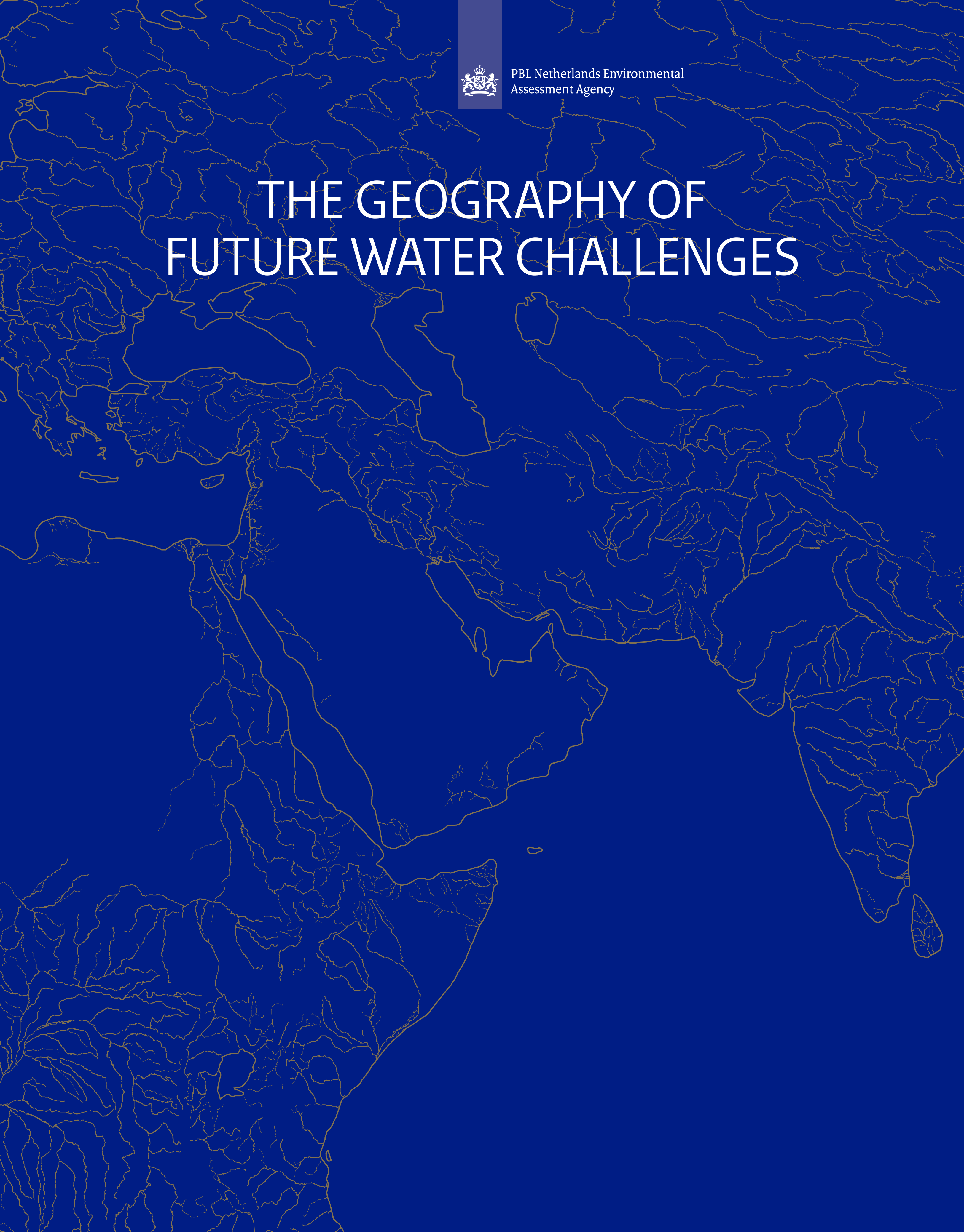
PBL Netherlands Environmental
Assessment Agency

THE GEOGRAPHY OF FUTURE WATER CHALLENGES



THE GEOGRAPHY OF FUTURE WATER CHALLENGES

The Geography of Future Water Challenges

Contents

Foreword

Water is key to life and, thus, to a sustainable relationship between the human world and its natural environment. As such, water is a precious resource, but can also be a threat. Water issues (i.e. too much, too little or too dirty) are affecting the lives of many millions of people today, and cause billions of euros in economic losses, each year.

The combination of a growing global population, increasing wealth-driven demand, the related increase in pressure on the ecological environment that is also exacerbated by climate change, is rapidly changing the world of water. In response to these rapidly changing conditions, three Dutch Ministries —the Ministry of Infrastructure and Water Management, the Ministry of Foreign Affairs and the Ministry of Economic Affairs and Climate Policy— requested PBL Netherlands Environmental Assessment Agency to provide a global overview of development scenarios and pathways forward, within the context of the water-related challenges up to 2050. Captured in a series of informative infographics and background documents, this results in an inspiring storyboard. As the saying goes: a picture is worth a thousand words. This storyboard shows how, under a Business-as-usual scenario, towards 2050, rapid population growth in combination with climate change will increase water-related risks in many regions across the globe. For dryland areas, food production and people's livelihoods are projected to come under increasing pressure. The growing concentration of people in cities and in vulnerable areas, such as coastal zones and deltas, will increase flood risks and long-term vulnerability for those communities and local economies. In addition, the planned construction of thousands of new hydropower dams will add pressure to transboundary collaboration in river basin areas, which are already vulnerable to climate-related weather extremes and economic developments.

In 2015 and 2016, two remarkable years, the global community entered into a new global commitment: the 2030 Agenda for Sustainable Development. The overarching Sustainable Development Goals capture and aggregate the goals and ambitions of the Sendai Framework for Disaster Risk reduction, the Addis Ababa Action Agenda on financing for development, the Paris Climate Agreement on combatting climate change and implementing adaptation, and the New Urban Agenda, which focuses on sustainable and inclusive urban development. These agreements and objectives express, at least on paper, the shared global commitment to make this world a better place!

Our main challenge, now, is to put these global commitments into practice. Across geographical scales, a new sense of urgency, new forms of imagination and new coalitions of the willing are needed to bridge interests and create concerted action in the right direction. Over time, water has proven to be an inspiring connector between various interests and a true source of collaboration rather than of conflict. The history of the Netherlands as a delta region has shown that water —in each of its socio-ecological landscapes and as part of river basins, delta cities, newly emerging metropolises and drylands— can be the basis for bridging interests, overcoming lock-ins and building a shared and sustainable future; creating a new geography of opportunities.

We hope that the research presented here in this imaginative storyboard will help increase awareness of the urgent need to tackle the challenges ahead. In the coming decades, there will only be a small window of opportunity for realising the necessary transformation towards a world that is sustainable, inclusive and climate-proof.

Hans Mommaas,
Director-General of PBL Netherlands Environmental Assessment Agency

Henk Ovink,
Netherlands Special Envoy for International Water Affairs, Sherpa to the UN / World Bank High Level Panel on Water

1
SETTING THE SCENE

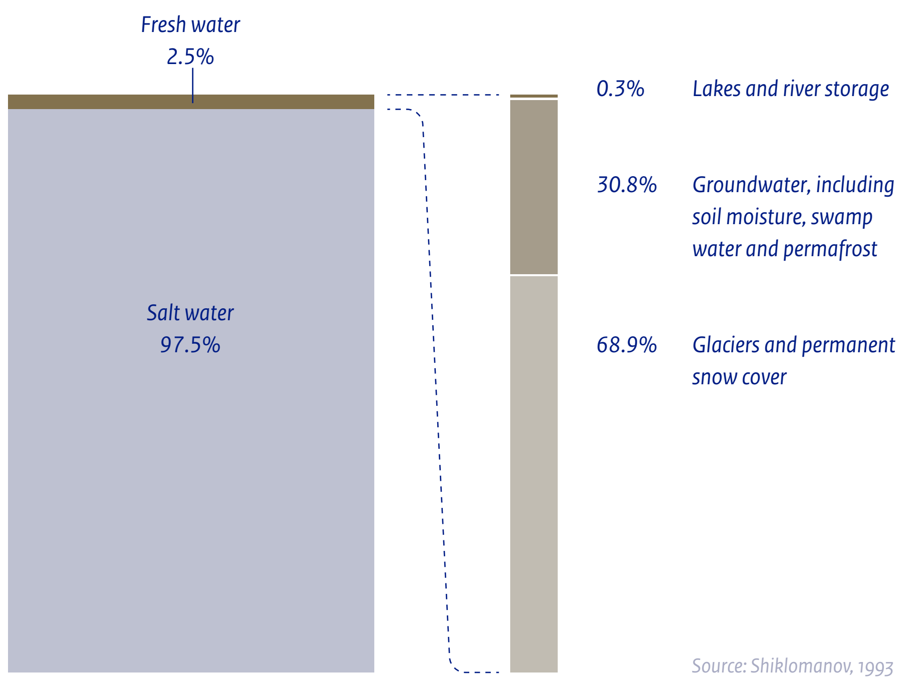
WATER, ESSENTIAL FOR LIFE

The worldwide degradation of natural resources is one on the major societal challenges. Water is one of the most important resources for humankind. It is a prerequisite for life on our planet and cuts across many social, economic and environmental activities.

The United Nations defines water security as:
'The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.'

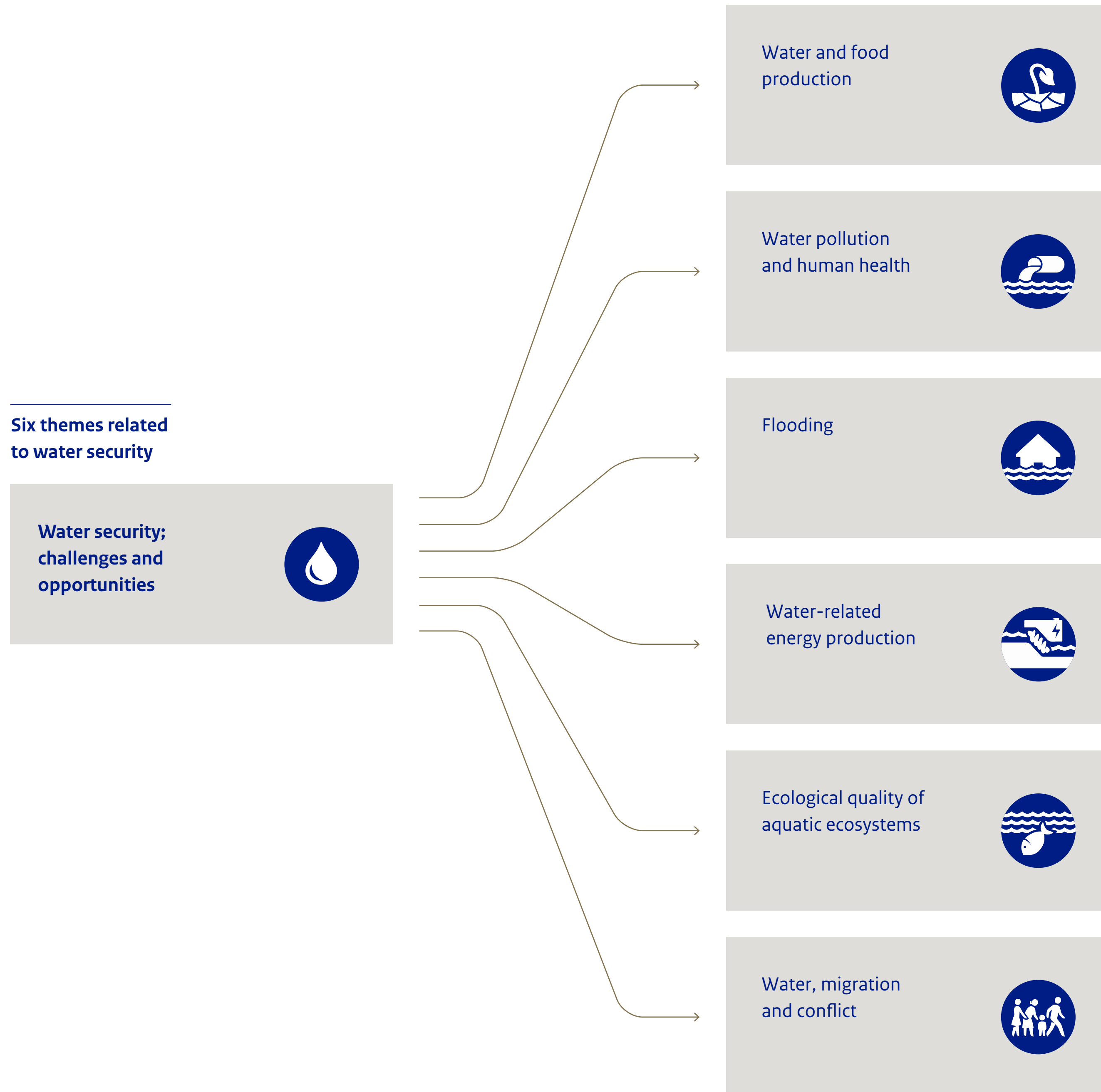
Water security is related to three water-related challenges: water scarcity (too little water), water pollution (dirty water) and flood risk (too much water). In the coming decades, these challenges and their impact on people's daily lives are expected to increase due to population growth, economic development, increased agricultural production and climate change, in turn affecting water availability, sea level rise and weather patterns.
In order to secure water resources, now and in the future, an understanding of the complexity of water-related challenges and the existence of possible gaps is essential, as a basis for the development of sustainable strategies that can adequately reduce risks for the population, economic development, ecosystems, and water associated migration and conflicts.
Following the first chapter's introduction of the general context for water-related challenges, the second chapter of this report explores six themes related to water security.

Fresh water: a precious resource
Only 2.5% of the water on earth is fresh water; about 70% of which is stored in ice, 30.8% in groundwater systems, and 0.3% is directly available in rivers and lakes.



Source: Shiklomanov, 1993

Six themes related to water security



Source: PBL

STRONG LINKS WITH SUSTAINABLE DEVELOPMENT GOALS

Many global commitments are linked to water; sustainable development, thus, needs to include adequate water management.

In 2015 and 2016, the world agreed on a complex set of global goals in the *Paris Climate Agreement* (2015), the *Sustainable Development Goals* (2015), the *Sendai Framework for Disaster Risk Reduction* (2015) and the *New Urban Agenda* (2016). Water is linked to these global commitments in many ways.
In the Paris Climate Agreement 2015, adaptation to climate change is on the level of national commitments to mitigate or combat climate change itself by reducing greenhouse gases. Major climate adaptation challenges include water security issues with respect to increases in water scarcity, drought and flood risk, and increasing water temperatures affecting water quality and biodiversity. With its link to human health and well-being, clean water and sanitation, food production, sustainable cities and communities, and the quality of ecosystems, water is directly and indirectly also linked to many of the Sustainable Development Goals (SDGs). Improving the protection against water-related disasters is also covered under the Sendai Framework for Disaster Risk Reduction. The New Urban Agenda specifically concerns the sustainable development of cities and encompasses the water-related goals that are also part of the SDGs and the Sendai Framework.

Global commitments related to water
On both a global and a national scale, the five global commitments provide opportunities as well as challenges in aligning goalsetting, implementing policies and developing reporting and evaluation processes.

Sendai Framework for Disaster Risk Reduction
Prevent and reduce hazard exposure and vulnerability to disaster

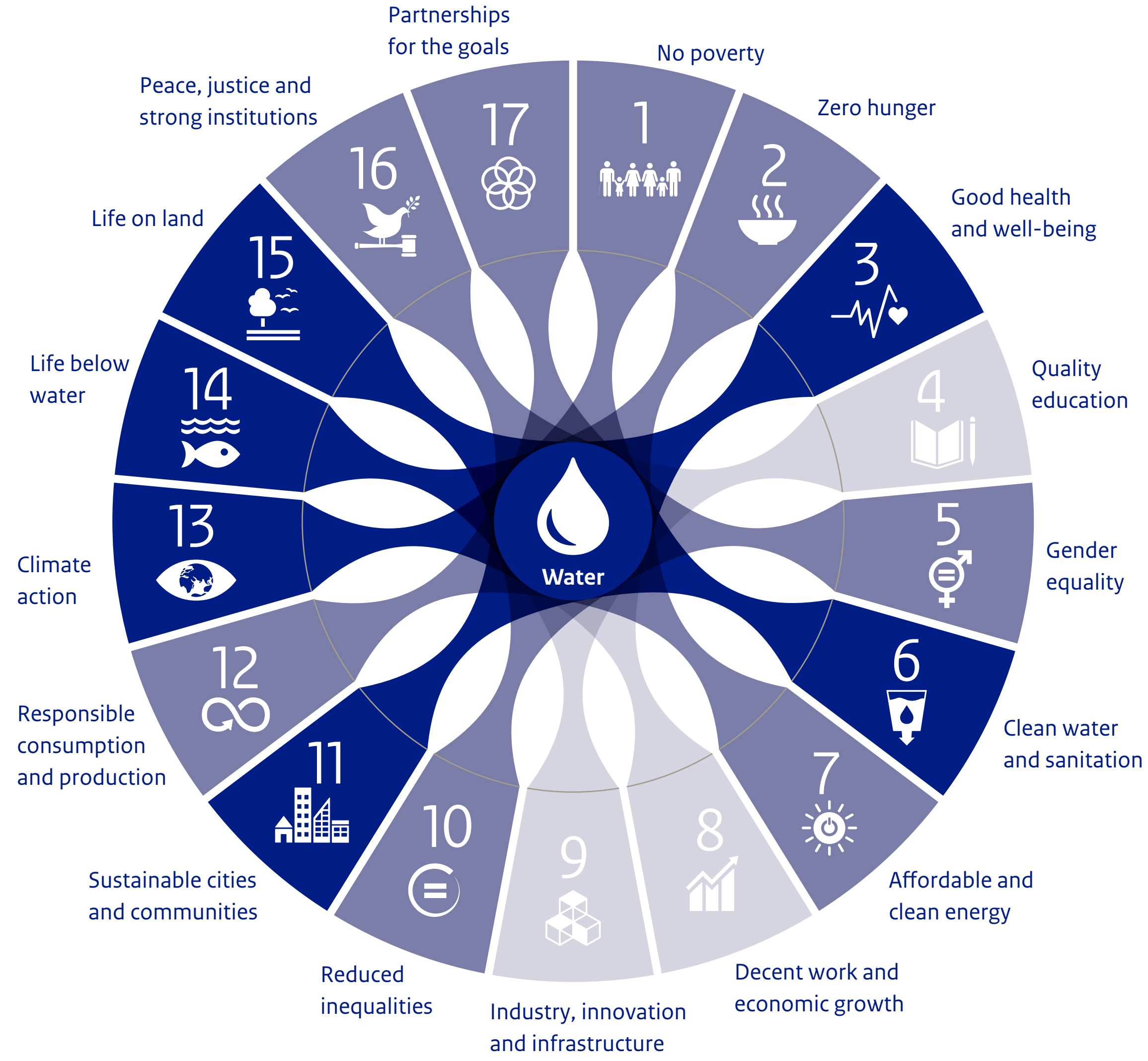
New Urban Agenda
Make cities and human settlements inclusive, safe, resilient and sustainable

The 2030 Agenda for Sustainable Development
A plan of action for people, planet and prosperity, concretised in 17 Sustainable Development Goals (SDGs) and 169 targets

Paris Climate Agreement 2015
Strengthen the global response to the threat of climate change, including mitigation and adaptation

Addis Ababa Action Agenda
Financing sustainable development and achieving the SDGs

Sustainable Development Goals related to water



Group 1 targets: strongly related to water
Group 2 targets: related to water
Group 3 targets: indirectly related to water

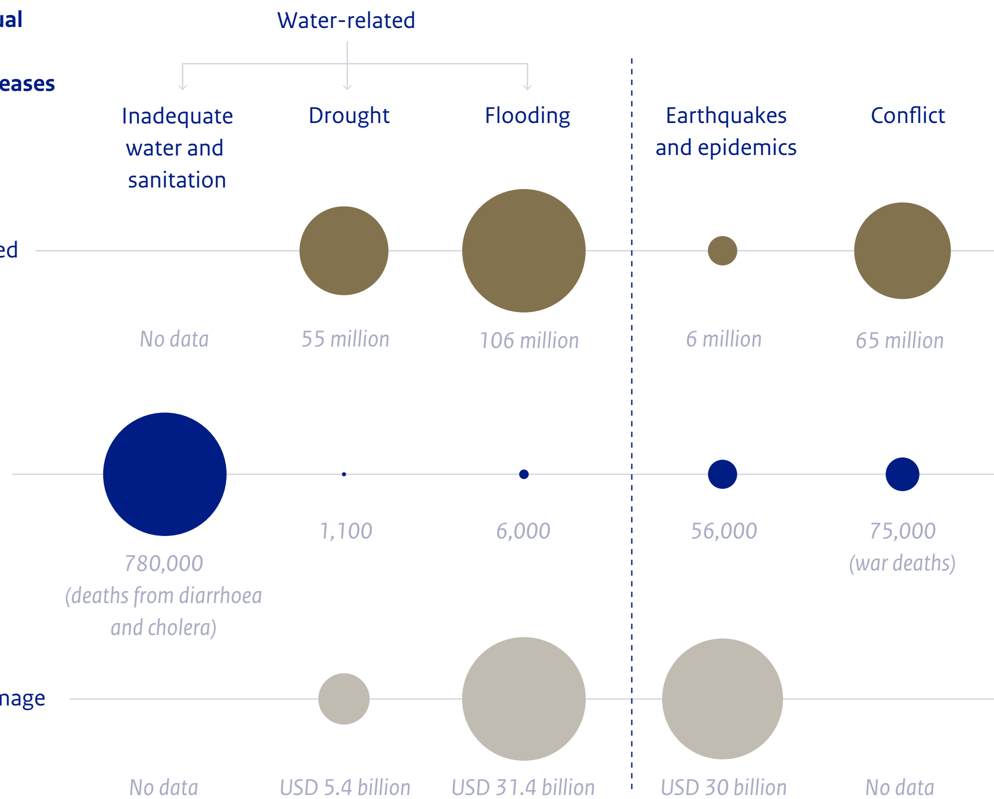
Source: PBL

THE SCALE OF WATER-RELATED DISASTERS

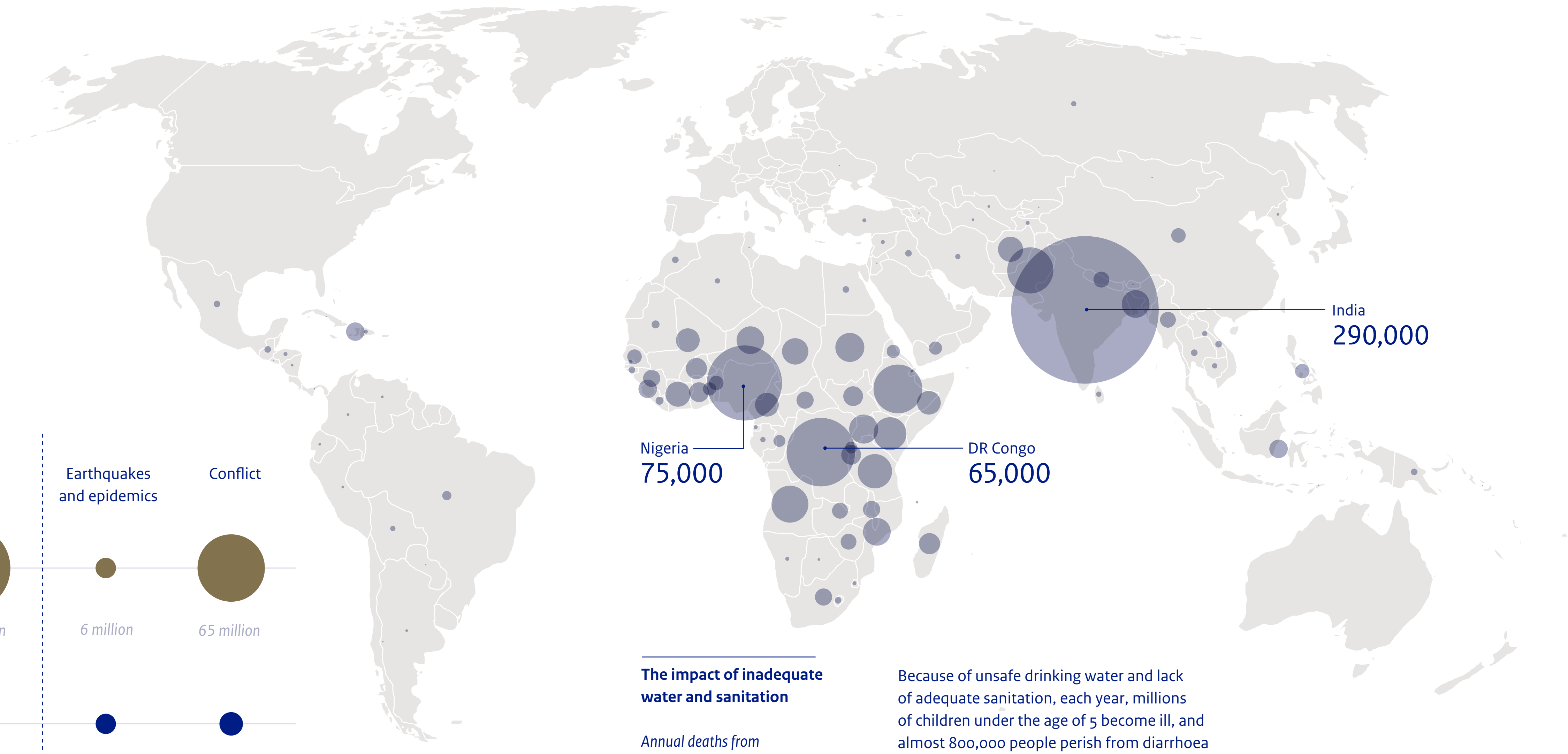
Water pollution and water-related weather extremes (drought, extreme rainfall, flooding, storm surges) affect the lives of millions of people and cause billions of euros in economic damage, each year.

Each year, water-related disasters, such as drought and flooding, affect approximately 160 million people, killing about 13,500 of them. Flooding affects most of these people (106 million, annually) and causes the largest economic damage (USD 31 billion, annually). Fortunately, due to improved early warning systems and increased disaster management capacity, the number of people killed by weather-related disasters has decreased, over the last decades.
Far more people are killed by other types of natural disasters, such as earthquakes and tsunamis, as well as by violent conflict.

Average annual impact from disasters, diseases and conflict

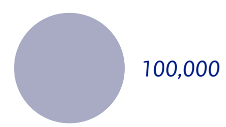


The impact of water that is too dirty



The impact of inadequate water and sanitation

Annual deaths from diarrhoea (2012) and cholera (2008–2012)



Source: Prüss-Ustün et al., 2014, Ali et al., 2015

Because of unsafe drinking water and lack of adequate sanitation, each year, millions of children under the age of 5 become ill, and almost 800,000 people perish from diarrhoea and cholera. Africa has the highest annual deaths, but numbers are also high in Southeast Asia.

THE GEOGRAPHY OF DROUGHTS AND FLOODS

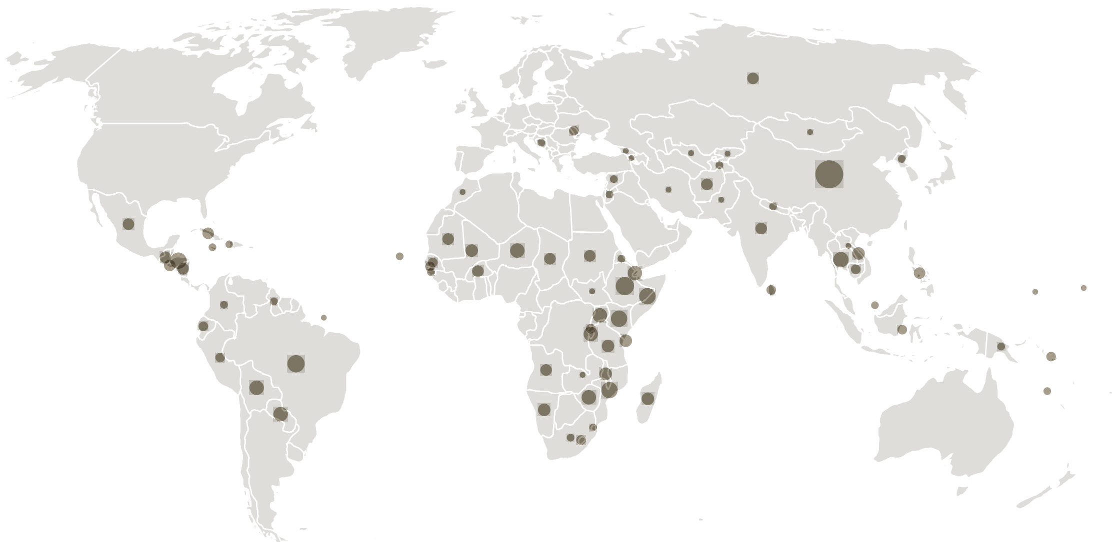
The impact of too little water

Drought occurrences 1996–2015
Droughts occur on all continents, but predominantly in the southern hemisphere.

Number of occurrences

10

Source: CRED

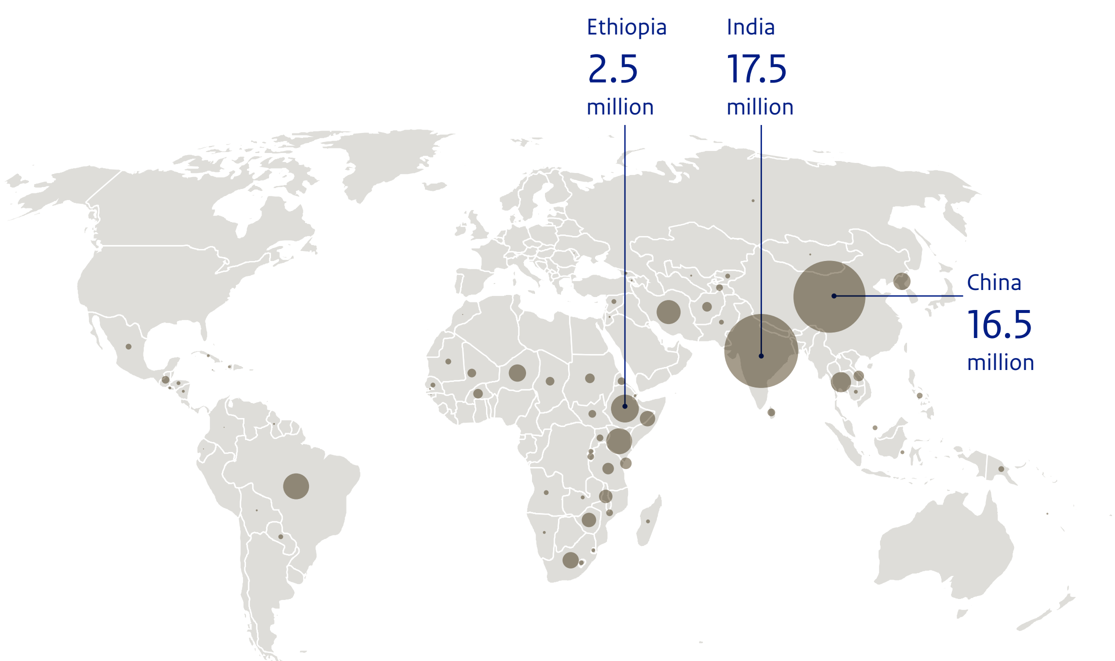


People annually affected by drought 1996–2015
Droughts lead to water scarcity for people, severe agricultural production loss, local food shortages, and wildfires.

Number of people affected, annually

10 million

Source: CRED



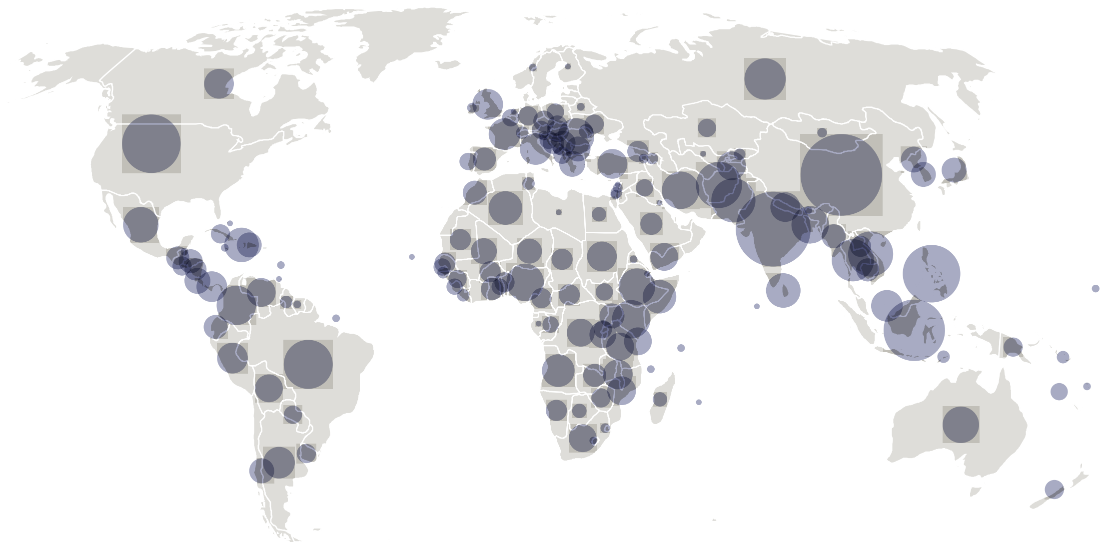
The impact of too much water

Flooding events 1996–2015
Flooding events lead to casualties, result in temporary displacement out of the area and high economic losses affecting both industries and households.

Number of occurrences

100

Source: CRED

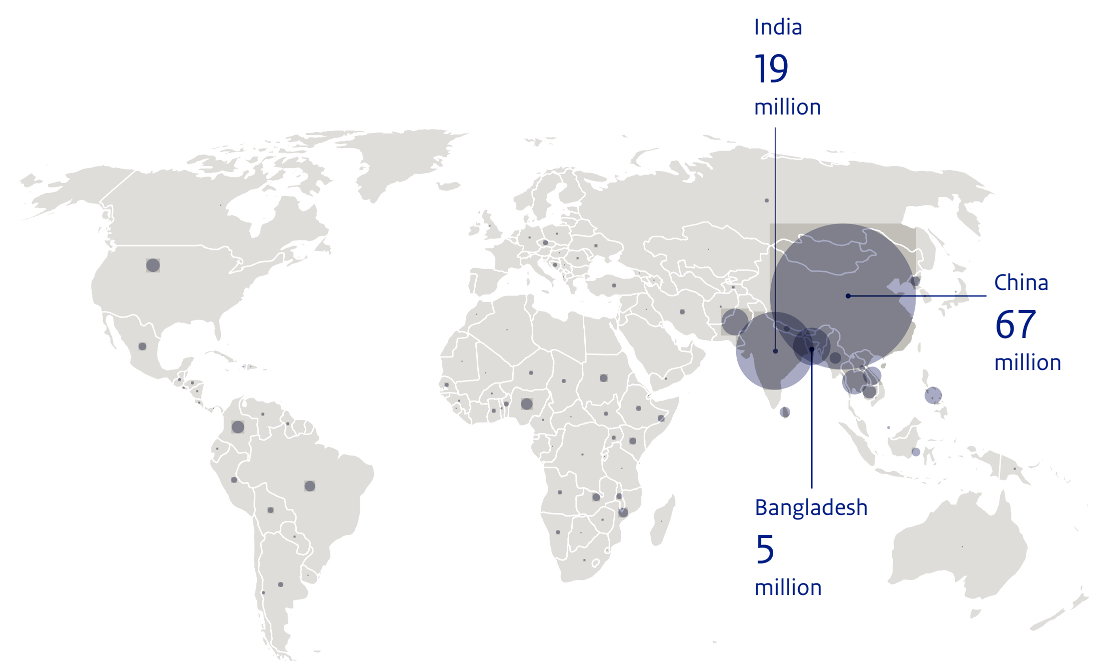


People annually affected by flooding 1996–2015
Flooding occurs all over the world, but the majority of the people affected live in Southeast Asia.

Number of people affected, annually

35 million

Source: CRED



PRESSURES ARE INCREASING

Between now and 2050, under a Business-as-usual scenario, the combination of further population growth, further economic development and climate change is projected to increase the water-related stresses of water scarcity, water pollution and flooding.

What the future holds is uncertain, but projections can be made. To explore the future, the scientific community has developed five so-called Shared Socio-Economic Pathways (SSPs) — narratives that broadly outline characteristics of a possible global future, in terms of population growth, economic and technological development, global collaboration and urbanisation. These five pathways result in a range of challenges for both mitigation (reducing greenhouse gas emissions) and adaptation (adjusting to the changing climate).

SSP1 Sustainability
low population growth
high economic growth
moderate climate change

SSP2 Middle of the road
moderate population growth
moderate economic growth
high climate change

SSP3 Regional rivalry
high population growth
low economic growth
high climate change

SSP4 Inequality
moderate population growth
low economic growth
high climate change

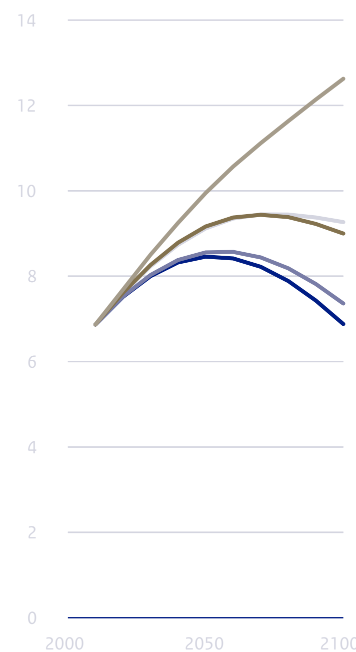
SSP5 Fossil-fuelled development
low population growth
high economic growth
very high climate change

Business-as-usual scenario towards 2050

The changes in water security by 2050, as explored in Part II, have been mapped by applying a Business-as-usual scenario, assuming Middle-of-the-road socio-economic and mitigation development (SSP2 Middle-of-the-road scenario). The Business-as-usual scenario is combined with a climate change scenario that results in a 3.7 °C temperature increase, by 2100. This combination, thus, assumes that the Paris Climate Agreement's target of a maximum global temperature increase of 2 °C by 2100 will not be achieved. This means that, compared to our exploration, scenarios with higher levels of population and economic growth and more global warming will yield more severe impacts, whereas those with less population and economic growth and less global warming will produce impacts that are less severe, thus reducing the water security challenges.

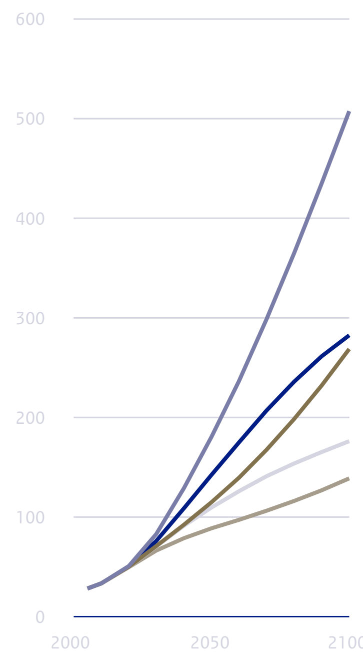
Global population

billion people



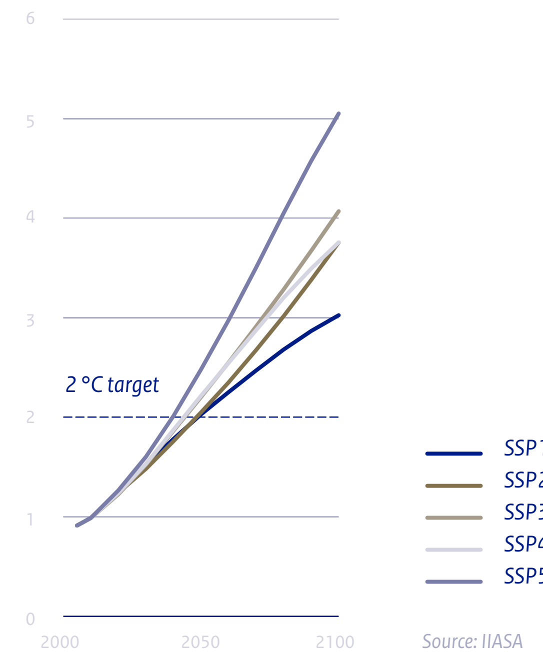
Global GDP

trillion USD_{2005} per year



Global temperature change

°C, compared to pre-industrial levels



Source: IIASA

Scenario without additional action

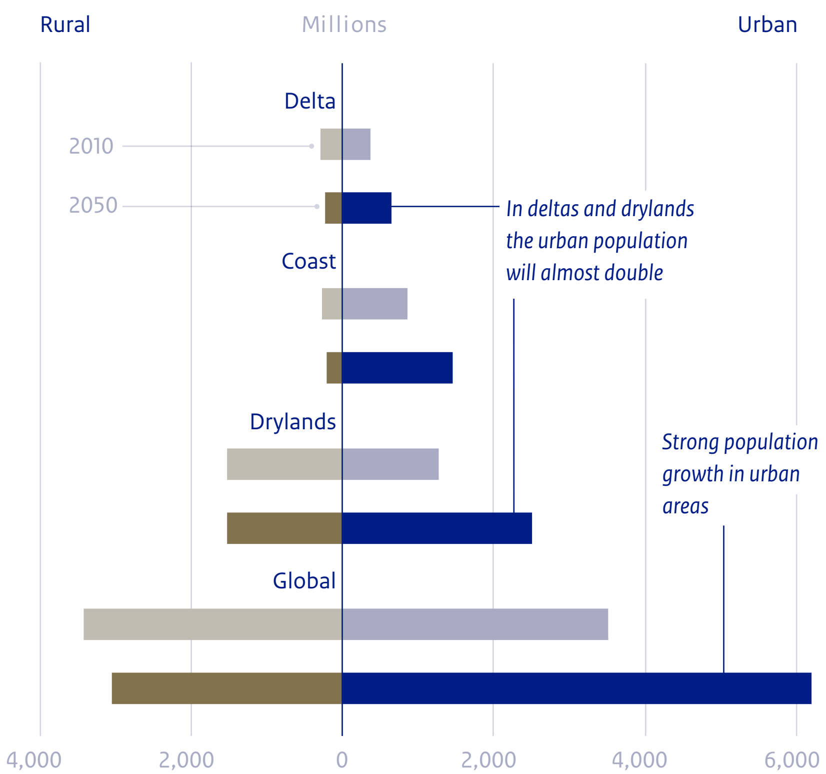
Population growth under the Business-as-usual scenario —from 7 billion people today to circa 9 billion by 2050— and the further economic growth are projected to strongly increase the use of and pressure on natural resources. Without adequate governance and water management, water stress will increasingly affect people, agricultural production, economic activities, water pollution levels and the quality of aquatic ecosystems. To explore the potential risks, the Business-as-usual scenario includes no additional actions taken to reduce water-related stresses and risks.

URBANISATION CHANGES GLOBAL VULNERABILITY

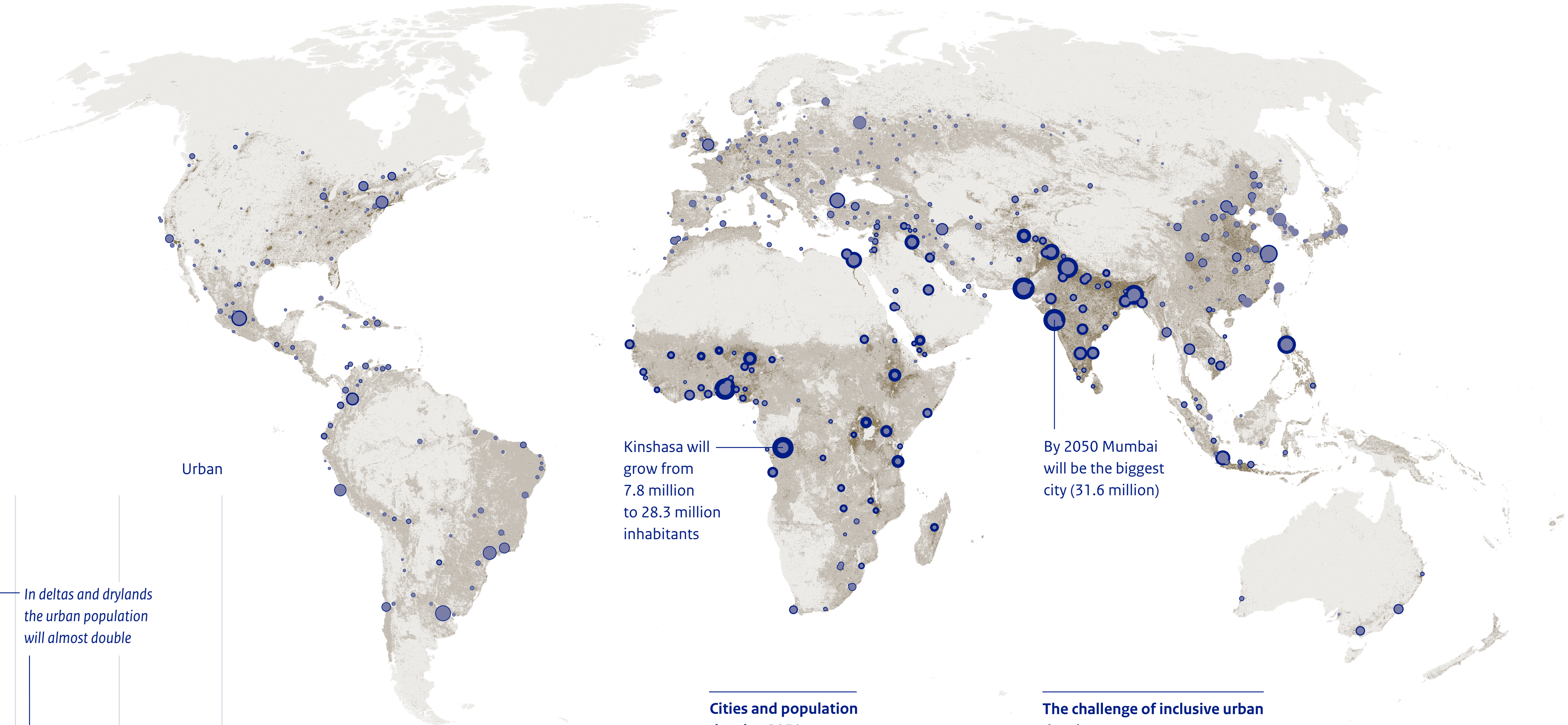
Because of continued global urbanisation, water-related risks will increasingly be concentrated in cities.

In the urbanising world, cities will increasingly become centres of population growth and economic development. By 2050, 70% of the world population is projected to live in an urban environment, and the 600 major cities in the world are expected to provide 60% of global GDP. The global urban area is expected to expand by more than 70%, not only in riparian and coastal areas and in deltas, but also in water-stressed regions, such as drylands. By 2050, 70% of the global population will be living on 0.5% of the global land area.

Change in urban and rural populations, per type of area, 2010–2050
Fast urban growth, more than doubling city sizes, occurs especially in the developing countries of East and South Asia and Sub-Saharan Africa.



Source: PBL



Cities and population density, 2050

Cities 2010
Cities 2050

Inhabitants (millions)
10
20
30

Population density (number of people per 30'' grid cell)
1–100
101–500
501–1,000
>1,000

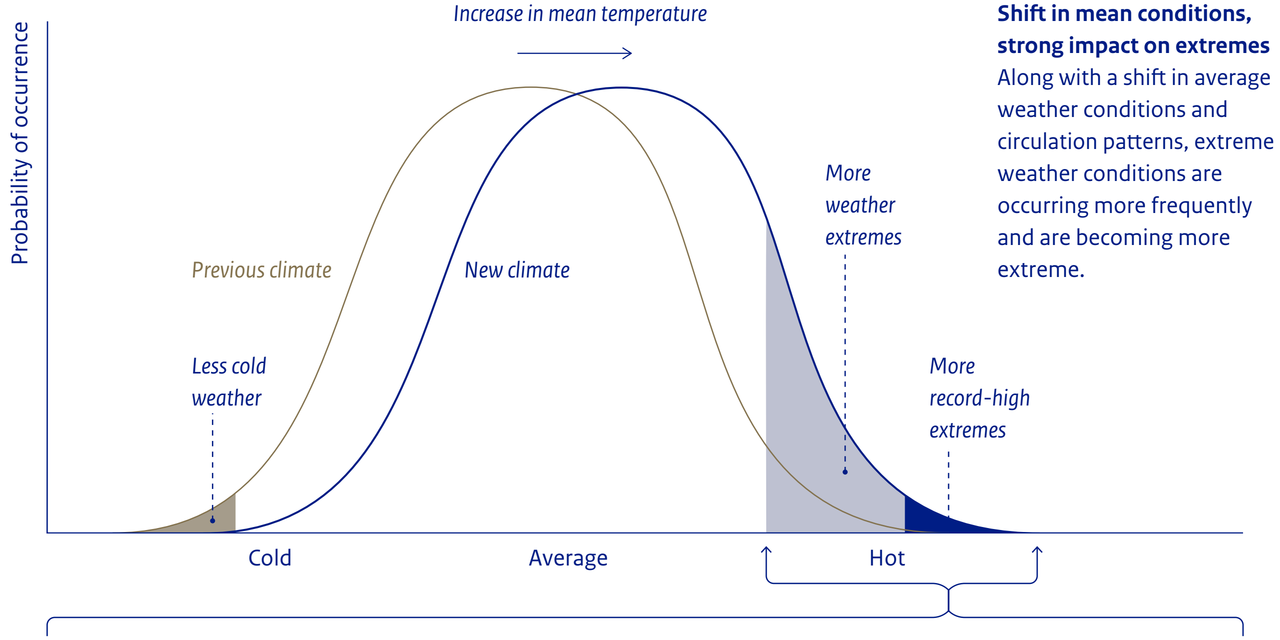
Source: PBL

The challenge of inclusive urban development
Today, about one billion people are living in urban slums. The rapidly growing urban population strongly increases the pressure on local resources, local environmental conditions, food availability, labour opportunities, and public services. Reducing inequality, insecurity and poverty in cities may be some of the major challenges, on the path towards 2050.

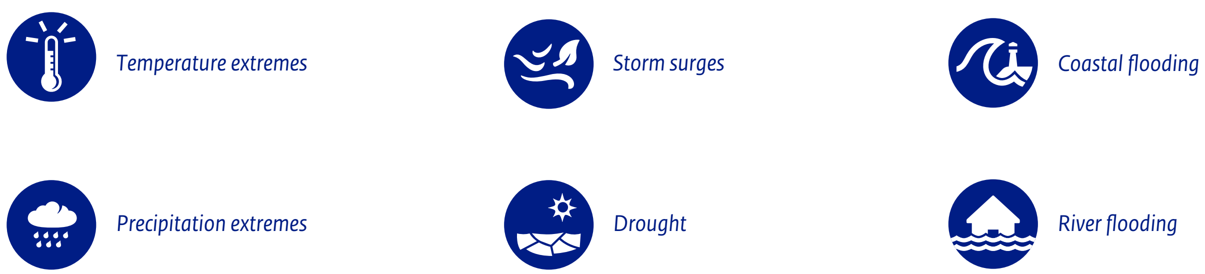
CLIMATE CHANGE AND WEATHER EXTREMES

Climate change involves both slow and gradual changes, such as in temperature, precipitation patterns and sea level rise, as well as changes in weather extremes, such as drought, flooding and storm surges.

Society is primarily impacted by climate change through changes in the global and local water system. Changes in precipitation patterns, weather extremes, water-related disasters, sea level rise, and melting sea ice affect both security risks and development opportunities. The warming of rivers, lakes, seas and oceans negatively affects the quality of their ecosystems.

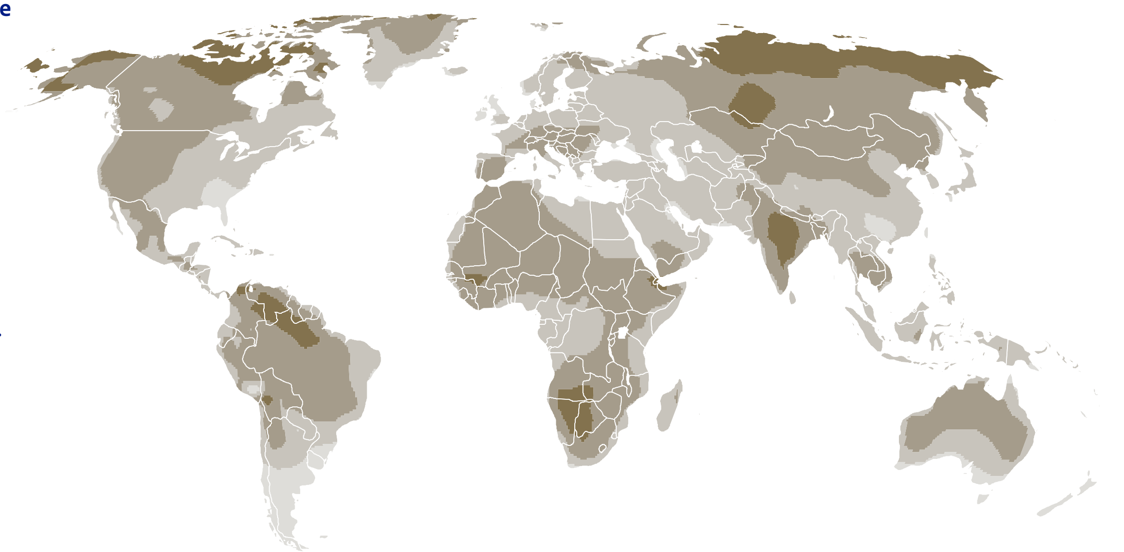


Shift in mean conditions, strong impact on extremes
Along with a shift in average weather conditions and circulation patterns, extreme weather conditions are occurring more frequently and are becoming more extreme.



Change in temperature 2010–2050
Global average temperature is projected to increase by around 2 °C by 2050, with large regional differences. The northern regions face relatively high temperature increases.

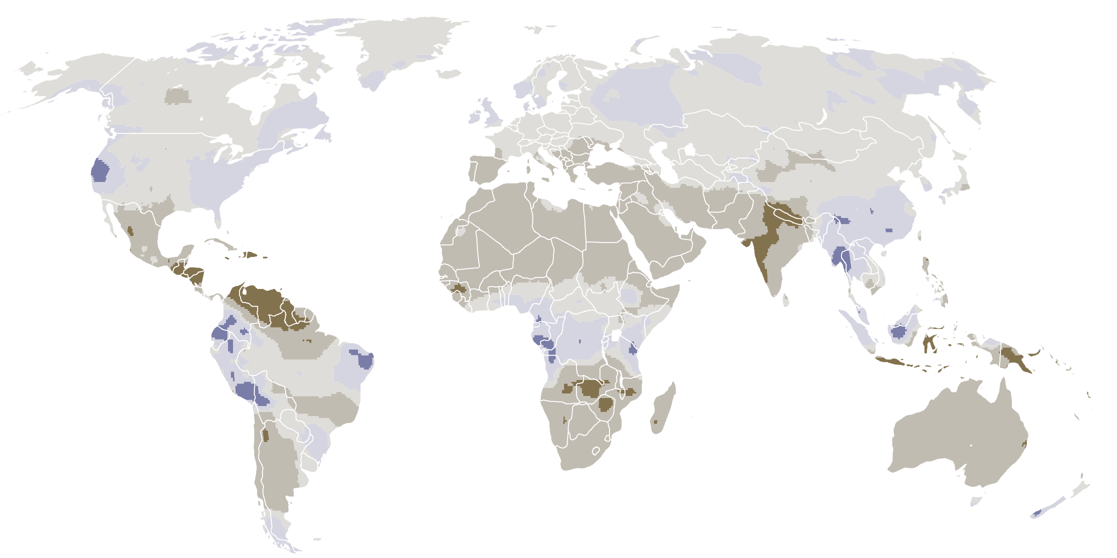
°C
- *0.3 – 1*
- *1.1 – 1.5*
- *1.5 – 2*
- *> 2*



Source: PBL

Change in net precipitation 2010–2050
In general, the net result of changing temperature, precipitation patterns and evaporation is that most dry areas will become dryer and wet areas wetter.

mm/day
- *< -0.5*
- *-0.5 – -0.1*
- *-0.1 – 0.1*
- *0.1 – 0.5*
- *> 0.5*



Source: PBL

EXPLORING FUTURE CHALLENGES

Sustainable development is linked to water security. Building a sustainable future requires insight into how water- and climate-related risks will develop between now and 2050. Which regions will become hotspots?

Water is linked to many processes and activities, affecting people, economical activities and ecosystems, in many ways. Exploring future developments, therefore, is not easy. At the request of the Dutch Ministry of Infrastructure and Water Management, the Ministry of Foreign Affairs and the Ministry of Economic Affairs and Climate Policy, PBL has collected information about future global water-related challenges, in collaboration with other institutes.

Acknowledging the complicated interactions, Part II explores the future challenges, for six selected topics:

- Water and food production
- Water pollution and human health
- Flooding
- Water-related energy production
- Ecological quality of aquatic ecosystems
- Water, migration and conflict

Per topic, the Business-as-usual scenario projects likely developments in water-related risks and hotspot regions.

Water-related challenges are interrelated

Source: PBL

2
MAPPING HOTSPOTS

WATER AND FOOD PRODUCTION

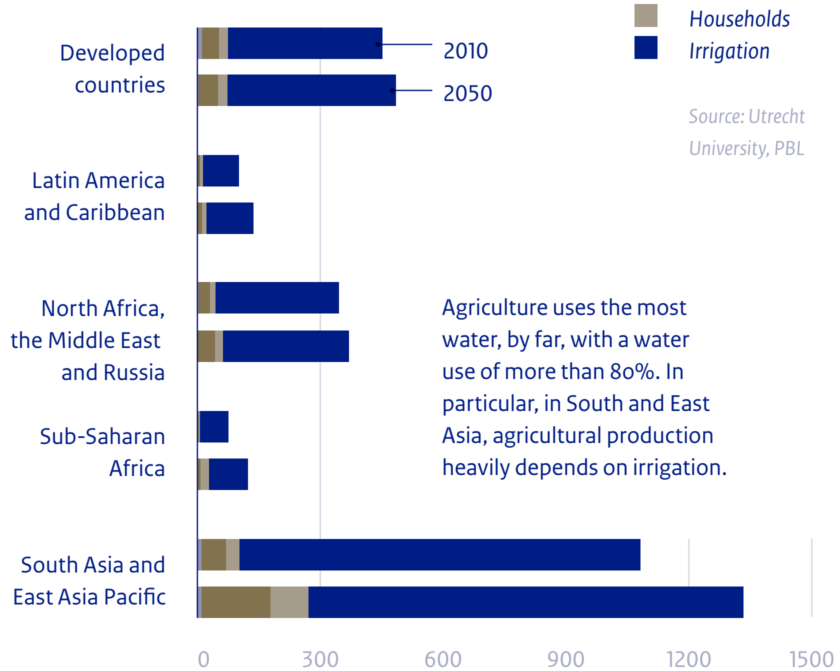
WATER STRESS BY 2050

Water consumption is increasing, especially that of households and industries. Agriculture will remain the largest user, though. High levels of regional water stress may limit agricultural production.

Between now and 2050, global water consumption is expected to increase by 25%, due to the growing number of households, the growth in industrial production and agricultural expansion and intensification.
Growing water demand and —in some regions— declining precipitation will increase the pressure on the available water resources, resulting in high levels of water stress in many regions.

Challenges
Climate change, which brings higher average temperatures and changing precipitation patterns, combined with increasing competition for water resources, may result in substantial increases in the number of people living under severe water stress.

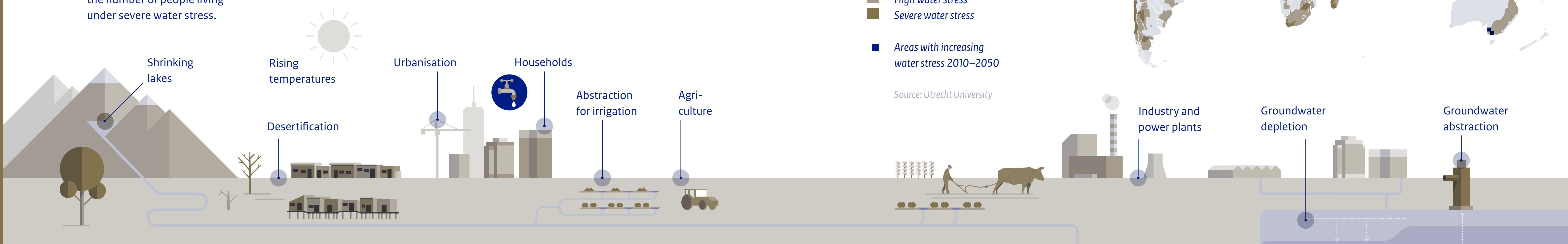
Water consumption
2010 versus 2050 in km³



Electricity
Industry
Households
Irrigation

Source: Utrecht University, PBL

Agriculture uses the most water, by far, with a water use of more than 80%. In particular, in South and East Asia, agricultural production heavily depends on irrigation.

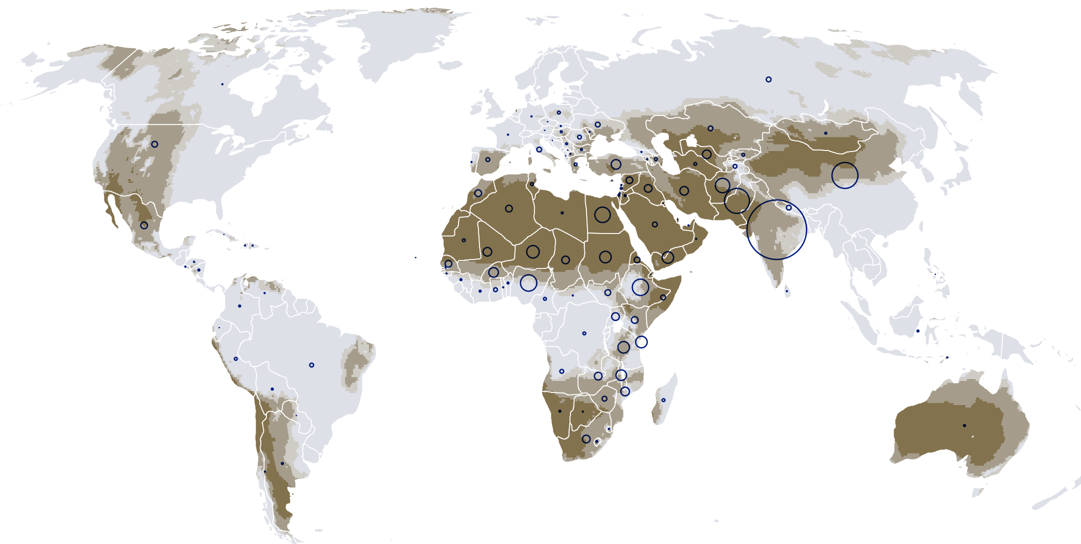


Dryland areas are the most vulnerable
Drylands' rural population and food production will especially be affected by changes in water availability, as a result of climate change.

Arid
Semi-arid
Dry sub-humid
Humid

Rural population 2050
300 million

Source: PBL

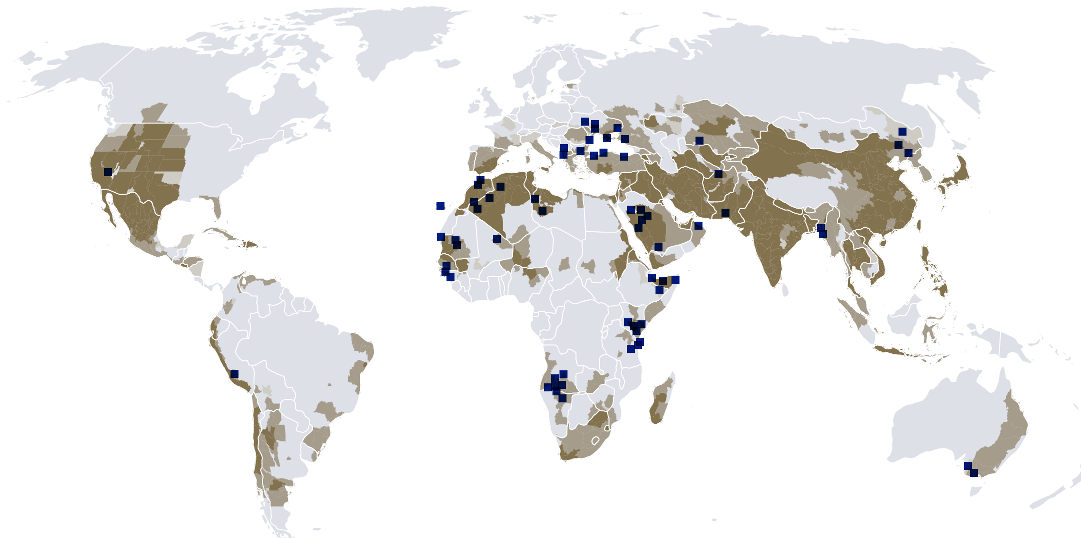


Increasing competition for water
Water stress may have a negative impact on agricultural production and economic development.

No to low water stress
Moderate water stress
High water stress
Severe water stress

Areas with increasing water stress 2010–2050

Source: Utrecht University

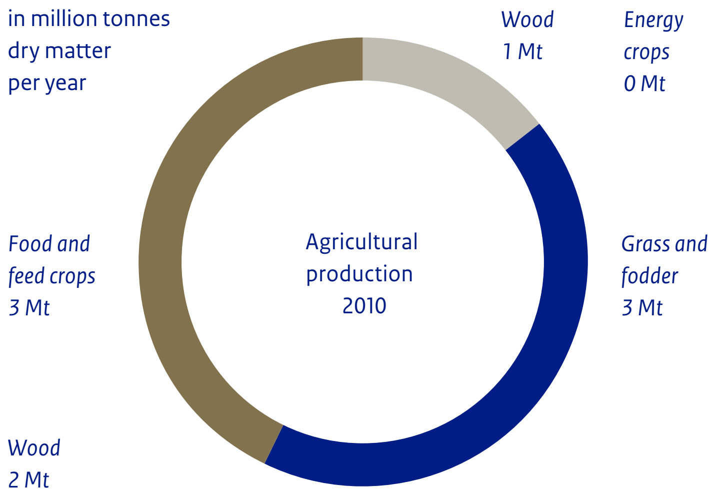


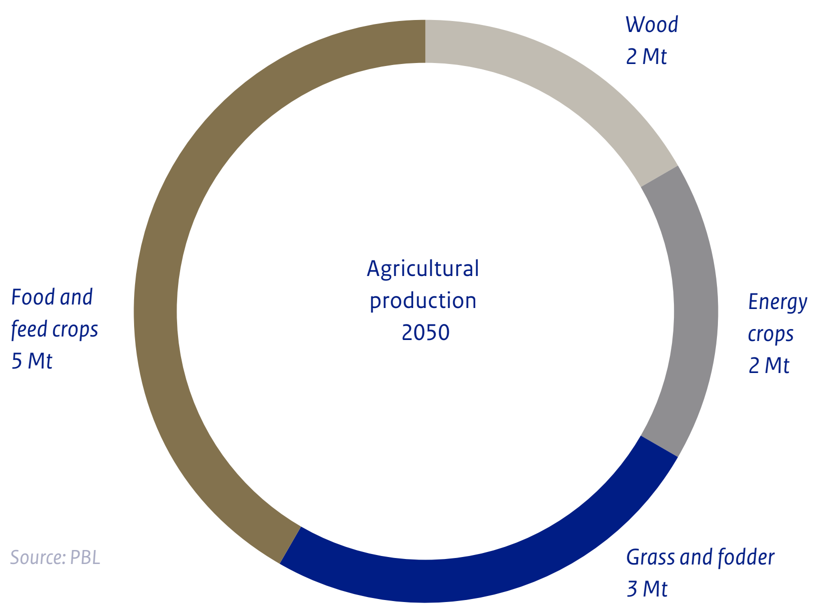
LOW CROP YIELDS REQUIRE WATER MANAGEMENT

Without improved water management, rainfed and irrigated agriculture are expected to experience substantial yield gaps by 2050.

Under the Business-as-usual scenario, total agricultural production is expected to increase by 70%, mainly due to more food and feed production and more energy crop production. These increases are projected to be about 10% lower than they would have been without climate change. This is mostly due to water shortages and too high temperatures. Especially the agriculture in tropical and subtropical regions are projected to be affected.

Agricultural production





Source: PBL

Twenty percent of the global agricultural area is irrigated, which represents 40% of the total in agricultural production. The remaining area (80%) fully depends on precipitation.

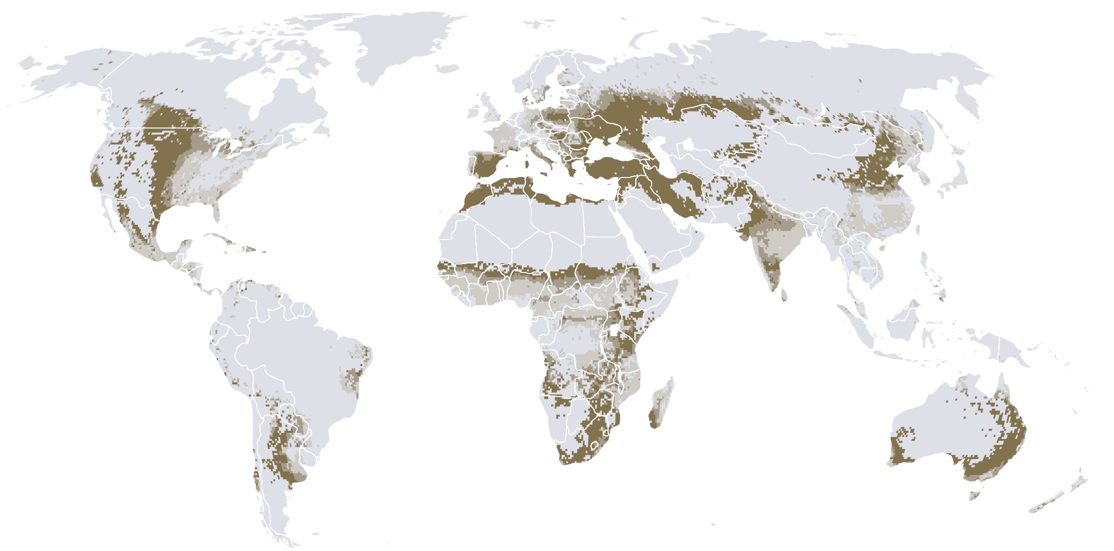
Water is a prerequisite for crop production. Water shortages directly lead to reduced crop production. In water-stressed areas, agricultural production levels can be increased by improving water management and increasing water efficiency ('more crop per drop').

Gap in crop yields rainfed agriculture, by 2050

Water shortages cause large yield gaps in many areas around the world. Improved water management may increase crop yields in rainfed agriculture, by 40% to over 60%.

Gap in crop yields
- 0–20%
- 20–40%
- >40%

Source: Wageningen University & Research

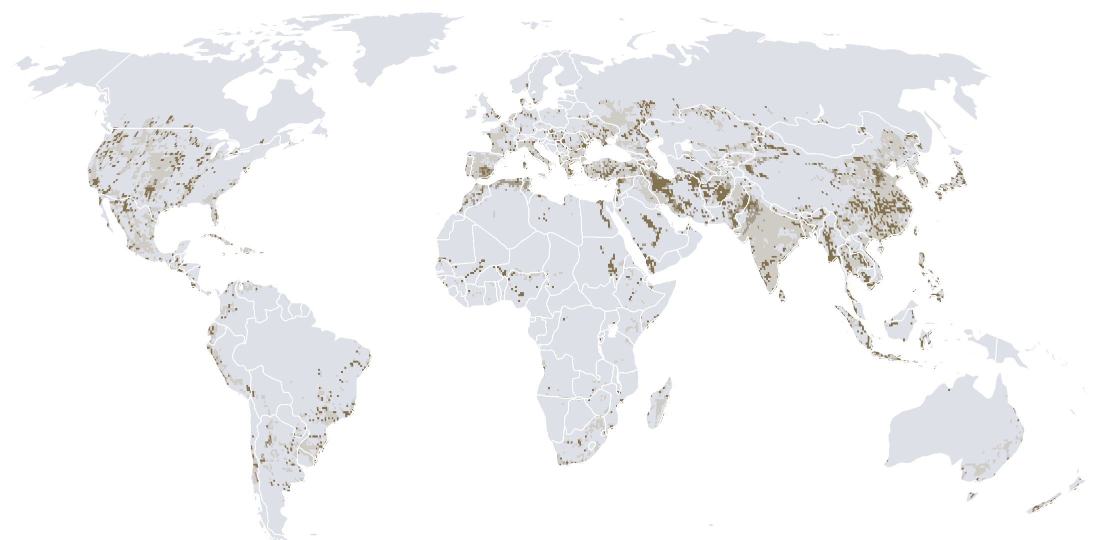


Gap in crop yields irrigated agriculture, by 2050

Improved water management may also increase crop yields in irrigated agriculture.

Gap in crop yields
- 0–20%
- 20–40%
- >40%

Source: Wageningen University & Research



RECONCILING AGRICULTURE AND NATURE

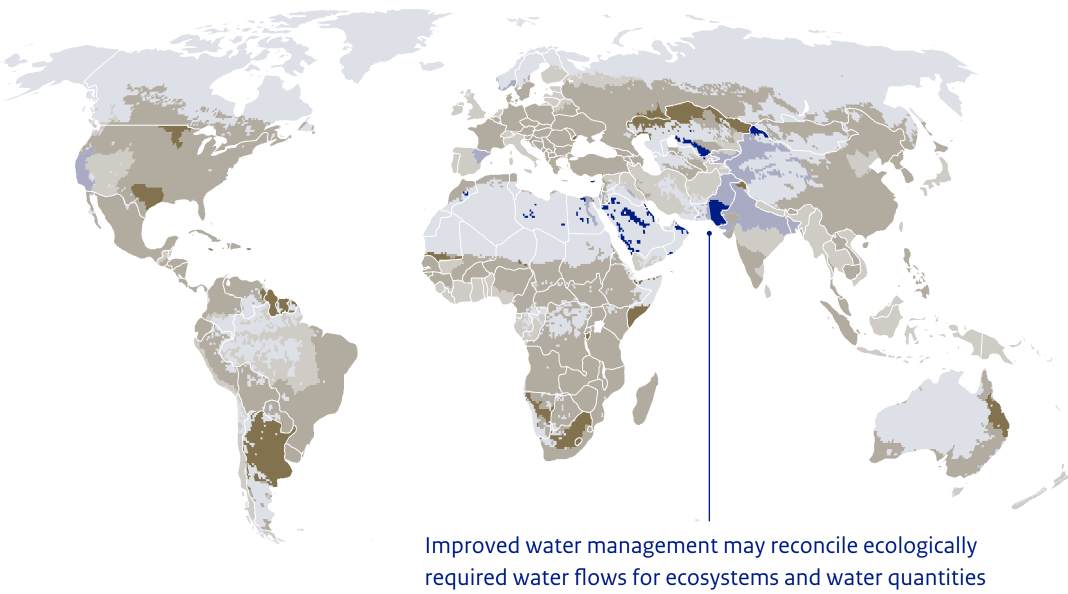
Improved water management and irrigation efficiency could reduce climate change impact (adaptation), increase local food production and reduce local impacts on nature.

In large parts of the world, improved water management, based on currently known techniques for water efficiency and water conservation, could decrease local yield gaps, while compensating for climate change impacts and retaining at least 30% of the water flows for nature. However, in the Himalayan region and areas north of it, this nature-oriented approach would not be effective and substantial yield gaps would remain.

Change in crop production under improved water management, allowing ecologically required river flows

Change in crop production (% Kcal)

- *No cropland*
- <-25
- -25–5
- -5–5
- 5–25
- >25



Source: Jägermeyr et al., 2017

Improved water management may reconcile ecologically required water flows for ecosystems and water quantities required for crop production. Still, in some regions, such as in the Indo-Gangetic Plain, this win–win strategy seems not possible, as ecological flow requirements (EFR) will not be met.

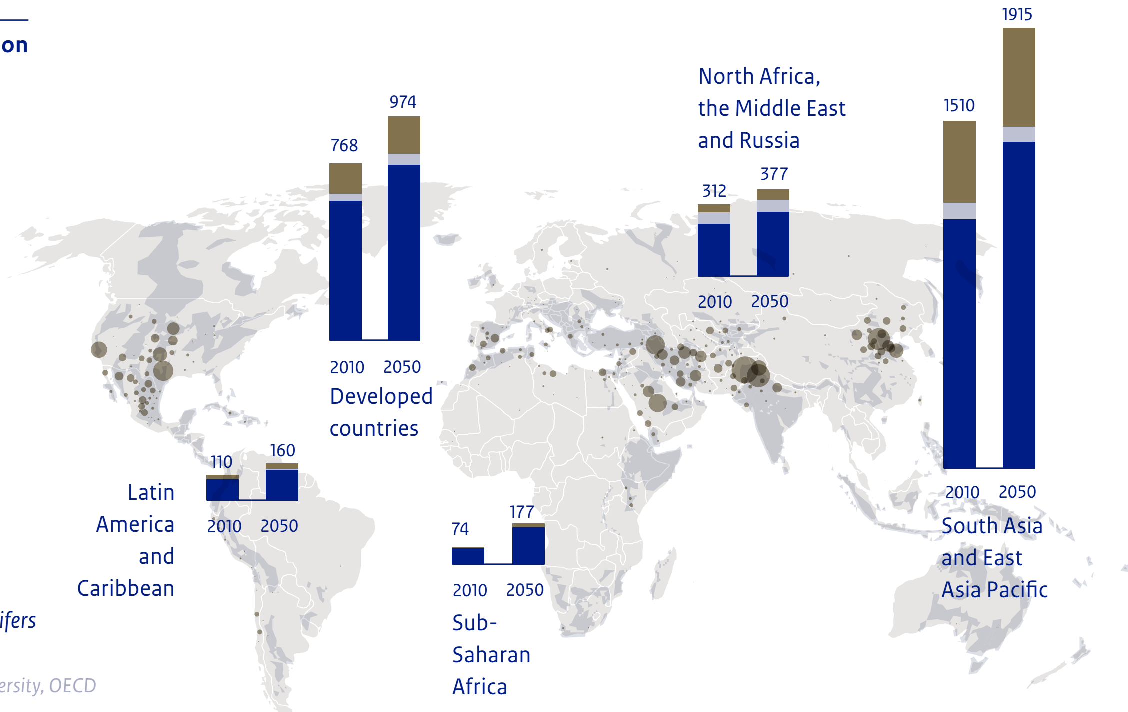
Water that is abstracted from lakes or rivers for irrigation may deplete them to such a degree that, in dry seasons, river flows hardly reach the coast and salt water intrudes into river mouths. This negatively affects the quality of aquatic ecosystems. Depletion of non-renewable groundwater reserves is a serious problem, threatening the supply of irrigation water and, thus, food production. In the United States (Ogallala Aquifer in the Great Plains), Indo-Gangetic Plain, Iran, China (Manchurian Plain), and Saudi Arabia, water is mostly abstracted from non-renewable aquifers. Water is crucial for irrigated agriculture, in all of these regions.

Water abstraction for agriculture (km³) 2050

- *From rivers and lakes*
- *From non-renewable groundwater*
- *From renewable groundwater*

Abstraction from non-renewable aquifers (km³)

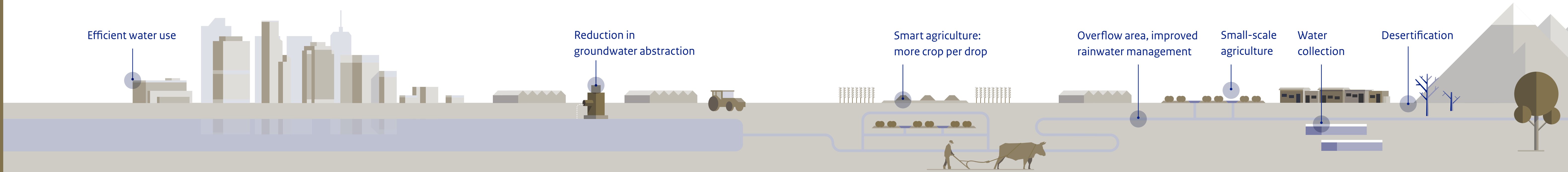
- *6 km³*
- *Overexploited aquifers*



Source: Utrecht University, OECD

Solutions

Improvements in land and water management (e.g. rainwater collection, increased irrigation efficiency and water storage capacity) as well as changes in crop types and allocation of water and land to agricultural producers may decrease the impact of water shortages.



WATER POLLUTION AND HUMAN HEALTH

DIRTY WATER: A THREAT TO HUMAN HEALTH

Although major improvements have been made, globally, one in eight people still lack access to clean drinking water, and one in three lack adequate sanitation facilities.

Lack of access to clean drinking water and lack of sanitation are two of the major causes of human illness and mortality. In combination, their impact leads to almost 800,000 human deaths, annually, in low- and middle-income countries. This is far more than the number of annual casualties from flooding, drought, or violent conflict.

Challenges

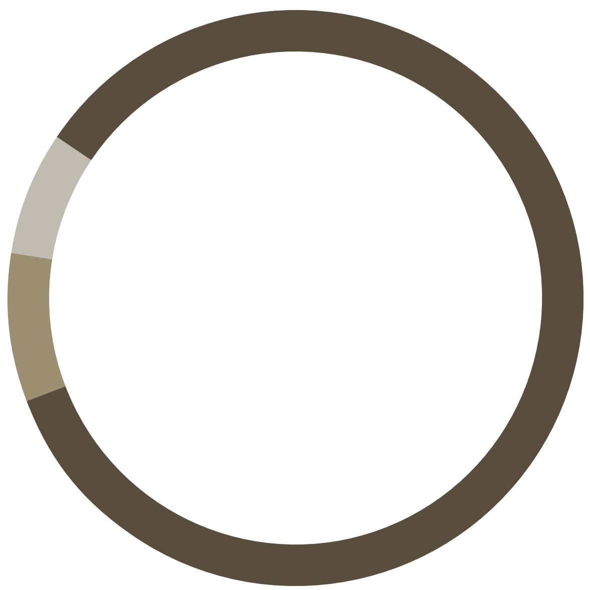
A century ago, the dominant flow for nutrients was their reuse in agriculture. Today, nutrients mostly end up in surface water. The increase in nutrient emissions may lead to algal blooms and deoxygenation, affecting the ecological quality as well as economic activities in these waters, such as fisheries, aquaculture and tourism.

Average number of deaths per year, 1980–2015
x 1,000

63
Natural disasters

75
Conflicts

780
Unsafe water

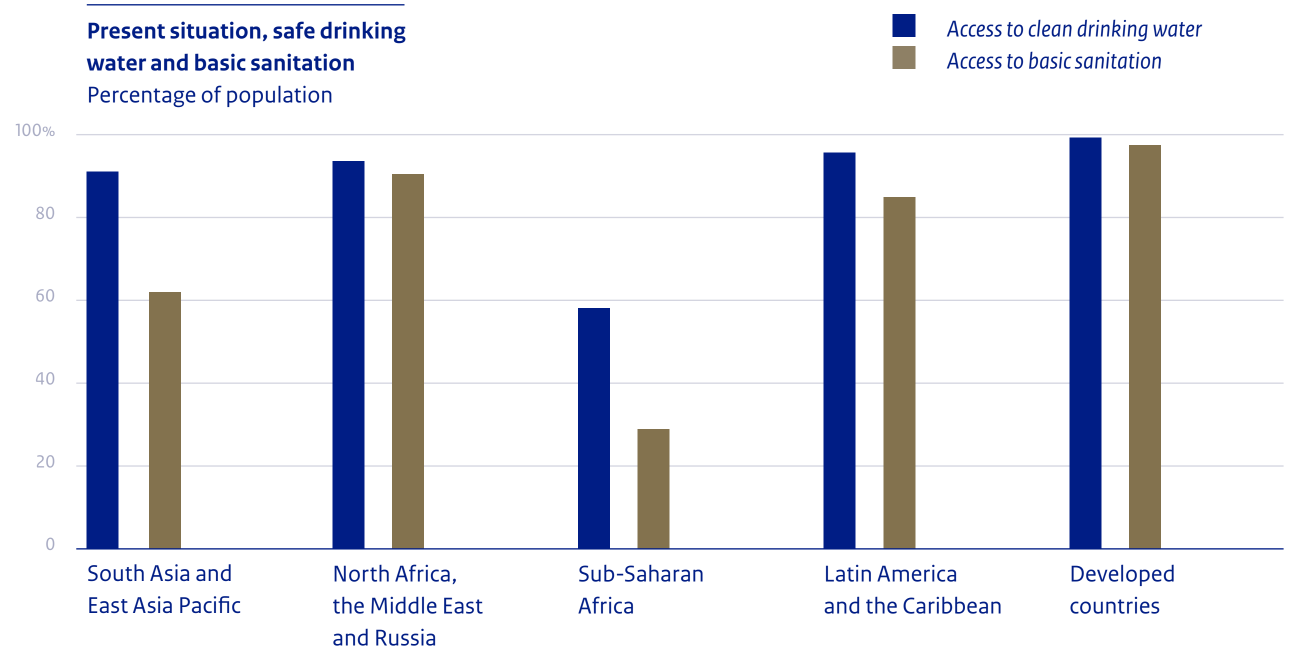


Source: CRED, WHO

One in eight people in the world have no access to clean drinking water and almost one in three lack basic sanitation facilities
Although access to clean drinking water and sanitation facilities has improved over the last decades, large differences remain between world regions. For instance, although since 1990, 2.6 billion people have gained access to clean drinking water, today 660 million people are still without, especially in Sub-Saharan Africa.

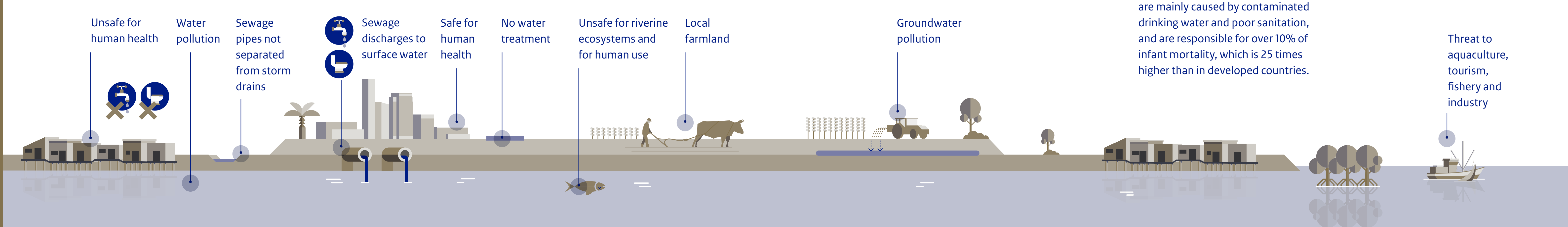
In addition, at least 1.8 billion people around the world use a drinking water source that is faecally contaminated. Improving sanitation in Asian and African countries is one of the major challenges, for the coming decades.

Present situation, safe drinking water and basic sanitation
Percentage of population



Source: WHO, Unicef

In Africa, diseases such as diarrhoea are mainly caused by contaminated drinking water and poor sanitation, and are responsible for over 10% of infant mortality, which is 25 times higher than in developed countries.

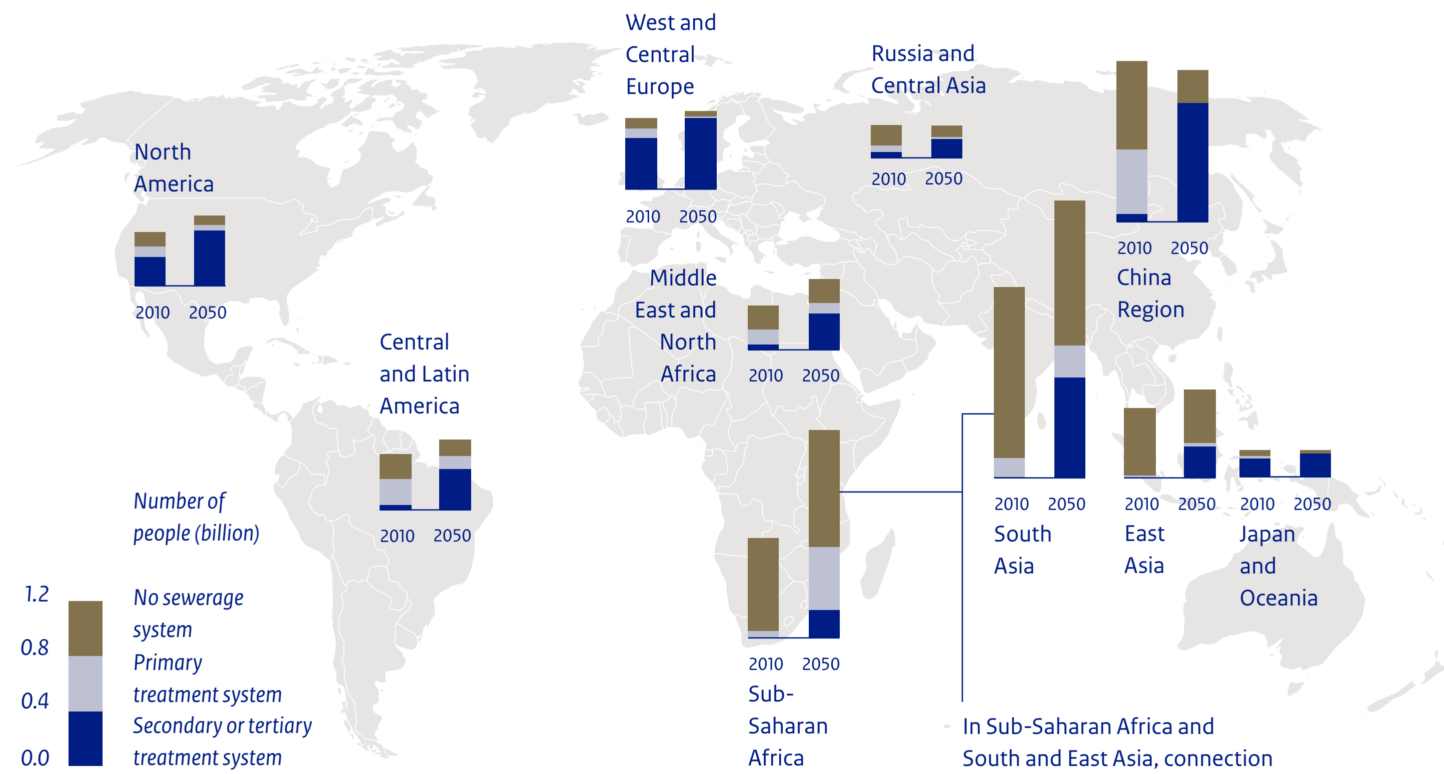


ACCESS TO DRINKING WATER AND SANITATION IMPROVES

Under the Business-as-usual scenario, by 2050, many more people are projected to have improved access to clean drinking water and sanitation. Sub-Saharan Africa and South and East Asia, though, may not be able to keep up with their fast population growth.

Under the Business-as-usual scenario, continued economic development will lead to more access to clean drinking water and further improved sanitation in most regions of the world. By 2050, only in Sub-Saharan Africa and South and East Asia, a substantial part of the population is projected to still be without adequate sanitation. The development of sanitation and wastewater treatment systems cannot keep up with the rapid increase in population and urbanisation.

Sewerage system connection and wastewater treatment



In Sub-Saharan Africa and South and East Asia, connection to sewerage and wastewater treatment systems is projected to lag behind.

Source: PBL

Sanitation without wastewater treatment: good for people, not for aquatic ecosystems
In developing countries, usually, there is a great difference in sanitation facilities between formal and informal settlements. In formal settlements, with adequate sanitation facilities, people generally are far less exposed to polluted water and pathogens, because a larger percentage of human waste is safely contained in septic tanks or removed by sewerage systems. The informal settlements of Lima hardly have any safe sanitation facilities.

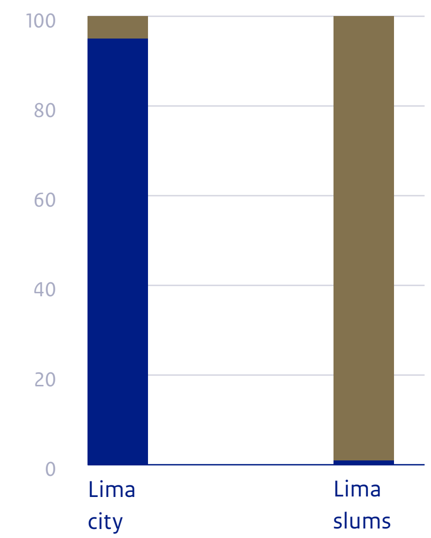
The importance of safe containment

% human waste safely/unsafely contained

Safe for people
Questionable
Unsafe for people

Source: World Bank

Adequate sanitation – good for people...



If sewerage systems are not combined with adequate wastewater treatment systems, the loading of nutrients and polluting substances to surface waters will increase. This will affect both ecological quality and ecosystem services (pp. 70–71). In informal settlements where pit latrines are used, the waste is not discharged to surface water.

The importance of safe discharge

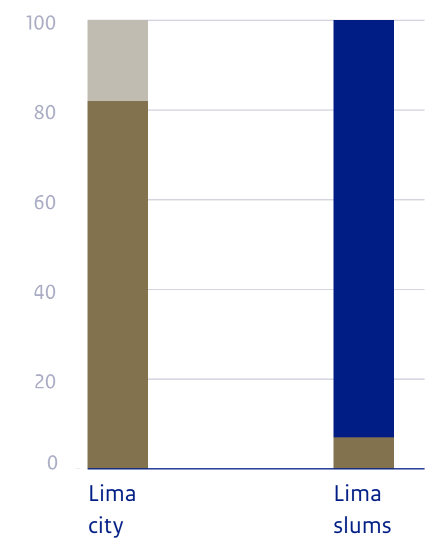
There would be less pressure on eco-systems if a higher percentage of human waste would be discharged safely.

% of human waste discharged safely/unsafely

Safe for ecosystems
Questionable
Unsafe for ecosystems

Source: World Bank

... but without adequate treatment, bad for aquatic ecosystems

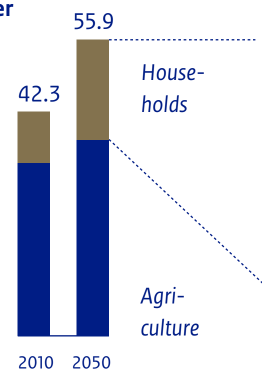


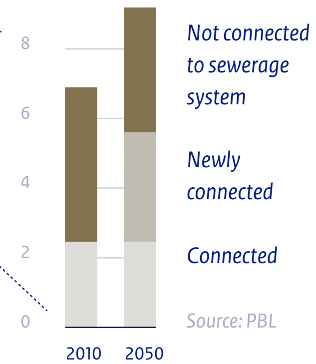
NUTRIENT EMISSIONS ON THE INCREASE

The emission of nutrients (nitrogen and phosphorus) to rivers, lakes and coastal seas has a negative impact on water quality and ecological quality and may affect economic functions, such as aquaculture, fisheries and tourism.

Nutrient emissions to surface water
In billion kg

Under the Business-as-usual scenario, a total increase in nutrient emissions of 25% from agriculture and households is projected for 2050. The increase in emissions from agriculture is estimated at around 10%; from cities at 100%.





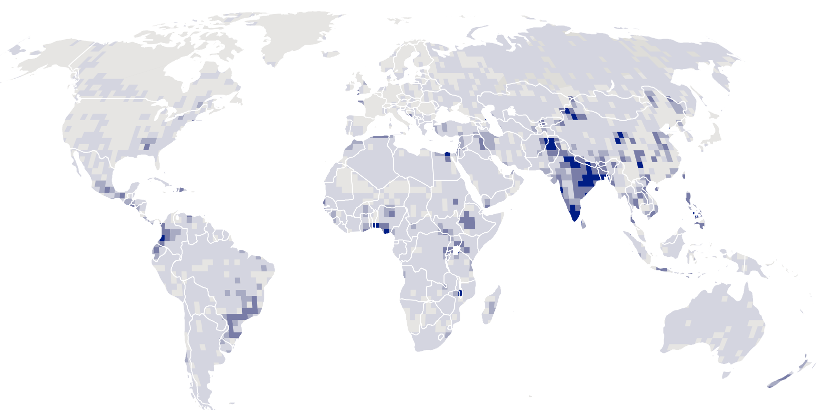
Number of people connected to a sewerage system is increasing
In billions

Nutrient emissions from households may almost double if the projected additional 3 billion people are connected to sewerage systems without adequate wastewater treatment.

For most regions, nutrient emissions to surface waters are projected to increase, with hotspots in South and East Asia, parts of Africa and Central and Latin America. The rapidly growing cities in the developing countries are projected to become major sources of nutrient emissions.

Increase in nutrient emissions to surface water 2010–2050

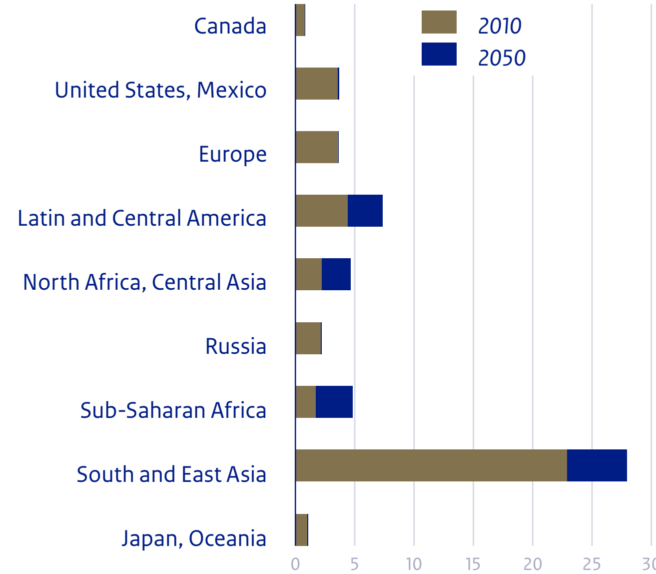
From agriculture and households, in kg / km²



>2,500
1,000–2,500
500–1,000
<500
Decrease

Source: PBL

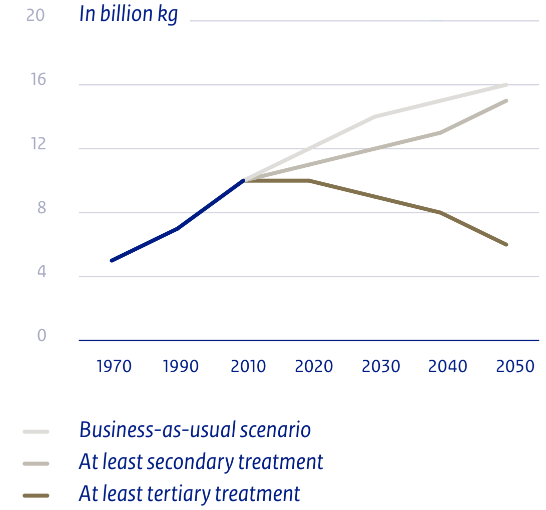
Total nutrient emissions to surface water
From agriculture + cities, in billion kg



Source: PBL

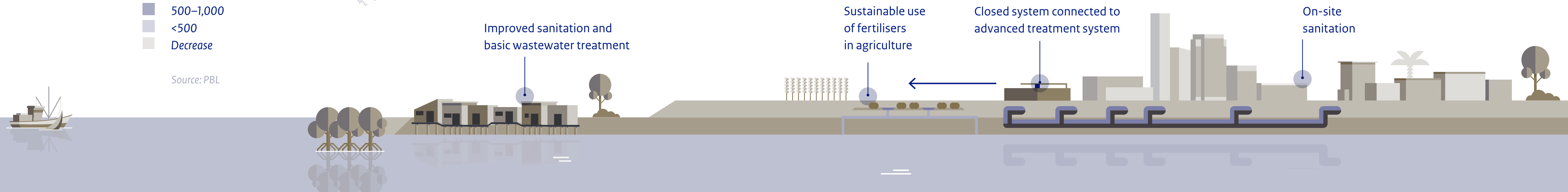
Reducing emissions from cities
Investments in wastewater treatment are required to reduce the additional emissions resulting from the connection of 3 billion people to the sewerage systems. There are three categories of wastewater treatment systems: primary treatment (average nutrient removal of 10%), secondary treatment (40%) and tertiary treatment (85%). Nutrient emissions are projected to decline only through the installation of tertiary treatment systems.

The impact of wastewater treatment on urban nutrient emissions
In billion kg



Source: PBL

Solutions
An option for improving wastewater quality is to combine wastewater collection with wastewater treatment to avoid the discharge of untreated waste water, and contribute to the reuse of nutrients in agriculture. For rural areas, on-site sanitation and better management of faecal sludge may be promising options. Sustainable use of fertilisers can reduce emissions from agriculture.

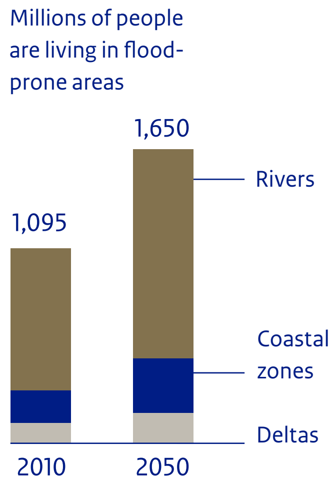


FLOODING

STRONG INCREASE IN POTENTIAL FLOOD RISKS

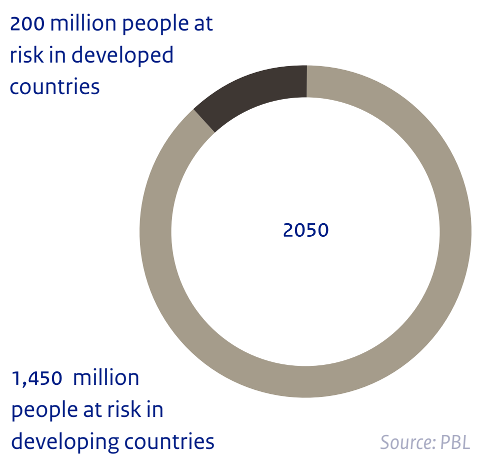
In 2010, around 1 billion people around the world were living in flood-prone areas, potentially exposed to either river or coastal flooding. This number is projected to increase to over 1.6 billion by 2050.

People living in flood-prone areas
2010–2050: The Business-as-usual scenario projects a 30% increase in the number of people potentially exposed to flooding and a threefold increase in economic damage. Many more people are potentially exposed to river flooding than to coastal flooding.



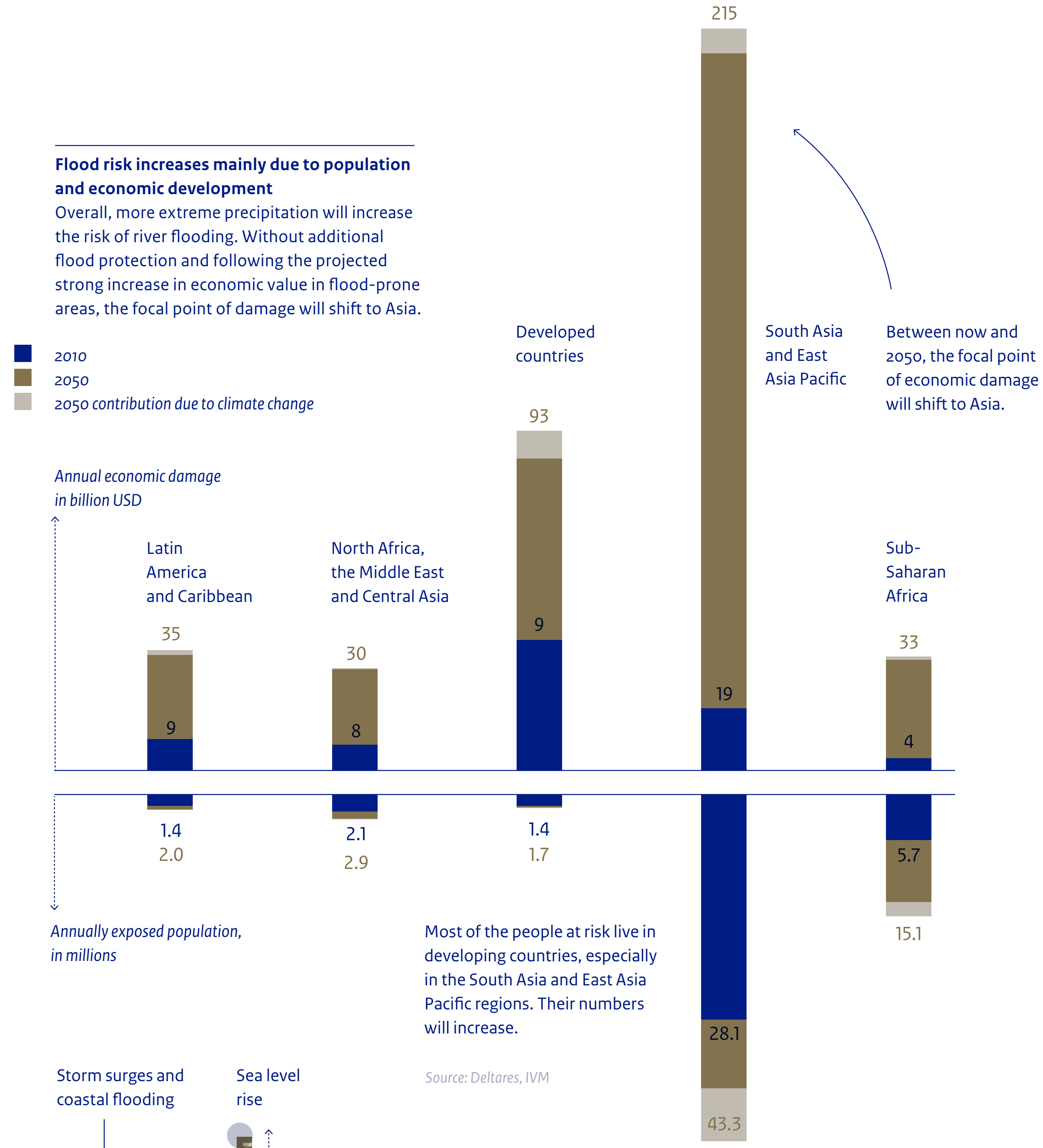
Source: PBL

Risks for people are unequally distributed
While the developed countries will face most of the economic damage, the majority of people at risk live in developing countries.



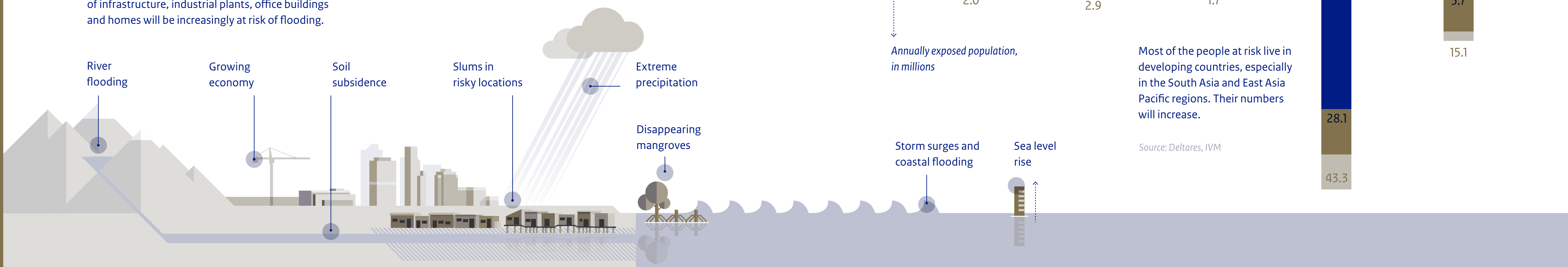
Source: PBL

Flood risk increases mainly due to population and economic development
Overall, more extreme precipitation will increase the risk of river flooding. Without additional flood protection and following the projected strong increase in economic value in flood-prone areas, the focal point of damage will shift to Asia.



Source: Deltares, IVM

Challenges
As urban areas expand, trillions of dollars worth of infrastructure, industrial plants, office buildings and homes will be increasingly at risk of flooding.



CITIES: FLOOD-RISK HOTSPOTS

Between now and 2050, the economic damage and the number of people potentially exposed to flooding will increase, especially in the rapidly growing cities in the developing countries.

Large cities are found along rivers, in deltas and along the coast. Concentrations of population and economic value in coastal zones and deltas increase not only the short-term flood risks, but also the long-term vulnerability with respect to sea level rise and storm surges. This will require continued protection efforts. The required protection will depend on population and economic developments in flood-prone areas, and developments in peak river flows, sea level rise and storm surge patterns.

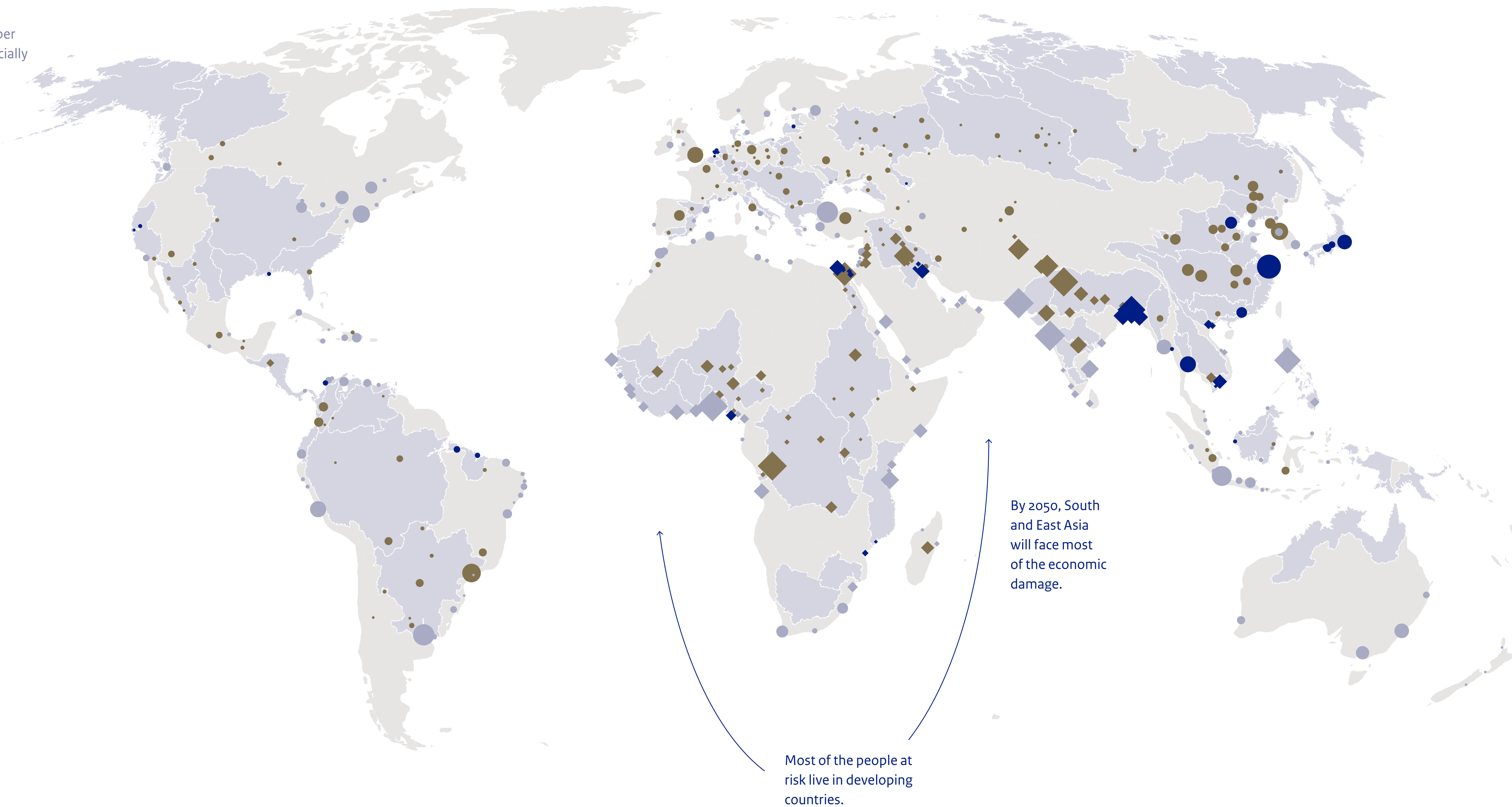
Rapidly growing delta, coastal and river cities

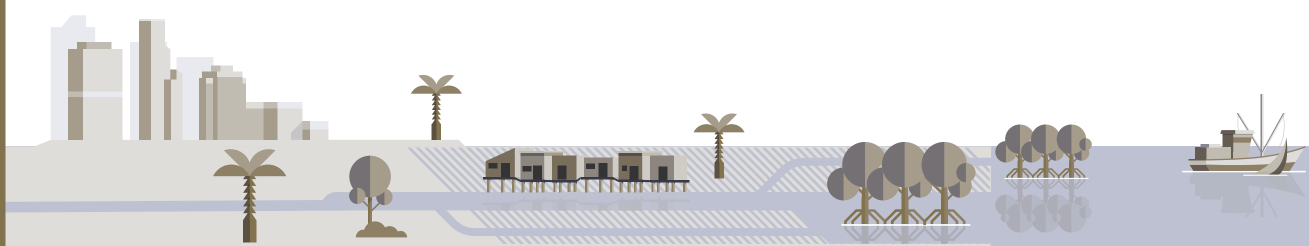
Rapidly growing delta city
Rapidly growing coastal city
Rapidly growing river city
Delta city
Coastal city
River city

Delta river basin

Diameter = relative size of urban population

Source: PBL



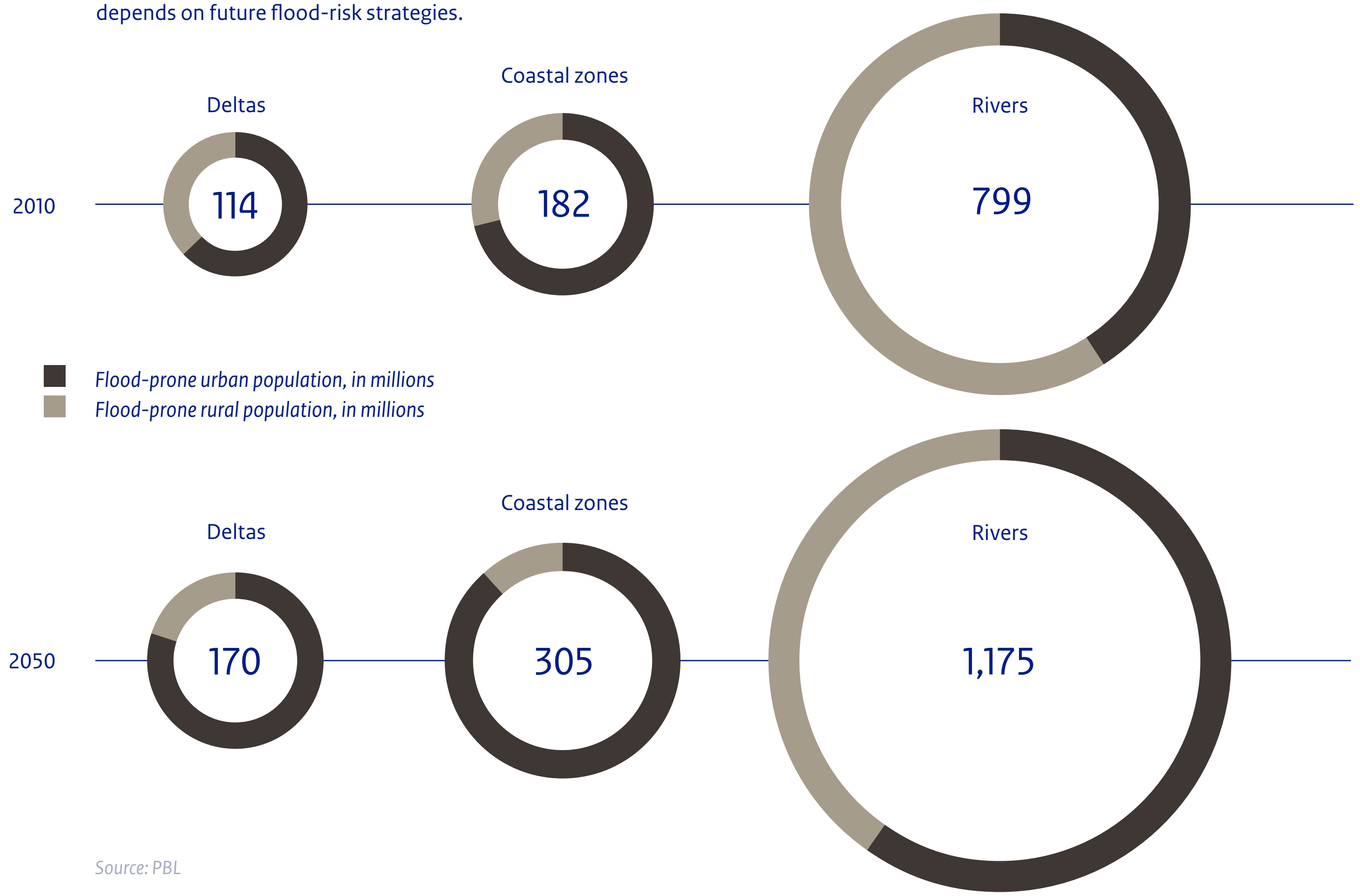


UNEQUAL FLOOD RISKS WITHIN CITIES

The number of people in flood-prone areas in the developing world is expanding rapidly. Without attention, flood protection inequality between urban formal and informal settlements will increase.

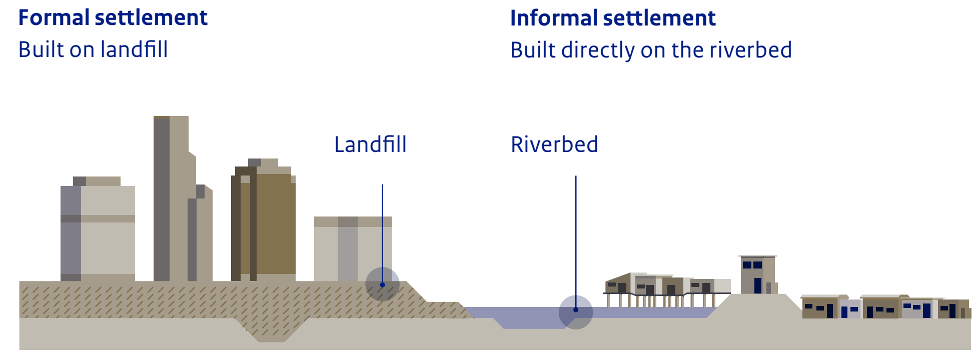
Global population growth will concentrate in cities
Globally, the population is increasingly concentrated in cities, most of which are located near rivers or the coast. This trend is projected to continue, between now and 2050. How flood risks and protection of formal and informal settlements will develop, depends on future flood-risk strategies.

Most people potentially exposed to flooding live in cities along rivers.

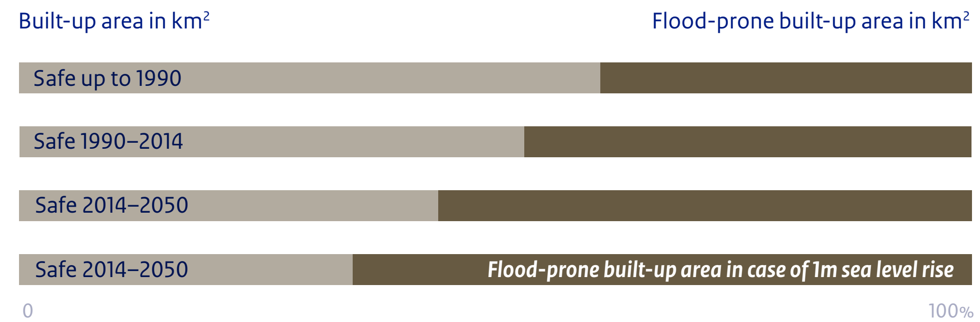


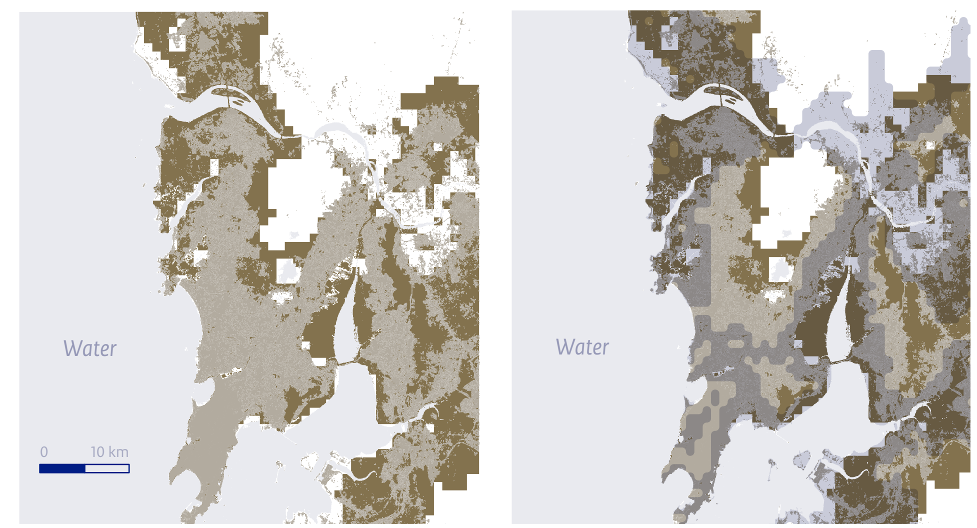
Source: PBL

Informal settlements are the most exposed
In many cities, especially in developing countries, the inhabitants of informal settlements make up more than 50% of the urban population. Water- and climate-related disasters disproportionately affect people living in informal settlements.



Built-up and flood-prone areas in Mumbai
From 1990 to 2014, the built-up area of Mumbai expanded by 26%, with a relatively large share of the expansion in flood-prone areas. This trend is projected to continue towards 2050, by which time around 60% of Mumbai will be located in flood-prone areas.
If sea levels would rise by one metre, the flood-prone area would become even larger and the number of people potentially exposed would increase further.



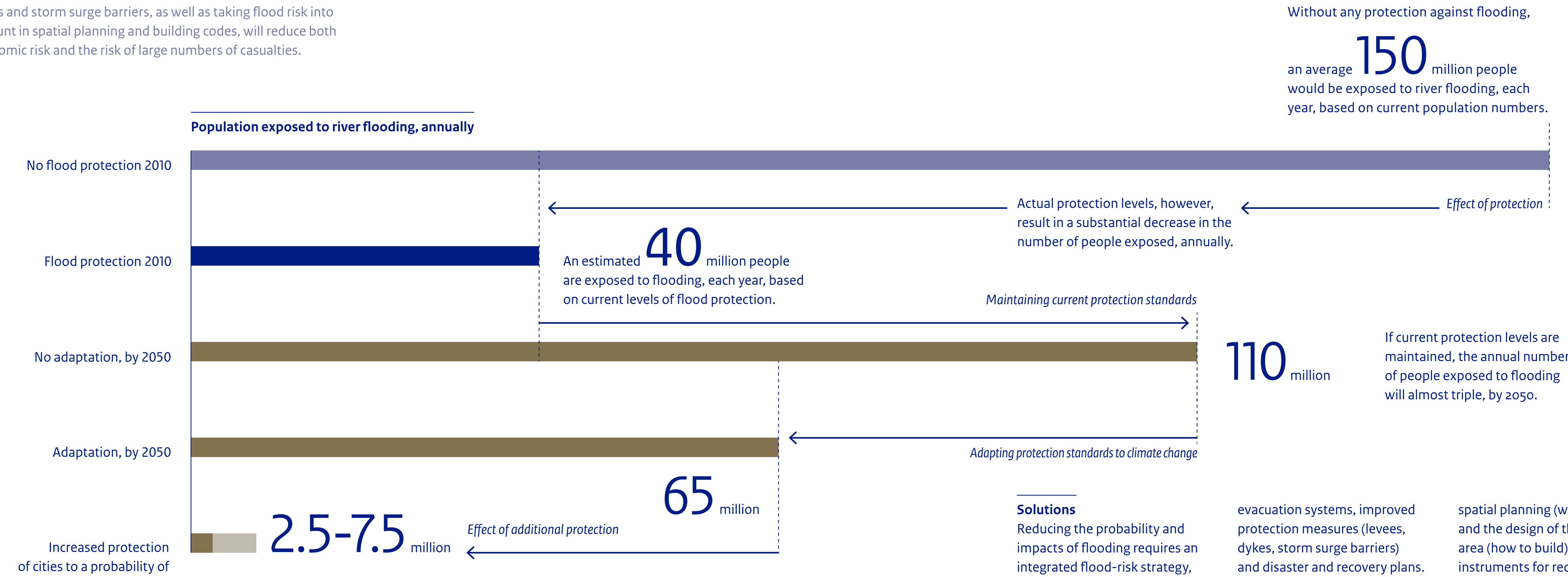


Built-up, up to 2014
2014–2050
Flood-prone area, 2050

Source: JRC, PBL

FLOOD PROTECTION PAYS OFF

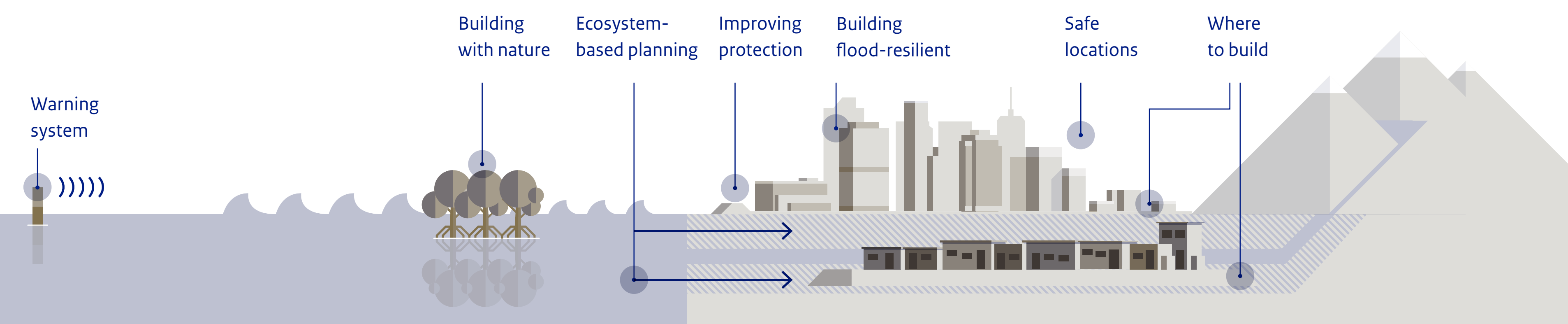
There are several ways to reduce flood risk. Investments in levees, dykes and storm surge barriers, as well as taking flood risk into account in spatial planning and building codes, will reduce both economic risk and the risk of large numbers of casualties.



Source: Deltares, IVM

Solutions
Reducing the probability and impacts of flooding requires an integrated flood-risk strategy, encompassing warning and evacuation systems, improved protection measures (levees, dykes, storm surge barriers) and disaster and recovery plans. Ecosystem-based approaches, spatial planning (where to build), and the design of the built-up area (how to build) are powerful instruments for reducing flood risks and future vulnerability.

Urban development is an opportunity to effectively reduce flood risk
If worldwide urban protection measures would be based on the probability of a flooding event occurring once every hundred to thousand years, this would strongly reduce the potential number of people exposed to flooding, annually.



WATER-RELATED ENERGY PRODUCTION

HYDROPOWER MAY INCREASE BY 80%

The Paris Climate Agreement will boost the use of renewable energy resources, which include hydropower and energy crops. Energy crop production may affect food production.

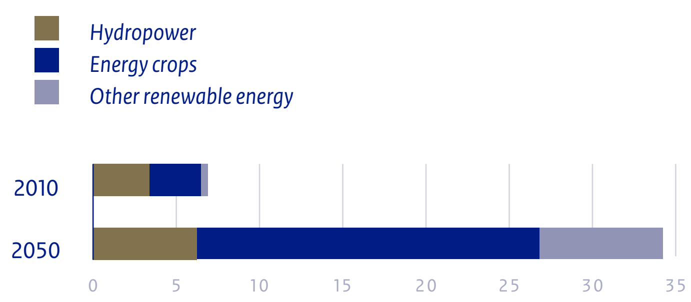
Role of renewable energy will at least triple
Under the Business-as-usual scenario, the global use of energy increases from 141 PWh in 2010 to up to 231 PWh by 2050 (+63%).

The share of renewable energy, such as hydropower, energy crops, wind and solar power, is projected to increase from 5% (7 PWh) to up to 15% (34 PWh). Under a more ambitious mitigation scenario, the total energy production by 2050 will be the same, but with a 45% (65 PWh) renewable share.

Challenges
Despite the renewable nature of hydropower and energy crops, these technologies also could have adverse social and ecological effects. Increased energy crop production may compete for water and land with local food production.

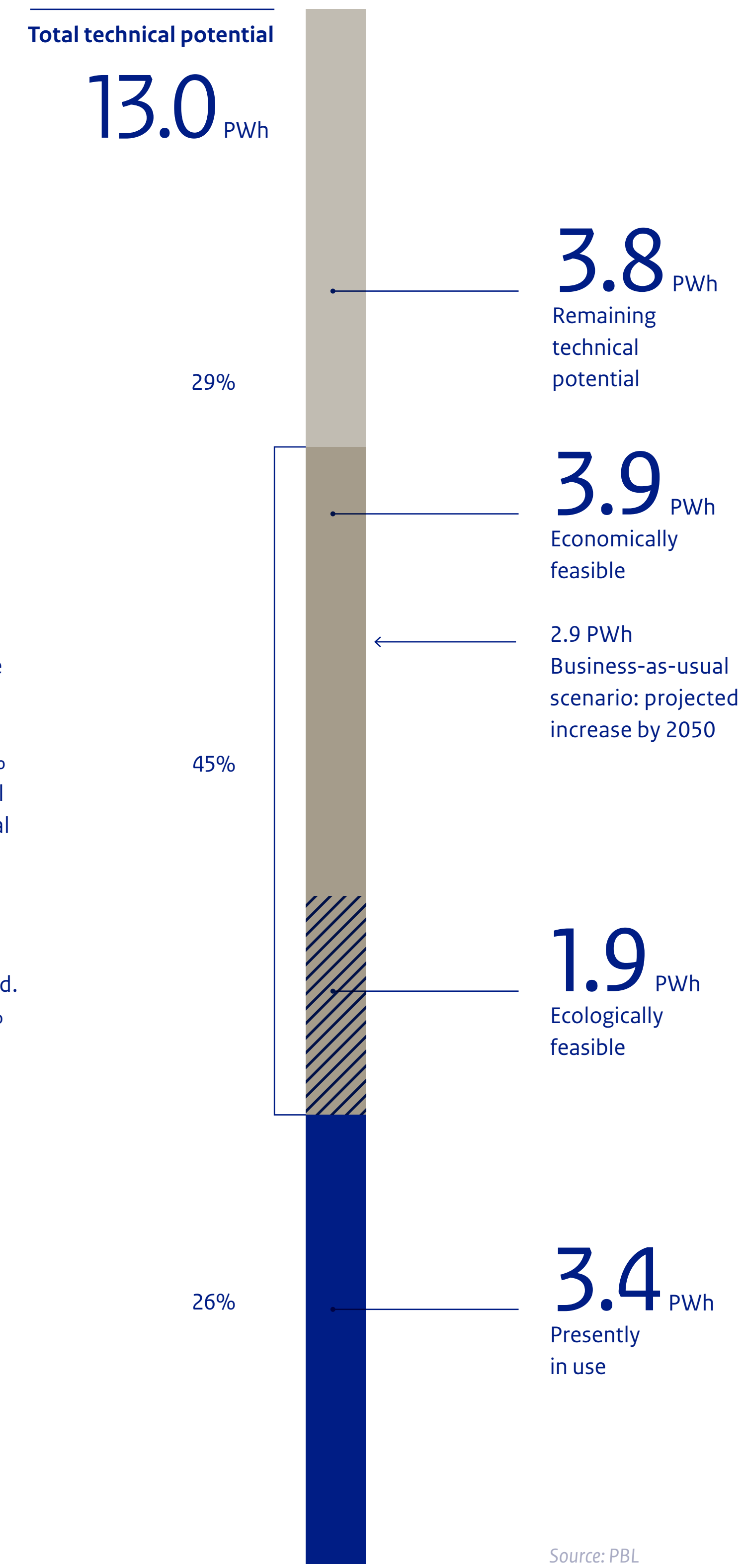
Strong increase in hydropower and energy crops
Under the Business-as-usual scenario, the hydropower production level indicated by the World Energy Council is projected to increase by more than 80% (+2.9 PWh) towards 2050, and energy crop production may increase sevenfold. Renewable energy for fuel and electricity is supplied by energy crops (60%), hydropower (18%), and from other renewable sources (22%). The global demand for renewable energy will increase in the rest of this century, resulting in more hydropower and energy crops, worldwide.

Use of renewable energy in fuel and electricity production in PWh

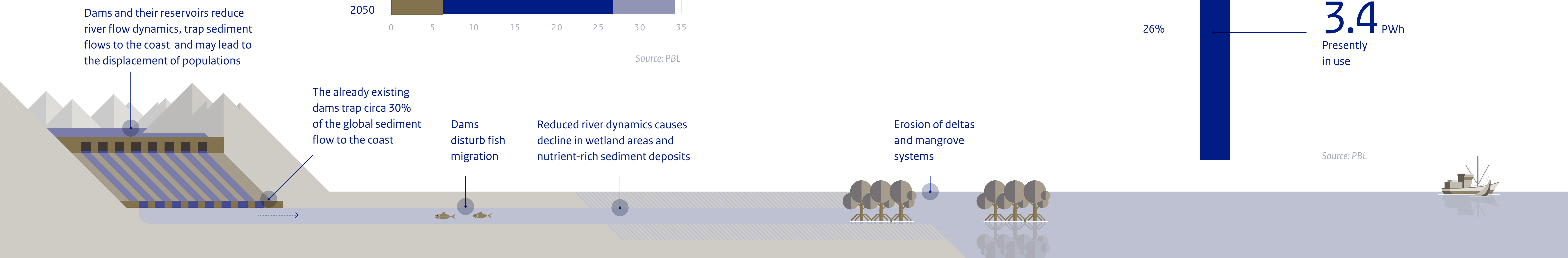


Source: PBL

26% utilisation of the total hydropower potential
In 2010, circa 26% of the hydropower potential was being utilised (3.4PWh). From an economic perspective, in the coming decades, hydropower production could increase by 5.8 PWh, the equivalent of 70% of the estimated total technical potential of 13 PWh. If ecological requirements with respect to river flow dynamics and fish migration would be leading, only 1.9 PWh (15%) of the economic potential could be utilised. In that case, globally, circa 40% of the technical potential of hydropower could be utilised.



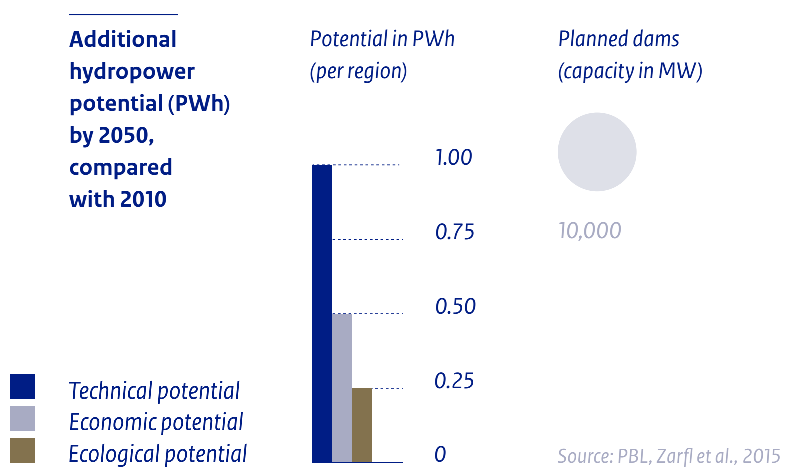
Source: PBL

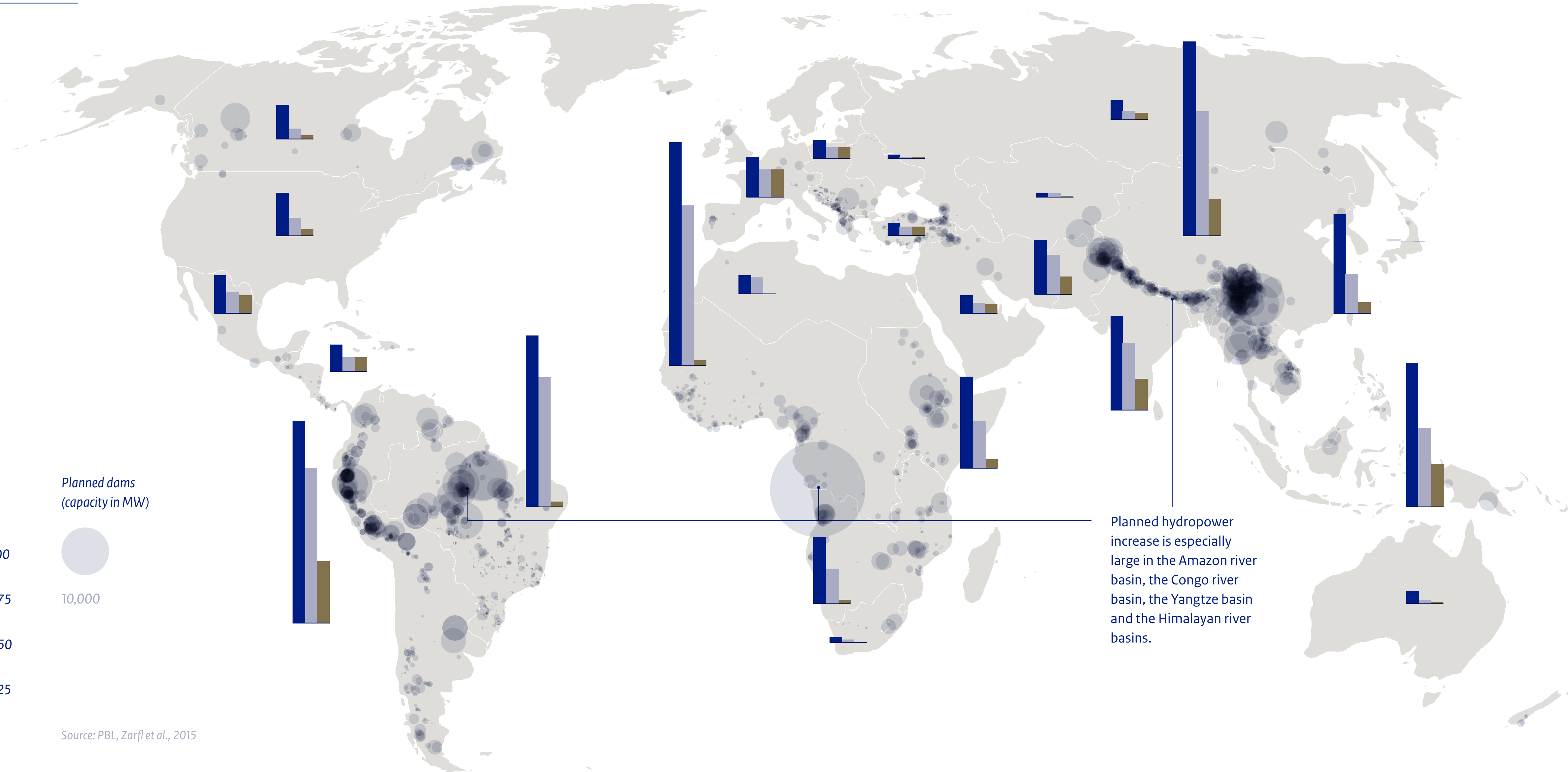


PLANS FOR 3700 NEW DAMS

In addition to the current 8600 larger dams, primarily designed for hydropower, 3700 new dams are planned, each with more than 1 MW capacity, over 500 of which are already under construction.

Ecological requirements would substantially lower hydropower potential, in many places around the world. This is especially the case for the river systems of high ecological quality of the Amazon and Congo, where hydropower potential would be close to zero if ecological quality is to be preserved. If all economic potential would be utilised, an estimated 8 million people could be at risk of displacement.





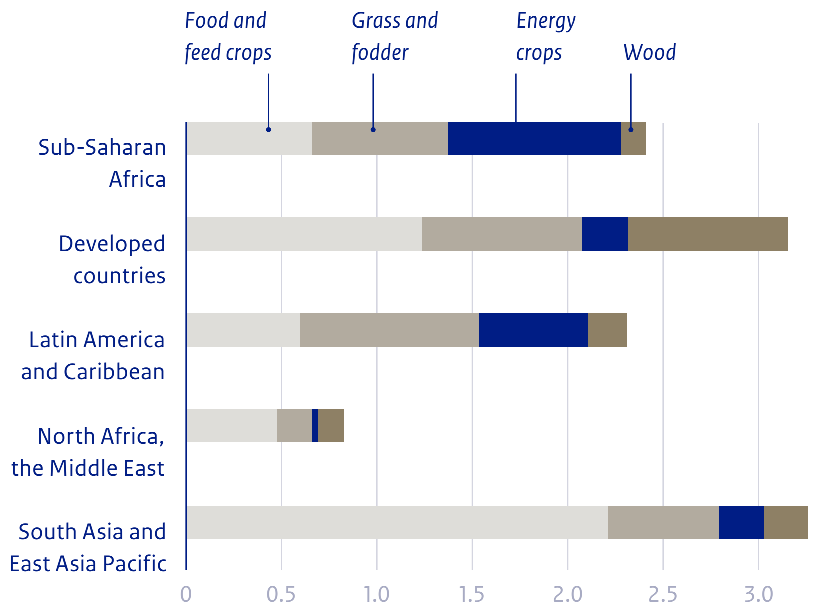
STRONG INCREASE IN ENERGY CROP PRODUCTION

Under the Business-as-usual scenario, global production of energy crops between 2010 and 2050 is projected to increase from 0.1 million tonnes dry matter, per year, to 2 million tonnes, supplying about 9% of the global energy production.

The projected increase in energy crop production would result in substantial claims on land. Energy crop production would cover 5% of the arable land in Sub-Saharan Africa, 6% in Latin America, 15% in South and East Asia, and 6% in Australia.

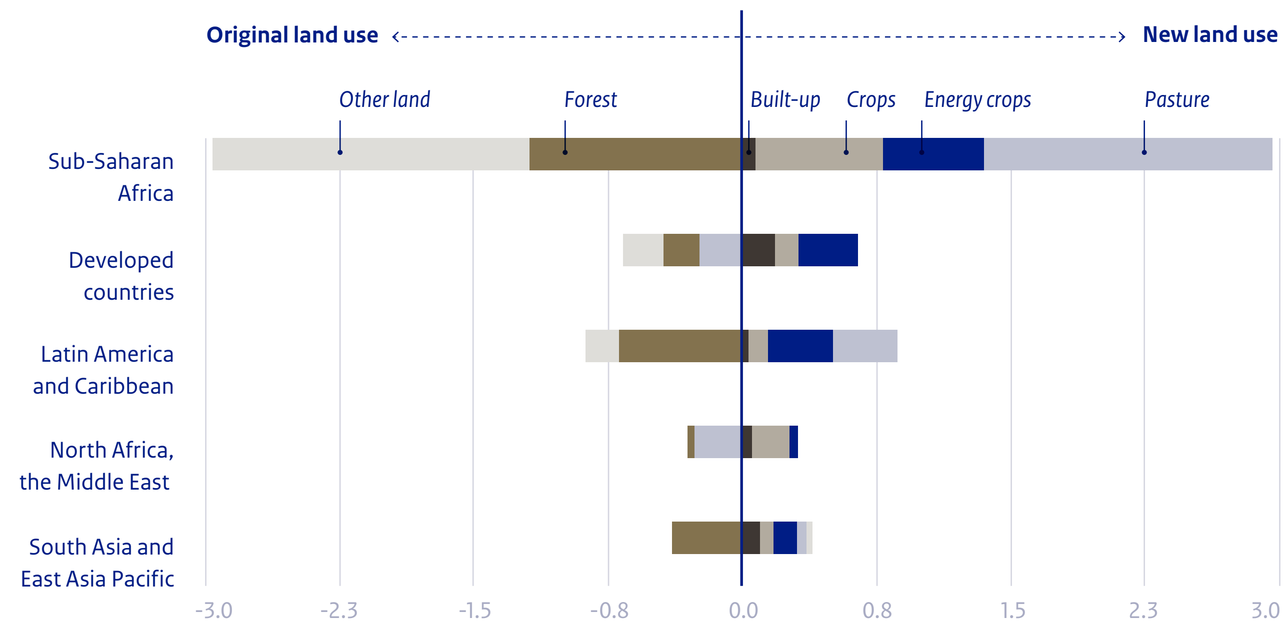
The major regions for energy crop production under the Business-as-usual scenario are Sub-Saharan Africa and Latin America, together encompassing around three quarters of total energy crop production. The competing pressures on land and water are most prominent in these regions.

Agricultural production, per region, 2050
Million tonnes dry matter, per year



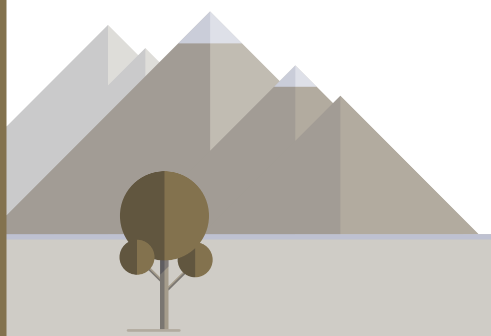
Source: PBL

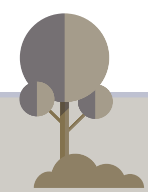
Land-use change
2010–2050, in million km²

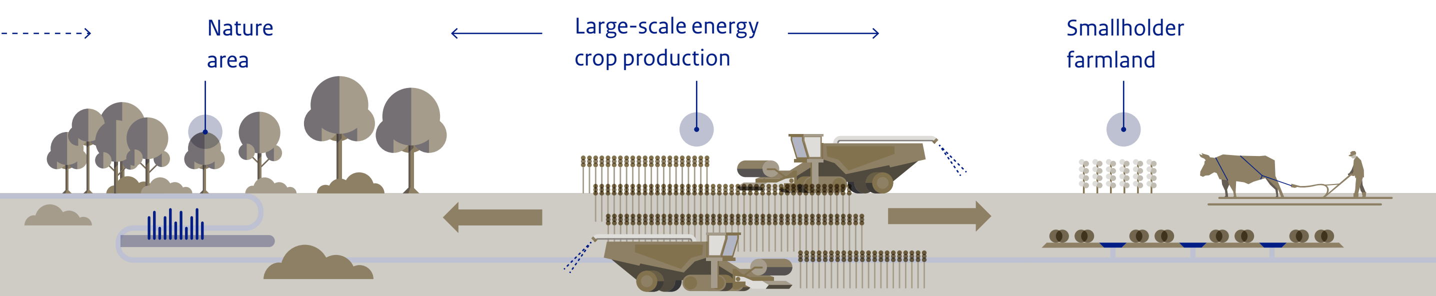


Source: PBL

Competition
Land use is projected to change. In all regions, more land will be used for growing food and energy crops, at the expense of forest and other nature areas. The production of energy crops could be competing with other types of land use, such as food production and nature.





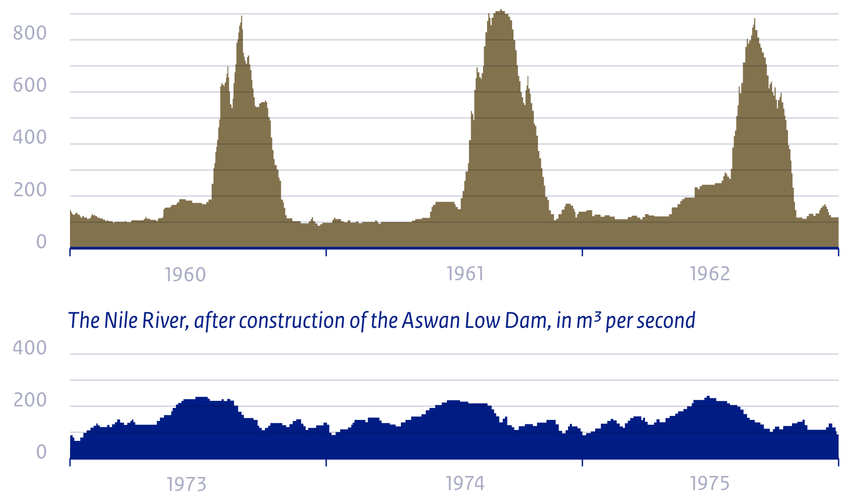


THE DOWNSIDE OF DAMS AND ENERGY CROPS

Using the potential of hydropower and energy crops may interfere with the functioning of land and water ecosystems, and land used for food production.

More dams will further affect rivers and coasts, and displace people
The projected 3700 new dams towards 2050 will further disturb river flow dynamics and fish migration, and trap sediment flows to coastal areas and deltas. The dams, thus, will have a negative impact on river ecology and the reduced sediment flows may result in increased erosion of coasts, deltas and mangrove systems. Around eight million people may face displacement, if all economic potential of global hydropower would be exploited using dams with reservoirs.

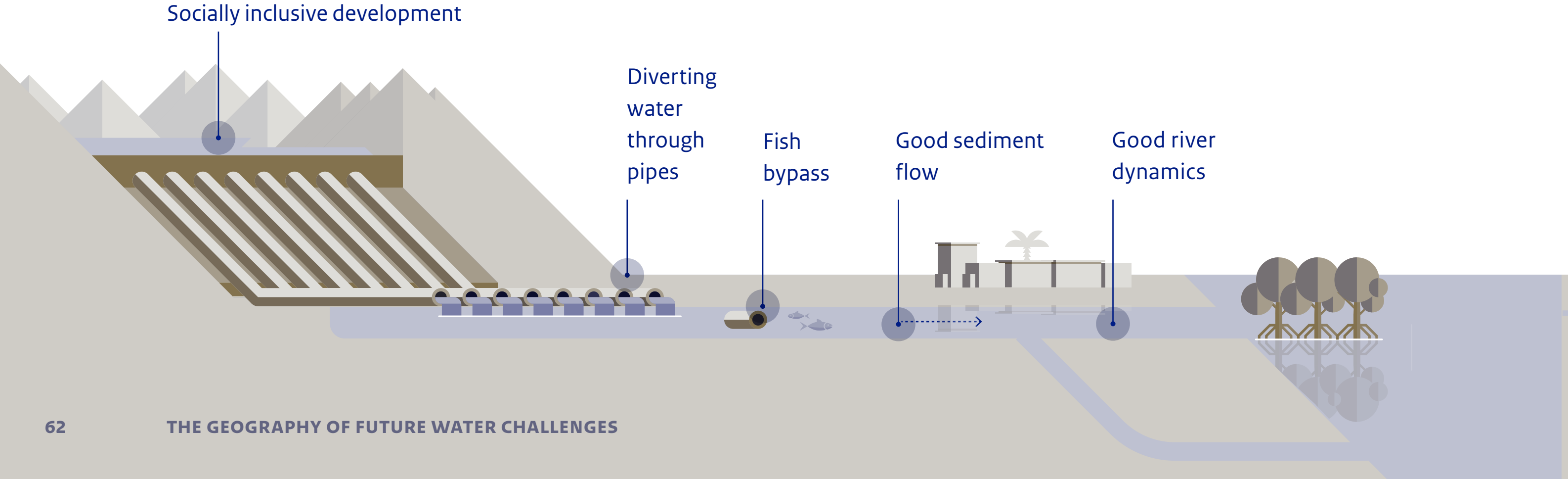
Seasonal river flow dynamics disappear
The Nile River, location of the Aswan Low Dam in Egypt –before its construction– in m³ per second



Source: Beaumont et al., 1988

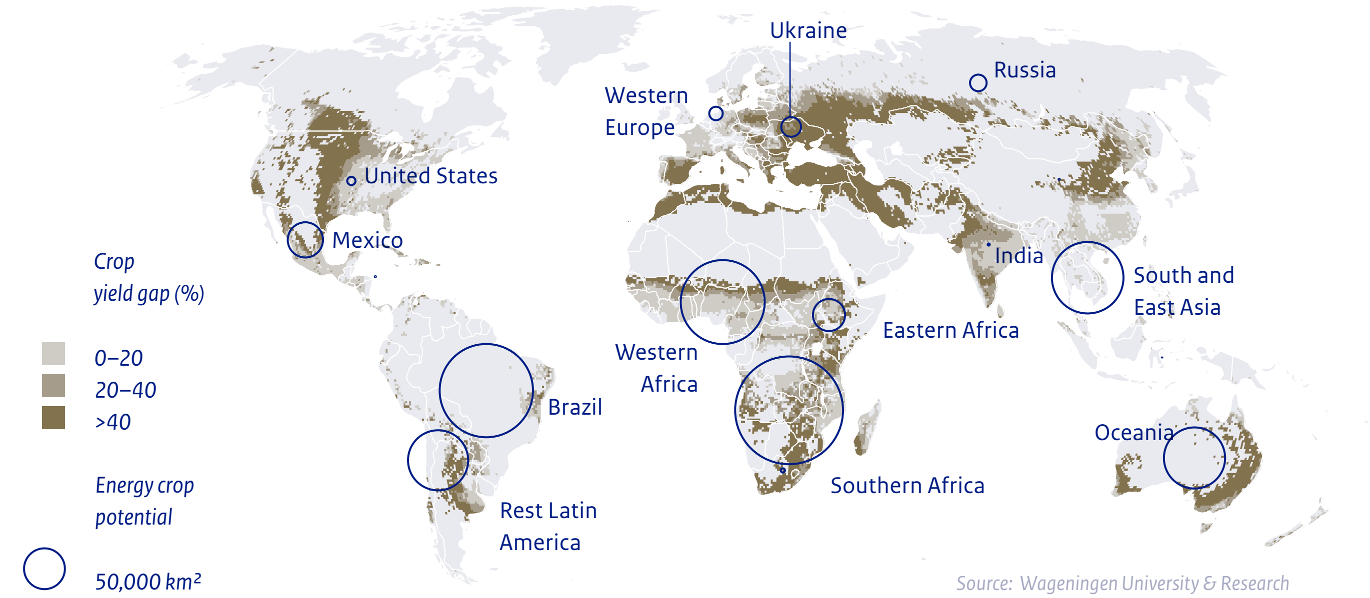
Solutions hydropower
Diverting water through pipes, without creating a reservoir, would be much more environmentally and socially friendly, although it would be less efficient. Where reservoirs are required, fish traps and an ecologically oriented water management could reduce negative ecological impacts.

Negative social impacts can be reduced by a participative approach and social inclusive development providing adequate compensation and new opportunities.



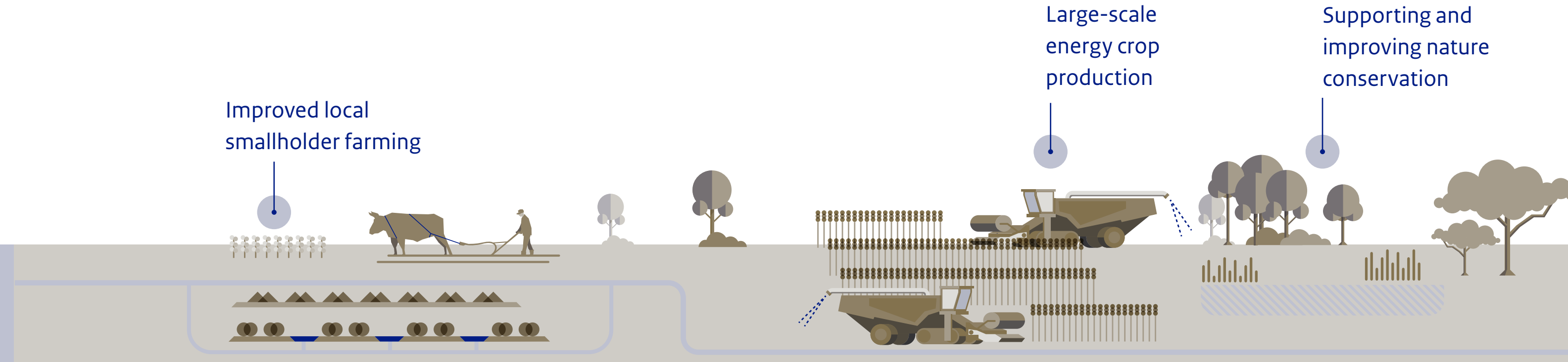
Potential interference by energy crop production in food production in water-scarce areas, by 2050

In particular, in Africa and Latin America, attention needs to be paid to the prevention of competition for land and water between energy crop production, local food production and nature; especially in areas where agricultural production levels already are low,or where water availability for agriculture is already under pressure.



Source: Wageningen University & Research

Solutions energy crop production
Large-scale energy crop production needs to prevent the infringement of land and water rights of the local population and improve water management in the area. It requires an ecological and socially inclusive approach, addressing local qualities and impacts and providing adequate compensation and new opportunities for the local population.



ECOLOGICAL QUALITY OF AQUATIC ECOSYSTEMS

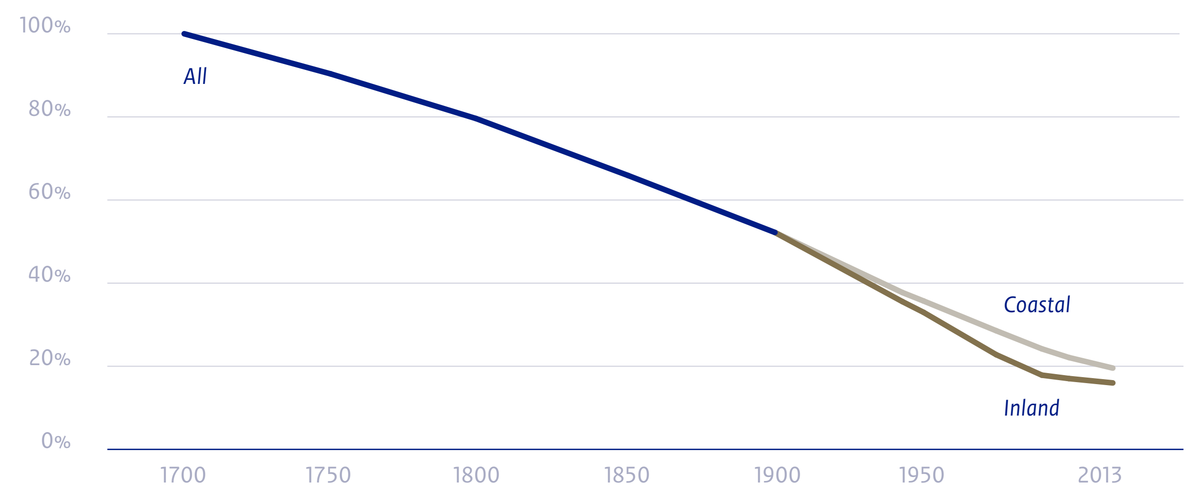
AQUATIC ECOSYSTEMS UNDER PRESSURE

High quality ecosystems contribute to people's health and quality of life. They purify and preserve water, store carbon, mitigate flooding, and deliver foods and fibres.

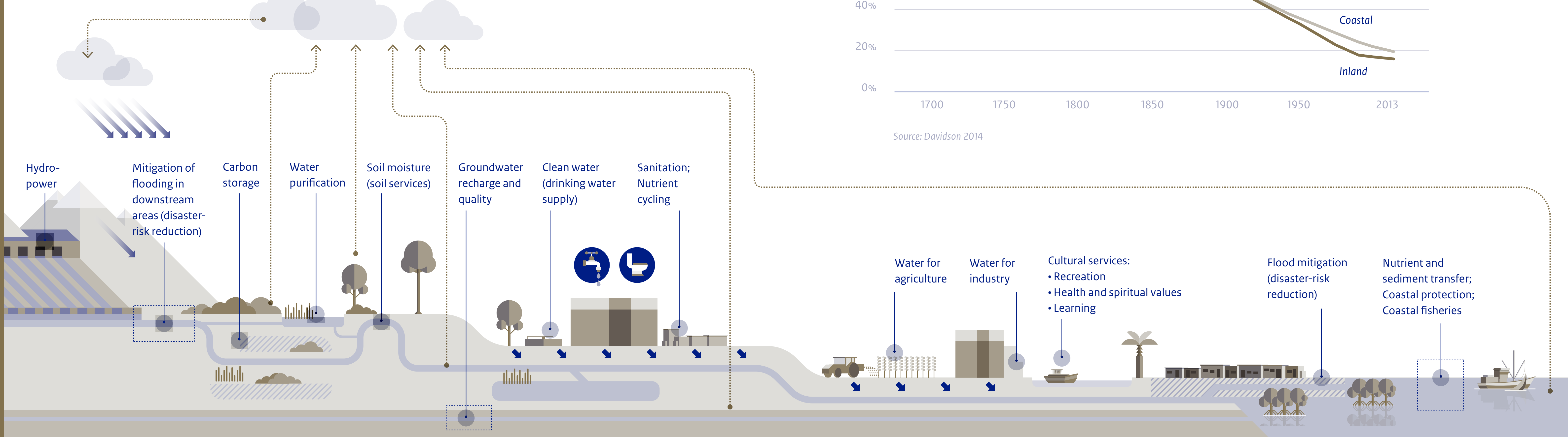
Challenge
Quality and functioning of aquatic ecosystems are influenced by developments in river basins and deltas: urbanisation, agricultural production, water abstraction for irrigation, industries and drinking water, dams constructed for hydropower, and water pollution caused by emissions from agriculture, households and industries. Apart from biodiversity loss, ecosystem services may also deteriorate, such as clean drinking water, irrigation water, fish resources, carbon storage, recreation, and natural flood protection. The negative aspects of these developments particularly affect people who depend on natural resources for their lives and livelihood.

Strong decline in wetland area
Wetlands belong to some of the most productive and biodiverse habitats and are of great importance for the functioning of aquatic ecosystems. About 80% of the world's wetlands, both inland and coastal, have already disappeared since 1700, and this loss is still continuing. The main causes are the reclamation of wetlands for agriculture and urban development, canalisation for shipping, and the construction of dams that reduce the inundation of wetlands and affect natural river flow. Wetland loss also means loss of carbon storage.

Remaining natural wetland area



Source: Davidson 2014



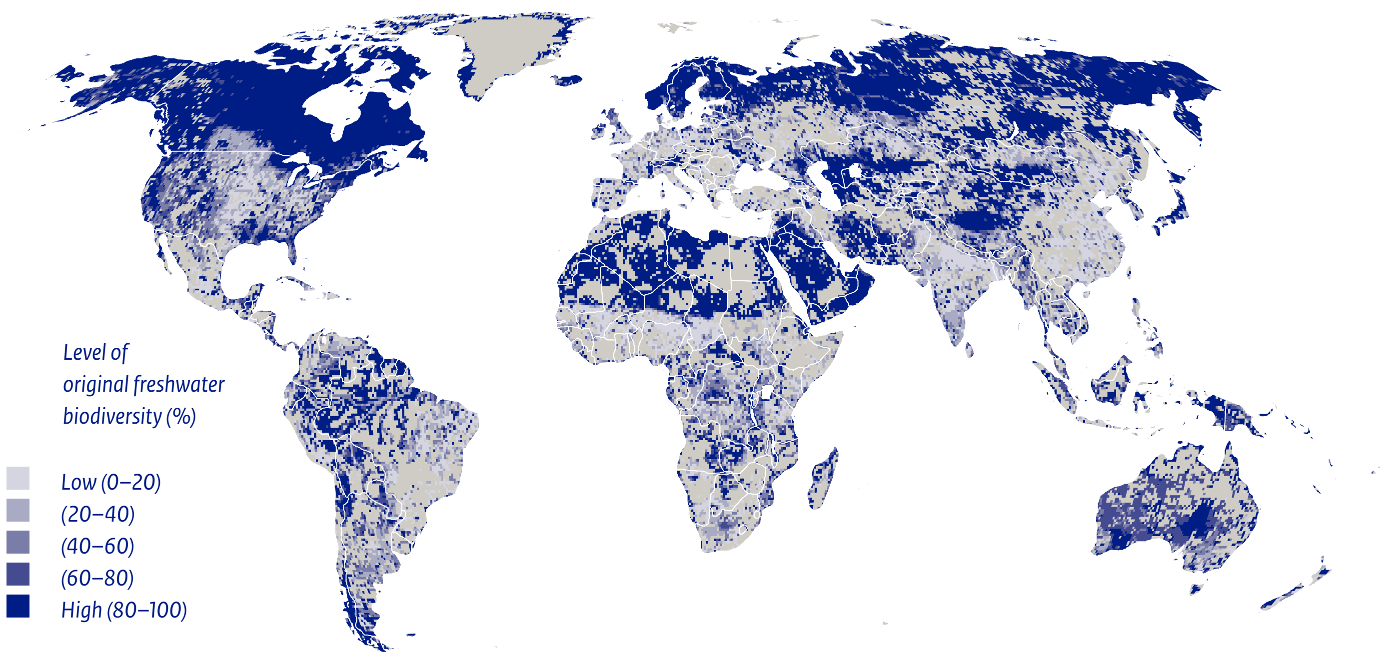
FURTHER BIODIVERSITY LOSS TOWARDS 2050

Under the Business-as-usual scenario, developments will result in further biodiversity loss in nearly 40% of the world's freshwater ecosystems.

Decrease in freshwater ecosystems with high levels of biodiversity
Tropical regions include the most biodiverse river basins. High-quality ecosystems in these regions, however, are already severely affected and will further decline in quality, between now and 2050. The strongest decline in quality is projected for Sub-Saharan Africa and parts of Latin America and Asia. In developed regions, such as Europe, the United States and Japan/Oceania, most of the decline in quality has already occurred. Overall, natural biodiversity will be preserved in less than 60% of the world's aquatic ecosystems, under the Business-as-usual scenario.

Projected quality of freshwater ecosystems, 2050

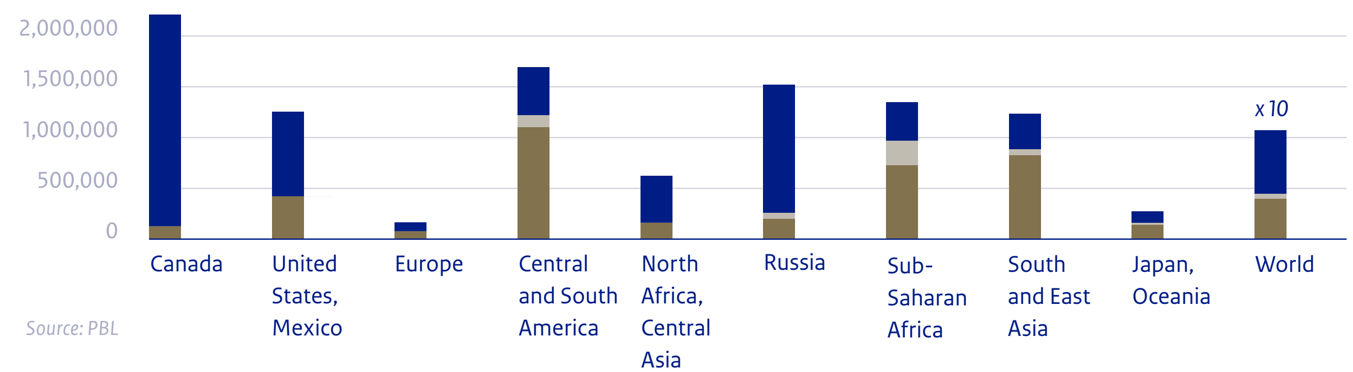
In the sparsely populated northern regions, the quality of freshwater ecosystems will be least affected.



Source: PBL

Decline in freshwater ecosystems with high biodiversity levels *(in 1000 km²)*

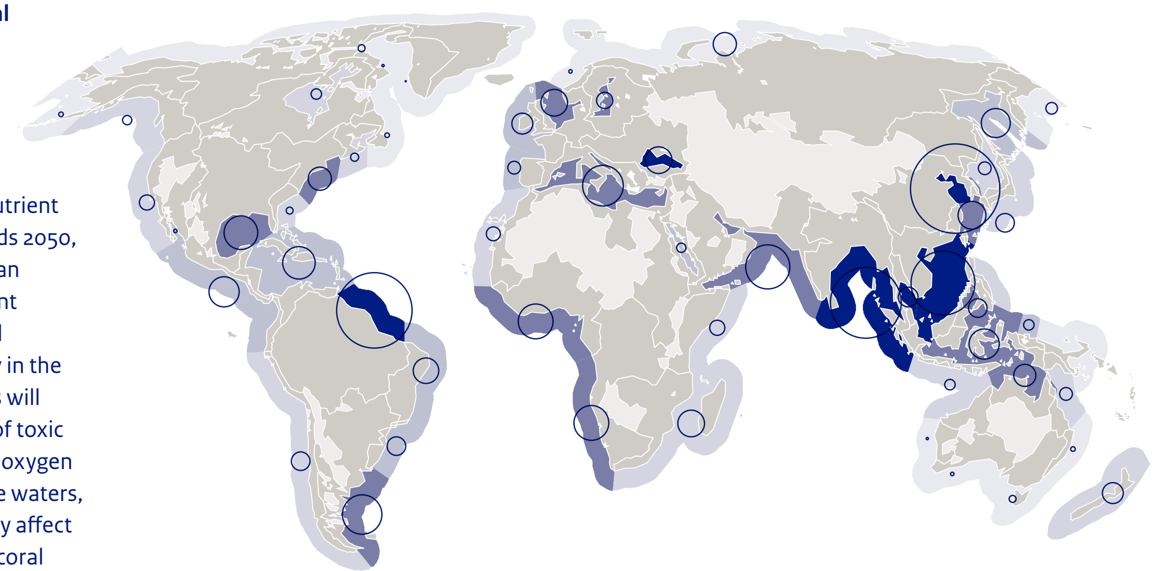
In the coming decades, most losses are expected to occur in the tropical and sub-tropical zones in Sub-Saharan Africa, Latin and Central America and South and East Asia.



Source: PBL

Quality of coastal seas threatened by increased nutrient loading

The increase in nutrient emissions, towards 2050, will also result in an increase in nutrient loading to coastal waters, especially in the Asian region. This will increase the risk of toxic algal blooms and oxygen depletion in those waters, and will negatively affect biodiversity (e.g. coral reefs) and ecosystem functions, such as aquaculture and fisheries.



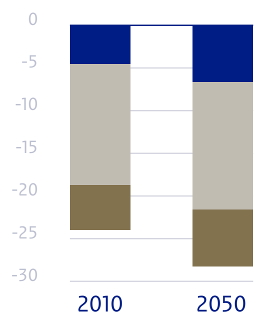
Source: PBL

FRESHWATER BIODIVERSITY LOSS: CAUSES AND SOLUTIONS

The main drivers of biodiversity loss are population growth and unsustainable economic development; their impact will be reinforced by climate change. Cities with poor wastewater treatment will continue to grow, and the number of dams in rivers is projected to increase.

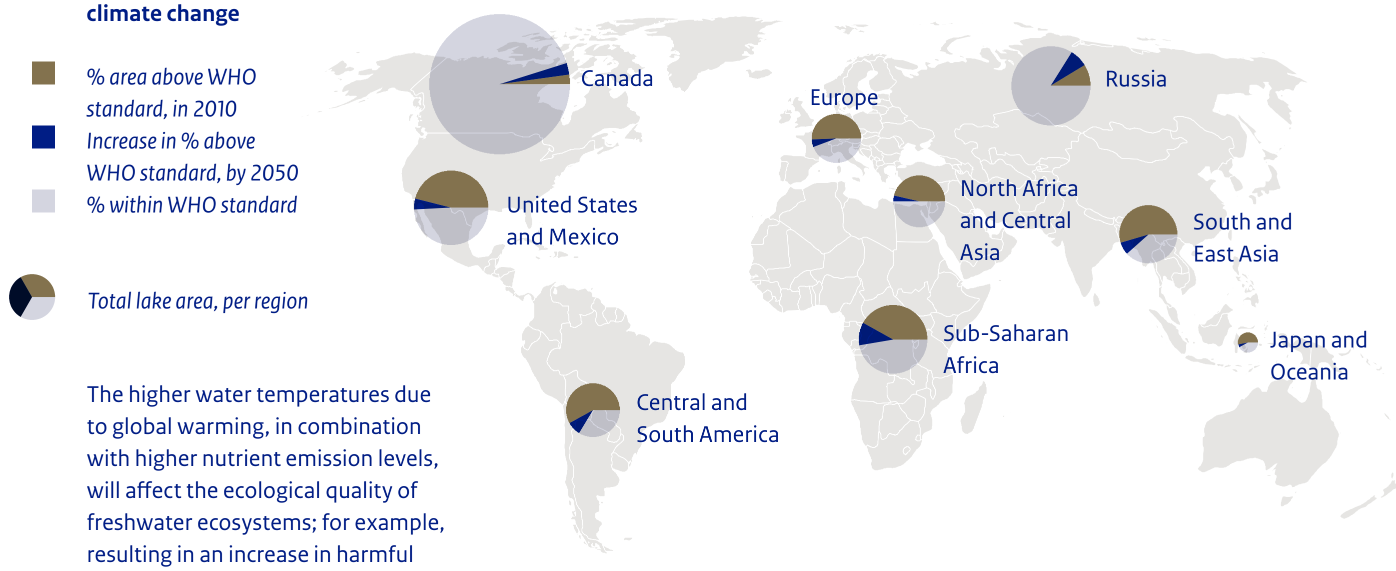
Causes of freshwater biodiversity loss
Globally, about three quarters of projected freshwater biodiversity loss will be caused by a further decline in wetland area and increasing eutrophication due to increased nutrient emissions from cities and agriculture (pp. 42–43). A quarter of the biodiversity loss is estimated to result from hydrological disturbance due to the thousands of newly planned dams (pp. 58–59).

Causes of freshwater biodiversity loss



Source: PBL

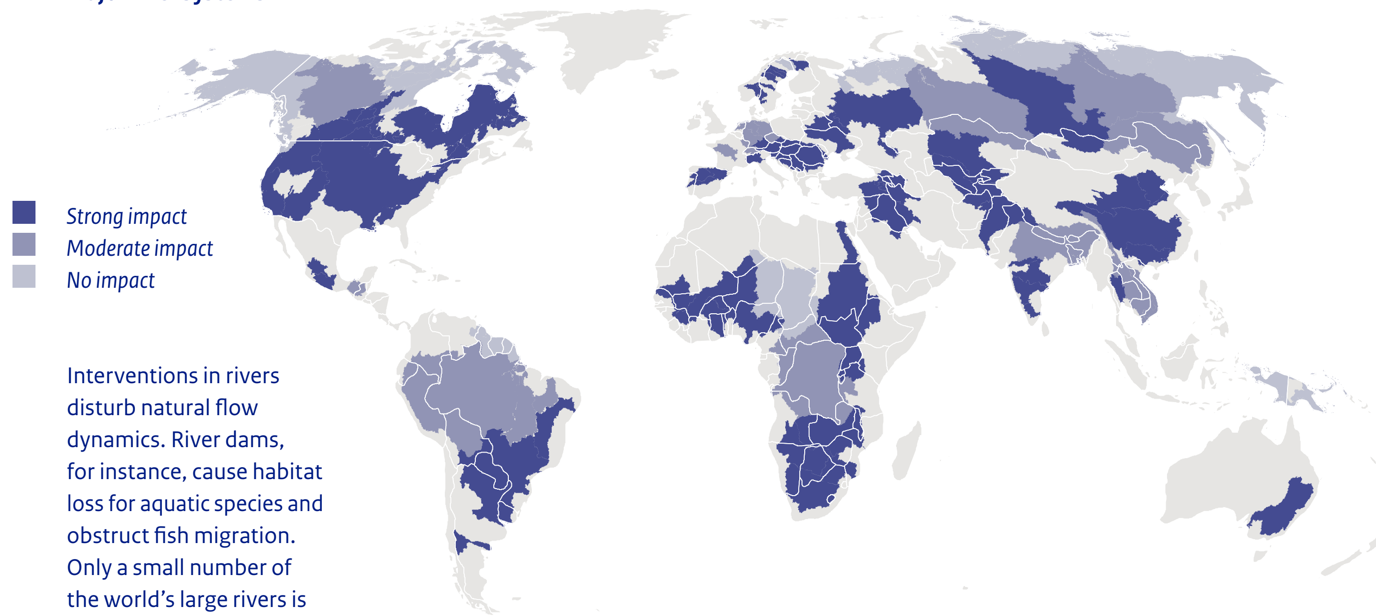
Algal blooms and climate change



The higher water temperatures due to global warming, in combination with higher nutrient emission levels, will affect the ecological quality of freshwater ecosystems; for example, resulting in an increase in harmful algal blooms in lakes.

Source: PBL

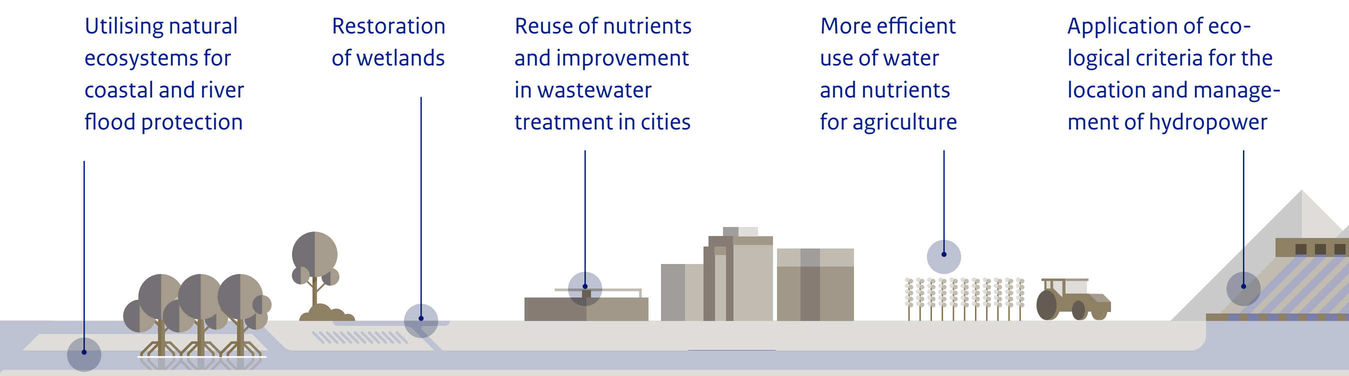
Impact from dams on major river systems



Interventions in rivers disturb natural flow dynamics. River dams, for instance, cause habitat loss for aquatic species and obstruct fish migration. Only a small number of the world's large rivers is unaffected by the dams already in place.

After Nilsson et al., 2005

Solutions
Preserving aquatic ecosystems requires an integrated ecosystem-based approach, on landscape scale, which acknowledges the diversity and quality of aquatic ecosystems.



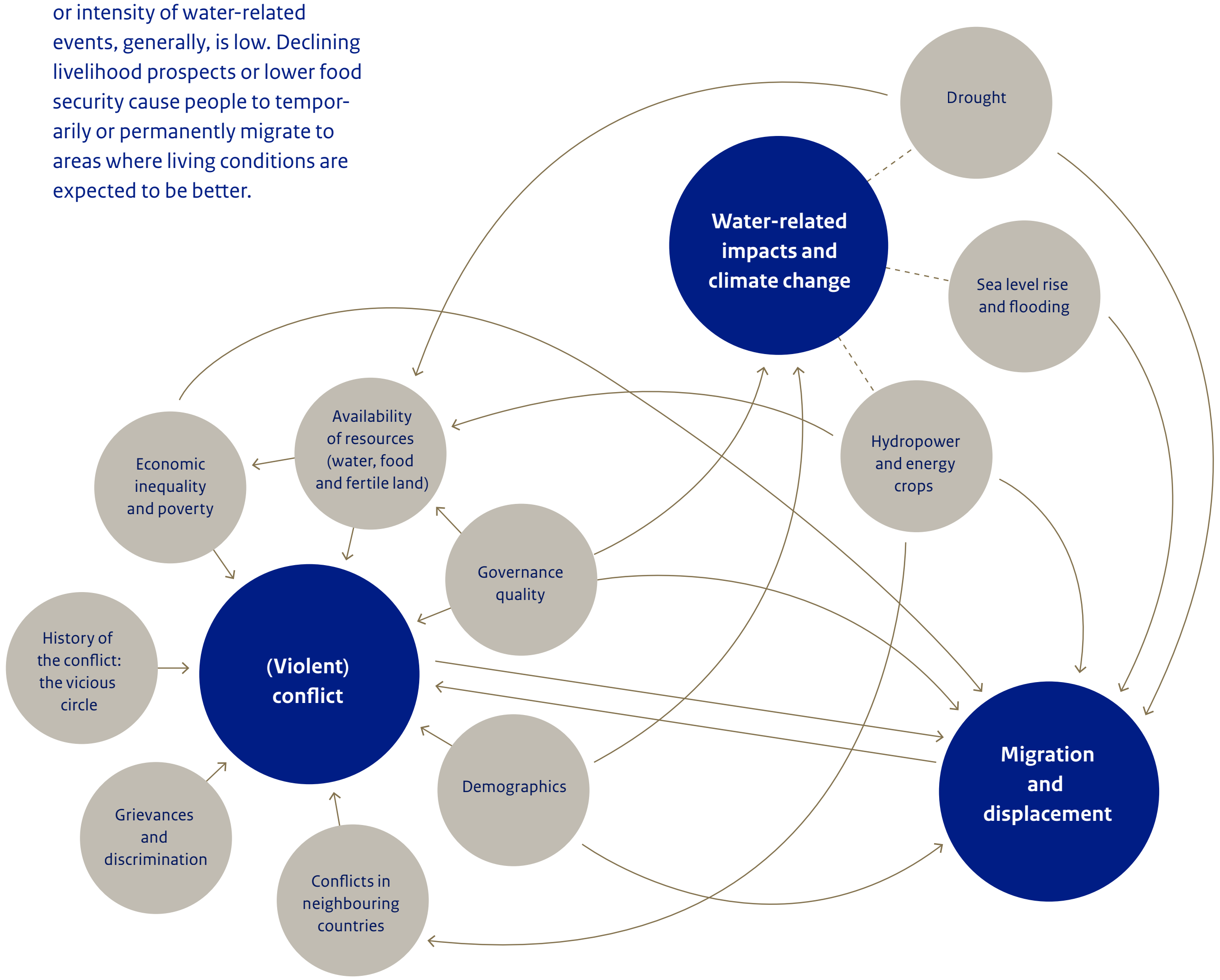
WATER, MIGRATION AND CONFLICT

WATER, MIGRATION AND CONFLICT

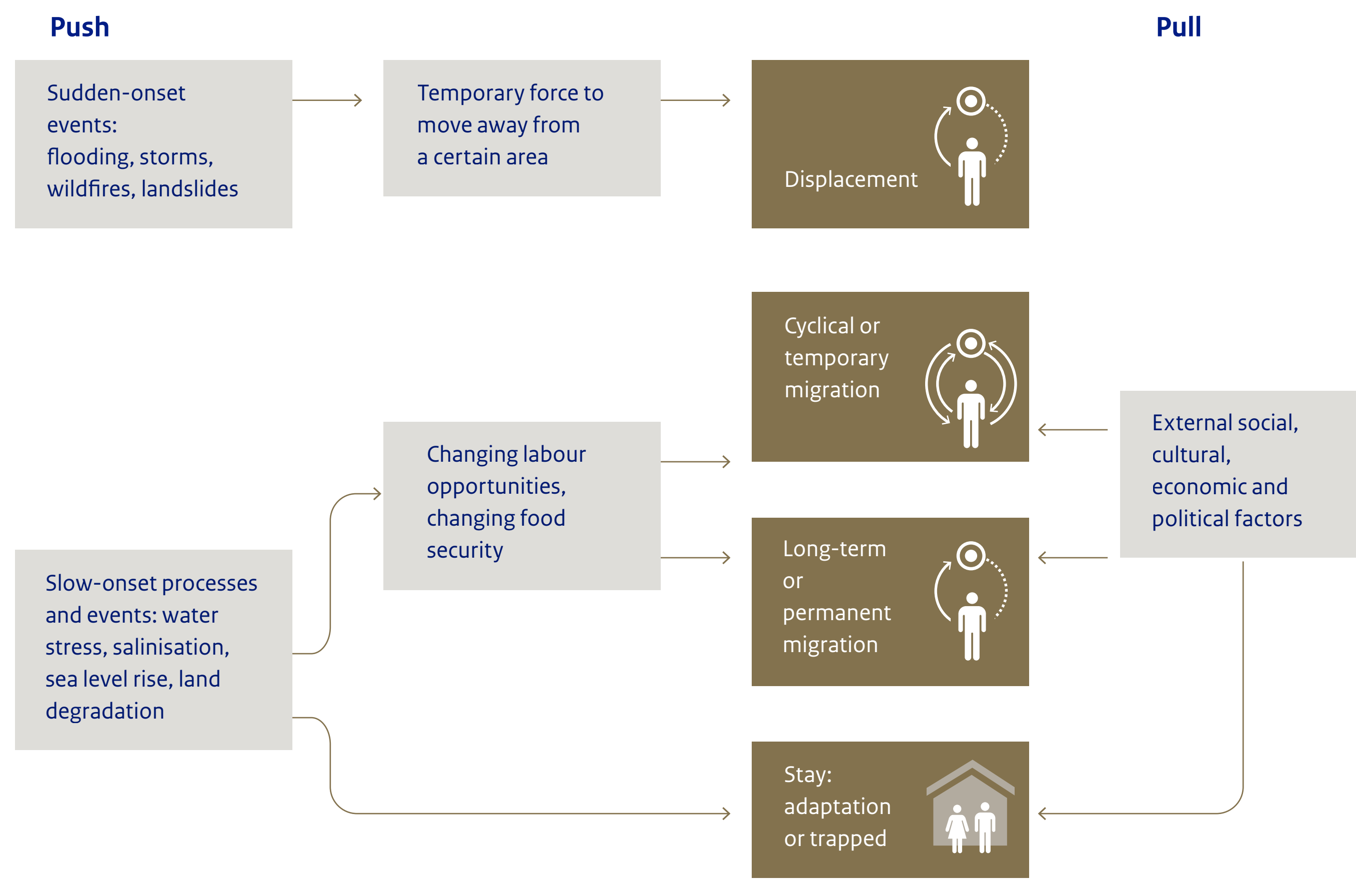
Conflict and migration result from complex social, economic and governance processes, which differ locally. Water issues can lead to collaboration, but in other situations these issues may contribute to migration and the risk of conflict.

Migration is the result of so-called pull and push factors. When countries are economically less developed, their capacity for adapting to increasing variability or intensity of water-related events, generally, is low. Declining livelihood prospects or lower food security cause people to temporarily or permanently migrate to areas where living conditions are expected to be better.

Water stress can result in local conflict over water or the remaining fertile land; transboundary water-sharing mechanisms can come under pressure due to an increase in demand or decrease in rainfall, but also due to the construction of large hydropower dams.



Sudden-onset events, such as flooding and storms, may cause direct displacement. The majority of inhabitants return to their area after an event. On average, 21.5 million people were displaced by weather-related events, between 2008 and 2015. Recurring displacement can deepen inequality and decimate communities, as it leads to people being impoverished and disempowered. In addition, slow-onset processes, such as water stress and sea level rise, may cause or affect migration patterns. Environmental pressures that intensify day by day, can increase the push to leave. The exact number of people migrating specifically because of deteriorating environmental conditions is unknown, since many other factors also play a role. The people who stay are those who are able to adapt and the extremely poor who cannot leave and therefore are 'trapped'.

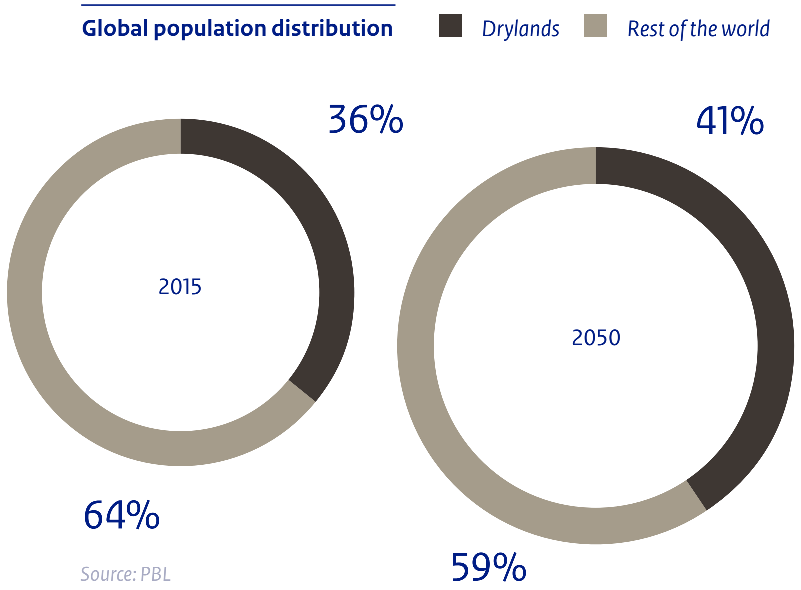


HOTSPOTS OF MIGRATION

Migration from rural areas to cities is among other variables associated with a lack of rural economic perspective, population growth and increased water stress. For 2050, water availability and soil quality are particularly expected to deteriorate in the drier and poorer areas of the world.

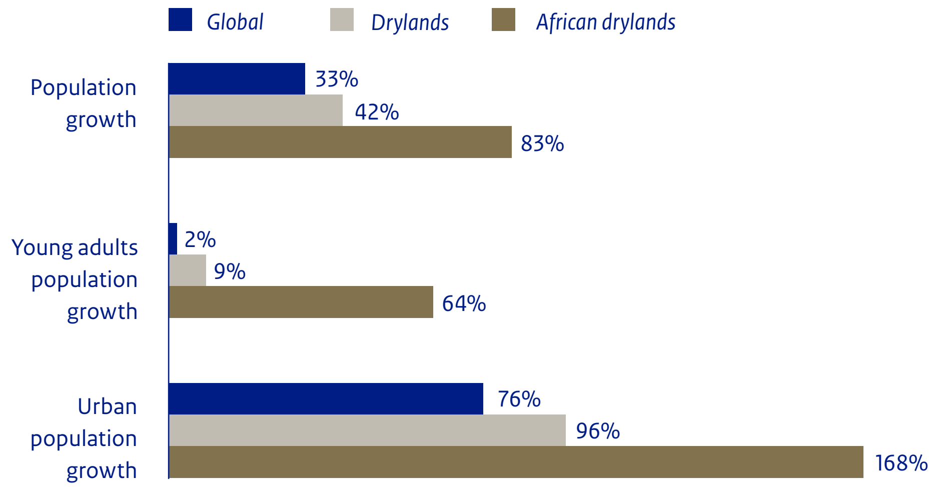
Strong population growth and urbanisation in drylands
The population growth rate in drylands exceeds the global rate. The dryland population is projected to grow from 2.7 billion today to over 4 billion by 2050, an increase of 40% to 50%.

Global population distribution



Source: PBL

Drylands compared to global averages
Strong population growth, especially in combination with a large share of young adults, affects migration processes. This is projected to be particularly the case for the African drylands.

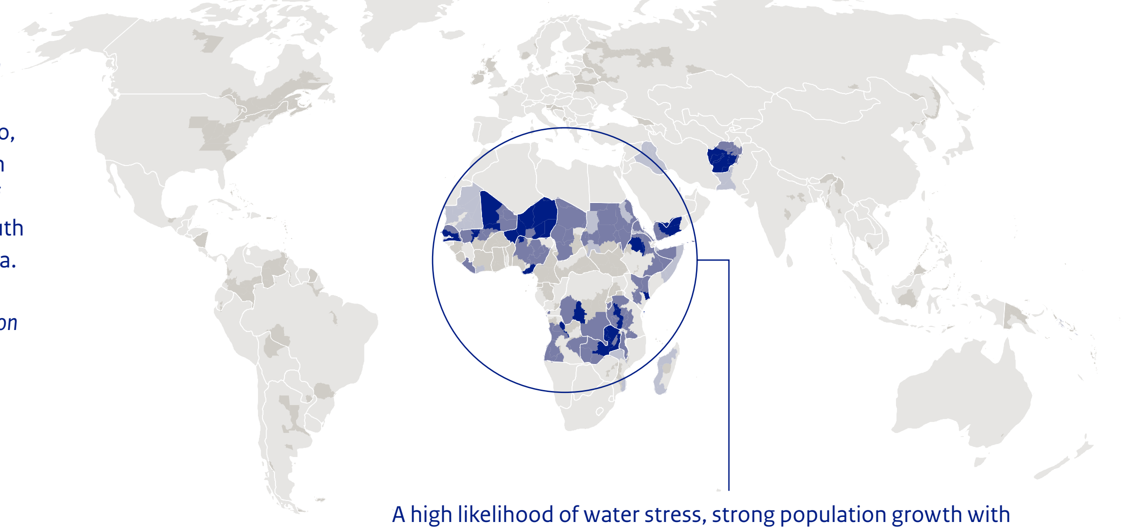


Source: PBL

Dryland hotspots of potential migration associated with water stress
Between 2000 and 2010, an estimated 40 million people migrated out of drylands, mostly in South America, Africa and Asia.

Potential levels of migration
Moderate
High
Very high
No data

Source: PBL



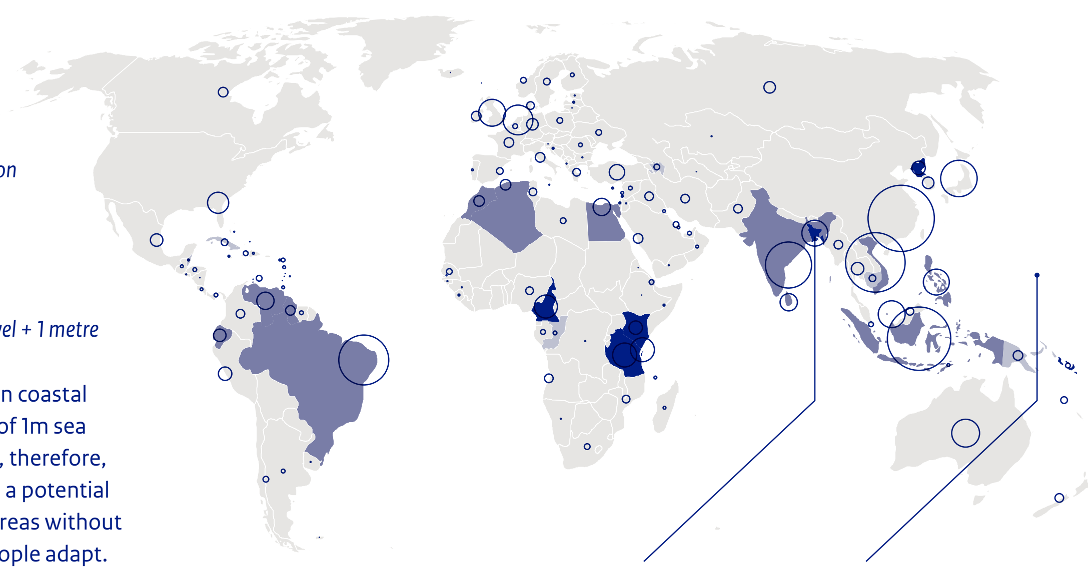
A high likelihood of water stress, strong population growth with a large share of young adults, and low income per capita, can be associated with water-stress-related migration. By 2050, these factors may all affect migration in many Sub-Saharan dryland regions.

Hotspots of potential migration due to 1 metre sea level rise

Potential levels of migration
Moderate
High
Very high

People living below sea level + 1 metre

Millions of people live in coastal areas within the reach of 1m sea level rise. Sea level rise, therefore, will eventually become a potential driver of migration in areas without the capacity to help people adapt. Hotspots of migration may be found especially in Southeast Asia, the Small Island Developing States and in Africa, based on projected coping capacity and number of people at risk.



The Bangladesh Government expects to have 20 million migrants around 2050, if the worst-case sea level rise scenarios become a reality.

Small islands in the Pacific Ocean are particularly vulnerable to sea level rise.

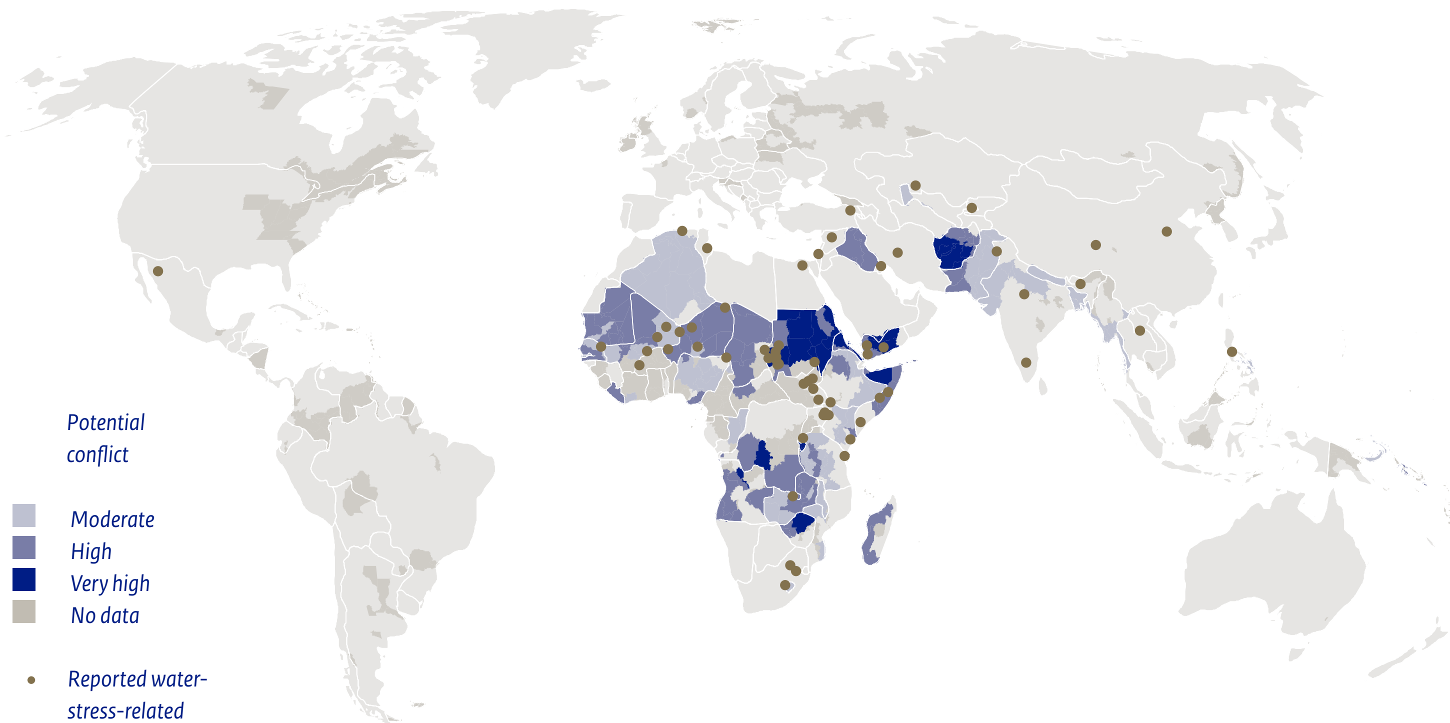
Source: PBL

COLLABORATION AND CONFLICT OVER WATER

Water issues may lead to either collaboration or conflict, on local, national and international scales. In river basins, the construction of dams may contribute to increasing tension.

Acknowledging the complexity and broader context, Africa and parts of Asia seem hotspots of water-stress-related conflict risk, based on the projected degrees of water stress, income per capita and present governance quality. These potential hotspots coincide with many of the reported historical locations of water-related conflict. The future development of local water-related risk, however, will largely depend on the quality of governance and water management.

Hotspots of potential local conflict risk associated with water stress in 2050



Potential conflict

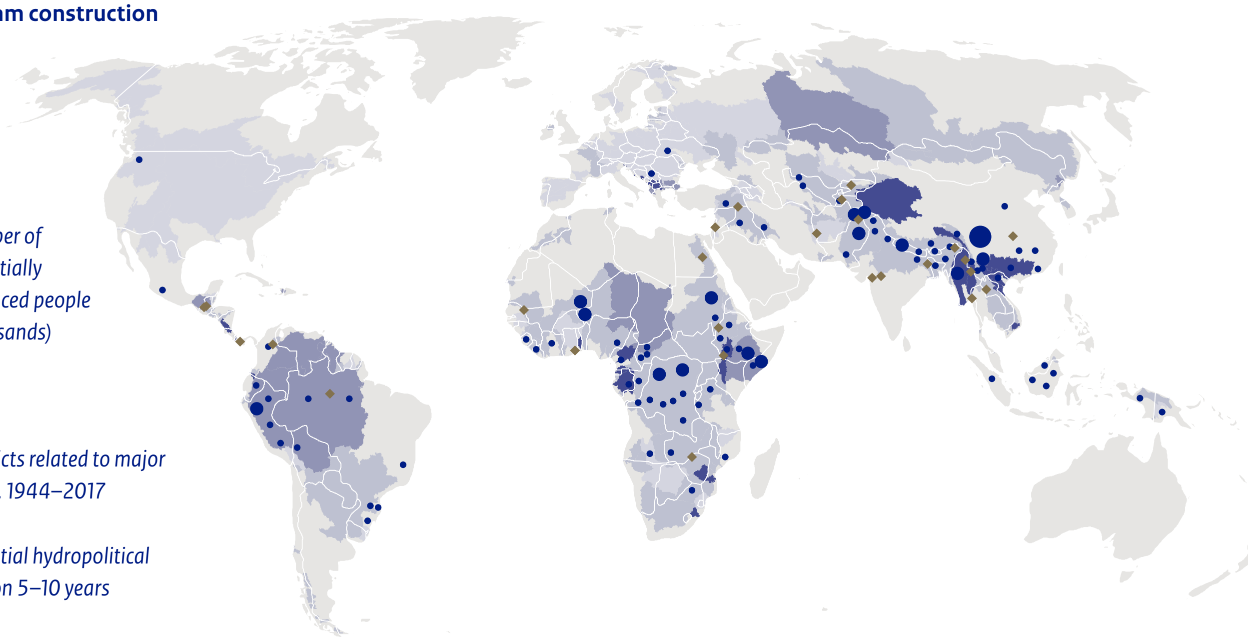
Moderate
High
Very high
No data

Reported water-stress-related conflict 1944–2017

Source: ECC Platform

Hotspots of potential pressure on collaboration in transboundary river basins
River basin organisations and international water treaties are instruments to govern the shared use of rivers. In many cases, in the past, sharing river water resources more often has led to collaboration than to conflict. However, a growing water demand from agriculture, cities, industry and households, reduced precipitation or the construction of dams, may increase the pressure on transboundary collaboration. Based on potential hydropower production and the quality of river basin treaties, among other things, the pressure on transboundary collaboration is indexed to be high in river basin areas in parts of Asia, Africa and South America.

Pressures in river basins related to dam construction



Number of potentially displaced people (thousands)

750

Conflicts related to major dams, 1944–2017

Potential hydropolitical tension 5–10 years

Low
Moderate
High
Very high

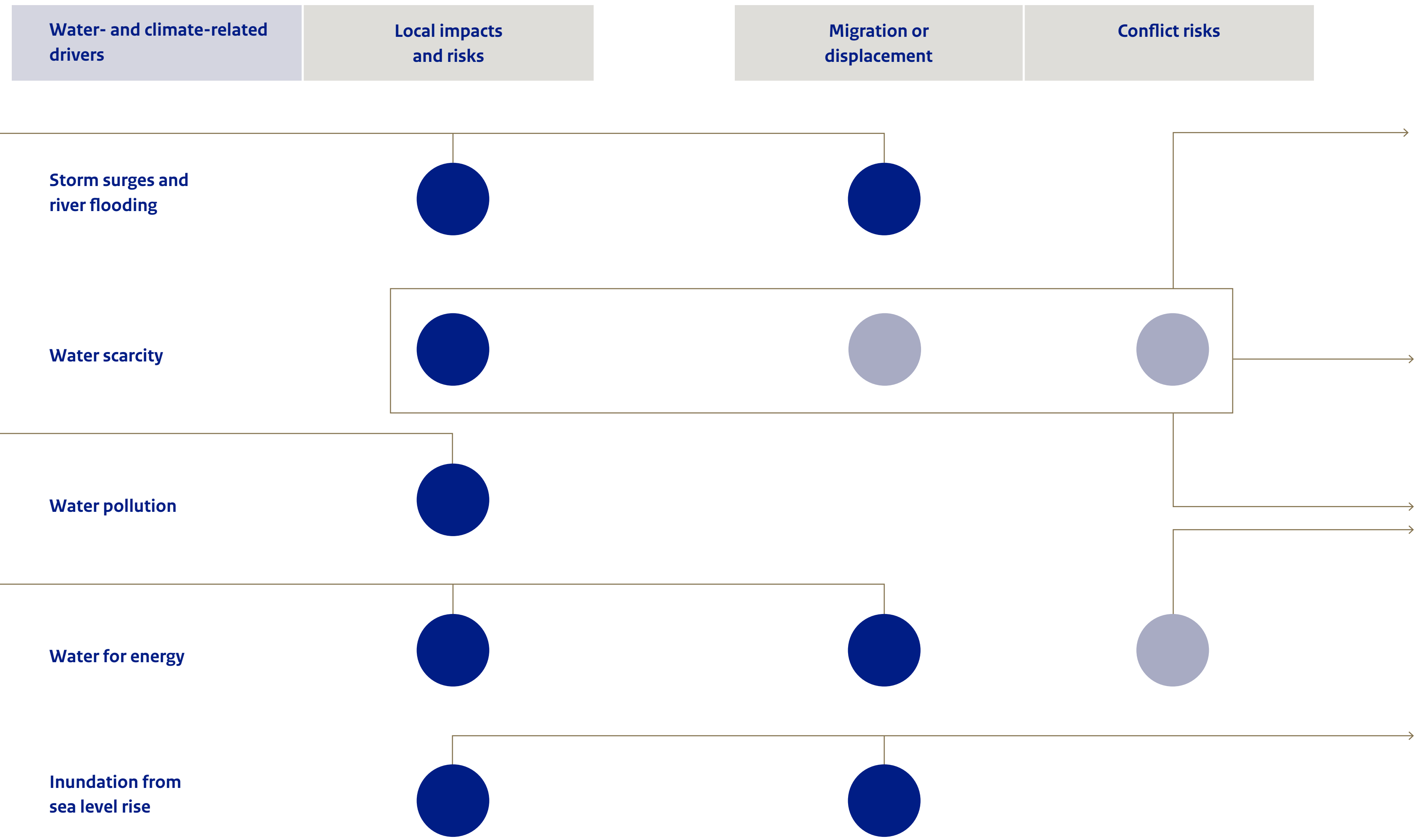
Source: Conflicts 1944–2017:
ECC Platform / Environmental Justice Atlas
Hydropolitical tension: De Stefano et al., 2017
Displaced people: Gernaat et al., 2017

Dams and local tensions
The displacement of many thousands of people following the construction of hydropower dams and reservoirs has often been a cause of local conflict. Acknowledging the hydropower potential in Asia, Africa and South America, numerous people could be at risk of displacement.

3
BENDING THE TREND

LOCAL IMPACTS, MIGRATION AND THE RISK OF CONFLICT

The interaction between water, climate and security is complex and diverse, encompassing local impacts, migration and the risk of conflict. Water- and climate-related impacts often affect poor people the most.



Of all natural disasters, river and coastal flooding kills or affects the largest numbers of people and leads to the highest economic losses, each year. On a global level, flood risks are increasing, and flooding events can lead to either temporary or permanent displacement.

Water pollution affects human health, causing the highest number of casualties of all water-related impacts. In addition, water pollution reduces the quality of freshwater ecosystems and coastal seas.

Dams lead to negative ecological impacts, reduced sediment flows to coastal areas and deltas, and the displacement of local populations. Increased energy crop production is competing with local food production and nature for land and water — especially in regions already facing water shortages.

More water scarcity will affect an increasing number of people, particularly those in dryland areas, with increasing water stress and decreasing food security affecting their livelihood prospects. These factors may also increase migration levels and the risk of local conflict.

Food scarcity and peaking food prices due to drought have been shown to spark riots and conflicts, especially in urban areas with a large share of poor people.

Increasing water demand and dams constructed for hydropower and/or irrigation may increase the pressure on transboundary collaboration on water distribution in river basins.

Sea level rise causes salinisation of coastal areas, affecting freshwater availability and agricultural production. Long-term sea level rise may lead to displacement or migration from low-lying coastal areas, deltas and islands.

Direct effect

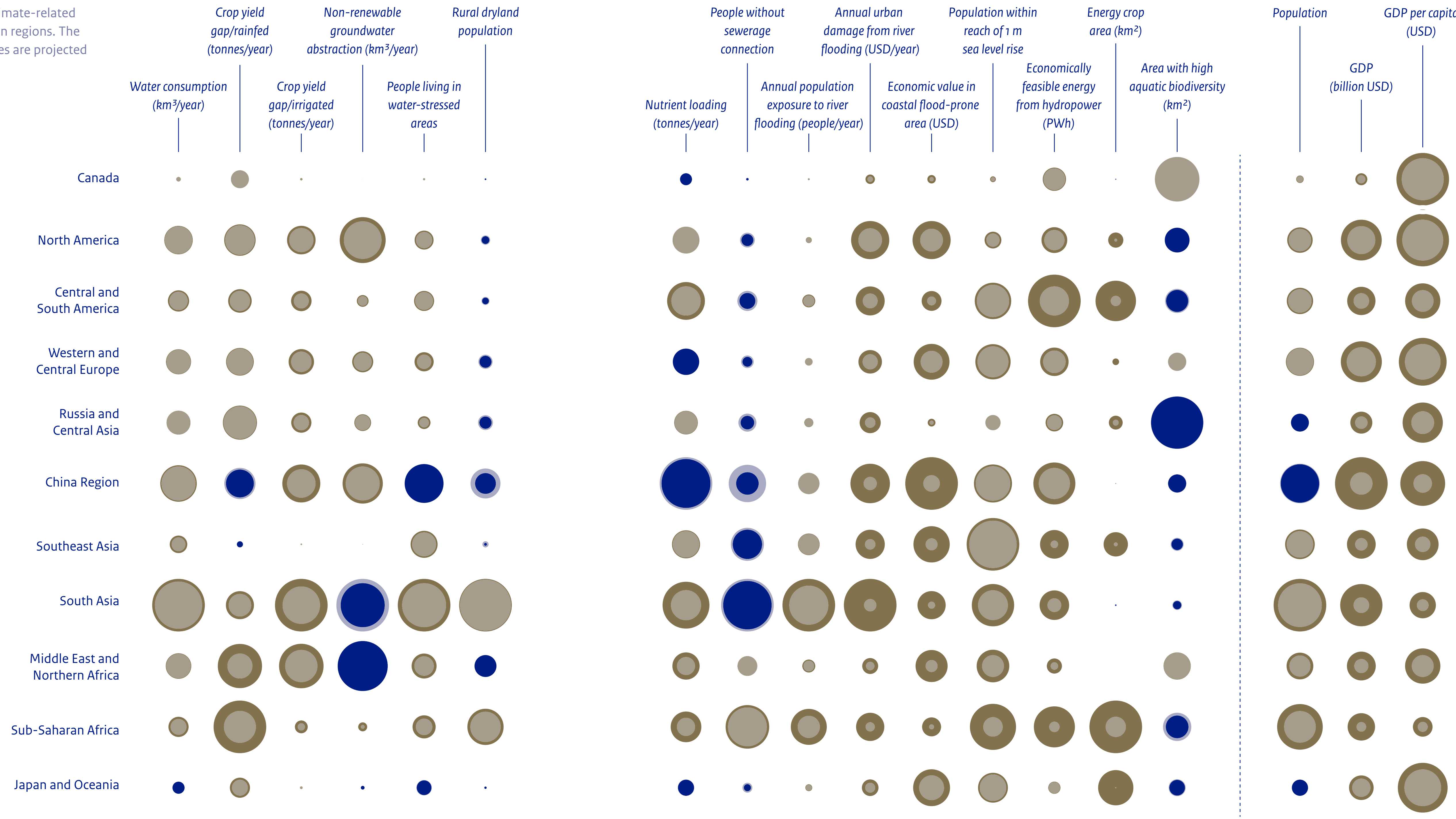
Indirect effect

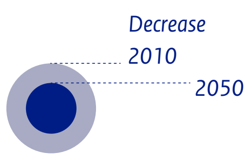
Source: PBL

WATER AND CLIMATE CHALLENGES: THE GLOBAL PICTURE

On the basis of the information in Part II, water- and climate-related risks and developments show large differences between regions. The largest increase in water- and climate-related challenges are projected for Sub-Saharan Africa and South Asia.

Summarising Part II, the projected changes between 2010 and 2050 are given for 15 relevant water- and climate-related indicators, for 11 geographical regions.
Under the Business-as-usual scenario, most substantial changes are projected for South Asia and Sub-Saharan Africa and, to a lesser extent, the Middle East and North Africa, and Central and South America. The projected damage related to river flooding and the economic value in flood-prone coastal areas will strongly increase, in all developed and developing regions.
In the China region and South Asia, water- and climate-related challenges were already serious in 2010, with major changes towards 2050 in hydro-power, flood-related damage and increasing yield gaps in irrigated crop production.
Rainfed crop yield gaps will increase the most in the Middle East and North Africa, and in Sub-Saharan Africa.





Source: PBL

HOTSPOT LANDSCAPES: CLUSTERS OF RISKS AND CHALLENGES

Four global landscapes encompass clusters of risks and challenges. These landscapes and their interdependencies provide a frame for building a more resilient world, on various scales.

Cities, infrastructure and the functioning of sectors are still largely based on the 'old climate'. As shown under the Business-as-usual scenario, the projected population increase, economic development and increase in climate change and weather extremes are likely to result in a strong increase in water-related health risks, damage and losses.
Large-scale examples of improved water management for food production (pp. 32–33), improved flood-risk protection (pp. 52–53) and improved wastewater treatment in cities (pp. 42–43) show that the trend can be bended. This calls for a vision on all scales and shared by all stakeholders, as well as dedicated action and making maximum use of mainstreaming opportunities.

Drylands and water-stressed areas
Increasing water stress
and crop yield gaps

The global dryland population is projected to increase from circa 2.8 billion today to 4 billion by 2050. The rural dryland population is projected to remain steady at circa 1.5 billion, with a decline of 50% in China, circa 25% in South America and a modest increase of 6% in Asia. For Sub-Saharan Africa, a 40% increase in the rural population is projected as well as a tripling of the urban dryland population. Embedded in complex local and regional processes, in combination with strong population increases, increased water stress and crop yield gaps may –especially in Sub-Saharan Africa– contribute to increases in migration and the risk of local conflict.

Exploitation of freshwater resources

Transboundary river basins
Increased hydropower production
and water stress

The planned 3700 new large dams for hydropower will cause a reduction in freshwater biodiversity and sediment flows, which, in turn, will slow down the natural formative processes of deltas and coasts. Such large new dams will create hotspots in the Himalayan region, Yangtse river basin, Congo basin and Amazon basin. Increasing water demand and water pollution as well as the new dams for hydropower and/or irrigation may increase the pressure on transboundary collaboration in river basins.

Building resilience

Governance challenges on all scales
Today, many countries, cities, infrastructures and sectors are still based on the 'old climate', and are already facing an adaptation deficit. Coping with the present, and adapting to future water- and climate-security issues are major governance challenges for all bureaucracies and communities operating within various landscapes and on various scales.

Source: PBL

Migration from rural areas to cities

River dynamics and sediment flows

Cities
Accommodating growth
and reducing inequity

By 2050, 70% of the world's population is projected to live in cities. Cities are expected to grow fast, particularly in Asia that will double in size and in Sub-Saharan Africa, which will see a twofold to fivefold increase. By 2050, the urban population in these regions will encompass 60% of the global urban population. In these regions, the challenges of providing an adequate water supply and reducing water pollution are the greatest in cities. Reducing the inequity between the formal city and informal settlements with respect to water services and water- and climate-related risks will be a major undertaking.

Urbanising coastal zones and deltas

Coastal zones and deltas
Coping with flood risks
and sea level rise

The autonomous increase in population and economic development in the attractive and productive coastal areas will increase the challenges of preventing migration and economic losses related to long-term sea level rise. By 2050, large concentrations of people and economic value are projected to form flooding hotspots in China, Southeast Asia, South Asia and Sub-Saharan Africa. Reflecting the economic growth towards 2050, the economic value in flood-prone coastal areas will strongly increase in developed and developing regions.

TRANSFORMATION CHALLENGES

Getting serious about a sustainable and climate-resilient development requires five fundamental transformations as well as taking action on SDG 13.

Five transformation challenges
Implementation of the international agenda for sustainable development requires fundamental changes to the root causes of unsustainable development as well as a search for new development pathways. Therefore, the 2030 Agenda —which encompasses the Sustainable Development Goals— stresses the need for transformation.

The main transformation challenges are:

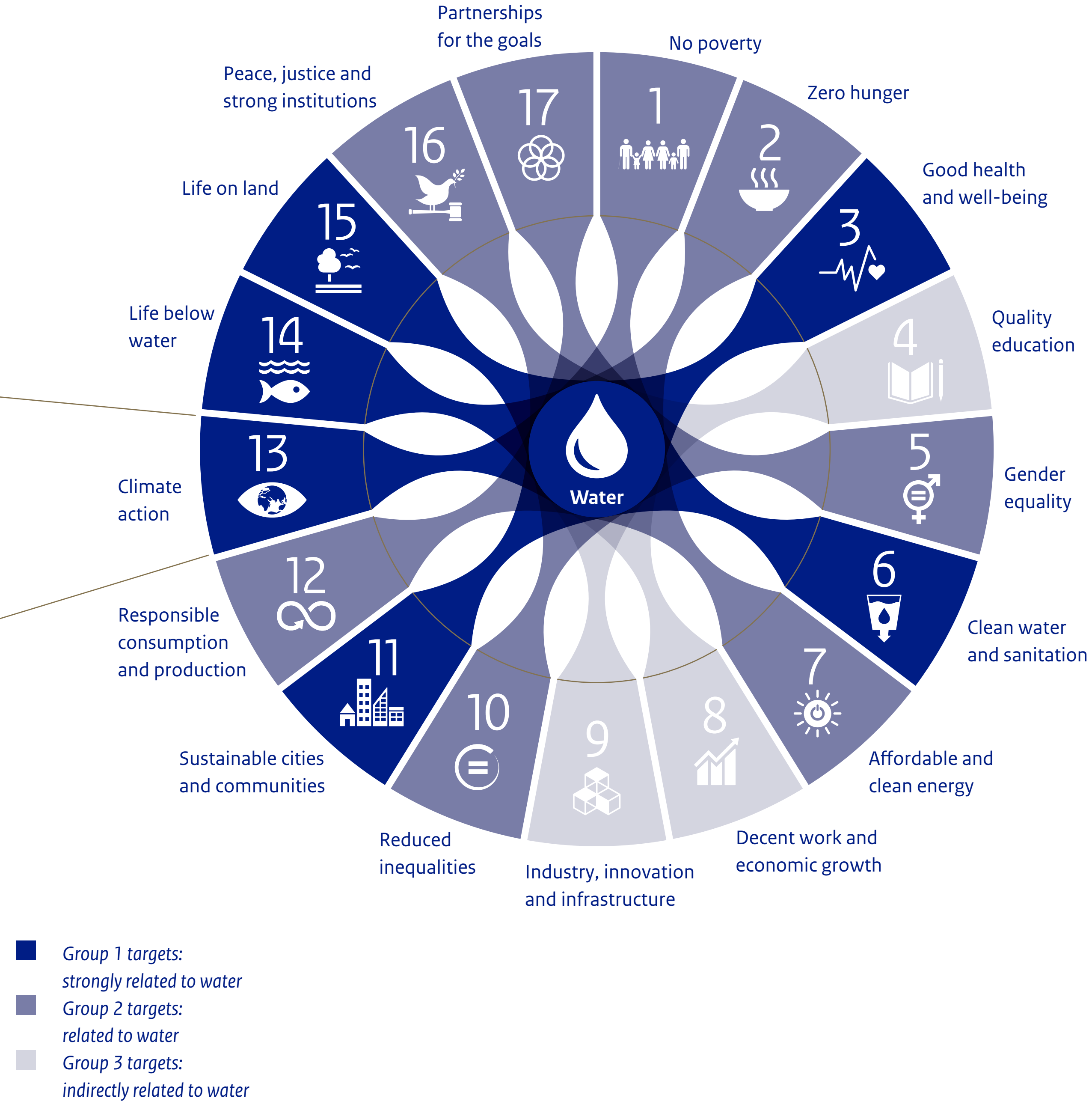
- Climate change and energy transition
- Sustainable management of water systems and water- and climate-risk reduction
- Developing sustainable agricultural and food systems
- Sustainable urbanisation and interaction with rural areas
- Sustainable use of resources and creating a circular economy

Challenges and possible development pathways differ per region, country and city, among other things, depending on the degree of population growth, economic development, natural resource use and ecosystem pressures. Managing these challenges requires strong institutions and a development strategy that acknowledges the interlinkages between them.

Building partnerships: water as a source of collaboration
Water is linked to many of the Sustainable Development Goals and cuts across the domains of transformation. Over time, water has proven to be a source of collaboration rather than conflict. Embedded in the various socio-ecological landscapes, water may form a basis for bridging interests, overcoming lock-ins and building a shared future.

SDG 13 Climate action
Supporting sustainable development, by strengthening climate resilience and adaptive capacity, and by integrating climate change and adaptation measures in national policies, strategies and development plans.

Sustainable Development Goals related to water



Source: PBL

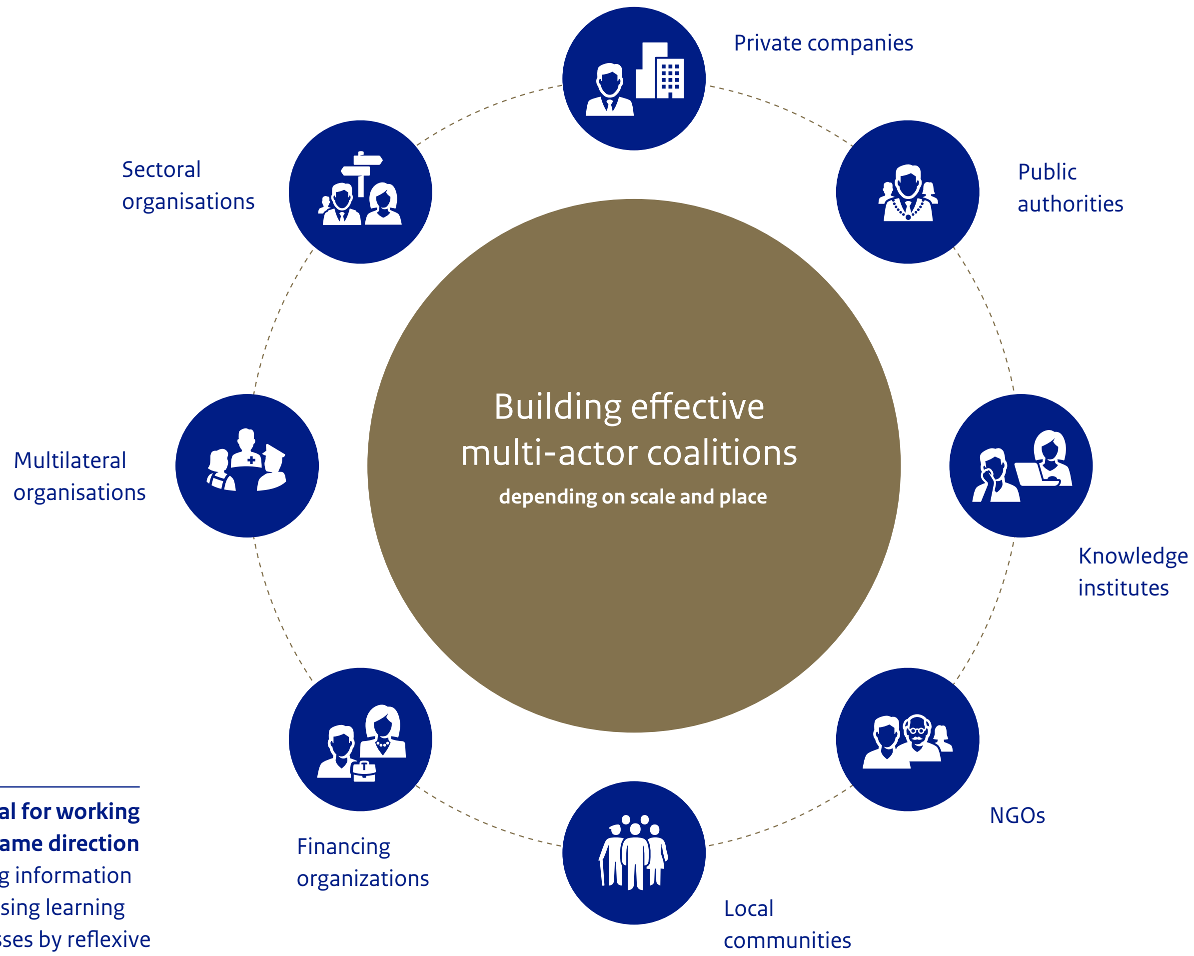
WORKING IN THE SAME DIRECTION

Integrating water- and climate-related challenges and global commitments in development strategies requires a transformation of how strategies are built and implemented. Scale- and place-based approaches and building coalitions will be key for working effectively in the right direction.

Developing scale- and place-based strategies that are anchored in the cultural and social environment offers chances for region-specific solutions.

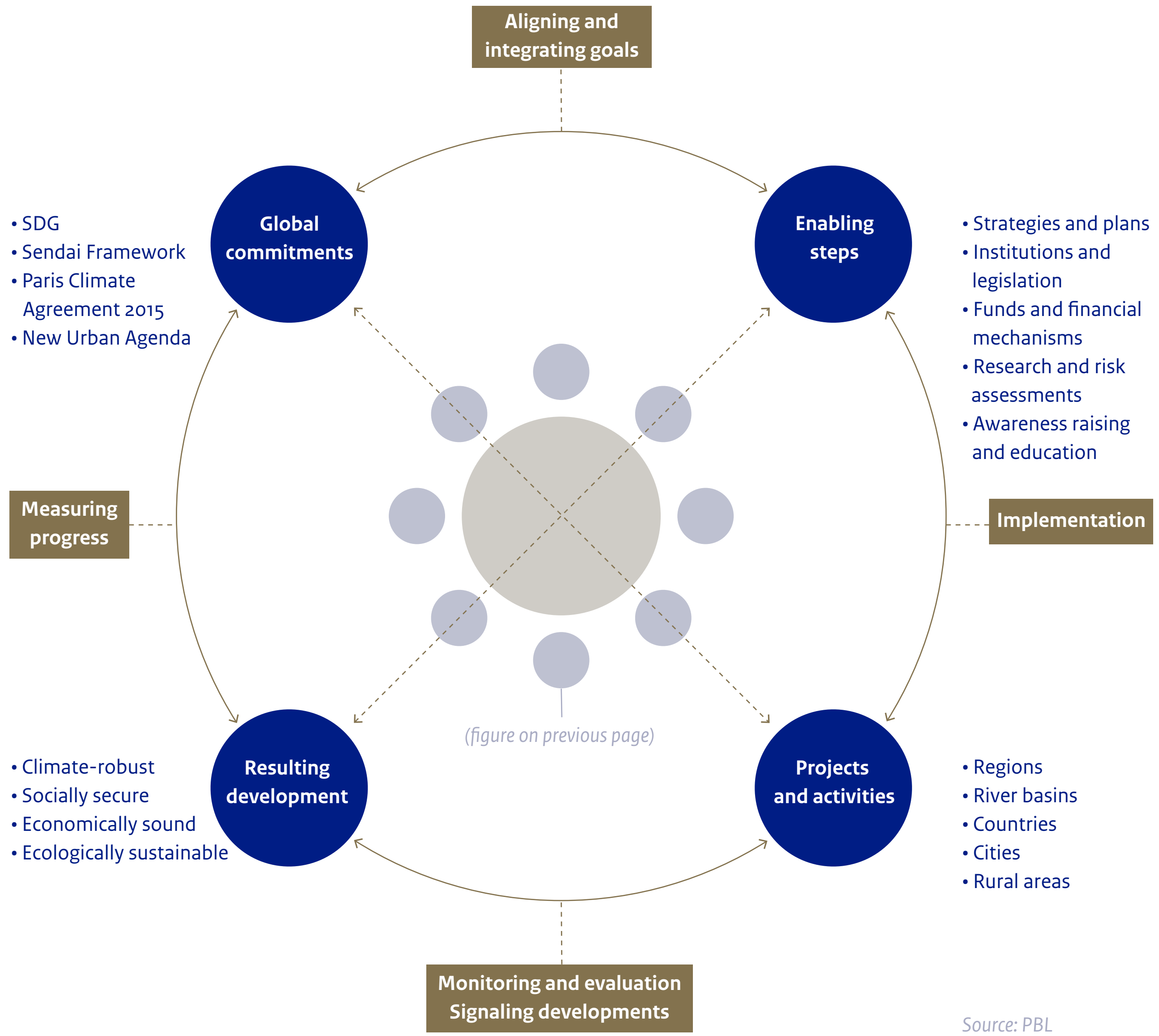
Building effective coalitions calls for commitment and the will to collaborate, and for shared values regarding the targets.

Overcoming lock-ins: collaboration and finding common ground enables finding new solutions and overcoming vested interests.



Essential for working in the same direction
- sharing information
- organising learning processes by reflexive monitoring and evaluation
- early recognition of new developments

Transforming work methods
Building on existing bureaucracies of various scales and integrating water- and climate-related challenges in sustainable development strategies require a transformative way of working as well as well-organised participative processes, involving all relevant actors. Depending on the scale and situation, the initiating party may vary, for instance, from national or local authority, to private company, NGO or sectoral organisation.



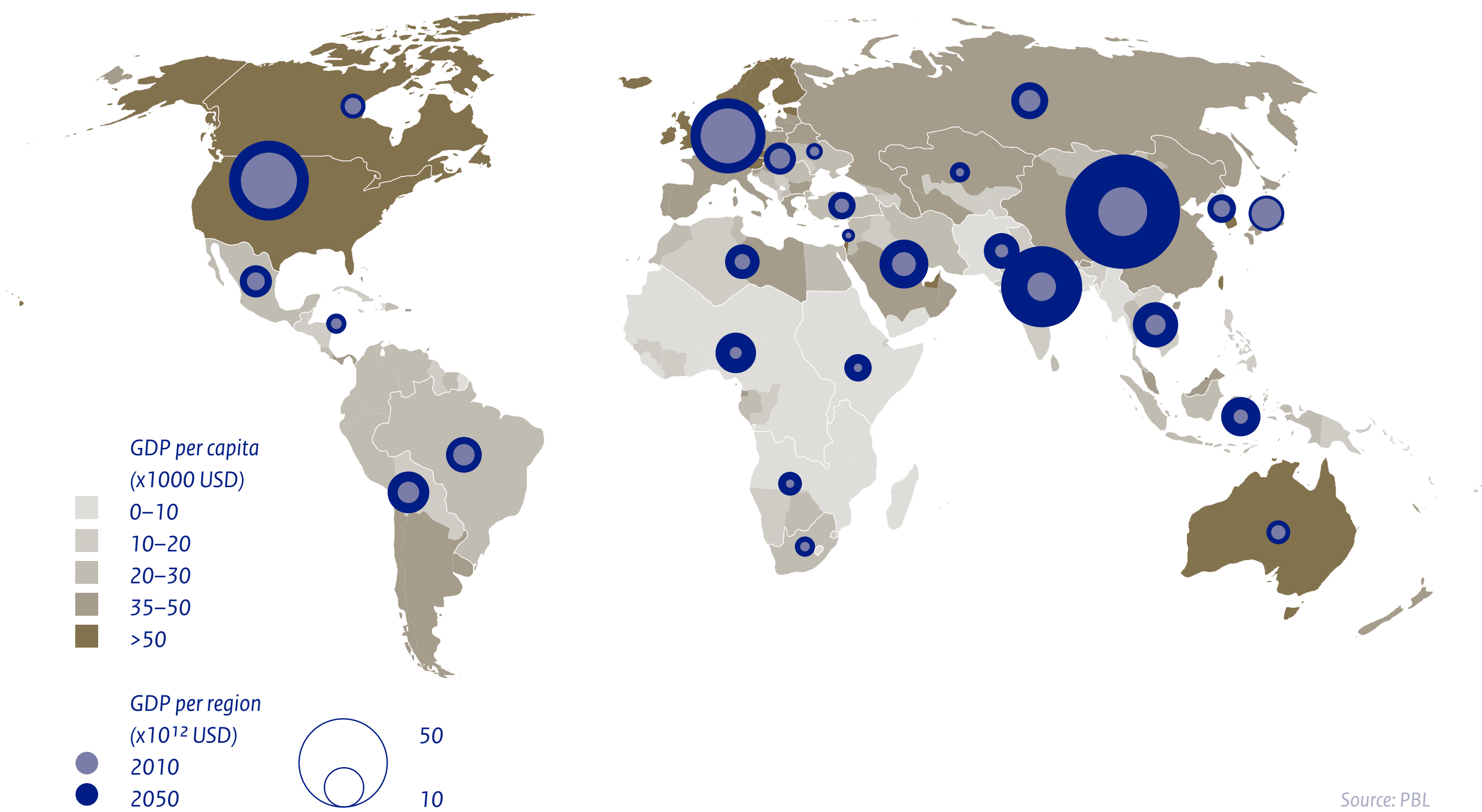
Source: PBL

TRANSFORMING ECONOMIC DEVELOPMENT

Transformation towards a sustainable world calls for improving human well-being while alleviating environmental degradation and risks. This requires strengthening of social and ecological values and risks in strategy development and investment decisions.

The opportunities for improving human well-being and reducing environmental degradation and risks differ per region. Regions for which economic development and per-capita incomes are projected to be high may have the best opportunities. Addressing human, environmental and adaptation needs in development strategies is a prerequisite for transformation and prevent investments that may be regretted, on the basis of knowledge and past experience.

GDP, 2010–2050

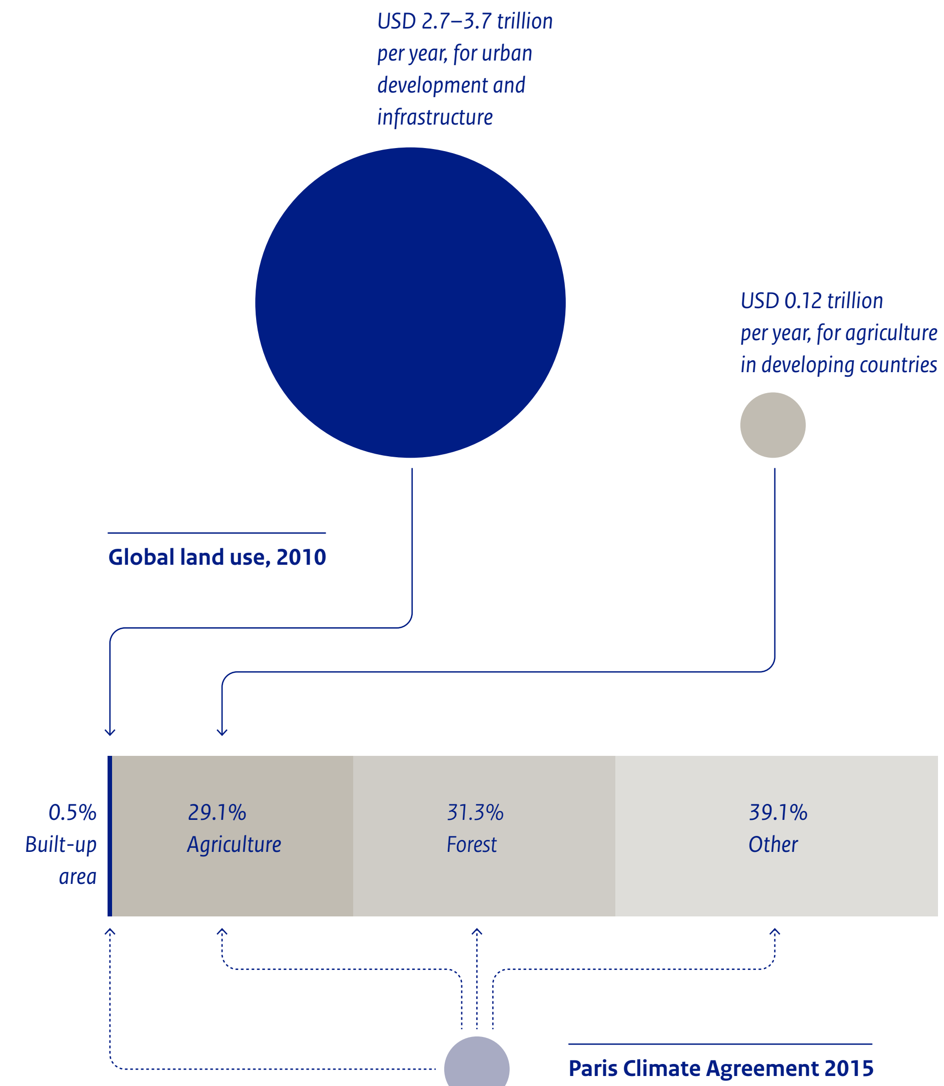


Source: PBL

Cities: focal points of investments
Steady economic development towards 2050 will result in ongoing investments in vital sectors, such as urban development, infrastructure and agriculture. The World Economic Forum estimates that, towards 2050, an annual USD 2.7 to 3.7 trillion will be invested in sustainable urban development and infrastructure, including water infrastructure. These investments will take place on around 0.5% of the global land area. This offers opportunities for effective investments to improve human well-being and reduce environmental risks for 70% of the global population.

Leave no one behind
Creating equitable opportunities for people in formal and informal urban settlements and those in rural areas will be a major challenge. Projected investments in the agricultural sector in developing countries are far lower than those in urban development and infrastructure.
Supporting the required transition towards sustainable agricultural intensification will require investment levels that go beyond those in the business-as-usual scenario.

Investments per year, 2016–2050



Source: WEF, PBL

Paris Climate Agreement 2015
Following the Paris Climate Agreement, it may be expected that, towards 2050, around an annual USD 0.1 trillion will become available to support both mitigation and adaptation projects in developing countries.

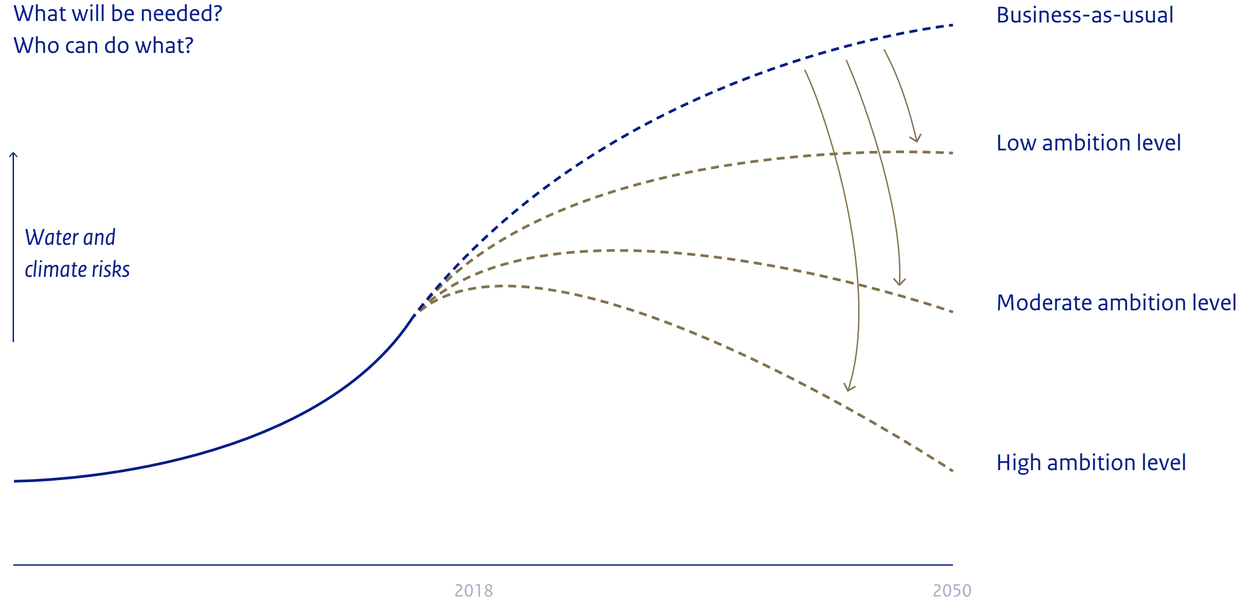
CREATING A SHARED VISION

Global coherent adaptation pathways are still lacking. Creating them is an essential, first step towards sustainable and climate-resilient development.

The need for adaptation
Our exploration shows that autonomous business-as-usual development leads to increased exposure and/or vulnerability to water and climate change hazards, especially affecting poor regions. However, the developed world also needs to adapt to the changing climate and sea level rise; cities, infrastructure and operations of many sectors are still based on the old climate. Although, worldwide, there are many water and adaptation projects, there is no shared view on what could be achieved in climate-proofing any future developments. For many years, the World Economic Forum has already warned about structural adaptation failure being one of the 10 major global risks. Creating shared future adaptation pathways, therefore, seems of evident importance.

What could be achieved? Creating shared pathways for adaptation
With respect to mitigation, global pathways for reducing greenhouse gas emissions are available. These provide a shared basis for weighing national efforts and choices for reducing greenhouse gas emissions and for monitoring and evaluating progress. For adaptation, these types of pathways still do not provide a frame for strategies and plans on various scales, for tackling interrelated problems and trade-offs, or for elaborating the efforts of collaborating stakeholders. As shown in the four hotspot landscapes that cluster the water- and climate-related risks and challenges, a transnational understanding of the challenges and pathways to solutions will be needed to bridge the various scales and build a safer and climate-resilient world, reducing the major risks for dryland areas, cities, transboundary river basins, coastal areas and deltas.

Bending the trend
What can be achieved?
What will be needed?
Who can do what?



Further steps

Taking action: mainstreaming adaptation in policies and future investments to climate–proof the world

While projected investments in the agricultural sector and the funds available for adaptation are far lower than those in urban development and infrastructure, annually, trillions of US dollars will be invested in spatial development. Mainstreaming water- and climate-related challenges in all development strategies, decisions and projects will be needed to really bend the trend.

Managing direction: building a shared knowledge base to measure progress and accelerate learning

Building coherent adaptation and development scenarios for the four global landscapes that cover the major water and climate challenges could be an interesting start for building a shared framework for learning (what could and could not work) and measuring successes and progress in reducing water- and climate-related risks in hotspot regions around the world.

THE GEOGRAPHY OF CHALLENGES

Grouping water- and climate-related risks and challenges into four global landscapes provides a framework for a climate-resilient and sustainable development.

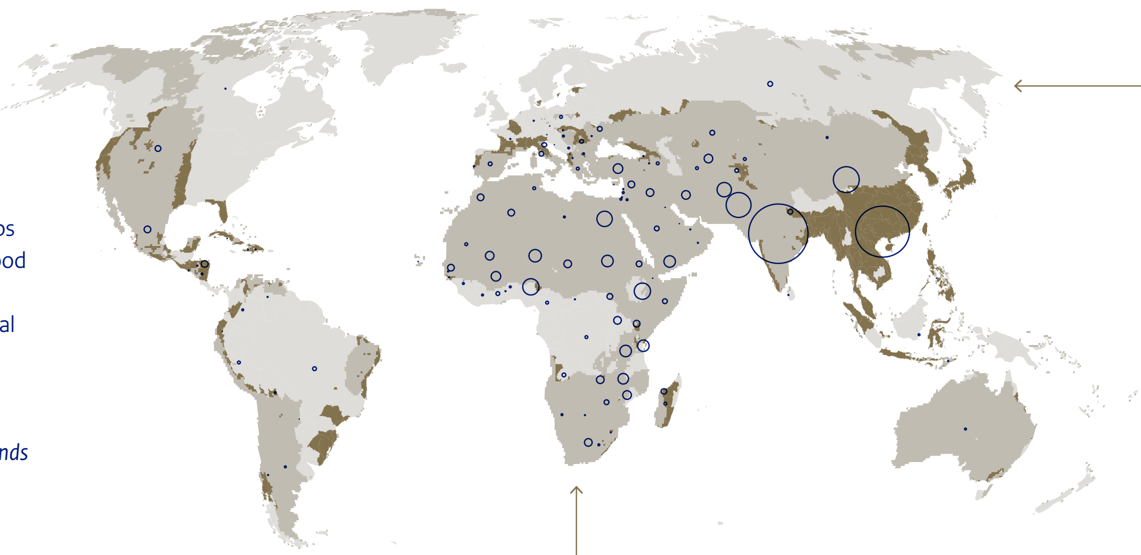
Drylands and water-stressed areas

Challenges:
- Improving water and land management
- Reducing crop yield gaps
- Improving local livelihood prospects
- Reducing the risk of local conflict

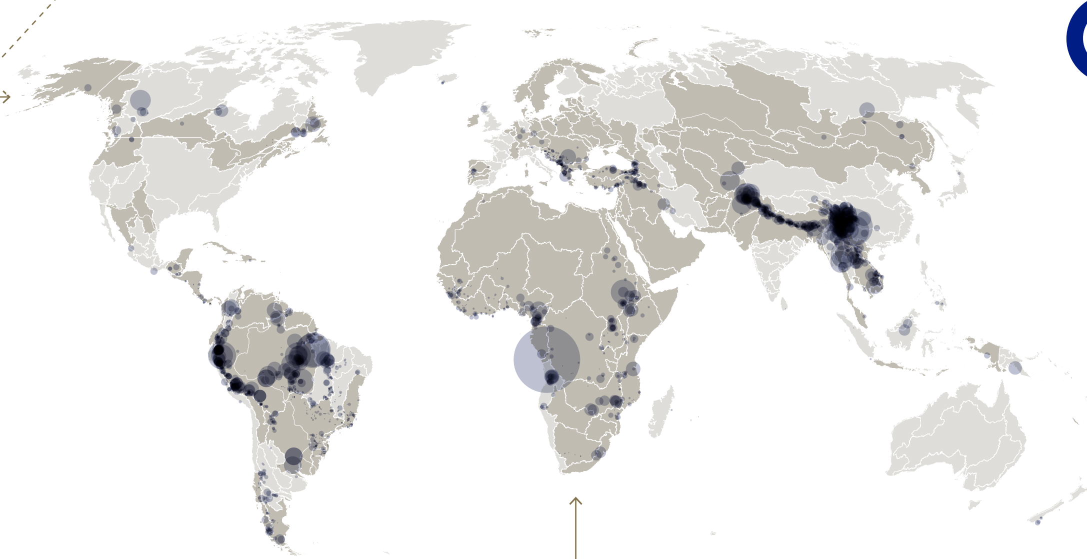
Drylands
Water stress outside drylands

Rural population 2050

Source: PBL



Exploitation of freshwater resources



Transboundary river basins

Challenges:
- Reducing the impact of dams
- Managing water demand and supply
- Preserving sediment flows
- Preserving ecological quality
- Retaining transboundary collaboration

Planned dam (capacity in MW)
10,000

Transboundary river basin

Source: PBL

Migration from rural areas to cities

Urbanising coastal zones and deltas

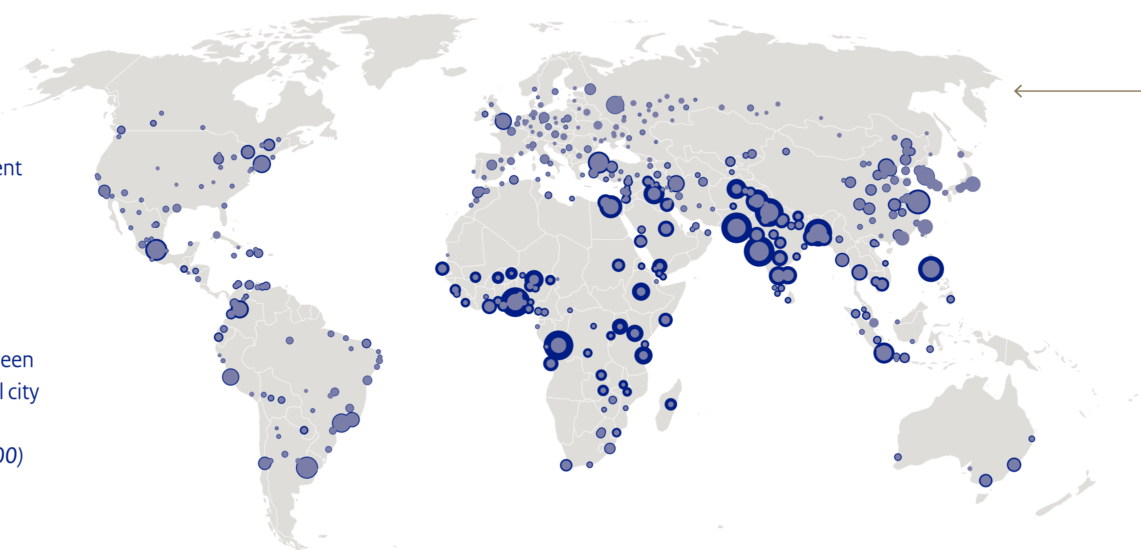
River dynamics and sediment flows

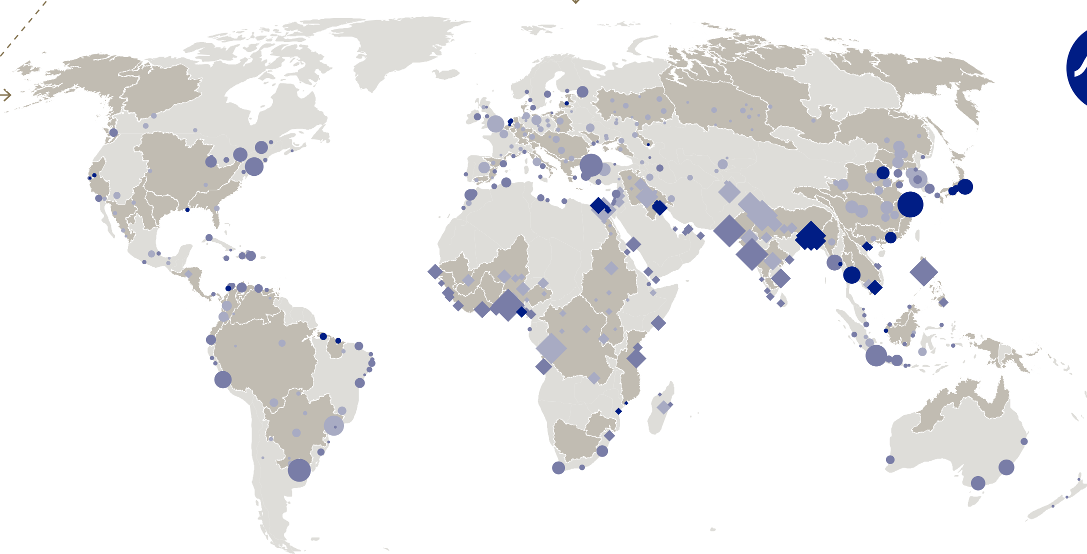
Cities

Challenges:
- Making cities and infrastructure climate-resilient
- Improving sanitation
- Reducing nutrient emission levels
- Reducing the risk of river flooding
- Reducing inequity between the formal and informal city

City (population > 500,000)
2010
2050

Source: PBL





Coastal zones and deltas

Challenges:
- Reducing the risk of river and coastal flooding
- Coping with sea level rise, soil subsidence and salinisation
- Preventing long-term migration and economic losses

Delta river basin
Delta city
Coastal city
River city

Rapidly growing cities

Source: PBL

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Photography

Water and food production, p. 28
Toshka, Egypt, 20 July, 2008
Shawn Baldwin for the New York Times
© Hollandse Hoogte/New York Times

On the Toshka farm in Egypt's desert, workers tended to a grape field in June 2008. The farm was started in 1997, but now has a renewed focus. Population growth and water scarcity have plagued the governments of the Middle East and North Africa for decades. But the current global food crisis has brought a new urgency to the twin dilemmas. None of the Arab nations of the Middle East have sufficient water resources today, and by 2050 the amount of fresh water available per capita will be half that of today, as the population grows to over 700 million, which is more than that of Europe.

Water pollution and human health, p. 36
Women Carrying Drinking Water, Haiti
Wesley Bocxe/Science Source
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Women and children carry drinking water through a polluted slum in Port-au-Prince, Haiti.

Flooding, p. 44
Houses are submerged by flood waters in Chennai, India, 3 December, 2015
© Hollandse Hoogte/AP | Associated Press

The heaviest rainfall in more than 100 years has devastated swathes of the southern Indian state of Tamil Nadu, with thousands forced to leave their submerged homes and schools, and offices and a regional airport shut for a second day on Thursday.

Water-related energy production, p. 54
Floodwater gushes out of the Three Gorges Dam on the Yantze River in Yichang city, central China's Hubei province, 20 September, 2014
© Hollandse Hoogte/Image China

Total electricity output of the world's largest hydropower project —the Three Gorges Project— exceeded 200 billion kilowatt hours (kWh) that year, as announced by the China Three Gorges Corporation (STGC) on 30 December 2014. The output was historically high and more than twice the electricity demand of Beijing, the company said in a press release. Beijing city's electricity consumption in 2013 was 91.3 billion kWh. The press release went on to say that 200 billion kWh is the equivalent of saving 100 million tonnes in coal and preventing carbon dioxide and sulfurdioxide emissions of 200 million and 2 million tonnes, respectively.

Ecological quality of water ecosystems, p. 64
Villagers clear aquatic plants on boats on outer Zibi Lake in Zibihu Township of Eryuan County of Dali Bai Autonomous Prefecture, southwest China's Yunnan Province,
20 November, 2017
© Hollandse Hoogte/Shen Hong Xinhua/eyevine

Water quality of Zibi Lake has improved since local authorities took measures including reversing land reclamation and restoring aquatic ecosystems.

Water, migration and conflict, p. 72
Thousands Displaced by Floods and Conflict near Jowhar, Somalia
12 November, 2013
© UN Photo/Tobin Jones

Carrying whatever possessions they can, women arrive in a steady trickle at a camp for Internally Displaced People (IDPs) established next to a base of the African Union Mission for Somalia (AMISOM) near Jowhar. Heavy rains in Somalia, coupled with recent clashes between clans, have resulted in over 4000 of these people seeking shelter at the base.

Colophon

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