures 15 and 16 illustrate where these new dams are projected to be built. In total, 80 new dams with a capacity of over 400 MW are projected to be built in transboundary basins by 2050, from a projected 96 dams in total.

Table 7
Calculation of the Hazard Score following water infrastructure development (adaptation of Table 1 in de Stefano et al. (2017)

Development of Large Dams	Hazard Score
No new developments (in the BCU or upstream of it)	1-LOW
New developments (in the BCU or upstream of it)	3-HIGH

Figure 15
Projected locations of new mega hydropower dams towards 2050



New mega hydropower dam

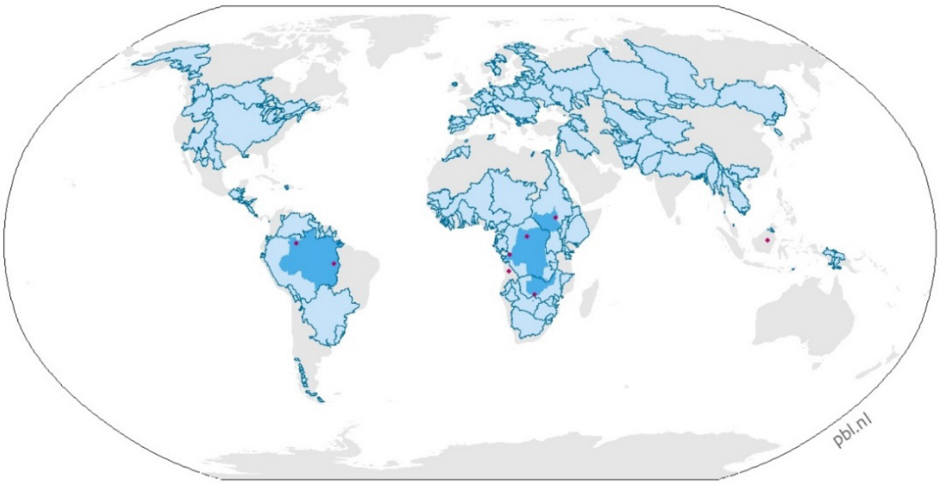
Transboundary river basin

New mega dam in or upstream the BCU (Basin Country Unit)

No new mega dam in or upstream the BCU

Source: PBL

Figure 16
Projected locations of new mega hydropower dams upward of 2050



- New mega hydropower dam
- Transboundary river basin
- New mega dam in or upstream the BCU (Basin Country Unit)
- No new mega dam in or upstream the BCU

Source: PBL

4.3.2 Institutional resilience

Building institutional capacity, in the form of treaties and river basin organisations, is found to decrease hydro-political conflict risk (Brochmann, 2012; de Stefano et al. 2012). Investigating the institutional design of river treaties, several studies have reported that the inclusion of specific features - such as requirements for data and information sharing and joint monitoring, conflict resolution, treaty enforcement, and the delegation of authority to intergovernmental organisations - actually makes river treaties more effective conflict managers (Brochmann 2012; Tir and Stinnett 2012). The same holds true for RBOs, which institutionalise cooperation even further, thereby providing more and more stable mechanisms for preventing or addressing conflicts (Schmeier 2013). Climate change may affect cooperation via increased risks because of increasing water variability, flooding, and water stress. There is evidence which points towards the importance of treaties and RBOs in these changing conditions. For example, Zeitoun et al. (2009) found that increased water stress due to climate change is less likely to result in conflict when treaties are equipped with certain institutional design features. Tir and Stinnett (2012) have also shown that the ability of treaties to adapt to increasing water stress resulting from climate change will depend on their institutional design. The more institutional the features, the better a treaty can cope with conflict due to water stress.

Data on the independent water treaties negotiated between 1820 and 2007 was derived from the Transboundary Freshwater Treaties Database (TFDD), using the 2018 update (Giordano et al. 2014). Treaties signed under colonial rule are excluded from the analysis. We adapted the approach by de Stefano et al. (2012) to score the institutional resilience BCUs. De Bruin et al. (2023) provided the details of this approach. The presence of an RBO was derived from the RBO Institutional Design

Database under the TFDD (Schmeier 2013). BCUs with zero or one component – or institutional feature in treaties – are classified high risk (risk score 3); presence of two or three as moderate risk (risk score 2); and presence of four or five as low risk (risk score 1). In the low ambition scenario, the total institutional resilience score was raised by one; In the high ambition scenario, the score was increased by two. Table 8 shows which indicators per BCU were considered to calculate the score for institutional resilience. Table 9 shows the overall risk score allocated per score.

Table 8
Scoring institutional resilience

Component	Presence	Absence
Presence of at least 1 water treaty	0	1
Inclusion of conflict resolution mechanism in treaty	0	1
Adaptation/variability mechanism	0	1
Principle of no significant harm + the principle of equitable and reasonable utilisation	0	1
Presence of a river basin organization	0	1
ambition	0	5

Table 9
Risk scoring for institutional capacity

Total score institutional capacity	Level of risk to conflict	Risk score associated with level of risk to conflict
0 1	High	3
2 3	Medium	2
4 5	Low	1

4.3.3 Exacerbating factors

Table 10 displays the indicators that were included in the analysis and the applied thresholds for scoring risks per BCU. The indicators were selected based on insights from the existing literature, particularly de Stefano et al. (2017). Ten out of the 811 original BCUs were too small to represent their polygons faithfully at the raster resolution of 5 arc minutes at which the model results were available, and were hence excluded. This resulted in the exclusion of six other BCUs since these were the only one left in the basin. Table 11 shows how the score will be calculated per indicator. An overall BCU score of 0-2 is considered as low exacerbating risk (risk score 1); 3-4 as moderate risk (risk score 2); and 5-6 as high risk (risk score 3).

Hydroclimatic factors

Factors A, B, and C are the hydroclimatic indicators that potentially exacerbate risk in BCUs. The indicators are derived from SSP2/RCP6.0 model runs of PCR-GLOBWB (Sutanudjaja et al. 2018). Factor A, water variability, was calculated by using the Coefficient of Variation (CV) of annual runoff. A threshold of 0.35 was defined, since rivers with a CV of < 0.35 are defined as rivers with a low interannual variability, following Adeloye (2012).

Table 10
Calculation of exacerbating score (adapted from De Stefano et al. (2017))

Exacerbating factors →	a Water Variability	b Water Availability per capita	c Dependence on basin	d Education (Proxy to Conflict Risk & adaptive capacity)	e Governance (Proxy to Conflict Risk & adaptive capacity)	f Income (Proxy to Conflict Risk & adaptive capacity)
Indicator → **Score ↓**	Projected Coefficient of Variation (CoV)	M3/person available per year	Water demand from basin	Education projections SSP2 (years of education)	Governance (Worldwide governance indicators WB 0-10)	SSP2 GDP per cap PPP
0	CV: < 0.35	> 1000 m^3 per capita per year	< 30%	> 9 years education	> 5.2	> $10,000
1	CV: ≥ 0.35	≤ 1000 m^3 per capita per year	≥ 30%	≤ 9 years education	≤ 5.2	≤ $10,000

Table 11
Calculation exacerbating factors aspect risk score

Total score exacerbating factors	Level of conflict risk	Risk score associated with level of risk to conflict
0 1 2	Low	1
3 4	Medium	2
5 6	High	3

Factor B considers water availability per person as a proxy for water stress in a BCU. People having access to less than 1,000 m^3 $person^{-1}$ $year^{-1}$ are considered as being water-stressed (Kundzewicz et al. 2007). Often, more water is available, but due to limited technical or institutional capacity and/or financial constraints, no more can be abstracted or provided. To account for this limited access to water resources, we defined water available for human consumption as 10% of all water available per capita in the BCU.

Factor C defines the water demand of a BCU that is dependent of a BCU on water stemming from the upstream transboundary river basin outside that country. River discharge is a reliable and accessible source of water and dependence on external inflow would make a BCU vulnerable to changes in the physical or socioeconomic conditions upstream. Therefore, the inflow of external water was considered crucial if it provides 30% or more of the available water in a BCU.

Domestic capacity: governance and socioeconomic factors

In addition to the hydroclimatic factors, conflict risk can increase due to the socioeconomic and political conditions in a shared river basin and in its respective riparian states. An important condition for transboundary cooperation is the domestic capacity to deal with water-related challenges, for which education, governance, and economic capacity is required.

There is existing research which has analysed the influence of domestic factors of conflict and cooperation over shared water resources. For example, Karreth and Tir (2018) have shown that states often fail to cooperate over such resources due to domestic situations in which there are incentives to prioritise national unilateral goals over cooperative behaviour. Such situations are often related to technical and institutional capacity and governance, low levels of which indicate a limited ability on the part of countries to act on domestic water problems (and thus indicate limited adaptive capacity to change). Additionally, low education and low governance levels represent a greater risk of overall conflict within countries (Besley and Persson 2011; Brown 2011; Mach et al. 2019). Factors D, education, and E, governance quality, are therefore used as proxy indicators for domestic capacity to deal with domestic water problems and internal conflict risk.

Low levels of education can have an indirect impact on conflict via socioeconomic exclusion of those less educated. It can also lead to low political inclusion (Barakat and Urdal 2009; Brown 2011). Barakat and Urdal (2009) found that conflict risk increases in areas where youth bulges are high and secondary education is low. The threshold for secondary education is set on nine years by Barakat and Urdal (2009); we adopt this same threshold for our study. For education, the SSP2 country projections by the Wittgenstein Centre is used (Wittgenstein Centre for Demography and Global Human Capital 2018).

For governance, the composite governance indicator composed of the Worldwide Governance Indicators (WGI) project was used, scaled from 0 to 10 per country (Kaufman and Kraay 2021). In the business-as-usual (BaU) scenario, the governance value was kept constant over the years, taking the 2020 value for 2050. The threshold for governance was set on 5.2 representing a threshold for increased conflict risk (based on an analysis by Visser et al. (2019)). In both the low and high ambition scenario, the governance quality per country was logarithmically increased. Countries with low 2020 governance values faced a higher increase than countries with high values. The formula below describes the governance value (G_t) based on the governance of 5 years ago (G_{t-5}) and has two criteria: i) the high ambition scenario had a higher increase than the low ambition scenario, therefore the C, a constant value, is 1.5 for the high and 0.8 for the low ambition scenario; and ii) countries could not exceed a governance value of 10.

$$G_t = C * (1 - log\ (G_{t-5})\ +\ G_{t-5})$$

In addition to education levels and governance capacity in a country, the economic situation is likely to determine whether a given country will be able to deal with water-related challenges (Yoffe et al. 2003). Factor F, GDP per capita in Purchasing Power Parity (PPP), was therefore used as an additional indicator to reflect the domestic situation’s contribution to transboundary conflict risk. GDP per capita PPP provided a proxy to adaptive capacity and vulnerability to natural hazards, as countries with lower GDP per capita tend to be more vulnerable to economic and environmental shocks and have relatively low levels of human assets (Hallegatte et al. 2016; Hallegatte et al. 2020). Hallegatte et al. (2020) found that people living in low-income countries are significantly less protected against natural hazards due to limited infrastructure than people living in richer countries. Most countries with low protection capacity had a GDP per capita PPP of less than USD 10,000. Aside from being a proxy for low adaptive capacity and vulnerability, a low GDP per capita has been linked to more transboundary conflict (Yoffe et al. 2003). For GDP per capita, the SSP2 country projections by the OECD ENV-Growth model was used (Dellink et al. 2017). This data was divided by population projections of the SSP2 scenario to gain GDP per capita PPP (Samir and Lutz 2017).

Table 12
Scenario changes per indicator by 2050

Exacerbating factors → **Scenario ↓**	**a Water Variability**	**b Water Availability per capita**	**c Dependence on basin**	**d Education**	**E Governance**	**f GDP per capita PPP**
BaU	SSP2 – RCP 6.0	SSP2 – RCP 6.0	SSP2 – RCP 6.0	SSP 2	2020 value	SSP 2
Low	Dams are implemented as hydropower reservoirs, reducing the variability of the river discharge.	Increased efficiency for new irrigated areas; Moderately improved efficiency for domestic and industrial water demands; Groundwater pumping capacity extrapolated into the future on the basis of the historic trend	Hydropower dams buffer more water, releasing it as a constant flow.	SSP 2	Low increase with log function	SSP 2
High	Dams are implemented as water supply reservoirs, matching their release to the downstrea	Increased efficiency for new irrigated areas; Strongly improved efficiency for domestic and industrial water demands;	Hydropower dams buffer more water, releasing it as a constant flow.	SSP 2	High increase with log function	SSP 2

	m demand of the BCU.	Unlimited groundwater pumping capacity but extraction limited to renewable groundwater only.

4.3.4 Combining the hazards, vulnerability, and exacerbating scores

To calculate the overall composite conflict risk per BCU, we combined the scores of the three different dimensions:

Overall conflict risk = Dam risk score (1-3) x Institutional resilience score (1-3) x Exacerbating risk score (1-3)

On the basis of the overall risk score per BCU, ranging from 1 to 27, the BCUs were categorised in different relative risk groups. Low: 1 - 4; moderate: 6; high: 9, 12; very high: 18, 27. To illustrate the results, we mapped the overall risk indications.

To arrive at an aggregated risk score per river basin, we took the following steps. First, only basins were included where at least one BCU was projected to be at (very) high risk. Second, the overall risk indicator per BCU was weighted based on the population in that specific BCU and the wider basin. Third, the relative scores were added up to derive at a basin wide average. Finally, a differentiation was made between relatively small basins (< 10 million people) and large basins (> 10 million people). We excluded basins in which over 90% of the population lives in one of the BCUs.

4.4 Results

4.4.1 Institutional resilience

Figure 17 presents the risk scores for institutional capacity in the BaU, low, and high ambition scenarios. Of the 4.4 billion people projected to live in BCUs by 2050, 1.1 billion people would live in a high-risk BCU in terms of institutional resilience. This number decreases to 723 million and 0 in the low and high ambition scenario, respectively. Most people – 2.4 billion – are projected to live in low-risk BCUs in the BaU scenario, which increases to 3 billion and 3.3 billion in the low and high ambition scenario, respectively. On the whole, Asia has the most BCUs with a high-risk score considering institutional resilience. Simultaneously, large parts of African transboundary river basins are also not covered by treaties nor governed by RBOs.

4.4.2 Exacerbating factors

Figure 18 illustrates the exacerbating risks for the BaU, low, and high ambition scenarios. In the BaU scenario, by 2050, 749 million people are projected to live in high-risk BCUs in terms of exacerbating factors: a combination of hydroclimatic, political, and socioeconomic factors.

Especially transboundary river basins in Africa face high exacerbating risks. Large river basins with several BCUs at high risk include: the Nile (Eritrea, Ethiopia, Rwanda, Uganda), the Juba (Ethiopia, Kenya, Somalia), the Niger (Burkina Faso, Mauritania, Niger), the Zambezi (Mozambique, Malawi), the Volta (Benin, Togo), and Lake Turkana (Ethiopia, South Sudan, Uganda). In Asia, particularly BCUs in Afghanistan and Pakistan are at risk, including the Indus, the Harirud, the Helmand, and the Aral Sea. In the low ambition scenario, fewer people are projected to live in BCUs at high risk compared to the exacerbating factors: 596 million people. In the high ambition scenario, 417 million people ae projected to live in high-risk BCUs. Most of these people – 316 million – live in Afghanistan and Pakistan, in the Aral Sea, Harirud, Helmand, and Indus basin. Similarly, in East Africa there are large swathes of the population projected to live in transboundary basins with high exacerbating risks: at least 77 million people.

Figure 17
Projected risk scores for institutional resilience for the BaU, low, and high ambition scenarios

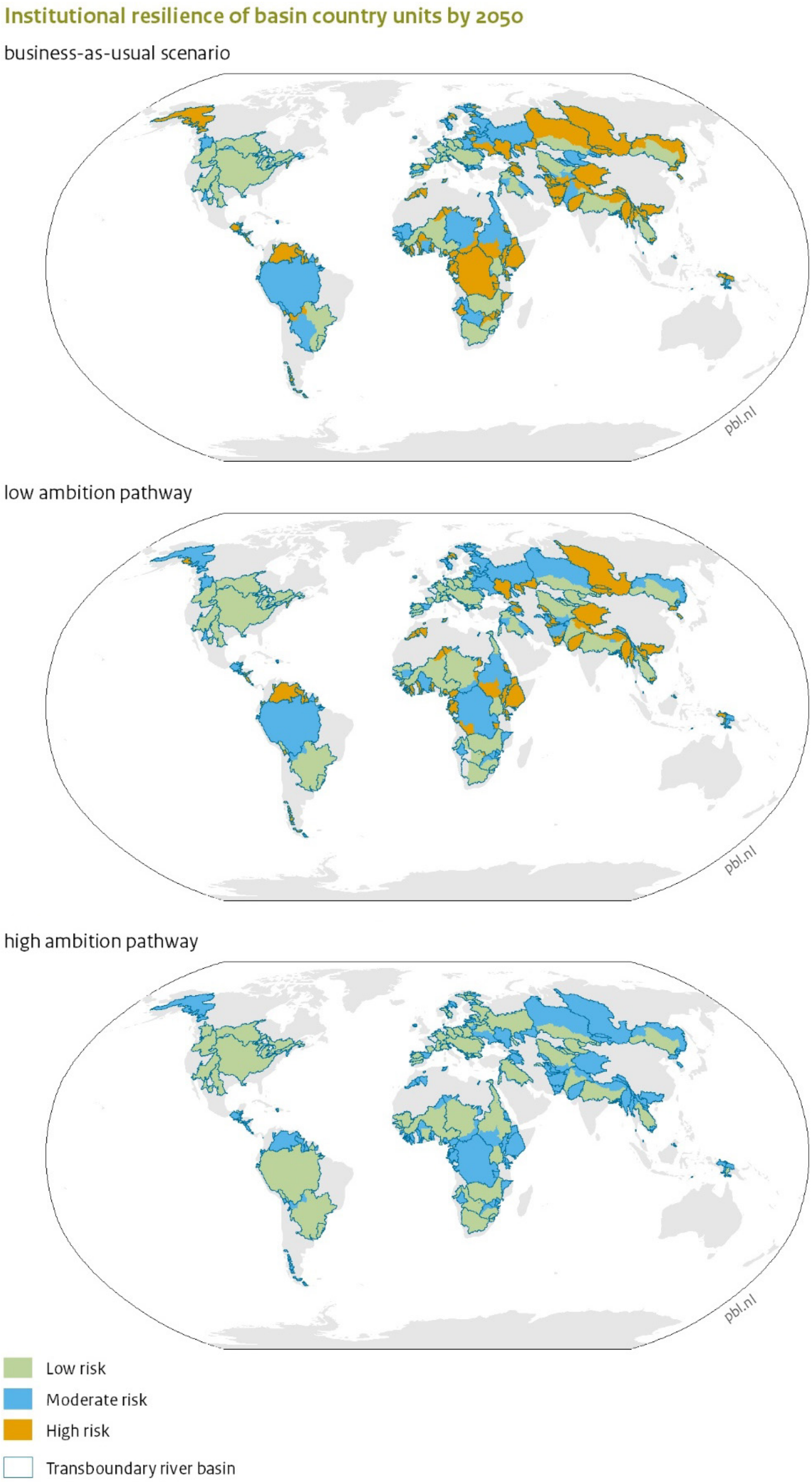
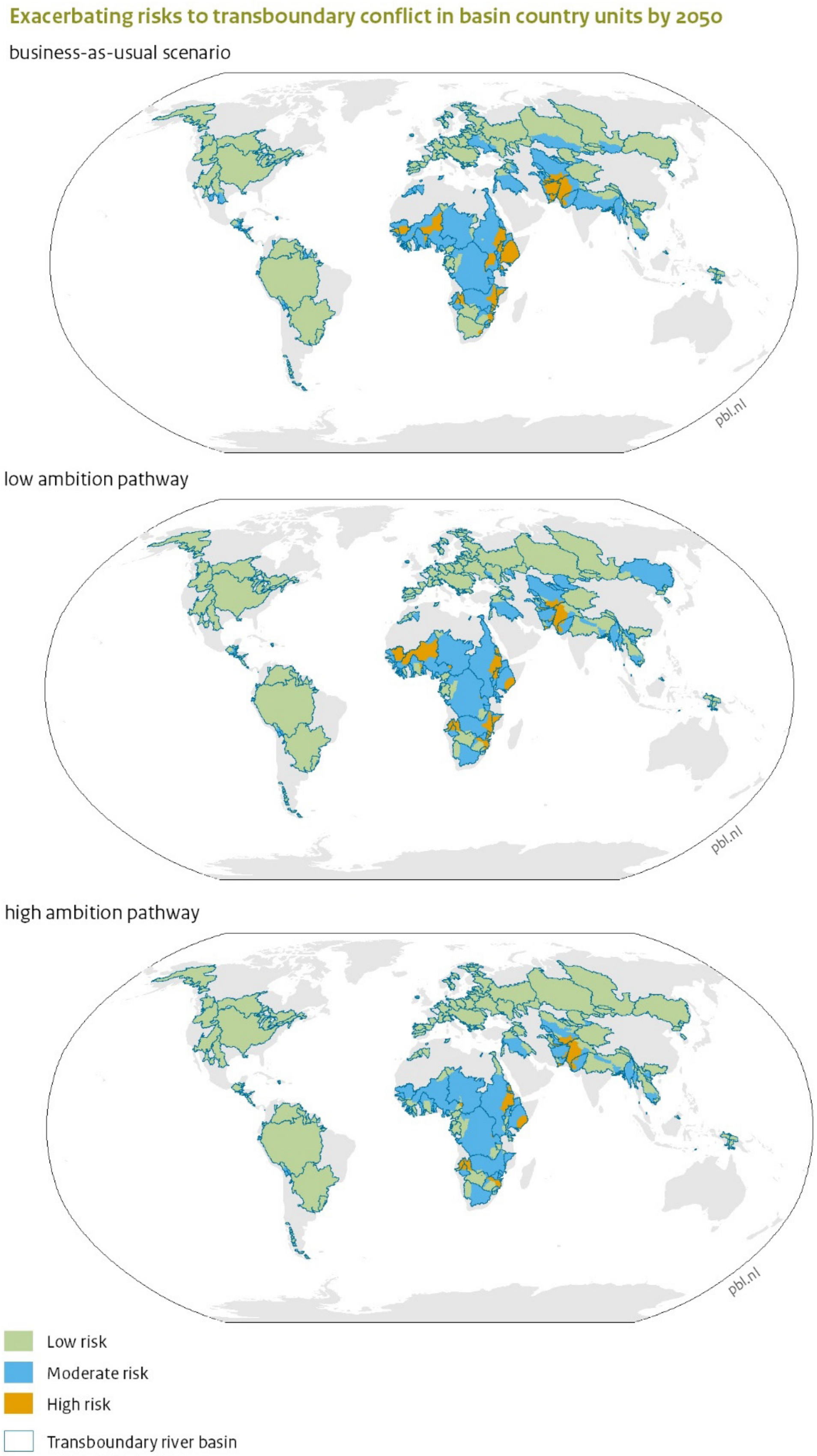


Figure 18
Projected risk score of exacerbating factors for the BaU, low, and high ambition scenarios



Source: PBL, WEnR, UU

4.4.3 Overall conflict risk in BCUs

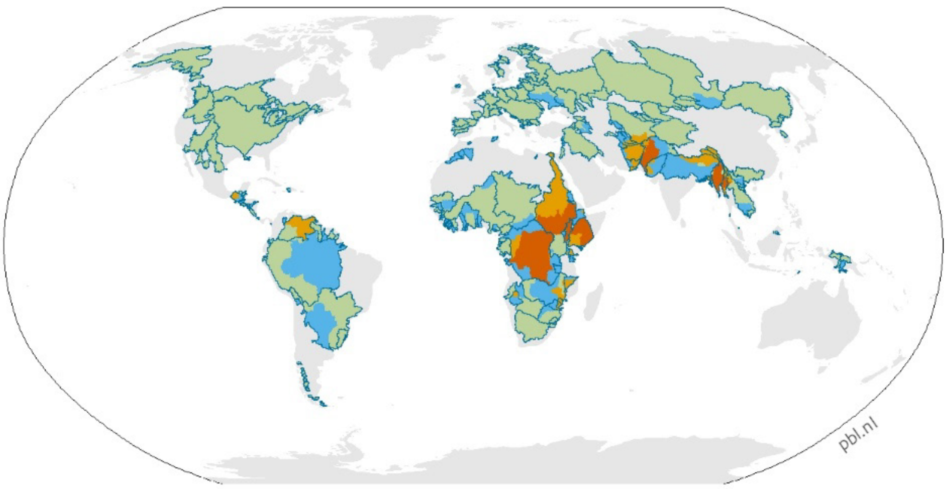
Figure 19 illustrates the overall risk score per BCU combining the three risk dimensions for the BaU, low, and high ambition scenarios. Overall, 4.4 billion people are projected to live in transboundary river basins by 2050. In the BaU scenario, 920 million people are projected to live in high to very high conflict risk BCUs, assuming no additional improvements in water measures and (water) governance other than the SSP2 baseline (Table 13). River basins with high compounding risks are the Nile, the Juba-Shibeli, Lake Turkana, the Congo, the Zambezi (all Africa); the Amazon, the Orinoco (South America); large parts of the Ganges-Brahmaputra, the Indus, and the Aral Sea (Asia). In the low ambition scenario, fewer people are projected to live in (very) high risk BCUs: 674 million. In the high ambition scenario, the number of people projected to live in high to very high risk BCUs decreases significantly to 537 million. The numbers for 2070 in Table 13 are used in FWC-2; the key messages at the beginning of this report are based on these numbers.

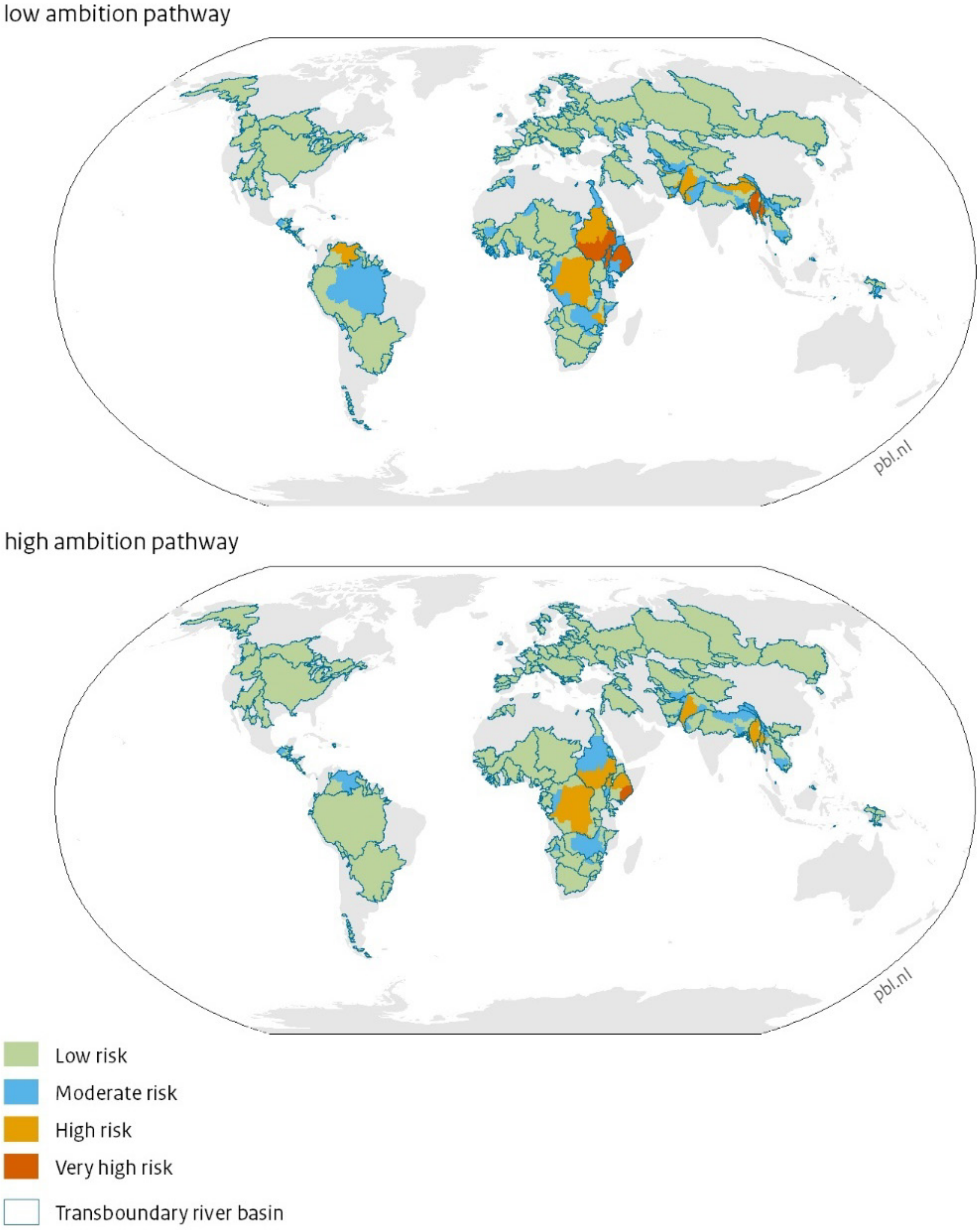
Table 13
Number of people projected to live in BCUs at risk by 2050 and 2070 (in millions)

Scenario	Low risk	Moderate risk	High risk	Very high risk
BaU 2050	1,915	1,596	381	539
Low 2050	1,596	815	503	171
High 2050	3,381	512	530	7
BaU 2070				868
Low 2070				427
High 2070				93

Figure 19
Overall transboundary conflict risk in basin country units by 2050

business-as-usual scenario





Source: PBL, WEnR, UU

4.4.4 Aggregating BCUs to transboundary river basins

Tables 14 and 15 provide an overview of the small (population < 10 million, but > 1 million) and large (population > 10 million) basins facing the highest aggregated risk by 2050 under the BaU scenario. Three African basins dominate as the large basins: the Juba-Shibeli, Lake Turkana, and the Congo basins. In the Juba, especially Somalia is projected to be highly dependent on water stemming from this basin's upstream; the 6.5 million people living in this BCU face a dependency of 93%. In the Lake Turkana basin, the Ethiopian and South Sudanese BCUs depend for almost 50% on inflow from upstream. The Indus, the third most populated basin in the world by 2050, faces high aggregated risks as well. The area of Pakistan situated in the Indus is projected to have a population of 230 million people by 2050; a dependence on this basin is 62%. The Indus will thus remain critically important to Pakistan in the future. The two smaller basins most at risk (the Kaladan and the Salween) are both situated in Asia, with Myanmar as the downstream country facing local upstream dependency of over 61% in both basins.

Table 14
Overall risk scores of large basins most at risk in the BaU scenario

Basin	Continent	Overall basin risk	Population by 2050 (millions)
Lake Turkana	Africa (Ethiopia, Kenya, South Sudan, Uganda)	25,7	25.9
Juba-Shibeli	Africa (Ethiopia, Kenya, Somalia)	23,6	45.2
Congo	Africa (Angola, Burundi, Cameroon, Central African Republic, Congo, Democratic Republic of the Congo, Malawi, Rwanda, Tanzania, Zambia)	15,4	186.1
Indus	Asia (Afghanistan, China, India, Pakistan)	15,0	315.8
Irrawaddy	Asia (China, India, Myanmar)	14,7	27.1
Nile	Africa (Burundi, Democratic Republic of the Congo, Egypt, Eritrea, Ethiopia, Rwanda, Tanzania, Sudan, South Sudan, Uganda)	9,5	425.6
Awash	Africa (Djibouti, Ethiopia, Somalia)	9,0	28.6
Helmand	Asia (Afghanistan, Iran, Pakistan)	8,8	24.0
Orinoco	South America (Colombia, Guyana, Venezuela)	7,8	15.9
Rann of Kutch	Asia (India, Pakistan)	6,9	103.0

Table 15
Overall risk scores of small basins most at risk in the BaU scenario

Basin	Continent	Overall basin risk	Population by 2050 (millions)
Kaladan	Asia (India, Myanmar)	14,1	1.0
Salween	Asia (China, Myanmar, Thailand)	13,6	7.8
Lake Azuei	North America (Dominican Republic, Haiti)	8,9	0.1
Murgab	Asia (Afghanistan, Turkmenistan)	8,1	5.3
Hamun-i-Mashkel/Rakshan	Asia (Iran, Pakistan)	8,1	1.7

Cuvelai/Etosha	Africa (Angola, Namibia)	8,0	2.6
Fenney	Asia (Bangladesh, India)	8,0	2.1
Muhuri (Little Feni)	Asia (Bangladesh, India)	7,6	5.0
Gash	Africa (Eritrea, Ethiopia, Sudan)	7,4	4.5
Mono	Africa (Benin, Togo)	7,4	4.6

5 Sea level rise and displacement in deltas and coasts

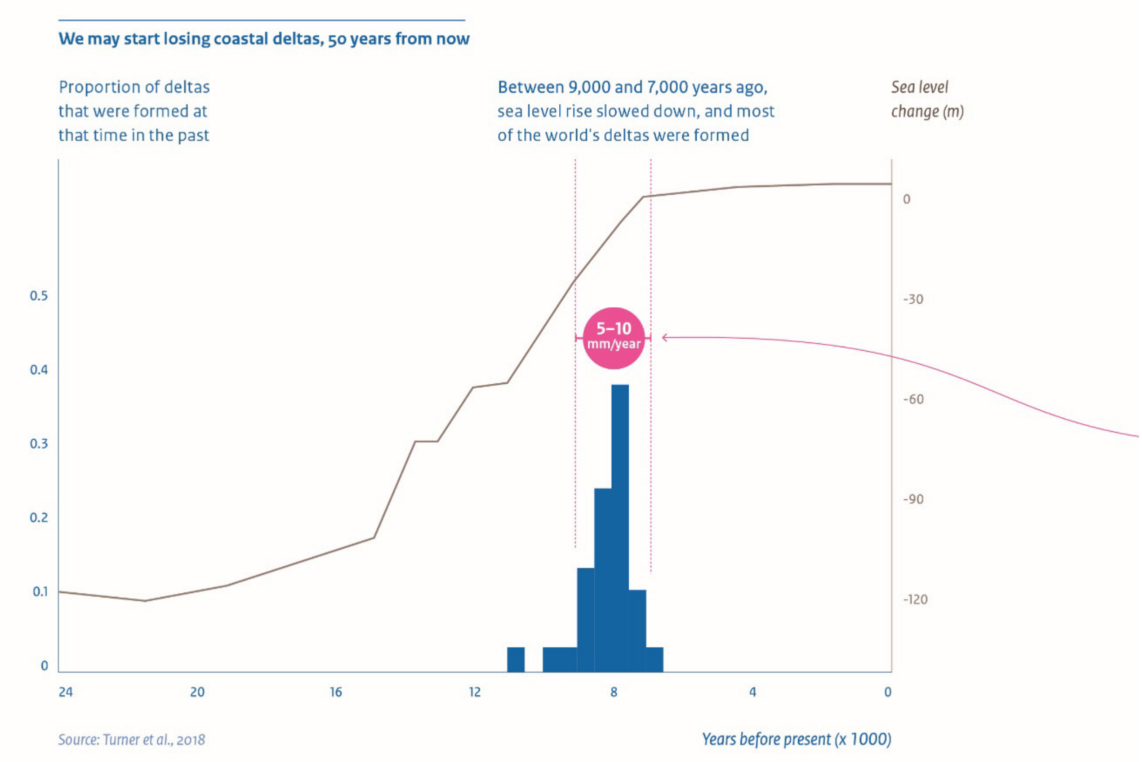
5.1 Background

Estimates of population exposed to potential flooding – under various scenarios of sea level rise and related hazards – have been used in scientific studies as proxy indicators for population migration and relocation (Foresight 2011; McMichael et al. 2020). Global estimates are generally in the order of tens or hundreds of millions of people exposed to coastal inundation or flooding for different timeframes and scenarios. However, there is no simple relation between the population exposed to coastal flooding and the numbers of migration. McMichael et al. (2020) have shown that migration is 'shaped by diverse socioeconomic, demographic, institutional, and political factors'. People may be 'trapped' because they lack financial means to move while others may prefer not to move for social, cultural, or political reasons, or because adaptive measures reduce the urgency to move.

Box 3: Climate change and international migration patterns: An estimate for previous decades
In a recent analysis of climate change effects on global international migration patterns Rikani et al. (2023)studied migration data over the last 30 years, from 1990 to 2020, and concluded that international emigration rates tend to be highest in middle-income countries, and lower in both low-income and high-income countries. Their explanation was that emigration rates are highest in countries where people are rich enough to afford moving to another country, and simultaneously poor enough to feel the incentive to do so. According to the authors, climate change is already a significant factor influencing migration patterns, though less influential than other drivers of migration, such as economic inequalities, education, and demographic, social or cultural factors. They conclude that 'recent climate change has acted to increase mobility in the richer parts of the world and decrease mobility in the poorest parts of the world'. In the richer parts of the world, more people feel the incentive to migrate in response to climate change and are able to do so. In the poorest parts of the world – as a result of the adverse economic impacts of climate change – fewer people will have enough money to migrate. Those that lack the financial means to migrate are the 'trapped population'. Rikani et al. also concluded that the estimated impact of climate change on global migration patterns in the last 30 years is very small, however. Globally there were about 70 million (international) migration movements per 5-year period on average, according to the authors' estimate. Climate change may have increased migration flows in the wealthier world regions by about 0.4%– 0.5%. In the poorest world regions, on the other hand, migration flows may have decreased by roughly 0.5%–0.7%.

A unique situation applies to the low-lying coral atoll nations, where population displacement is considered likely because livelihoods are being disrupted and land becomes uninhabitable even at relatively modest sea level rise (Mcleman 2018, in: McMichael et al. 2020). Scientific studies have shown that the tipping point to eroding and drowning deltas may already occur in the next 50 years (Figure 20). The vulnerability of deltas to flooding will increase this coming century for several reasons. In addition to sea level rise, subsidence – because of groundwater and fossil fuels extraction – and dams that trap sediments in rivers are significant stressors that threaten the future of deltas (Figure 21).

Figure 20
Projected rate of global sea level rise and the critical range of 5-10 mm/year that is estimated to be a tipping point to eroding and drowning deltas (Source: Ligtvoet et al. 2023)



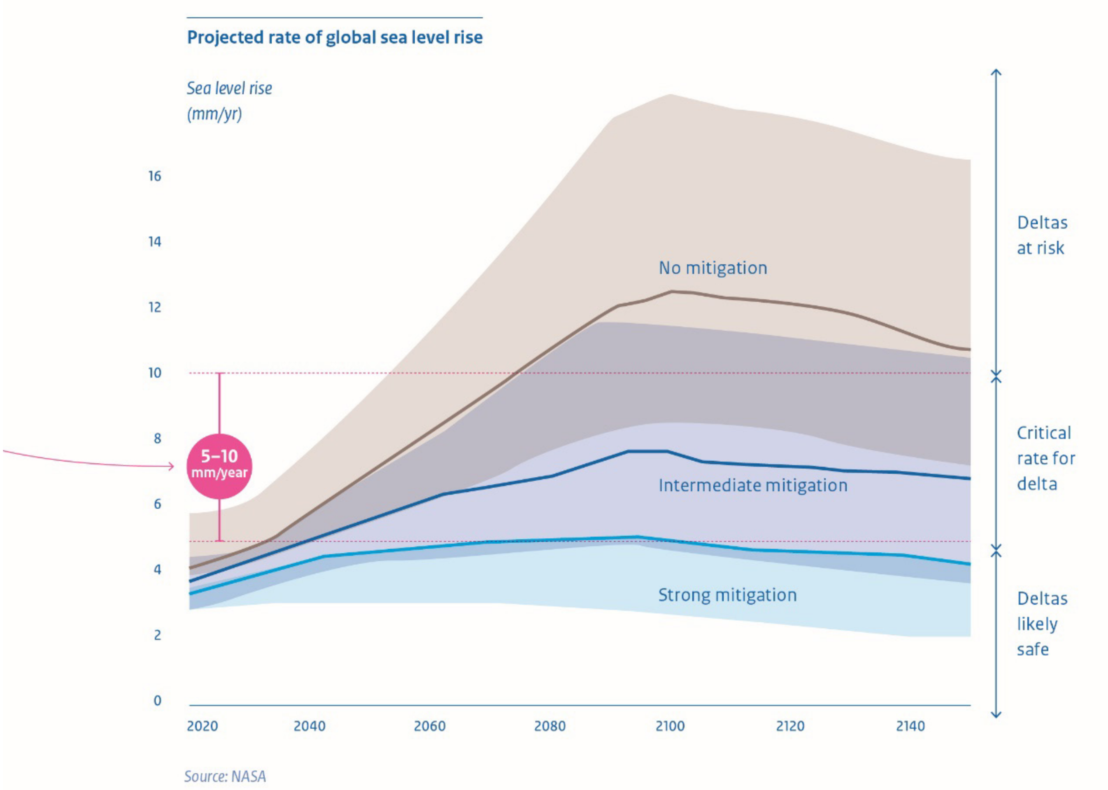
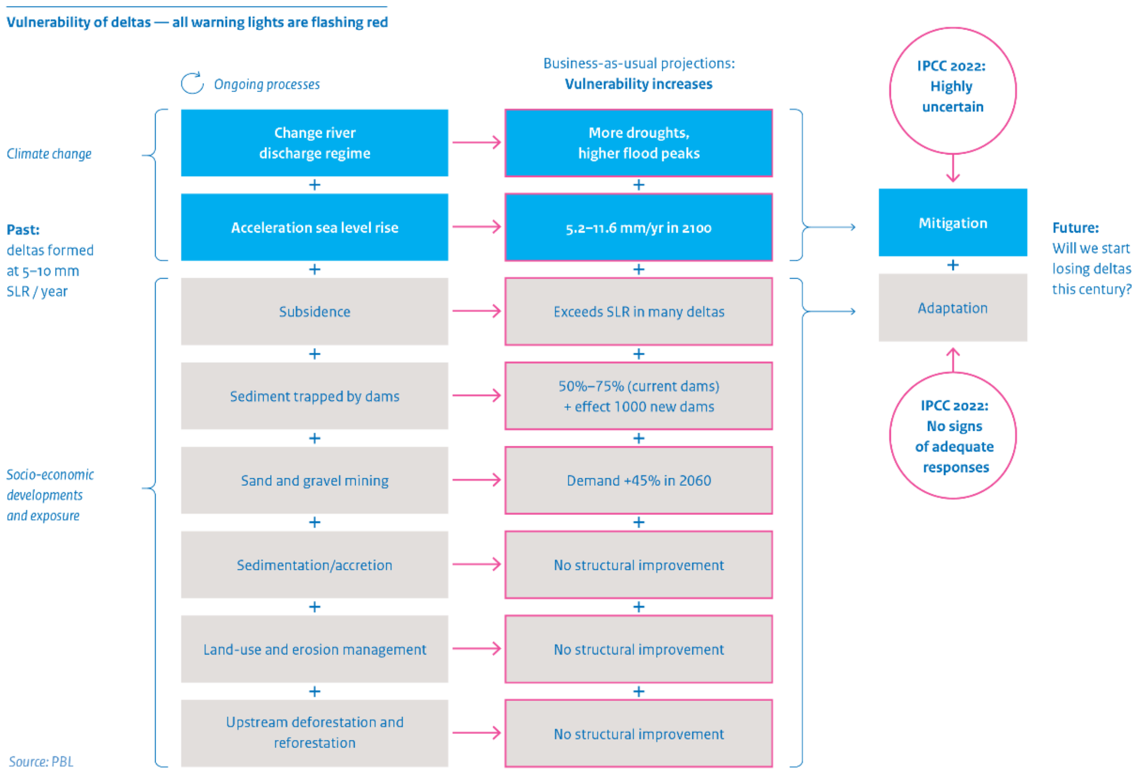


Figure 21
Deltas are vulnerable to several stressors and this vulnerability is projected to increase this century (Source: Ligtvoet et al. 2023)



In this study, we want to distinguish between 'displacement' and 'migration'. The number of people displaced out of flood-prone coastal zones because of increasing flood risk – or sea level rise – will be much more closely linked to the number of people exposed to potential flooding than the numbers of migration. For displacement, flood risk is a dominant push factor. For migration, flood risk is only one of many causal factors. In this study we exclusively use data on flood exposure as an indicator for the number of people that could move out of the low-lying coastal zones. Therefore, this chapter presents a view on displacement, and much less so on migration.

The increasing flood risk will exacerbate inequalities between low- and high-income countries. An estimate has been made of the population currently exposed to a once-in-a-hundred years flood event, either fluvial or coastal, under the assumption of no flood protection (Rentschler et al. 2022). The results show that nine out of ten people affected live in low- and middle-income countries. Although the assumption of no flood protection does not agree with reality, these results do stress that the increasing flood risk mainly affects the poor.

5.2 Solutions

Displacement, is just one of several options to deal with sea level rise. In time, this option may be the only one for the population of, for instance, the low-lying coral atoll nations. For many people living in low-elevated coastal zones, other options are more obvious. The three main categories of options are: (1) protection by flood defences; (2) accommodation, otherwise known as living with the consequences of sea level rise; (3) migration or relocation (Oppenheimer et al. 2019).

Protection by flood defences will be cost-effective in coastal zones with a high population density and a high GDP. It has been suggested that flood protection is cost-effective for 90% of exposed populations, living on only 13% of the world's coasts (Lincke and Hinkel 2018). As a larger part of the coast can be cost-effectively protected against sea level rise, the migratory pressure will subsequently decrease. Accommodation – living with sea level rise – may be an interesting option for wealthy people and a necessity for the poor. Wealthy people may be able to afford to adapt to sea level rise *in situ* and they may choose to do so (Hauer, 2017, in: McMichael et al. 2020). Poor people may not be able to both move and adapt *in the place they live* and may be 'trapped' in vulnerable conditions.

The success of adaptation through (combinations of) flood defences, nature-based solutions, zoning, and/or accommodation at the site not only depends on the wealth and governance capacities of nations, but also depends on the available time to adapt and whether population and investments are concentrated or spread over large areas. A recent study has indicated that the available time to adapt may be less than previously thought (Vernimmen and Hooijer 2023). Indeed, the latest data on the elevation of coastal zones shows that the land area many poor coastal communities live on is actually lower than previously assumed. As a result, the likelihood of coastal flooding when the sea level rises by 1 or 2 metres, and with it the number of people exposed to coastal flooding in the next, say, 100 years, is much greater than estimates have indicated so far. Furthermore, the global land area that is below mean sea level appears to increase much faster in the earlier stages of sea level rise. This means that countries that rely on satellite data for their flood risk assessment have considerably less time left to prepare for the projected increased exposure to flooding than has been assumed to date. According to this latest data, the additional number of people living below mean sea level under a scenario of 1 metre sea level rise is tens of millions higher than previous estimates have indicated. For a 2 metre sea level rise, the difference is over 100 million people.

On the other hand, the ongoing and continuing urbanisation means more and more people are living in cities on a small part of land in a low-elevation coastal zone. As a result, investments in flood protection will become more cost-effective, as mentioned above. In 2000, over 10% of total global urban land was located within the low-elevation coastal zones (LECZ, defined as 'the contiguous area along the coast that is less than 10 m above sea level') that covers only 2% of the world's land area. Most of the urban land in the LECZ was primarily located in the developed countries in northern America and western Europe, along with China. By 2030, however, most of the urban land within the LECZ will be found in developing countries. In 2030, compared with 2000, the amount of urban land within the low-elevation coastal zones is projected to increase globally by 230%. A broad shift is projected in the urban exposure from the developed world to the developing world. The emerging coastal metropolitan regions in Africa and Asia will be larger than those in developed countries and will have larger areas exposed to flooding. By 2030, India, southern Asia, and southeastern Asia are expected to have almost three-quarters of their urban land under high-frequency flood risk (Güneralp et al. 2015).

5.3 Approach and methods

In the scientific literature, population exposed to potential flooding is estimated in different ways. Three definitions of exposure are being used (McMichael et al. 2020):

1) the population impacted by specified levels of sea level rise;
2) the population impacted by coastal flood events with a specific return period;
3) and the population living in low-elevation coastal zones.

This study presented an overview of numbers of population exposed to sea level rise, following this distinction in definitions of population exposed to potential flooding. The inventory in this overview is summarised in the Tables below. This overview gives a good impression of current scientific insights into exposure to potential flooding as a driver of potential future displacement – or migration – under various scenarios of sea level rise.

The numbers on population exposed to flooding in tables 15-17 should be interpreted with care since they are based on datasets, projections, and assumptions that each have their own uncertainties. These uncertainties are not limited to future scenarios of climate change, sea level rise, and population growth. Moreover, data on current land elevation, extreme sea levels, and population distribution across coastal floodplains are highly uncertain in parts of the world. Different datasets of extreme sea levels resulted in a 28% difference in population exposed (Muis et al. 2017, in: McMichael et al. 2020). Additionally, it may not be possible to tell if someone who migrates does so exclusively because of climate change. In the words of Kelman (2019): 'a robust, repeatable, and verifiable methodology might not be feasible for counting and calculating climate change migrants'.

The impacts of sea level rise and associated coastal flooding is often estimated by using the simple method of projecting the flood surface that corresponds with a certain sea level onto a digital elevation model of the study area (the 'bathtub method'). This simple approach may both overestimate and underestimate the population exposed to flooding. An overestimation may result when water level is attenuated in coastal flood plains due to vegetated surfaces, because flood plains and wetlands accrete and offset part of the sea level rise (McLeod et al. 2010; Vafeidis et al. 2019, both in: McMichael et al. 2020). An underestimation may result when more land is exposed to flooding because of the extra impact of waves (Anderson et al. 2018, in: McMichael et al. 2020).

Additionally, the concept of return periods – such as a once-in-a-hundred-year flood event – assumes that the statistics of water levels do not change over time, which is incorrect due to climate change.

5.4 Results

Population impacted by specified levels of sea level rise

Estimates based on specified levels of sea level rise are difficult to compare as they focus on different time scales, use different values of sea level rise and climate scenarios, and are based on different assumptions about flood protection and population size and distribution. However, these estimates do give an impression of the order of magnitude of population exposed (Table 16). 1 metre sea level rise will probably impact an area populated by about a hundred million people. This number rises to estimates of areas populated by about half a billion people under extreme scenarios of 5-6 metre sea level rise. These extreme estimates often do not include adaptation such as improving flood protection, however.

East, southeast, and south Asian populations face the greatest overall exposure to sea level rise both this century and later. Of all nations with a total population of at least 25 million, Asian countries make up nine of the top ten most at-risk nations. Land home to over half the populations of Bangladesh and Vietnam may become exposed to coastal flooding even if warming is limited to 2 °C. Many smaller nations, particularly islands, will become extremely vulnerable to coastal flooding. With 2 °C global warming, more than 80% of the population of the Cocos Islands, Maldives, Marshall Islands, Kiribati, Cayman Islands, Tokelau, Tuvalu, and the Bahamas in the long run will be living in land threatened by flooding. With 4 °C global warming, this percentage will be over 90% (Strauss et al. 2021).

Table 16
Published data on population exposed to specified levels of sea level rise

Reference	Time frame	Sea level rise	Population exposed	Flood protection included
Rowley et al. (2007)		1 – 6 m	107.94 – 431.44 million	?
Nicholls et al. (2008b)		1 – 5 m	131 – 410 million	?
Li et al. (2009)		1 – 6 m	107.9 – 431.4 million	?
Marzeion and Levermann (2014)		2.3 m per degree of global mean temperature increase	2.2% of global population at 1 °C (178 million)[a]; 4.7% at 2 °C (381 million): 6.9% at 3 °C (559 million); 9.1% at 4 °C (737 million); 10.5% at 5 °C (851 million)[1)]	?
Hinkel et al. (2014)	2100	1.2 m	Up to 4.6% (310 million) of global population is expected to be flooded annually in 2100	Yes
Kummu et al. (2016)	2010; 2050	5 m	380 million (2010); 495 million (2050)	?
Strauss et al. (2021)	2100	0.48 – 0.73 m	170 – 200 million	No
Watts et al. (2021)		1 m; 5 m	145 million (1 m); 565 million (5 m)	No

a) Numbers between brackets are estimates based on the percentages in the literature and the population in 2023.

Table 17
Published data on population exposed to coastal flood events with a specific return period (based on McMichael et al. 2020)

Reference	Time frame	Return period	Population exposed	Flood protection included

Nicholls et al. (1999)	2080s	1/1,000 year storm surge	Up to 195 million	Yes
Nicholls (2002)	2100	1/1,000 year storm surge	424 – 755 million	No
Nicholls and Tol (2006)	2020s 2050s 2080s	1/1,000 year storm surge	increases by 2050, from a 1990 baseline of 200 million, and then diverges from the 2080s	No
Vafeidis et al. (2011)	2000, 2030, 2060	1/100 year floods	206 million in 2000, 290 – 312 million in 2030, 343 – 451 million in 2060	No
Jongman et al. (2012)	2010, 2050	1/100 year floods (coastal and river)	271 million in 2010, 345 million in 2050	?
Neumann et al. (2015)	2000, 2030, 2060	1/100 year floods	189 million people (2000); 282–286 million (2030); 316–411 million (2060)	?
Muis et al. (2017)	2015	1/100 year floods	158 / 218 million (different methods)	No
Brown et al. (2018)	2100	1/100 year floods	1.5% (110 million) – 5.4% (880 million) of global population	No
Kulp and Strauss (2019)	2050; 2100	annual flood levels	up to 340 (2050) or 630 million (2100)	?
Haasnoot et al. (2021)	2050 (RCP4.5, 0.15 m SLR); 2150 (RCP4.5, 0.75 m SLR)	1/100 year floods	83 million (2050); 166 million (2150)	Yes, but no further improvement in the future

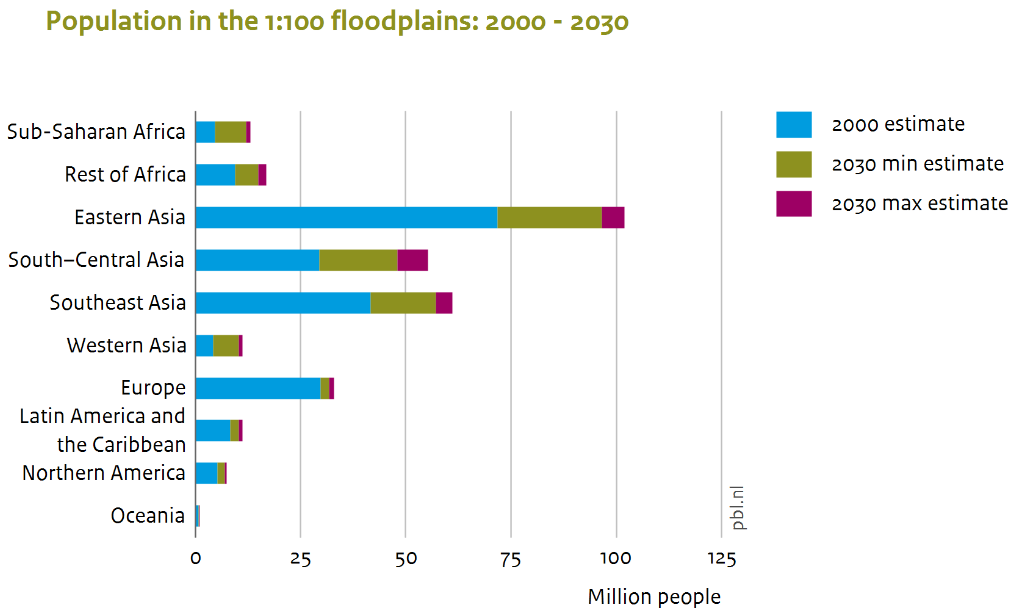
Population living in coastal floodplains or storm surge zones

Estimates of the population impacted by coastal flood events with a specific return period are mostly based on the population exposed to a once-in-a-hundred years flood event, either assuming no flood protection or assuming current flood protection and no further improvement in the future. These studies neglect (future investments in) flood protection for a practical reason: information on flood protection was not available at a global scale at the time these studies were carried out. Moreover, future investments in flood protection, globally, depend on many (socioeconomic, political) factors that cannot be projected decades ahead. These estimates, therefore, overestimate the global population exposed to potential flooding. They do, however, present an indication of worst-case conditions that drive displacement and migration this century.

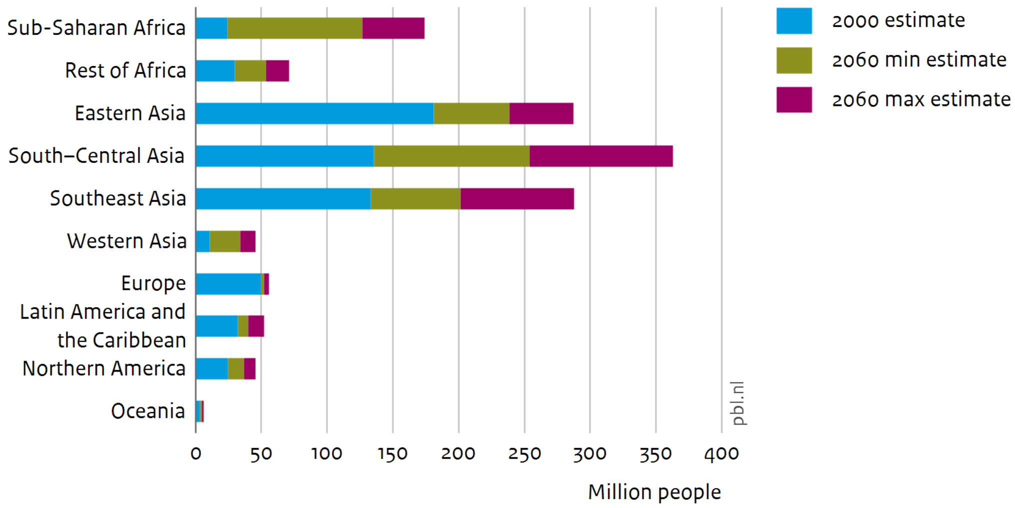
Studies published so far have indicated that the population exposed to a once-in-a-hundred years flood level, neglecting (investments in) flood protection, is about 100-200 million people today, and continues to increase this century to a few hundreds of millions by mid-century and several hundreds of millions by 2100 (Table 17).

Data on the number of people living in deltas and coastal zones at an elevation below the once-in-a-hundred years flood level has been published by Foresight (2011) for the situation of 2000 and projections for 2030 and 2060 under four socioeconomic scenarios (Vafeidis et al. 2011). This data gives a good impression of regional differences across the globe in vulnerabilities to coastal flooding with possible impacts on displacement and migration. This data is summarised in Figure 22. Evidently, southern and eastern Asia are the main hotspots of populations vulnerable to coastal flooding, both now and in the future. The increase of population exposed to flooding in Asia is much larger from 2030 to 2060 than from 2000 to 2030.

Figure 22
The number of people living in deltas and coastal zones at an elevation below the once-in-a-hundred years flood level for the situation of 2000 and projections for 2030 and 2060 (data from Foresight 2011)



Population in the low-elevation coastal zone: 2000 - 2060



Populations living in low-elevation coastal zones (LECZs)
The number of people living in low-elevation coastal zones – mostly defined as the coastal land area less than 10 metres above sea level – is high because many large cities (e.g. Shanghai, Kolkata, Jakarta, London, and New York City) are situated at least partially within these coastal zones. According to recent estimates, this number is about 600-700 million for the current situation (Table 18), about half of which is living in urban areas (McGranahan et al. 2007, in: McMichael et al. 2020). Studies project both a decrease (Jones and O'Neill, 2016, in: McMichael et al. 2020) and an increase (Merkens et al. 2016, in: McMichael et al. 2020) in the population in these low-elevation coastal zones by the end of this century, depending on the scenario of economic growth. Most studies project an increase that could reach 1.4 billion people by as early as 2060 under high population growth (McGranahan et al. 2007; Vafeidis et al. 2011; Neumann et al. 2015, all in: McMichael et al. 2020).

Data on the number of people living in the low elevation coastal zone – defined as the coastal area less than 10 metres above sea level – has been published by Foresight (2011) for the situation of 2010 and projections for 2030 and 2060 under four socioeconomic scenarios (Vafeidis et al. 2011). This data gives a good impression of regional differences across the globe in vulnerabilities to coastal flooding with possible impacts on displacement and migration. This data is summarised in Figure 23. Evidently – similarly to the situation with respect to the once-in-a-hundred years water level (Figure 22) – southern and eastern Asia are the main hotspots of populations vulnerable to coastal flooding both now and in the future, under various scenarios of sea level rise. In addition, sub-Saharan Africa is projected to become a hotspot of populations vulnerable to coastal flooding as well.

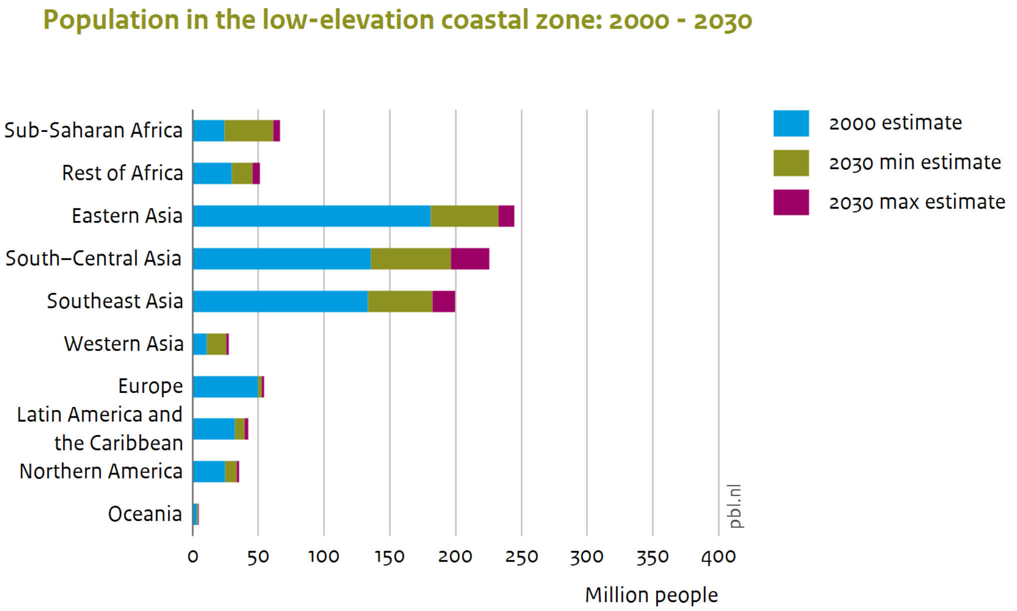
Table 18
Published data on population living in low-elevation coastal zones

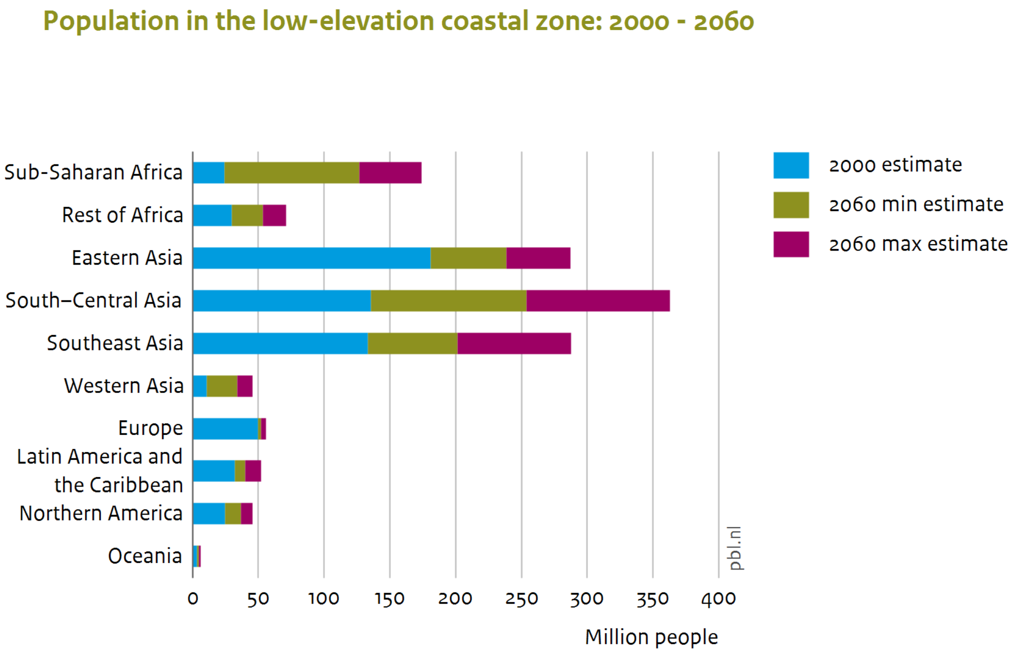
Reference	Time frame	Definition low-elevation coastal zone	Population exposed
Small et al. (2000)	2000	Within 20 m of mean sea level and 20 km of a coastline	400 million people
Anthoff et al. (2006)	1995	Within 1 m and 10 m of high water level	146 million (1 m) people and 397 million (10 m) people
McGranahan et al. (2007)	2000	Coastal area less than 10 m above sea level	10% (618 million) of the world's population and 13% (352 million) of its urban population
Lichter et al. (2011)	2000/2006	Coastal area up to 1 to 10 m above sea level	557 (1 m) – 709 million (2 m)
Vafeidis et al. (2011)	2000, 2030, 2060	Coastal area less than 10 m above sea level	625 million (2000), 879-949 million (2030), 1053-1388 million (2060)
Neumann et al. (2015)	2000, 2030, 2060	?	625 million (2000); 879–949 million (2030); (1053 – 1388 million (2060)
Jones and O'Neill (2016)	2000, 2100	Coastal area less than 10 m above sea level	702 million (2000); 493 – 1146 million (2100)
Merkens et al. (2016)	2000, 2050, 2100	Coastal area less than 10 m above sea level	637 million (2000); 1005 – 1091 (2050); 830 – 1184 million (2100)

Relevance for migration
Although many studies present numbers on projected population exposed to coastal flooding, only a few convert these numbers into projections of migration. According to Nicholls et al. (2011), 2 metres of sea level rise may lead to the '*forced displacement*' of up to 187 million people, especially those living on small islands, in Africa, and in parts of Asia. According to McMichael et al. (2020), population exposed to sea level rise and related impacts 'should not be conflated with inevitable migration' because, in addition to environmental factors, also economic, social, demographic, institutional, and political dimensions determine people's decisions to stay or move (see also: Foresight (2011)). And even if people would like to move, they may be unable to do so for economic reasons.

According to the IPCC 'there is *limited evidence* of migration occurring directly as a consequence of impacts associated with environmental change generally and SLR specifically' (Oppenheimer et al. 2019). Things may change this coming century, however. The IPCC found '*robust evidence* of planned relocation taking place worldwide in low-lying zones exposed to the impacts of coastal hazards'. It concluded that 'there is *high agreement* that climate change has the potential to drastically alter the size and direction of migration flows', but 'there is *low confidence* in quantitative projections of migration in response to SLR and extremes of sea level' (Oppenheimer et al. 2019). According to an inventory by the Lancet Countdown, by 2020, 37 countries had national policies that connected climate change and migration (Watts et al. 2021).

Figure 23
The number of people living in the low elevation coastal zone for the situation of 2000 and projections for 2030 and 2060 (data from Foresight 2011)





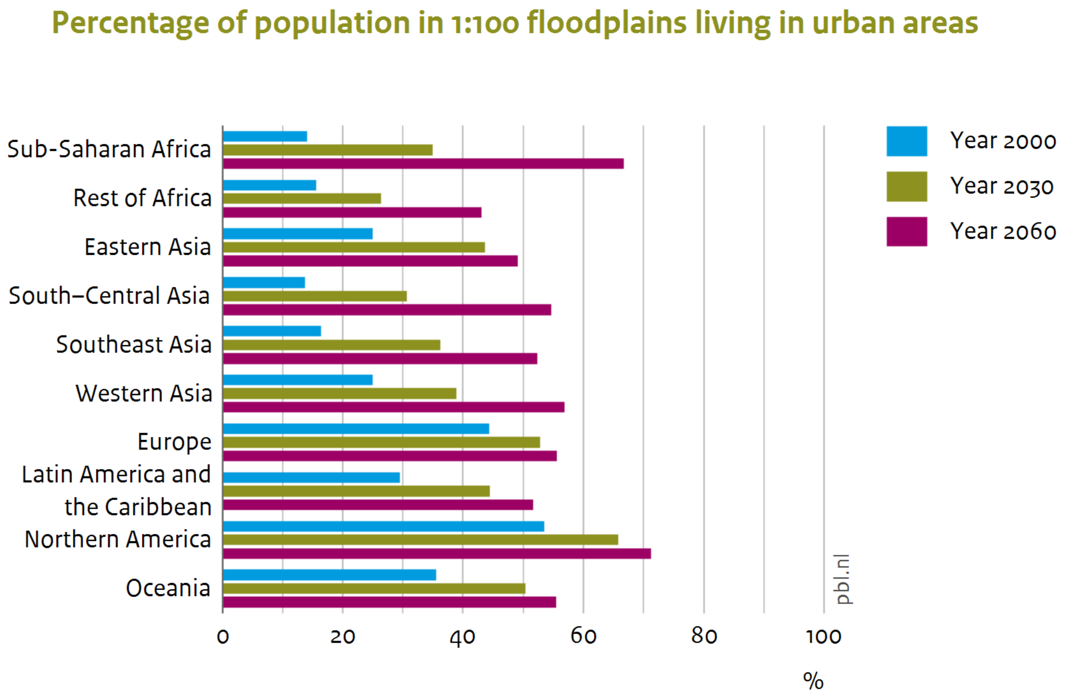
The IPCC also concludes that there is *robust evidence* of disasters displacing people worldwide, but limited evidence that climate change or sea level rise is the direct cause. They present the following numbers for 2017: ‘18.8 million people were displaced by disasters, of which 18 million were displaced by weather-related events including 8.6 million people displaced by floods and 7.5 million by storms’ (IDMC 2017; Islam and Khan 2018, both in: Oppenheimer et al. 2019). Migration mostly stays within the borders of affected countries (Warner and Afifi 2014; Hunter et al. 2015; Nawrotzki et al. 2017, all in: Oppenheimer et al. 2019).

Meanwhile, scientists warn that inland migration may not be that simple (Geisler and Currens 2017). It faces several barriers, both natural and anthropogenic. According to Geisler and Currens, inland living space is ’mortgaged for transportation, carbon storage, toxic and waste dumps, urban sprawl, deserts and other wastelands, war zones, unexploded ordinance graveyards, large private enclaves held by wealthy people, and a variety of semi-permanent polluting uses’. Among the barriers-to-entry in interior areas are so-called depletion zones: territories unlikely to support future human existence without unprecedented investment. These territories include degraded lands, dry-lands, and thawing permafrost landscapes. Sea level rise adds dramatically to the problem of providing a suitable living environment for millions of people by encroaching on some of the world’s most fertile landscapes - global coasts and deltas - and turning them into largely barren lands. According to Geisler and Currens, an unprecedented transboundary effort, commitment, and collaboration will be necessary. Coastal and interior landscapes must be managed consciously in anticipation of major population shifts from the former to the latter. Land use planning tools include government purchase of at-risk lands, major development restrictions, and managed retreat. The first is expensive and the second often beset by legal challenges, so the authors state. Managed retreat, the gradual clearance of structures as coastlines recede inland, seems promising because, in the words of the authors, ’it relaxes assumptions that coastal improvements and ownership patterns are immutable’.

Implications of ongoing urbanisation

As mentioned in section 5.2, protection by flood defences will be especially cost-effective in coastal zones with a high population density and a high GDP. As a larger part of the coast can be cost-effectively protected against sea level rise, the migratory pressure will decrease. In this respect, it is interesting to look at projections of the ongoing urbanisation of flood-prone deltas and coastal zones. We have done this with the Foresight (2011) data, which distinguishes between the part of the population living in urban and rural areas. Figure 24 shows the results of this. Between 2000 and 2060, the part of the population living in urbanised areas at an elevation lower than the once-in-a-hundred years flood level sharply rises, especially in Asia and sub-Saharan Africa. These are the future hotspots of sharply increasing population exposed to potential flooding. Apparently, a large part of the increase of the number of people living in flood-prone parts of deltas and coastal zones in these world regions refers to urban population. These projections contain a hopeful message; it may be cost-effective to protect a large part of the increase of the population in flood-prone deltas and coastal zones since they will be living in cities, which may reduce the pressure of this increase on future projections of displacement and migration.

Figure 24
Part of the population in deltas and coastal zones living in urban areas at an elevation below the once-in-a-hundred years flood level for the situation of 2000 and projections for 2030 and 2060 (data from Foresight 2011)



Annex 1: Drought risk assessment

By: dr. Niko Wanders, Utrecht University

To assess the future drought risk as a result of climate change, we have compared the future projections of drought to the historical benchmark for a series of climate models and a frequently used meteorology drought indicator.

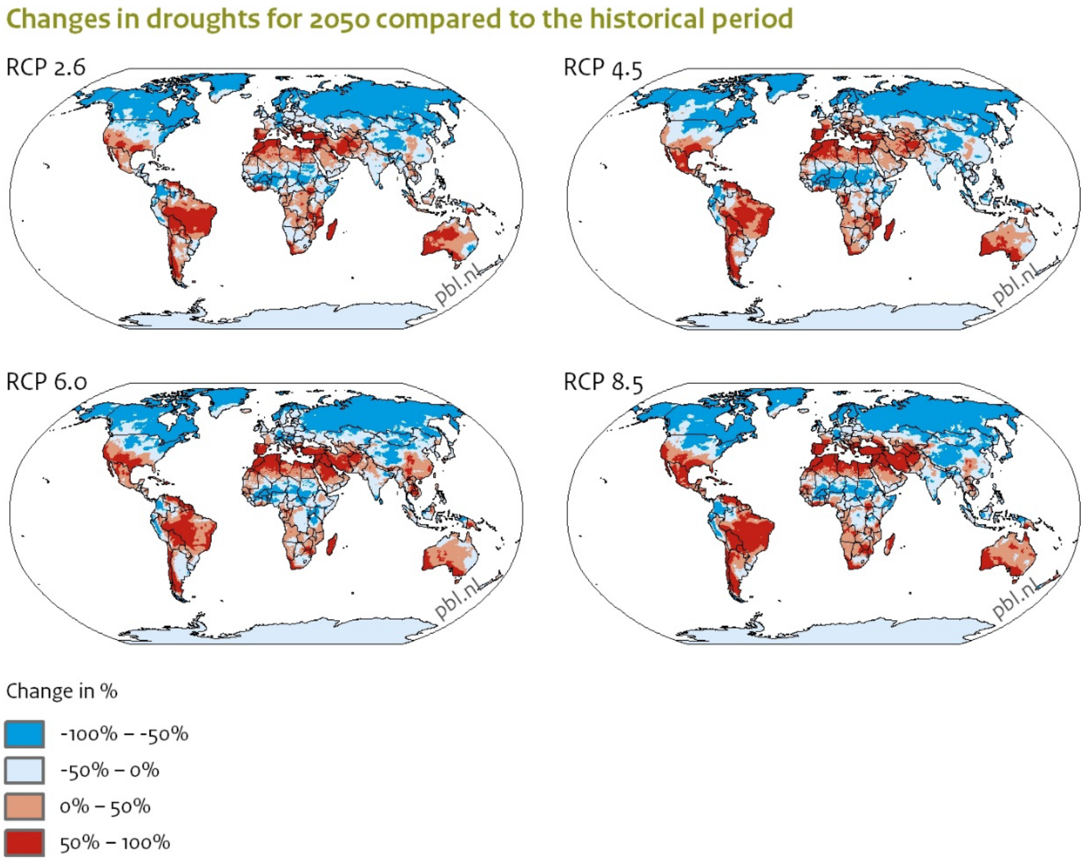
The drought risk is assessed using the Standardised Precipitation Index (SPI, McKee et al. 1993), which was also adopted by the World Meteorological Organization as the indicator of choice for monitoring meteorological drought risk (Hayes et al. 2011). The SPI uses solely precipitation data to determine the severity and duration of droughts. In this work the SPI has been selected because, firstly, the precipitation projections can be directly obtained from climate models without the need to use impact models to translate the drought signal from precipitation to other components of the hydrological cycle. Secondly, the SPI is widely adopted and as such provides a good benchmark. Finally, the SPI provides a good assessment of potential drought risk related to changes in precipitation and as such is directly comparable to results from the IPCC assessments.

The SPI comes with different temporal aggregation windows for drought assessment. The current standard is that a 1-month aggregation of precipitation characterises meteorological droughts, while agricultural/soil moisture droughts are captured by longer aggregation periods of 3 months and hydrological impacts with a 6 or 12 months SPI aggregation (Barker et al. 2016). As this study looks at long-term drought risk, we have adopted the SPI-12 (months) to quantify long duration and multi-year drought impacts in a future climate. The SPI-12 takes monthly precipitation anomalies and standardises these values to provide a normalised distribution of values where 0 indicates normal conditions, and negative and positive numbers show below and above normal precipitation conditions respectively. In this assessment we have taken a threshold value of -1, indicated as moderate drought by McKee et al. (1993), to look for droughts . Values of < -1 occur 16% of the time in the historical climate. Any changes in drought would be reflected in a shift in this default 16% of time below this -1 SPI threshold. The shift can lead to more drought (> 16%) or less drought (< 16%).

To quantify future drought risk, the SPI-12 was computed for both a historical and future scenario to compute changes in the drought occurrence. The historical period (1951-2005) is used as a benchmark to compute the model and location specific parameters of the SPI-12 for each location around the world and apply these to any future scenarios. Four future scenarios are identified (RCP2.6, 4.5, 6.0 and 8.5) for five different climate models of the CMIP5 ensemble (GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, NorESM1-M). The historical period of all models has been bias-corrected against the WATCH forcing data (Weedon et al. 2010) as part of the ISI-MIP project (Warszawski et al. 2014). The future drought risk is then assessed by looking at changes in the occurrence of values below the SPI-12 drought threshold. By looking at the change in drought occurrence over a 30-year period in the future, we then quantify the changes in drought risk for a given location in the world. These changes are then averaged for the five climate models to give a robust assessment of future changes in drought risk.

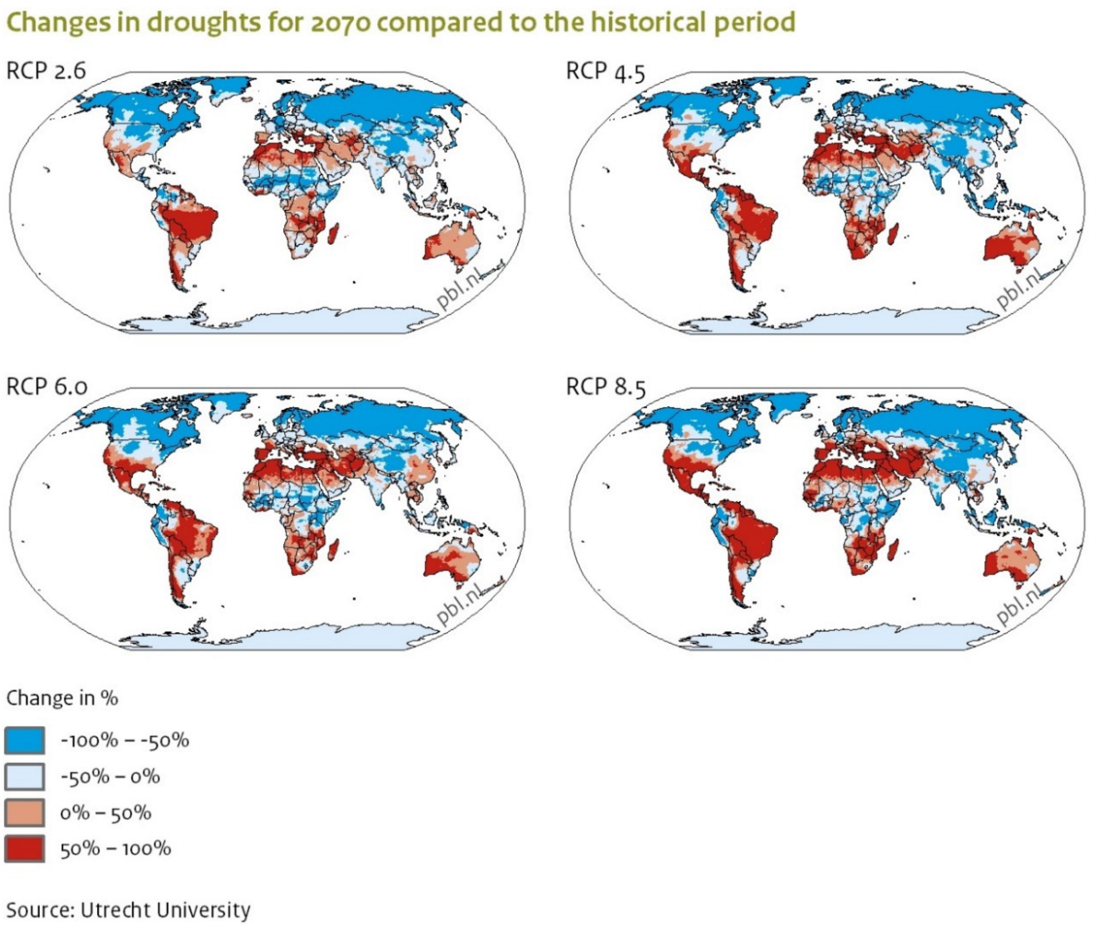
The final product of this assessment is a drought risk quantification for two periods in the future (2035-2065, 2055-2085) and four different climate scenarios. The maps indicate the average change in drought risk across the climate models for a SPI-12 indicator.

Figure 25
Percentage change in drought frequency based on rainfall patterns for 2050 compared to the historical period for SPI-12. The numbers are derived from an ensemble of five Global Circulation Models and for four Representative Concentration Pathways



Source: Utrecht University

Figure 26
Percentage change in drought frequency based on rainfall for 2070 compared to the historical period for SPI-12. The numbers are derived from an ensemble of five Global Circulation Models and for four Representative Concentration Pathways



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