Getting Inspired: Applying other countries' drought measures to the Netherlands

A case-study for Water Authority Hoogheemraadschap de Stichtse Rijnlanden

Master's Thesis

By

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Cover image: photo taken at the Laaggravenseplassen Noord, Utrecht (27 June, 2021).

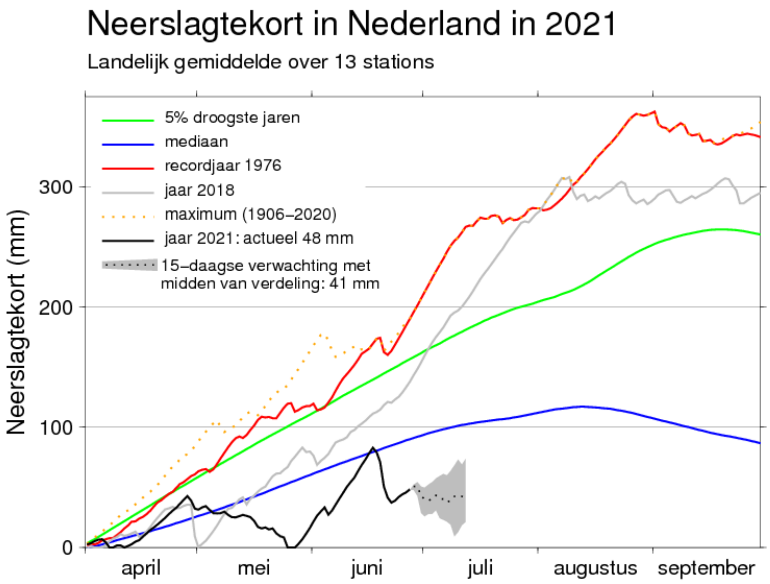
Abstract

Water shortage is a globally occurring phenomenon whose economic, social, and environmental impacts are the product of the meteorological and hydrological fluctuations and the influence of society on this climate variability. Future climate scenarios by the Dutch weather forecasting service (KNMI, 2014) indicate that it is possible that more severe drought is becoming a natural part of the Netherlands' climate. Therefore, Water Authorities should increase their resilience to water shortages before 2050. This research applies an international social learning approach to suggest improvements to the drought management of Water Authority Hoogheemraadschap de Stichtse Rijnlanden (HDSR). Seventeen drought measures which are applied in other countries have been collected for HDSR drought management challenges through explorative research. The useability of these theoretically applicable measures is assessed for the context of HDSR practicalities through focus-group discussions. Implementation of the ten resulting measures requires further research and piloting. The measures are extrapolatable to most other Water Authorities in the Netherlands. This research exemplifies an international social learning approach. With the uncertainties of climate change development in mind, such social learning approaches are useful to increase innovation towards higher resilience to drought.

Preface

When I started writing this thesis in February, concerns about a fourth consecutive dry summer were high. Today, June 28th, the precipitation deficit is lower than most monitored years. Media attention on the topic and the uncertainty of drought progression are what make my research fascinating for me. In sustainability science, I am taught to always look for the wrongs to correct. It can be daunting to always have this focus. For my internship at the Water Authority of HDSR I researched the drought management challenges that should be solved, but during this process I also gained great admiration and gratitude for all that they have already managed to do. I find it incredibly interesting how we have learnt to adapt to the diverse conditions that we face and I am curious to see how well we can learn to anticipate the climate in this quickly altering system. Due to my experience at HDSR I am excited to become a part of the Dutch (and international) water management field.

Charlotte Offringa, Utrecht, 28th of June 2021



(KNMI, 28-06-2021)

Contents

Laaggravenseplassen Noord, Utrecht (27 June, 2021)

Abbreviations

AEI | Aither southern Murray–Darling Basin Entitlement Index
ARK | Amsterdam Rijnkanaal
CA | Conservation Agriculture
DMP | Drought Management Plan
DVI | Drought Vulnerability Index
HDSR | Hoogheemraadschap de Stichtse Rijnlanden
KNMI | Royal Netherlands Meteorological Institute
KWA | Climate Resilient Water Supply
LCW | National Coordinating Committee on Water Distribution
MEW | Monitoring and Early Warning
MSF | Multi-Slot vertical slot Fishway
MUSIC | Model for Urban Stormwater Improvement Conceptualisation
PET | Potential Evapotranspiration
RAS | Regional Adaptation Strategies
VIC | Veenweide Innovatie Centrum (Peatlands Innovation Centre)
WA | Water Accounting
WSCP | Water Shortage Contingency Plans

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1. Introduction

The delta of the Netherlands regularly faces natural hazards, of which hydrological extremes provide prominent examples (High-level Experts and Leaders Panel, 2019). The North Sea flood of 1953 killed 1836 Dutch citizens and strengthened the conviction to mitigate against water excess. However, the more 'creeping disaster' of water shortage is a known hazard that occured in the summers of 1949, 1976, 2003, and 2011 (van Duinen, Filatova, Geurts, & van der Veen, 2015). The three consecutive droughts in the summers of 2018 to 2020 are considered to be an indicator that the Netherlands will face more and more water shortages in the future (Deltares & HKV, 2019). The total quantifiable economic damage thereof in 2018 is between 900 million and 1,65 billion euros (Beleidstafel Droogte, 2019).

Water shortage is a globally occurring phenomenon. The impact thereof occurs on the environmental, social and economic level due to the combined effect of drought and the influence of society to the climate variability (Wilhite, 1997). Drought is the umbrella term for meteorological-, soil moisture-, hydrological and groundwater drought, that occur with seasonal climate variability. The possibility that more extreme drought is becoming a natural part of the Netherlands' climate, is confirmed by the Royal Netherlands Meteorological Institute (KNMI). In their future climate scenarios of 2014, they expect precipitation deficits to increasingly occur during the growing seasons of the 21st century. Especially in 'H'-scenarios, where high-pressure areas have a greater influence on the weather in summer, providing more easterly winds and warmer weather (Klein Tank, Beersma, Bessembinder, van den Hurk, & Lenderink, 2015). Based on these projections, national Water Management Plans have been drawn up to make the Netherlands more resilient to a changing climate. Resilience increases adaptability to multiple future climates (Davidson et al., 2016; Scheffer & Van Nes, 2018). In management, it is a promising strategy to cope with the climate change uncertainties (Davoudi, Brooks, & Mehmood, 2013). The *Delta Decision Freshwater* (Deltaplan Zoetwater), is published every 6 years by Rijkswaterstaat and contains the general policy to make the Netherlands resilient to freshwater shortages by 2050 (Ministerie van Infrastructuur en Waterstaat et al., 2020). The policy measures aim: 1) frugality; 2) better retention; 3) smarter distribution; and 4) acceptance of damage. This requires, among other things, better steering possibilities to distribute fresh water from the main water system over the various parts of the Netherlands in times of drought. To this end, an investment package of € 800 million is proposed for the period 2022-2027. The Policy Table Drought is the national expert panel to review and advise drought management. In their advisory report of 2019, they recommend, amongst other things, to increase the consideration of the limited freshwater availability in spatial planning (Beleidstafel Droogte, 2019).

Whilst innovating to keep safe from natural hazards, the Netherlands has achieved a leading position in water science and management. Not only to solve national problems but also to strengthen the competitiveness of the water sector and contribute to problem-solving worldwide (Unie van Waterschappen, 2014). However, since 2018, water excess is no longer the main driver of innovation. Water shortage is a relatively new challenge that requires regional development based on the nationally defined goals of Rijkswaterstaat (Ministerie van Landbouw Natuur en Voedselkwaliteit, 2020). Regional water management is the responsibility of the 12 provinces, the 21 Water Authorities, and the 352 municipalities of the Netherlands. Considering water shortage, many countries are more familiar with the high occurrence of this pressing danger than the Netherlands (Federman, Arreguín, & Pérez, 2014; Hervás-Gámez & Delgado-Ramos, 2019; Stone, 2014; Wilhite, 1991). Therefore, this research aims to explore drought management plans (DMPs) in countries other than the Netherlands and investigate their drought measures. Such international social learning can contribute from the bottom-up to the general policy of the Delta Decision Freshwater in making the Netherlands resilient to freshwater shortages by 2050. Useability of the identified drought measures are assessed for the Dutch Water Authority of Hoogheemraadschap de Stichtse Rijnlanden (HDSR), a centrally located authority within the Netherlands. The main research question addresses in this thesis is:

What can HDSR learn from other countries' drought management measures?

This main question is operationalized through three objectives:

1. *Describe the HDSR study area drought problem and determine the drought management challenges.*
2. *Explore other countries' drought management plans for drought measures that can solve HDSR management challenges.*
3. *Test the applicability of the drought measures to the HDSR study area.*

The first objective is achieved through a literature review of policy reports and climatological data of HDSR. The second objective involves an explorative research of other countries' DMPs and scientific literature on drought measures, delineated by the findings of objective 1 on HDSR drought management challenges. In the third objective, the literature findings of objective 2 are presented to HDSR employees in focus-groups to discuss the usability thereof from their point of view. The main question is answered through combining the results with a system's thinking approach. This research starts with a conceptual framework on drought and drought management, to introduce the scope of the three objectives.

2. Conceptual Framework – Defining Drought

Drought is a complex phenomenon that has multiple definitions, as water availability is a fundamental need for society in direct and indirect ways. In this conceptual framework, I will define drought for the scope of the Netherlands. Because the economic, social, and environmental impacts of drought are the product of both the meteorological and hydrological context (paragraph 2.1) and the influence of society (paragraph 2.2) to this climate variability, the definition will be built up by these two pillars. Thereafter, Dutch drought management (paragraph 2.3) will be elaborated on, narrowing down to the responsibilities of the 21 Water Authorities.

2.1. Defining drought – Pillar I: meteorological and hydrological context

The KNMI often refers to a precipitation deficit to assess drought. This is an important indicator of meteorological drought (van Loon, 2015). However, a complete definition of drought integrates that the deficit is transformed into hydrological drought, soil moisture drought, and groundwater drought, and that human influences can negatively and positively affect this transformation (van Loon et al., 2016; Wossenyeleh, Verbeiren, Diels, & Huysmans, 2020).

Physical-geographical units

How meteorological drought is transformed into hydrological-, soil moisture-, and groundwater drought primarily depends on the physical-geographical conditions in which the water cycle transfers (Berendsen, 2008). The different soil types of deposits of multiple geological formations from the Pleistocene and Holocene Epochs affect the soil use and hydrology. Hereby, different infiltrative capacities exist within the soils that allow for formation of multiple storage reservoirs, amongst which are big and small rivers, groundwater reservoirs, lakes, and polders.

Meteorological drought

The difference between potential evapotranspiration (PET) and rainfall is the common indicator for meteorological drought. Regional rainfall differences in the Netherlands are expected to be minimal but differ from the west to the east (Beersma, Buishand, & Buiteveld, 2004; Klein Tank et al., 2015). Besides precipitation quantity, the timing and intensity are important variables for drought development.

Hydrological drought

Long periods of low precipitation amounts can develop into hydrological drought, propagating as negative anomalies in surface water (van Loon, 2015). These surface hydrological droughts are subject to international influences, as droughts throughout Southern Europe affect the Rhine and Meuse discharge in the Netherlands. More than 50% of the Rhine discharge at Lobith, the entry point to the Netherlands, originates from foreign mountainous areas (Beersma et al., 2004). Rainfall largely determines the height of the Rhine discharge in summer and the discharge originates for 70-80% from Switzerland at low water conditions (Beersma et al., 2004; Kleinn, 2002). Meuse discharge dependents solely on rainfall. If summer precipitation declines, this may be compensated by groundwater flux from winter storage.

Soil moisture drought

Meteorological drought can also develop into soil moisture drought as a moisture deficit in the root zone. Drought of this kind is often referred to as 'agricultural drought', as it damages crops (van Loon, 2015). Recent research by S.Y. Philip et al. (2020) showed that agricultural droughts occurred more frequently in the Netherlands in 2018 than in 1950.

Groundwater drought

A temporary decline in subsurface water over a longer period is defined as groundwater drought (Wossenyeleh et al., 2020). The likely threat of such drought in the Netherlands became evident in the recurrent droughts of 2018-2020. During these years, the accumulative effects of multiple dry summers manifested as increasingly low groundwater levels and stream discharges (Pouwels, de Louw, Hendriks, & Hunink, 2020). Slow-responding regional recharge areas require a long recovery period of the groundwater table (van Huijgevoort, Voortman, Rijpkema, Nijhuis, & Witte, 2020). Rainfall in winter shows a slight increase since 1907 (Klein Tank et al., 2015).

2.2. Defining drought – Pillar II: the influence of society

A complete drought definition also includes how human influences negatively and positively affect the meteorological-, soil moisture-, hydrological- and groundwater drought transformations (van Loon et al., 2016). Especially in the Netherlands, human influence is as fundamental to drought as natural climate variability (Sivapalan, Savenije, & Blöschl, 2011). Due to the dense population and high economic activity rate, water levels in most of the Netherlands have been artificially established to provide sufficient water quality and quantity to all asset- and user-functions that covers more than 10% of the considered basin area (Claassen, 2008). Surface water level management affects the groundwater level, whereby the effects on the groundwater table are indirectly included in the assessment (Boer, Riebel, Zevenbergen, & Nederlof, 2019). Much of the Dutch water system has thus been altered by human interventions to keep up with the growing societal reliance on freshwater. Therefore, a fifth definition has been established to identify drought: socio-economic drought. This definition covers the human influence on the drought phenomena, as the growing societal reliance on freshwater is just as important to the potential impact of a drought event on society as the possible increase in frequency and intensity of the natural event.

2.3. Defining drought – Pillar III: management

Now that drought has been defined, this part of the thesis will explore how drought management has been executed in the Netherlands. All legal agreements on water system management of the Netherlands are laid down in the Water Act. When it comes to drought, the Water Displacement Series is the most relevant article of the Act (Article 2.9, Waterwet). It indicates the ranking of socio-economic needs to be taken into account in the distribution of available water during a drought event. It divides activities into 4 categories. Category 1 contains the highest rank and includes guaranteeing safety against flooding, whereby the stability of water barriers is maintained and clay compression prevented (Kort & Hoppenbrouwers, 2019). Since 2004, the prevention of irreversible damage to nature is also classified in this category (Runhaar, 2006). Category 2, 3 and 4 cover the drinking water supply and energy supply, small-scale high-value use, and other needs such as shipping, agriculture and industry, consecutively. The ranking of interests within categories 1 and 2 is established at national level. Within categories 3 and 4, ranking can either be done by the provinces or be left to the Water Authorities. Interestingly, groundwater management falls outside of the scope of the Displacement Series and responsibility lies with the provinces and municipalities.

Drought measures aim to increase water availability, or to decrease demand. To help water managers with decision making and measure (de)activation, the National Coordinating Committee on Water Distribution (LCW) provides a drought indicator system. Their monitor calculates the water availability and expectations for a possible water shortage. It reports every few weeks in drought season. The indicators are: 1) precipitation deficit [mm]; 2) discharge of the Rhine and the Meuse [m^3/s]; 3) groundwater level [level relative to monthly mean of previous years]; 4) salinity [mg Cl/L]; 5) water demands of agriculture, the drinking water sector, nature and shipping; 6) water quality [blue-green algae] and [fish-death].

To supplement this water availability data with societal water demands, a new policy instrument is being developed in the Delta Freshwater Program, called Water Availability. The ambition is to have a country-wide picture of water availability by the end of 2021. This should provide insight into the anticipated amount of freshwater available for possible uses and calculated risks can be considered for agreements. The cumulative droughts of 2018-2020 proved that more indicators for drought are urgently needed (Boer et al., 2019; Weijers, 2020). Figure 2 visualizes how drought measures can affect water availability and water demand.

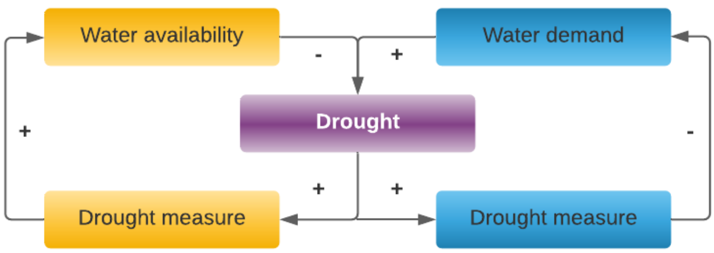

Figure 1 | A visualization of drought management. Drought measures can have an increasing effect on the water availability (+ = change in the same direction), or a decreasing effect on the water availability (- = change in the opposite direction). More drought will activate more drought measures (+).

3. Research Method

3.1. Objective 1, 2 & 3

In this thesis, an explorative research is conducted to discover drought management measures for HDSR through social learning from other countries. Social learning is a powerful tool for shifting to a more integrated and adaptive water management regime (Pahl-Wostl, 2007), and has been applied frequently in stormwater management (Chouli et al., 2007; Gimenez-maranges, Pappalardo, La, Breuste, & Hof, 2020). The useful aspect of international social learning is that ideas are born from a different way of thinking and in a different climatic-, cultural- and economical context. Figure 3 visualizes the theory behind international social learning, where drought measures can be born from a different way of thinking, altered to fit local context, and implemented to solve a management challenge.

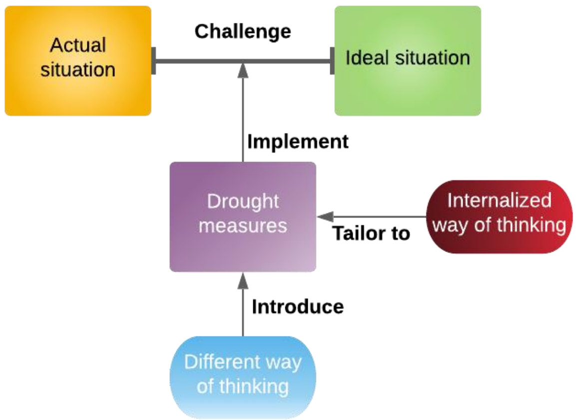

Figure 2 | How international social learning practices can provide innovative practices to challenges in another climatic, cultural and economic context. Arrows represent influence from one parameter to another.

Therefore, Objective 1 of the method aims to define the regional drought management challenges for the main physical-geographical units within HDSR. Objective 2 is to conduct a problem-oriented literature research of the regional adaptation strategies from other countries that may be introduced into HDSR management. Objective 3 targets the implementation of selected measures by tailoring them to the HDSR context.

Objective 1: *Describe the HDSR study area drought typologies and determine the drought management challenges.*	
Approach: To recognize useful and innovative drought measures for HDSR, the current drought problems in the study area are categorized and existing countermeasures are identified. Abiding the conceptual framework, first, the HDSR catchment is subdivided into physical-geographical units and the meteorological and hydrological aspects of drought are explained. KNMI climatic data and scenarios, and HDSR OWASIS data collections on soil moisture, are reviewed. Second, societal influence on drought is integrated into the drought definition to determine the overarching cause and effect of drought within each physical-geographical unit. HDSR GIS maps and policy documents are consulted to that end. Third, implemented drought measures are summarized from HDSR policy documents through a literature review. The policy plans on vision and aims for HDSR beyond 2021 are summarized to deduct the most important DMP challenges for each unit. Hereafter, query terms are selected to adequately represent the challenges. These are used in the problem-oriented search method of objective 2.	

<table>
<tr><td>Objective 2: Explore other countries' drought management plans for drought measures that can solve HDSR management challenges.</td><td></td></tr>
<tr><td colspan="2">Approach: Inspiring drought measures for HDSR can be identified at sub-basin level. This is the level at which all elements of a water management regime are at play, for it is influencing, whilst being influenced by, higher and lower management levels (Huntjens et al., 2011). Most DMPs at sub-basin scale are written in the national language. Therefore, English written DMPs provide the basis of this literature review. The first selection of countries and states to focus on was determined with "Addressing Drought : A Survey of Canadian and International Experiences" (Roth & de Loë, 2015). This research is conducted by a multi-university, collaborative research team by the name of Water Policy and Governance Group. It evaluates many of the drought management processes in multiple Anglo-Saxon countries. Guided by this research paper and the query terms from Objective 1, I was prompted to preselect: Indiana, USA, for groundwater management strategies and the applied stages of conservation; Canada for forest drought adaptation measures and for fish flow-through related solutions; California, USA, for citizen awareness and water markets; and Australia for exploring water trading systems. The UK was later incorporated in the research because of similarities to the Netherlands with regards to drought in combination with flood risk.

In my literature review I started by googling 'drought management in [Country/state]. I read through all governmental reports, policy papers and websites that contained information about any one of the previously identified management challenges of HDSR. Thereafter, a more focussed search was activated at regional, sub-basin scale within the country or state that showed most evolved drought management practices. When drought management measures were identified that could be matched to the HDSR management challenges, scientific papers were sought on the method. This led to inclusion of many other countries into the literature review, as well as to case-study specific examples of the drought measures.</td></tr>
<tr><td>Objective 3: Test the applicability of the drought measures to the HDSR study area.</td><td></td></tr>
<tr><td colspan="2">Approach: To assess the applicability of the identified drought measures to the HDSR authority, employees were asked to evaluate the applicability of the measures. The drought measures were categorized in water management themes that match the expertise of several departments within HDSR. Based on this subdivision, seven focus-groups were created, consisting of 2-4 participants with overlapping specialties in water management. A more detailed description of this process is described in the result section (chapter 4.3). I served as host for the focus-group discussions, by introducing the problem analysis and presenting the drought measure selection. After a short introduction on the measure, participants were asked whether this measure already existed in HDSR. Thereafter, I facilitated a discussion on the bottlenecks and opportunities of these measures for HDSR. As the sessions were hosted online, I prepared a powerpoint presentation for each of the focus-groups to visualize the theories. I tracked the discussion by screen sharing a virtual whiteboard where I monitored the bottlenecks and opportunities on post-it notes. I only intervened to elaborate on ambiguities, or to steer the discussion back to exploring suitability of the different drought measure aspects to the HDSR study area. The brainstorm resulted in an assessment of the applicability of the drought measures to the study area and within the existing management culture.</td></tr>
</table>

3.2. Synthesizing objectives

A systems thinking approach was applied to compose an answer to the main research question: *What can HDSR learn from other countries' drought management measures?.* "Systems thinking is a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them in order to produce desired effects. These skills work together as a system" (Arnold & Wade, 2015). Following this theory, an influence diagram was designed, to conceptualize a holistic view of drought and to identify how the drought measures interact with the concept (Galanakis, 2006).

4.1. Objective 1: Describe the HDSR study area drought problems and determine the drought management challenges

In the following chapter, the HDSR study area is described by means of the concepts introduced in the conceptual framework. First the meteorological and hydrological context is explained (paragraph 4.1.1), then the influence of society is described (paragraph 4.1.2) and then the management of drought in HDSR is reviewed (paragraph 4.1.3). The latter results in a list of drought management challenges that HDSR currently faces.

4.1.1. Defining drought – Pillar I: meteorological and hydrological context

Physical-geographical units

Sub-regional differences in drought exist within the HDSR area. The area is commonly divided into four functions: 1) peat pastures; 2) urban area; 3) river area; and 4) ice pushed moraine, also known as the Utrechtse Heuvelrug (Figure 3a). This subdivision is created to categorize the water management needs of every area. These four regions will henceforth be used to subdivide the HDSR study area into the four physical-geographical units.

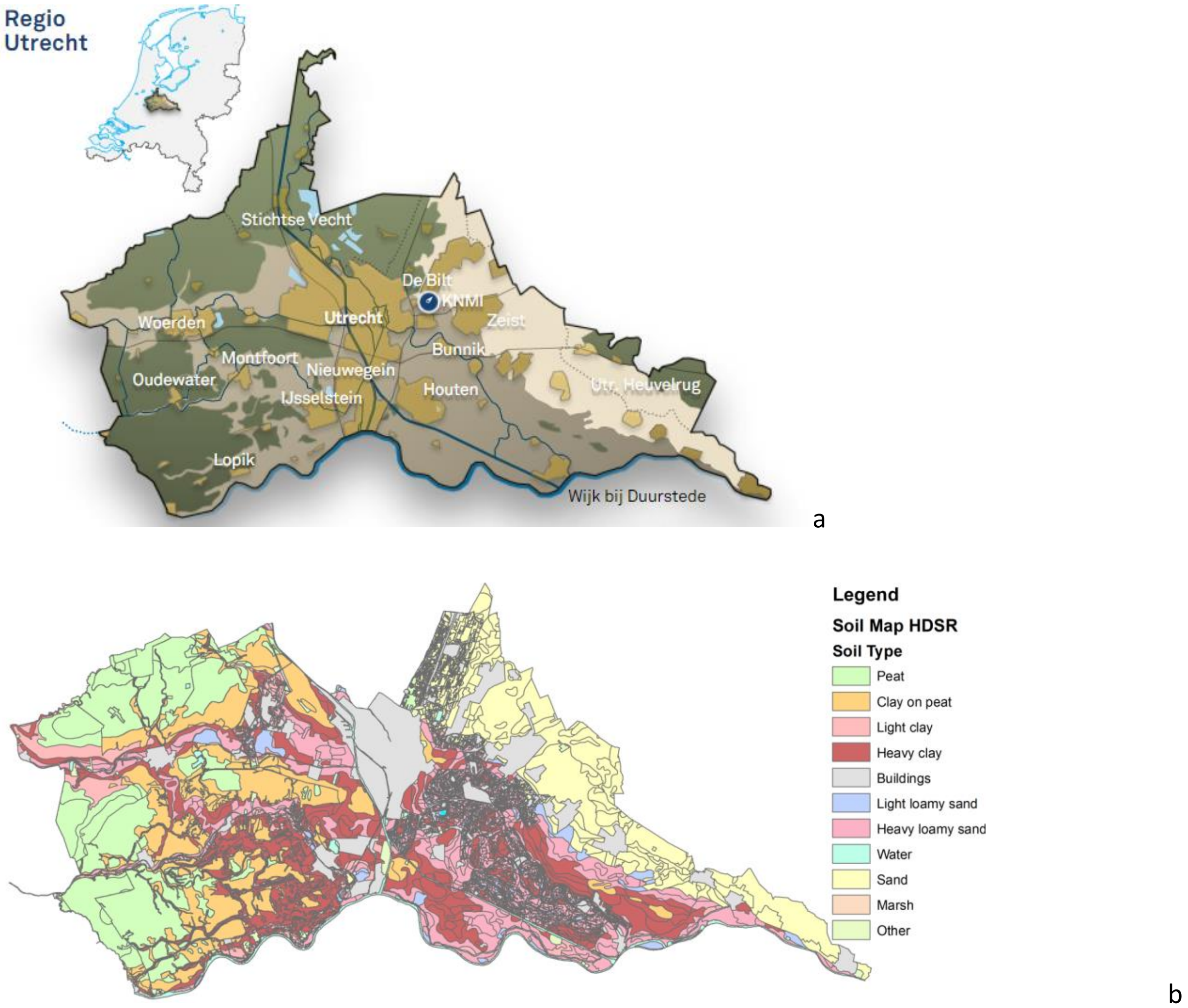

Figure 3 |The HDSR study area. a) The four common distinctions of the HDSR area. Green = peat pastures; yellow = buildings; brown = river area; sandy = ice pushed moraine (HDSR et al., 2018), **b)** soil type map.

The soil types have been a deciding factor for the current land function (Berendsen, 2008). The peat in the western area is naturally wet, which keeps the plant residue from oxidizing and decomposing. The soil type of the urban area can be deduced from surrounding soils and varies from clay and clay on peat to sand and loamy sand. The buildings and their foundation impact the hydrological dynamics, as infiltration capacity is lower. The river deposits are clayey or of loamy sand and have created a layer of clay on peat further from the banks in the western area of HDSR. Clay has a high shrink-swell capacity, whereby the soil is extremely different in wet and dry times. The ice pushed moraine is sandy, with loamy sand at the edges. Therefore, this hill has a high infiltrative capacity and water easily flows through. The East-edge of the HDSR area cuts at the foot of the higher elevated ice pushed moraine, that will continue to elevate to about 70 m NAP.

Meteorological drought

Between 1981 and 2010, the precipitation deficit [mm] was lowest above the moraine and highest in the pastures. In the summer of 2018, the deficit was more than 240 mm (Figure 4).

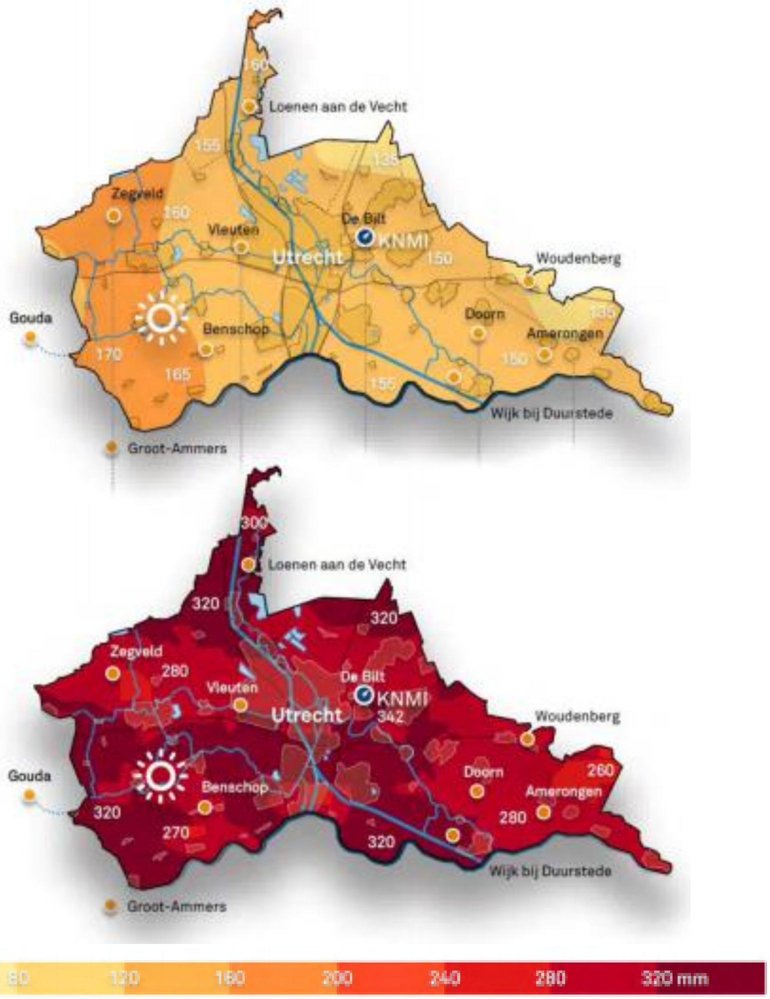

Figure 4 | Average precipitation deficit [mm] during the summers of 1981-2010 and 2018 (April 1st - September 30th) in HDSR area (HDSR et al., 2018).

The deficit occurred in spring due to the increased evaporation rates. A precipitation surplus occurs in winter months. Then flood protection is most important (HDSR et al., 2018).

Hydrological drought

South of the HDSR area flows the Nederrijn, which continues into the Lek and branches out northward as the Amsterdam Rijnkanaal (ARK). Via these surface streams, HDSR is responsible for its own water provision, as well as that of western located Water Authorities. Within HDSR, three sub-systems exist: 1) Kromme Rijn system; 2) Leidsche Rijn system and 3) Oude Rijn system. The Rhine, a meltwater and rainwater river, has a regular discharge pattern and is navigable throughout the year. 22% of what enters the Rijn at Lobith, ends up in the Lek. On average, the discharge is highest in winter due to high precipitation and low evaporation. In summer, the discharge remains relatively high due to meltwater in the Alps. According to the KNMI 2014 climate scenarios, summer discharges will decrease due to less precipitation and increased evaporation (HDSR et al., 2018). In 2050, monthly mean discharges may increase by up to 20% in winter and decrease by up to 20% in summer, according to the most extreme scenarios (Beersma et al., 2004).

Soil moisture drought

Meteorological drought may also transfer to soil moisture drought whereby flora and fauna can dry. Figure 5 depicts the percentage [%] soil moisture that remained in the soil in HDSR area in august of 2018, relative to the mean value of 1970-2015.

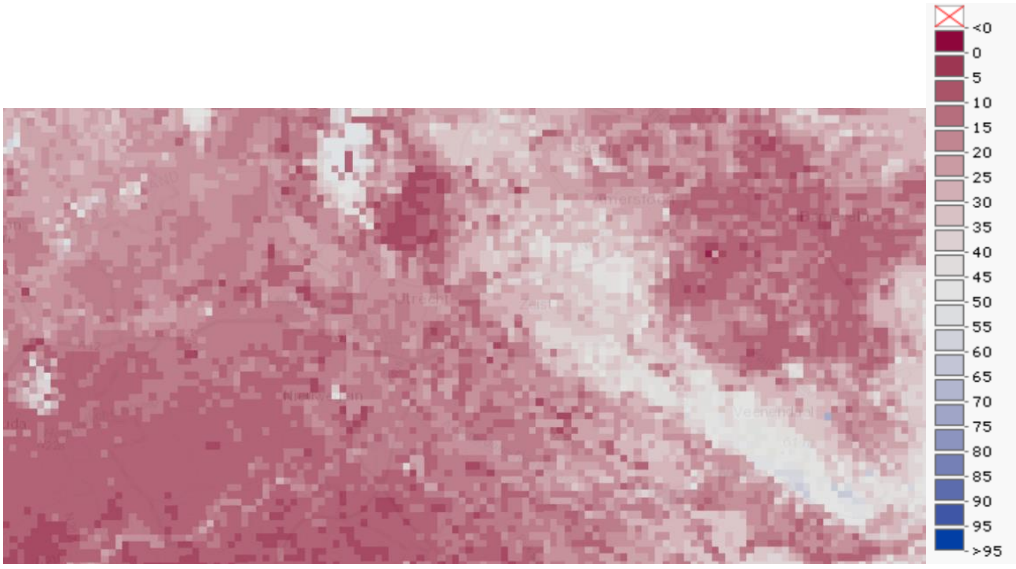

Figure 5 | Percentage groundwater storage in HDSR area of august 2018 relative to historical records (OWASIS, HDSR).

Groundwater drought

Groundwater drought occurs throughout all of the HDSR area. It impacts the rivers that flow at the foot of the moraine. When looking at the groundwater level (Figure 6a) we see a mean yearly level of 2 to 20 meters below surface level (sl). The groundwater storage in August of 2018 is depicted as a percentage [%] of the historical mean value of 1970-2015 (figure 6b).

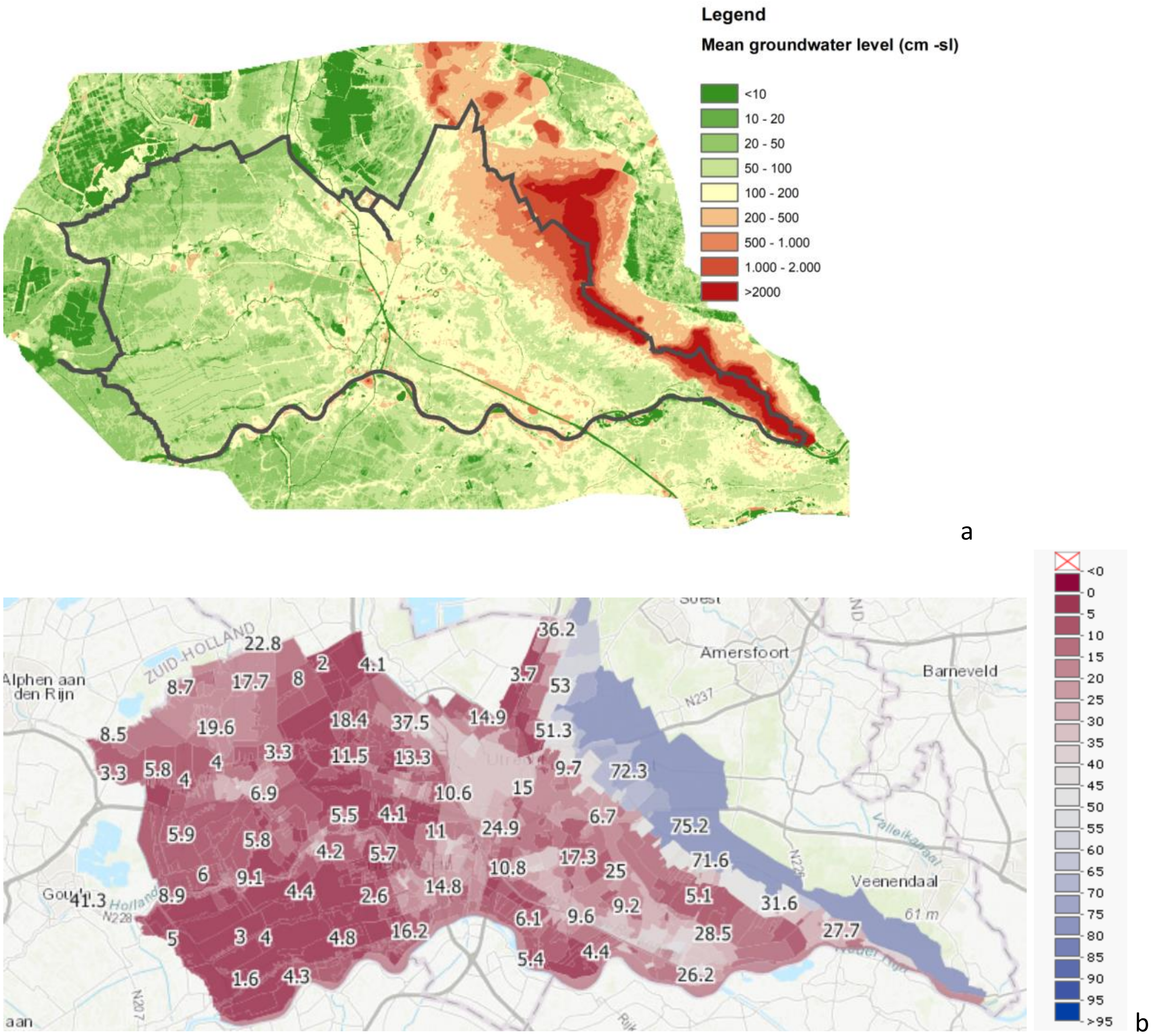

Figure 7 | Groundwater drought in the HDSR study area. a) Groundwater level in cm below surface level, **b)** percentage groundwater storage in august 2018 relative to historical records (OWASIS, HDSR).

4.1.2. Defining drought – Pillar II: the influence of society

Due to the dense population and high economic activity rate, water levels in most of HDSR are established and artificially maintained by HDSR. The water levels within peat pastures are seasonally determined, while the urban area has year round fixed water levels. The fixed level may vary per time unit or season. The target level remains the same within this time unit. This is also applied to the rivers, with exception of the Nederrijn and Lek, which are passively managed like the Utrechtse Heuvelrug. Natural water level management allows the water level fluctuate without an upper or lower limit under the influence of precipitation, evaporation, seepage and discharge. Flexible water level management is similar to natural water level management, where the water level can fluctuate naturally, but within a predetermined upper and/or lower limit. When levels turn out to be unsustainable and insufficient, it will be reconsidered. Currently, HDSR is in a likely transition from level management by modelling system SOBEK, to a more dynamic level management strategy in D-Hydro that uses real time optimization. Dynamic level management allows the level to fluctuate over time within a predetermined upper and/or lower limit. Depending on the groundwater level, soil moisture content and weather conditions, the surface water level can be set at or between the predetermined upper and lower limits. It is therefore proactive, anticipatory water level management. However, more water may be required to manage this new method.

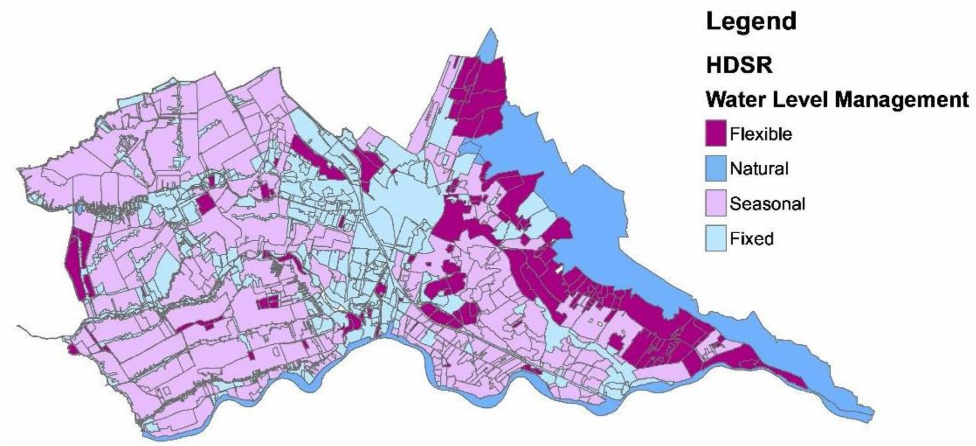

Figure 8 | Water level management types in HDSR area.

Table 1 summarizes the cause and effect of drought vulnerability within the four physical-geographical units of HDSR. Meteorological- and hydrological droughts are often the cause of drought problems, and soil moisture- and groundwater droughts are the effects. An unattainable water level is the socio-economic form of hydrological drought, where anthropogenic interests are incorporated in the definition.

Table 1 | Drought typology per physical-geographical unit.

Physical-geological unit	Cause	Effect
Peat pastures	Meteorological drought & hydrological drought	Seasonal water level management cannot be maintained & soil moisture drought & groundwater drought
Urban area	Meteorological drought & hydrological drought	Fixed water level management cannot be maintained & soil moisture drought & groundwater drought
River area	Meteorological drought & hydrological drought	Natural water level management cannot be maintained
Moraine	Meteorological drought	Natural water level management cannot be maintained & soil moisture drought & groundwater drought

4.1.3. Defining drought – Pillar III: management

Water shortage requires regional drought measure implementation, based on the nationally defined goals of Rijkswaterstaat. In the following paragraphs, the drought management of HDSR is described.

Indicators

Indicators that provide timely notification of irregularities are required to activate risk mitigation measures. Besides the national drought indicator reports of LCW, monitoring systems are actively used within HDSR to indicate and update the situation. Activation of drought mitigation measures are based on the monitoring data from the field and on VIDENTE, which combines weather and water data with models and knowledge of the local situation, generating in-depth information on the current and expected situation of the water system. HDSR has several calculation tools that are used within VIDENTE to quantify drought: the SOBEK model, HYDROMEDAH and the LHM, the latter has been specifically developed for drought modelling. Furthermore, to control HDSR hydraulic structures, the Centrally Automation Water Management (CAW) system is applied (Table 2).

Table 2 | Monitoring software per drought cause and effect.

	Cause	*Cause & effect*	*Effect*	*Effect*	*Effect*
Drought type	Meteorologic	Hydrologic	Soil-moisture	Groundwater	Level management
Indicator monitoring system	VIDENTE (Precipitation deficit [mm])	VIDENTE (Discharge [m3/s])	VIDENTE (evaporation deficit & soil moisture)	VIDENTE (water table relative to monthly mean of previous years [dm -sl] & storage capacity)	CAW (water table [mm] & river discharge [m^3/s])

The Drought Monitor of the KNMI identifies meteorologic and hydrologic drought (Netwerk Water & Klimaat, 2020). The Drought Monitor references the precipitation deficit to 5% of the driest years. Extreme drought exists if the deficit is higher than in those years. CAW has clear indicator target values and the system is fed with meteorological data. Target values are less well defined for the VIDENTE data. CAW submits data to VIDENTE, but not vice-versa. Currently a VIDENTE 2.0 is being developed, where the data should also be submitted to CAW.

Current drought measures in HDSR

The aim for water to be a guiding principle for spatial planning is set nationwide. User functions will thus preferably be carried out where they fit in the natural functioning of the soil and water system (Rijkswaterstaat, 2021). Therefore, citizen compliance is needed in most cases (Garrick, 2018). HDSR has multiple regional project plans with drought measures. In this paragraph, the main drought management challenges are deducted from HDSR policy reports, plans and aims for the future. Query terms are in italics if they are representative for the drought management challenge, to provide a problem-oriented basis for the internationally focused social learning of objective 2.

Peat Pasture

The Soil Subsidence Program in the peatlands focusses on piloting projects for water infiltration systems, underwater drainage, active groundwater level management and for water quality improvement and biodiversity increase (HDSR, n.d.). The Regional Peat Pasture Strategy contains management aspects and agreements on monitoring, finances and the process of the peatland area until 2050 (HDSR, 2020). HDSR cooperates with the research institute of Peatlands Innovation Centre (VIC) in Zegveld, Woerden, that focuses on the reorganization of the cultural and agricultural landscape to become more climate adaptive (Netwerk Water & Klimaat, 2020). Furthermore, multiple projects exist to stimulate knowledge sharing amongst farmers. During drought events, measures taken to preserve water are abstraction and irrigation prohibition. More climate adaptation measures are implemented in peat pastures (Ministerie van Landbouw Natuur en Voedselkwaliteit, 2020). Lively Farm Ditches are increasingly implemented to provide biodiverse riverbanks.

Challenge:

In the *peat pastures*, the aim is for the natural *carrying capacity* of the water system to become the leading principle for *climate adaptive* development (Netwerk Water & Klimaat, 2020). *Monitoring* therefore requires further development. *Digitalization* is an important aim for HDSR, to increase effectiveness and efficiency in all practices (HDSR, 2020).

Urban area

All Water Authorities are part of the 'Water boss' campaign, to incentivize ownership amongst citizens. In the urban areas, heat stress is a major issue that is mitigated through greening (Netwerk Water & Klimaat, 2020). Communication tools have been developed to visualize local climate adaptability and heat stress resistance. Decreasing urban temperatures is also profitable for less surface water evaporation. However, evapotranspiration of plants requires more water to decrease the heat, whereby groundwater levels are lowered. More efficient use of rainwater is aimed at to counteract these issues, by increasing local infiltration and storage capacity. Many municipalities have subsidy opportunities for disconnecting rainwater and installing green roofs.

Challenge

HDSR aims to determine and achieve target values for water quality and quantity in *urban areas*, and to implement a *no-waste* and *circular* water cycle within the city (Netwerk Water & Klimaat, 2020). The government aims to *decouple rainwater* from the *sewage* system. Thereby, rainwater can be used to *resupply groundwater* and to release pressure on the sewage system. During hydrological drought, *purified water* is an increasingly large component of the discharge, which has effects on the naturally existing water quality (Rijkswaterstaat, 2021). Furthermore, *citizens* and business owners are looked upon to increase their individual *awareness* and *adaptation* to dryer summers (Netwerk Water & Klimaat, 2020). Therefore, vital and vulnerable functions require *transparent information* on their *vulnerabilities* in relation to drought.

River area

The capacity increase of the Climate Resilient Water Supply (KWA) aims to double the water flow through capacity of the Rhine (to 15 m^3/s). The Improved Rhine Inflow Possibility (VRAM) indicates an adaption to the intake pumping station near the Kromme Rijn, to release pressure on the Amsterdam Rijnkanaal and maintain discharge into the Kromme Rijn area during drought (HDSR, 2020). Other water saving measures in the river area are water saving locks and inspection of drought prone quays. To counteract salinization, a bubble wall has been installed in the ARK.

Challenge

In the r*iver area*, *preserving ecological value* is a main challenge during drought. Regularly encountered dilemmas by water authorities concern the retention of water with weirs versus the preservation of *fish migration* and the preservation of natural values, or the enhanced flood risk due to water retention (Gool, 2021). During drought, discharge in the KWA may be too high for ecological preservation. At the same time, fish passageways around pumps can get closed during low discharge, whereby *flow-through* is not guaranteed. Lower flow-through mainly leads to lower water quality in smaller waterways.

Moraine

To increase the regional water storage capacity, The focus is on the Utrechtse Heuvelrug. This is due to the fact that other surface water storage possibilities are prone to high evaporation risk. Therefore, the Blue Agenda has been set up. Water levels around the flanks of the Heuvelrug in the Gooyerwetering are already elevated due to this Agenda (Netwerk Water & Klimaat, 2020). HDSR has authority over the most common groundwater abstractions in the area (Rijkswaterstaat, 2021). Plans for improving the groundwater quantity management are beyond HDSR responsibility, however groundwater quality management is a priority in Soil and Subsoil Implementation Program (UP) (Sterk Consulting, 2020).

Challenge

In all of HDSR, but with focus on the moraine, *groundwater management* needs to be reorganized and more proactive (Netwerk Water & Klimaat, 2020; Sterk Consulting, 2020). The *displacement series* is not applicable to groundwater and should be designed for the more *slow timescales* of groundwater changes.

4.2. Objective 2: Explore other countries' drought management plans for drought measures that can solve HDSR management challenges

Based on the identified drought challenges in HDSR, inspiring drought measures were identified at the sub-basin level in other countries. This is the level where all elements of a water management regime are at play, for it is influencing, and influenced by, higher and lower management levels (Huntjens et al., 2011). In the following paragraphs, the results from the problem-oriented explorative research are listed and described. The query terms from objective 1 served the basis of the literature review. The measures have been sub-categorized in five drought management challenge themes: 1) towards proactive drought management; 2) for provision of agricultural needs; 3) for provision of ecologic needs; 4) for better use of indicator data for drought management; and 5) to improve water literacy and urgency to adapt. In total, 17 drought measures from other countries were assessed to be promising for social learning. One by one the measures will be elaborated upon.

4.2.1. Towards proactive drought management

The Water Market

Since 1922, Australia has made a big mindset-change from reactive hazard management to proactive climate adaptation and risk mitigation (Stone, 2014). Here, allocating water from its source for consumptive uses (e.g. irrigation, domestic, industry) and for environmental purpose, is coordinated by means of water access entitlements and planning arrangements (Burdack, Biewald, & Lotze-campen, 2014; Productivity Commission, 2021b). Water entitlements are decoupled from land rights, to facilitate water trading based on market-based regulation. Such markets also exist in South Africa, the UK, Chile, Canada and the US (Bakker, 2005; Bate, 2007; Holman et al., 2019; Lund et al., 2014; Wittrock & Wheaton, 2007). Entitlements are statutory based and provide water users with a right to extract water from a specific resource conforming to a transparent process (Productivity Commission, 2021c). Herein, the interaction between surface and groundwater is recognized to integrate the management. The entitlement indicates the yearly volume of water that an owner has the right to receive. Only a percentage thereof is permitted for allocation (abstraction), to consider water availability fluctuations. Moreover, abstraction limits for catchments and groundwater systems are abided to protect the basin. Water entitlements are viewed as a secure financial asset and trading thereof is interesting as water demand levels can change across a venture's lifetime (Productivity Commission, 2017, 2021c). Trading amongst farmers may stimulate change of production for example as diversification of cropping systems (Gautam & Bana, 2014). These secure property rights have also encouraged farmers to either do longer term investment planning or to exit the industry (Productivity Commission, 2017).

Public water entitlement register

Such a water market requires a publicly accessible register. The Bureau of Meteorology in Australia maintains a dashboard on Water Markets, whereby the trade of water volume entitlements is made transparent, including the price of the entitlements (Bureau of Meteorology, 2017). The dashboard tracks the location, the type of water source ([ML] surface and/or groundwater), the type of water products (allocation trade or entitlement trade), and the time periods (years, monthly, weekly or seasonal) (Bureau of Meteorology, n.d.). An example of an elaborate regional water entitlement register is the Victorian Water Register (The State of Victoria, 2021). The register is accompanied by a 'Where can I trade' tool, to estimate inter-trade zone trading opportunities.

Water value

Water prices are provided for such a water market and provide all stakeholders with an understanding of the dynamic characteristics of the water resource (Aither, 2018, 2019b; Hanak & Stryjewski, 2012). Valuing water is a growing business case for the environmental, agricultural, energy, industry and business sector (Productivity Commission, 2021a; Schmidt, 2019). It can contribute to decision making, maintaining and enhancing revenues, reducing costs and managing risk (WBCSD, 2013). Water pricing also allows better comparison of investment costs for water protection and conservation initiatives, to costs of reactive initiatives that clean or restore degraded water basins (Thompson Jr, 2000). Furthermore, a water owner can compare the value of the water to the value of the potentially produced product (Bate, 2007). The Murray-Darling Basin has one of the most well developed Water Plans and trading systems wherefore a water entitlement index has been designed by the esteemed Australian advisory firm, Aither. Aither publishes monthly estimates of the Aither southern Murray–Darling Basin Entitlement Index (AEI), indicating the pricing of major water entitlements (Aither, 2019a). Furthermore, the firm publishes a yearly Water Market Report in which water demand and climate conditions are related to water price, trade and agricultural developments (Aither, 2019b). Volume-weighted average prices and annual price change are calculated and it provides water market participants, investors, consultants and policy makers with a recap and projection of the market drivers.

Water Shortage Contingency Plans

Besides knowledge on the water availability in a system, trade-offs are required to incentivise smart coexistence of all water users and balance the objectives of environmental, economic and consumptive use. An interesting example of prioritisation of water demands in cities is practiced in Indiana, USA, where water shortage contingency plans (WSCP) are activated during times of prolonged drought (Urban Drought Guidebook, 2008). Public water supply systems activate their WSCP throughout predefined stages that specify at least 4 emergency phases for which triggers and measures are described that can be activated and deactivated by the district and customers (Indiana Department of Natural Resources, 2015; Las Virgenes Municipal Water District, 2016).

The government of British Columbia, Canada, has created a similar Drought Response Plan (Ministry of Environment and Climate Change Strategy, 2018). This plan provides 4 categories of drought classifications (from normal to extremely dry). The stages are complemented by demand reduction goals in percentages, where a distinction is made between an objective of being prepared, voluntary conservation, mandatory restrictions, and regulatory action. Surveys can be applied to track the progression with regards to reduction goals. The WSCPs are publicly available whereby all residents are made aware of expectations and the 'myth of water abundance' fades.

4.2.2. For provision of agricultural needs

Irrigation permits with predefined restrictions

Besides prioritization of water provision during scarcity, more frugal and efficient water use can reduce the pressure on the system. Water provision for agriculture is a focus point for drought mitigation and adaptation practices all around the world (Giller et al., 2015; Scanlon et al., 2017; Smit & Skinner, 2002; van Duinen et al., 2015; Wittrock & Wheaton, 2007; Wreford & Topp, 2020). Improving sustainability of the soil and reducing crop production costs are focal points in the paradigm of Conservation Agriculture (CA). CA is adopted less frequently in Europe than in regions such as North Africa, South-East Asia and Latin America (Lahmar, 2010). In the UK, spray irrigation is restricted according to predetermined threshold values of the corresponding water resource at which conditions the holder has to reduce or stop spray irrigation (Environment Agency, 2017). These threshold values cover surface and ground water and are set in the irrigation licence to protect the environment. In Indiana, USA, irrigation is allowed only during non-peak evaporation and evapotranspiration hours and avoided under high wind conditions (Indiana Department of Natural Resources, 2015). Moreover, groundwater abstraction is limited to protect surface water flow, level or volume (Environment Agency, 2017). Abstraction limits to preserve waterways and aquifers are established through correlating the maximum allowed pumpage with the recharge capability of aquifers (Indiana Department of Natural Resources, 2015).

Diversification

In times of extreme water shortage, the Australian National Water Initiative (NWI) module Considering Climate Change and Extreme Events in Water Planning and Management suggests water resource planning with alternative water resources (stormwater, recycled water or desalinated water) (Australian state and territory governments, 2017). This provides a pathway to maintain irrigation capacity and provide environmental protection. In India, rainwater is stored in agricultural fields by means of farm ponds of which the size can be easily estimated and is approximately 10% of the field area (Prabnakorn, 2020). Digging pits to effectively store and infiltrate rainwater (potholing) in meteorologically dry areas is also what JustDiggIt aims to make groundbreaking progress with (*Justdiggit*, 2021). Little scientific literature exists on the conservation technologies of such potholing tactics, however, combining water bunds (half-moon pits), zaï and stone bund with smart nutrient application currently provide drought adaptation practices for smallholder farmers in South Africa (Zougmoré, Jalloh, & Tioro, 2014).

Agricultural polymers

To increase the drought resistance of rainfed agriculture, farmers in India and the Northwest Himalayas are using agricultural polymers (Gautam & Bana, 2014; Shankarappa et al., 2020; Zaremba & Smoleński, 2000). The application of such superabsorbent polymers find their origin in the forestry sector but their applicability in rainfed agriculture is being researched in countries such as Brazil and Iran (Allahyari et al., 2013; Barros et al., 2017). These insoluble and hydrophilic synthetic polymers, also known as Hydrogel, can be applied in soil amendment to improve water-use efficiency and increase crop yield (Zaremba & Smoleński, 2000). They can absorb and retain water as much as 80 to 180 times their original volume (Bowman & Evans, 1991). Due to its physical properties, it can modify soil properties such as infiltration rate, density, soil structure and compaction (Zaremba & Smoleński, 2000). Biodegradable nano-polymers are being developed and tested for sustainable agricultural farming (Ramesh, Vundavalli, Nakka, & Rao, 2015).

Weather index insurance

Crop insurance and agricultural subsidies are a widely used drought coping measure in drought prone areas (Barnett & Mahul, 2007; Hazell et al., 2010; Smit & Skinner, 2002). The aim thereof is risk sharing amongst producers (Glauber, 2004). Weather index insurance (WII) is currently a leading practice for agriculture insurance in developing countries (Fuchs, Wolff, & Davis, 2011). WII aims to provide that an insured farmer remains to have the same economic incentives to smartly manage her crop as an uninsured farmer (Hazell et al., 2010). The insurance covers a certain weather index (e.g. precipitation or soil moisture), that has a high correlation to the farmer's yield and which can be monitored with a local weather station (Glauber, 2004; Hazell et al., 2010; Wittrock & Wheaton, 2007). The insurance covers deviations from a predefined threshold value of the weather index. Therefore, rather than receiving an indemnification based on yield reduction, farmers receive compensation for e.g. a shortage in rainfall as measured by a local weather station (Dalhaus, Musshoff, & Finger, 2018). Moreover, the need for in-field assessments disappears (Hazell et al., 2010).

4.2.3. For provision of ecologic needs

Environmental water entitlements

An increasingly important resource competitor within the water trade-off is nature. To sustain 'Nature's contributions to people', Australia has granted Environmental water entitlements to a statutory authority that ensures protection and provision of ecologic needs: the Victorian Environmental Water Holder (VEWH) (Productivity Commission, 2021a; Schmidt, 2019; Victorian Environmental Water Holder, 2020). The authority can decide on the most effective use of their environmental water entitlements. Outcomes and objectives of environmental conservation should be specific, with clear indicators to enable monitoring of long term performance. Indicator/trigger values to signal drought timely should be established, and flow targets should be set to protect critical ecosystems (Productivity Commission, 2021a; Write a drought plan, 2015).

Streamflow minimum requirements for fish habitat

A recommendation to determine priorities in Indiana's WSCP is to consider both instream (such as recreation/swimming) and withdrawal uses from surface water resources (Indiana Department of Natural Resources, 2015). To sustain the instream uses of a given stream, the minimum flow of streams must be determined and protected. The instream flow that suffices to the needs of fish habitat indicates the streamflow minimum requirements in Indiana. Therefore, withdrawal from a stream is only recommended if the discharge is higher than the instream flow required for fish survival, which is set at the median flow estimated from the lowest flow with a duration of 61 days, occurring between May and October. It is not uncommon to base a minimum acceptable flow on instream habitat preferences from one of the main fish species, however it can also be determined with more elaborate modelling packages (Arthington, Rall, Kennard, & Pusey, 2003). It is important that the calculations incorporate the needs of the vegetation and geomorphology that the fish habitat consists of (Stromberg & Patten, 1990). Providing such legally guaranteed instream flow rights can protect fish and their habitat.

Multi-slot vertical slot fishway

Technical developments can help decrease the pressure of ecological requirements on the total water interests' trade-off (Romão et al., 2021). Fishways with lower water consumption that still guarantee effectiveness are being designed, such as the multi-slot vertical slot fishway (MSF)(Figure 8) (Romão, Branco, Quaresma, Amaral, & Pinheiro, 2018). A MSF operates with up to 34% lower discharge than a vertical slot fishway (VSF), while maintaining all other important functionalities (Tauber & Mader, 2009).

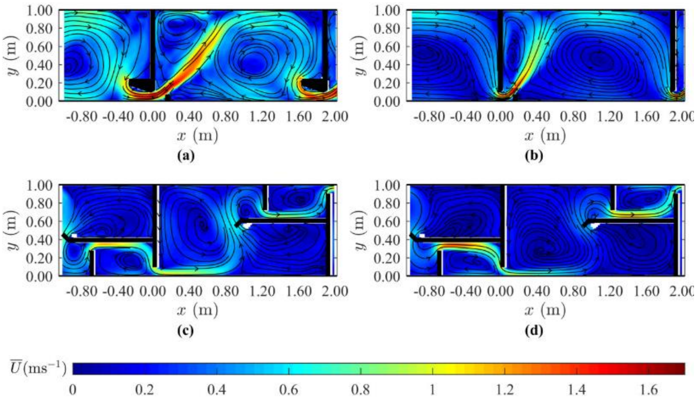

Figure 8 | Mean velocity magnitude and streamlines in the VSF (a,b) and the MSF (c,d) (Romão et al., 2021).

4.2.4. For better use of indicator data for drought management

Composite indicator

Water Authorities must create a monitoring and early warning (MEW) system with drought trigger values to timely indicate drought and the end of drought. Historical benchmarks are useful aspects to a MEW, for they can serve as comparison for current status within the context of past droughts (Watts, Christierson, Hannaford, & Lonsdale, 2012). In the U.S., drought is tracked and indicated by the U.S. Drought Monitor by means of quantitative multivariate composite indicators (Hannaford, Collins, Haines, & Lucy, 2019). Composite indicators for drought typically blend a range of hydrometeorological indicators and are a good addition to MEW systems. Moreover, improving the forecasting capacity of MEW systems is a must for pro-active drought management. Therefore, the UK has set up the IMPETUS programme to monitor meteorological data, surface water fluctuations and groundwater levels and to incorporate this with domestic demand to provide forecasts on monthly to decadal timescales.

Water accounting

When the in- and outflows of the hydraulic system are monitored at all times, it is possible to develop a Water Accounting (WA) system. WA is a computational tool that can model future water scarcity scenarios, as it combines demand increase with supply decrease (Vardon, Lenzen, Peevor, & Creaser, 2007). Although multiple forms of WA exist, this chapter elaborates on the Water Accounting Plus (WA+) (Karimi, Bastiaanssen, & Molden, 2013). This decision was made as this framework also incorporates the role of land use changes and land use planning. Such geohydrological parameters are increasingly important in integrated water management (Garrick, 2018). Furthermore, the main input data for WA+ is available through remote sensing. The framework is built up of four sheets including: 1) a resource base sheet, providing a hydrological summary; 2) an evapotranspiration sheet, on water depletion; 3) a productivity sheet, on biomass production by photosynthesis; and 4) a withdrawal sheet. The latter provides quantification of gross and net withdrawals of managed water use, of which the input data requirements cannot be obtained through satellite data. WA+ offers a set of standard performance indicators that users can supplement, based on their specific interest. Surface and groundwater systems are distinctly separated because their management options are quite different. Within WA+, water depletion is related to data on production outputs of biomass, production of food and carbon sequestration in different land-use categories. This is the key to identifying best practice and increasing water productivity. The WA+ framework can be applied to evaluate the impact of interventions such as water redistribution, reducing groundwater abstractions, alternative irrigation practices, artificial recharge and deforestation.

Water management modelling tools

Australia has multiple water management tools that contribute to the national MEW system and help policy makers and managers make informed decisions on water division in a dry climate. Amongst these are Source, MUSIC, Urban Developer, Toolkit, and Water Quality Analyser (*eWater Tools*, n.d.). Together, these provide data for integrated climate adaptation, where climate change induced water shortages, cultural dynamics and stakeholder dependencies, interact (Aither, 2018). Source is a tool for water crises, to manage scarce and highly variable water resources. MUSIC (Model for Urban Stormwater Improvement Conceptualisation) is a tool for water sensitive urban design, that can identify the best way to create circular stormwater runoff use by modelling a diversity of treatment devices. The Urban Developer can improve urban water efficiency and consider resource diversification through analysing urban water demand. The Toolkit contains a collection of other online hydrological, ecological and catchment management models and databases. Water Quality Analyser is a tool that monitors water quality and estimates pollutant loads to set water quality targets. In addition, rural Australia has developed a Spatial Simulation project, AussieGRASS, to provide early warning of drought episodes that lead to large problems for grazing stock and feed availability (Mckeon et al., 2018). The alert system warns farmers of potential land degradation episodes by coupling stock number data and pasture production with seasonal forecasting. Every month, maps of 5x5 km are published with indicators of total standing dry matter [kg/ha], rainfall, potential stream flow, and a probabilistic risk assessment for future pasture growth (DSITI, 2015).

4.2.5. To improve water literacy and urgency to adapt

Instruments that increase public individual participation in water frugality

Besides trust in the water authority, trust in others in the community (farmers, industry and neighbouring residents) to responsibly use water is key to induce voluntary water consumption reduction (Jorgensen, Graymore, & O'Toole, 2009). Therefore, the Australian government facilitates daily, weekly or monthly billed water consumption for comparison between neighbours or city residents in similar context (Aither, 2018). The governmental website of British Colombia provides many video-tutorials on how to conserve water and adapt to drought. Moreover, Australia piloted the Water efficiency labelling and standards (WELS) scheme, that allows quick improvement of residents on their water frugality through smart purchases of water-using household appliances (Chong, Kazaglis, & Giurco, 2008). In some areas of Indiana, packaged kits of water conservation devices are provided for free to decrease domestic water use (Indiana Department of Natural Resources, 2015).

Storytelling

Research in Australia and rural Iran proves that drought cannot only impact the physical health, but also mental health is at risk (Bryan et al., 2020). Sharing citizens' experiences with drought through narrative research is applied in multiple countries, such as Australia, South Africa and the UK (Rangecroft et al., 2018). One initiative is the Drought Risk and You (DRY) programme in the UK. Through Drought Narratives, stories and memories of drought in the UK are built and shared through a variety of methods to provide societal context to expert knowledge for water management (*Drought Narratives*, n.d.). Stories are collected at festivals and river walks, through audio recorded micro-interviews and short video creation. These stories can adequately elucidate drought related problems in developed countries, such as with gardening and access to nature (Bryan et al., 2020). Furthermore, co-creating future drought narratives (storylines) based on hydrological scenario modelling is practiced in South Africa (Rangecroft et al., 2018). Through workshops with relevant storylines, set in a local context, participants can create personal future narratives that allow them to explore possible drought events outside their range of experiences. Hereby, societal awareness is raised and bottom-up preparedness is increased to mitigate and adapt to drought. Narratives can also be valuable in supporting the policy dialogue around future adaptation strategies for drought (Bryan et al., 2020). Cape Town's "Day Zero" plan of 2017 and 2018 is a good example of how a disaster plan that warns of catastrophic outcomes through time series analysis evoked a bigger behavioural change in society than water use restrictions or tariff increases (Booysen, Visser, & Burger, 2019; Nhamo & Agyepong, 2019). "Day Zero" quickly boosted 'hydraulic citizenship', whereby all types of users created water conservation methods and technologies (Robins, 2019).

Community monitoring events

Increasing community water-related knowledge is an important variable to facilitate sustainable water management (Bureau of Meteorology, 2017; McCarroll & Hamann, 2020). This can be improved by adopting more monitoring practices that involve delta residents, often referred to as micro-resilience initiatives (Kraus-polk & Milligan, 2019). In Durban (South Africa), Gorakhpur (India), and Cebu City (the Philippines), micro-resilience initiatives were strong facilitators of community empowerment (Johannessen et al., 2019). These initiatives consisted of local bottom-up action, such as individual monitoring of water quality. By reflecting on the learning process and by co-creating new learning strategies, norms and values can be changed (Snell & Chak, 1998). Multiple community-based forestry organizations in the west coast of the USA also organize community monitoring events (Ballard et al., 2006; Fernandez-gimenez et al., 2008). These are independently, locally organised and supplementary to the national monitoring practices. These non-profit alliances have various objectives for their monitoring projects, from learning about the natural system, to building trust, to determining the effects of management actions, to managing conflict, or to train local people for jobs.

4.2.6. Drought measure collection

These 17 drought measures are the final result of the explorative research on other countries DMPs and scientific literature on the drought measures. They cover mitigation as well as adaptation measures, that each focus on their own aspect of the integrated problem.

4.3. Objective 3: Test the applicability of the drought measures to the HDSR study area

To test the applicability of the 17 drought measures elaborated upon in the previous chapter to the HDSR management practices, the measures were re-categorized in drought management themes that match the expertise departments within HDSR. Thereby, seven focus-group specializations were formed. (1) East HDSR, specialized in the Kromme Rijn area and the moraine, was asked to discuss the regional applicability of a Water Market, the public register thereof, water value, and the WSCP. These measures target facilitating a transition towards proactive drought adaptation and fair trade-offs between stakeholders. Focus group two, (2) West HDSR, specialized in the Oude Rijn area and peatlands, was asked to reflect on the same measures. The third group, (3) valuing water, is specialized in national water management policy and could assess the applicability of the Water Market and valuing water at national scale. The fourth category is (4) ecology, specialized in water quality and biodiversity protection, who were asked to assess irrigation permits with predefined restrictions, environmental water entitlements, streamflow minimum requirements for fish habitat, MSF fishway, and diversification. These measures target insufficient protection and provision of ecologic needs. The fifth group, (5) agriculture, is specialized in innovation management in peatlands. This focus group assessed the value of irrigation permits with predefined restrictions, diversification, agricultural polymers, and weather index insurance, that aim to decrease the pressure of agriculture on the total water trade-offs and to mitigate investment risks in the business. Focus group six, (6) digitalization, is specialized in data management and utilization. They discussed the purpose of WA, a composite indicator, and water management modelling tools for better use of indicator data for drought management. Lastly, (7) strategy & communication, was asked to evaluate instruments that increase public individual participation in water frugality, storytelling, and community monitoring events. Their specialization in strategy formulation for climate adaptation and communication allowed for a discussion on whether these measures could improve water literacy and urgency to adapt in HDSR. Table 3 shows the focus group participants and their job description.

Table 3 | The focus-group participants and their position. WB = HDSR department of water management and OSA = department of research, strategy & consultancy.

#	Person	Position	Focus-Group
1	Peter Smorenburg	WB – Area administrator Oude Rijn	West HDSR
2	Winfried van Leeuwen	WB – Area administrator Kromme Rijn	East HDSR
3	Marco Schoenmakers	WB – Area administrator	East HDSR
4	Dennis van de Waardt	WB – Area manager Kromme Rijn	East HDSR
5	Dolf Kern	Coordinating Advisor to the Delta Commissioner's Staff	Valuing water
6	Durk Klopstra	Executive Director at HKV lijn in water	Valuing Water
7	Frank Lessinck	Director at Veenweiden Innovatie centrum	Agriculture
8	Maarten Hoetmer	WB – Advisor waterways	Ecology
9	Danneke Verhagen-Bakker	OSA/Knowledge - Advisor Ecology	Ecology
10	Nikki Dijkstra	OSA/Knowledge - Advisor Ecology	Ecology
11	Roger de Crook	OSA/MID – Advisor Monitoring Waterquantity	Digitalization
12	Epke van der Werf	OSA/Kennis –Hydrologist	Digitalization
13	Marcel Wijstma	OSA/Planning – Coördinator urban climate adaptation	Communication & strategy
14	Saskia van Otterloo	OSA/strategy – Strategic advisor	Communication & strategy
15	Astrid Russchen	Communication – Communication advisor	Communication & strategy
16	Joost Heijkers	OSA/Knowledge – Hydrologist	West HDSR, East HDSR, Valuing water, Digitalization

In the following paragraphs, the focus-group discussions are synthesized to an assessment on the suitability of other countries' drought measures to HDSR. The relevant focus groups are in brackets behind each statement.

4.3.1. Towards proactive drought management

The Water Market

Trading water entitlements is not easily implemented in HDSR because it would require total institutional change at national level (East & West HDSR). However, enhancing the legal status by giving water an economic value is an interesting aspect that may be applicable to the HDSR permit system for fruit cultivation. Demanding payment therefore would certainly increase the efficiency of water use, but would likely also lead to resistance of farmers (East HDSR). A meaningful purpose would have to be determined for the money obtained for the water rights (West HDSR). HDSR has very few, small and temporary groundwater extractions, therefore market based regulation might be more applicable in areas of the Netherlands with more groundwater abstractions or more salinization. Implementation of such a market would give an impulse to the monitoring effort (East HDSR). However, monitoring and enforcing fair water use in accordance with regulations is very difficult in the HDSR area because of all the open water and the relative ease by which one can install his own pump. The market based regulation shows some correlation with the emerging nitrogen rights market that is now being developed in the Netherlands. However, the sustainability of trading and compensating for environmental pollution in such a manner is debatable (West HDSR). Furthermore, water shortages in HDSR are not yet great enough for the necessity of a water market (East & West HDSR).

Public water entitlement register

Making the water consumption of all stakeholders and abstracters transparent in a public register could increase efficient use and consumption awareness amongst farmers. Putting a flow meter on each pump to monitor abstraction is an easy thing to do. However, making this abstraction data openly accessible might lead to resistance from abstractors (West HDSR) and could lead to privacy and national security conflicts (Valuing water). Furthermore, the publicly accessible registers of all inputs and withdrawals are not likely to improve water consumption awareness among citizens. Therefore, it would be better to put the costs of water and drought in the product itself through labelling of a Water Footprint Analysis score (East HDSR).

Water value

Providing the economic value of water through an entitlement system should be introduced on a national scale, or even on an EU scale. Implementing such a system would however likely cost more money than it would yield. A price incentive method could be applied to groundwater abstraction for farmers. It would be useful to map out how efficiently withdrawals are made (Valuing water), because the economic value of water could stimulate people to think more about the necessity and methods of their water use (West HDSR). In addition, it would be interesting to be able to compare agricultural and natural needs through price weighing (Valuing water). HDSR could calculate and indicate the costs of water transport from one place to another by means of pumps and pumping stations (Ecology).

Water Shortage Contingency Plans

Prioritization of water resources at a local scale through WSCPs, could be an operational execution of the Delta Program on Climate Adaptation, because it provides a locally applicable pre-crisis addition to the national displacement sequence (East & West HDSR). Such response plans already exist within HDSR, but only for private use. Making publicly accessible WSCPs is therefore a suitable elaboration of HDSR drought measures (Strategy & Communication). The WSCP would be a refinement of HDSR's role as mediator in times of water shortage. The agreements reached between water users, mediated by HDSR during the summer of 2018, can provide the basis for this plan (West HDSR). It would raise awareness on the finiteness of water resources and offer prospects for action within the risk dialogue that HDSR needs to conduct with its residents (West HDSR & Strategy & communication). It will be challenging to determine how the pursued percentage of water use reduction will be shared among the users (East & West HDSR), as the activated measures per phase will be viewed critically by citizens in comparison to the measures demanded by other water authorities (should they have a similar scheme) (Strategy & communication). Furthermore, it should be clearly discussed with users at each stage of the planning process what HDSR can provide and expect (East HDSR). A WSCP might give HDSR more control over groundwater extractions (East HDSR).

4.3.2. For provision of agricultural needs

Irrigation permits with predefined restrictions

Rules on when and how to irrigate already exist in HDSR and other authorities. Since irrigation is expensive and labor-intensive, it is rarely done in a non-frugal manner. For instance, fruit growers in Boskoop already use drip irrigation (Agriculture).

Diversification

Diversification can provide new water resources to mitigate drought in times of water shortage. HDSR has two water fluxes that provide the major diversification possibilities: effluent water and stormwater. Current practice with effluent water is to discharge this into larger water bodies. Infiltration of effluent water into the Utrechtse Heuvelrug is being investigated at this moment (Ecology). In these high sandy soils, increasing the organic matter content to better retain water is currently practiced (Agriculture). Exploring the use of effluent water in smaller important water bodies for throughflow guarantee might also be interesting to investigate. However, the quality of effluent water may be damaging to the system, due to high levels of nutrients and medicine residues (Ecology). Furthermore, HDSR might start implementing dry storage instead of peak storage. Farmers would have to give up a plot of land at the end of May that can be flooded to provide additional water storage for dry months July-August. HDSR would probably have to buy up these pieces of land. Willingness and lack of space are related problems. Moreover, high evapotranspiration rates and large phosphate releases may make this practice unsustainable (Agriculture).

Agricultural polymers

Polymers that increase water retention and aid rain-fed agriculture are not yet needed in HDSR. In sandy soils, increasing the organic matter content has the same water-retaining effect. Peat can already retain water very well and a chemical application would not be desirable. However, further research into biodegradable polymers is interesting to follow. The costs involved are also relevant in the considerations (Agriculture).

Weather index insurance

To ensure farming against risk of failure is already possible in the Netherlands. The Broad Weather Insurance is the only possible insurance against drought. The weather index is an interesting vantage point, however, buffering and storing water is a more proactive form of self-insurance. Water retention with weirs in polders is much applied and effective. Underwater drainage is currently in pilot phase, and even arranging water buffers in Switzerland or Germany could provide some form of water insurance. Nonetheless, monitoring and predicting weather indexes such as soil moisture and groundwater is very useful (Agriculture).

4.3.3. For provision of ecologic needs

Environmental water entitlements

The entitlement system does not fit within HDSR's culture that shares water in a centrally organized manner. However, more 'quid pro quo' systems are suitable, such as rewards for ecological conservation or subsidy schemes. Allowing ecology to have a more prominent role in the water distribution process is the most obvious way forward (Ecology).

Streamflow minimum requirements for fish habitat

Setting minimum streamflow requirements based on fish habitat requirements, is most applicable to the Kromme Rijn. This watercourse is fed by the intake at Wijk bij Duurstede and under normal circumstances this can be done by free fall in case of water shortage there is a pump. It would be possible to calculate a minimum flow for fish with a perspective on ecology protection. However, the interests of fish for water quality are already taken into account in the established water level. Furthermore, rather than a minimum required flow, a maximum flow would be more suitable for HDSR, due to the authority's responsibility to quickly transport plentiful water to the West through the KWA. Nevertheless, there are places with flow shortages in HDSR. No flushing and stagnant water is a problem there. However, it is then more logical to focus on reducing duckweed and algal growth rather than focusing on fish needs. More flexible water level management is therefore now emerging at HDSR (Ecology).

Multi-slot vertical slot fishway

This water frugal fishway design offers a possible innovation method for certain HDSR fish passages. The applicability and usefulness should be further investigated for HDSR functionalities, because some of HDSR's fish passages are actually exposed to very high water flows in dry times (Ecology).

4.3.4. For better use of indicator data for drought management

Composite indicator

A composite indicator would be very useful in HDSR, and the Netherlands in general. There is no such indicator yet, but it is being developed. A composite indicator can be incorporated within VIDENTE. Predictive power of such an indicator would be a valuable aspect (Digitalization).

Water accounting

Water Accounting (WA) to monitor supply and demand in a hydraulic system could primarily be used for operational tactical water management in HDSR, through integration in VIDENTE. Currently, the Netherlands' approach to drought is to seek reductions everywhere, but perhaps this can also be used to increase supply. The spatial scale up to which this can be done is still a matter of discussion, but it is likely to be at drainage area scale through area managers and area administrators. WA could be used to estimate and track the impact of major strategic water management choices on water budgets, such as the planned innovations to the ARK. If we create an accounting system now, we can create a baseline situation that allows us to learn a lot from the progress and impact of our strategic long-term plans. Moreover, if the displacement series is activated, WA can be used to evaluate and improve the choices within the implementation. The challenge for such a system remains gaining insight into the actual abstractions, especially at a more detailed level in HDSR. Therefore, in order to keep the monitoring effort realistic, HDSR would have to build up from large to small scale. The other challenge is that drought is difficult to indicate. Drought vulnerability is not the same as climatic drought, so this needs to be very carefully considered in the use of WA practices (Digitalization).

Water management modelling tools

The tools can serve to enhance integrated management by providing insight into which part of a problem ends up with which authority (Digitalization). Three tools have potential for HDSR: 1) Water Quality Analyzer; 2) MUSIC; and 3) Urban Developer (Digitalization & Ecology).

1) HDSR is aware of the water courses that are likely to run dry in the drought season. In anticipation thereof, abstraction bans are declared, partly to protect ecological values (Digitalization). Improving the overview of drought sensitive watercourses with a poor ecological status, can be useful within the distribution trade-offs in dry times (Ecology). For the HDSR area, such a tool could also be used to prevent overflow of effluent water, as HDSR does not currently monitor whether the effluent can still be sufficiently diluted in the channel it is deposited in. Sewage treatment the Bilt may be an interesting case-study (Digitalization).

2) MUSIC is interesting for the need to disconnect more and more rainwater from the sewage system. The effectiveness of decoupling is questionable because sewage systems sometimes suffer from a shortage of water (Digitalization).

3) With regard to the planned housing constructions within the urban areas, Urban Developer would be interesting to give HDSR better insight on how much this will influence the water demand, whereby HDSR can better anticipate bottlenecks (Digitalization).

4.3.5. To improve water literacy and urgency to adapt

Instruments that increase public individual participation in water frugality

Most of the groundwater related instruments to increase water frugality go beyond the responsibilities of HDSR, as drinking water company Vitens manages the drinking water consumption. However, the WELS scheme from Australia offers a good opportunity for HDSR to cooperate with Vitens and other organizations to reduce water consumption during the drought season (Strategy & communication).

Storytelling

Creating narratives to enhance public awareness of national issues is already applied in the 'water bosses' campaign. However, it capitalizes more on positivity, pride and encouraging good behaviour. Working out the doom scenarios and sharing negative experiences is a new method. The experiences of drought vulnerability within HDSR are very diverse. Therefore, collecting all kinds of HDSR residents' stories will nearly elucidate the complexity of the phenomena, but not achieve a clear story line. Therefore, the doom-scenario story telling might not necessarily increase urgency. However, HDSR is also not very familiar with it, so it's a new possibility that could be further investigated (Strategy & communication).

Community monitoring events

Monitoring events by means of (voluntary) public participation have been proven effective and are desirable within HDSR. By cleverly giving away a bit of power to the citizens involved, you create room for connection between all stakeholders (Strategy & communication). Data acquired from such initiatives is also often well appreciated by all users (West HDSR). The usefulness of the acquired data must be clear, which is relatively easy in the case of drought since this is such a relatively new problem. Citizens can really contribute to this knowledge challenge. Educational groundwater tubes are probably the easiest and first approach. However, drought indicators are still difficult to determine and this is where further research is needed (Strategy & communication).

4.3.6. Collective assessment

Ten of the seventeen drought measures are assessed to have suitable aspects for HDSR, according to the focus-group participants. These are: water value, WSCPs, diversification, MSF, composite indicator, water accounting, water management modelling tools, instruments for water frugality, storytelling, and community monitoring events.

5. Synthesis: What can HDSR learn from other countries' drought management measures?

To formulate an answer to the main research question: *What can HDSR learn from other countries' drought management measures?*, a systems thinking approach is adopted. Systems thinking helps to understand systems, to predict direct and indirect behaviour of components, and to structure modifications to produce desired effects (Arnold & Wade, 2015). Exercising this theory, an influence diagram is designed (Figure 9) by conceptualizing a holistic view of drought and identifying how the drought measures interact with the concept of drought. The complexity of the drought definition is visualized by integrating all concepts. Meteorological and hydrological drought represent the drought causes (blue). Soil-moisture and groundwater drought represent two of the possible drought effects (orange). All four drought definitions are embedded in the drought typology effect of socio-economic drought. This refers to all types of drought where water level management cannot be maintained and all dependent variables, such as plant growth and economically valuable assets, are incorporated indirectly. Together, these five definitions form the concept of drought, for which the ten suitable drought measures are depicted in the diagram. The drought measures can have an increasing effect on the water availability (+ = change in the same direction), or a decreasing effect on the water availability (- = change in the opposite direction). More drought will activate more drought measures (+). An arrow from one measure to another, means that its functionality is influenced thereby. The following chapter explains this interaction to cumulatively counteract drought.

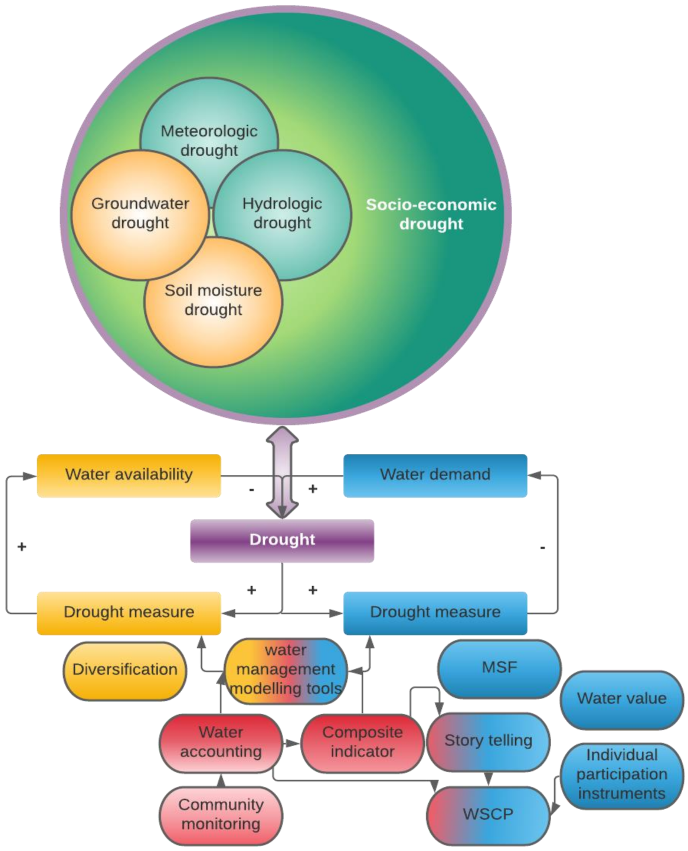

Figure 9 | Systems' thinking visualization of the measures to manage drought in the HDSR area. Yellow measures increase water availability. Blue measures decrease water demand. Red measures indirectly influence either availability or demand. (+ = change in the same direction, - = change in the opposite direction, ⍰ = influential connection).

Diversification can increase the water availability by providing new water resources. Effluent water is the most unexplored and obvious alternative water resource for the HDSR area. The potential profits of higher effluent reuse can be calculated by internalizing modelling software qualities from Water Quality Analyzer and MUSIC into the standard HDSR modelling tools of MetaSWAP, MODFLOW, SOBEK, and D-Hydro. HDSR should mainly opt for complementary calculation functionality within such new water management modelling tools, to optimise decision making and improve risk calculation. The Urban Developer tool integrates water demand fluxes into everyday drought management, whereby the relevance of further developing the Urban Water Availability tool (Stedelijk Waterbeschikbaarheid) identified in objective 1, is confirmed. Through WA, the most effective distribution of the water balance can be identified. Such accounting tools require increased efforts of the HDSR data monitoring team. Furthermore, WA will more clearly integrate surface- and groundwater management, and it can provide valuable information to integrate water quantity with water quality. Obtaining information on the actual abstractions is difficult and unauthorised abstraction is relatively easy in the HDSR area/the Netherlands. Community monitoring events can be implemented to supply useful data on drought perturbation. However, the need for better defined drought indicators is thereby confirmed. The lack of indicators and a composite indicator elucidate a drought definition problem, that entails the need for useful drought definitions that both integrate the multi-dimensionality of drought and maintain its functionality for management. WA, facilitated in VIDENTE, can likely help to create these definitions, whereafter composite indicators for drought can be composed. Predictive capacity of these indicators is important for proactive management. Both WA and storytelling are useful in creating a publicly accessible WSCP. Individual participation instruments can be implemented to help citizens meet expectations of the WSCP, for example by decreasing groundwater demand in cooperation with Vitens. Implementing a system to economically value groundwater could also increase efficient use of this resource and further integrate groundwater into the HDSR drought management. More “quid pro quo” measures can be implemented to rebalance the water division between nature and agriculture. The MSF fishway is an example of how innovation can possibly decrease part of ecological needs within the division trade-offs. Overall, the combination of these measures aims to integrate drought management into the climate adaptation capacity of HDSR.

6. Discussion

In this chapter, the results of chapters 4 and 5 are discussed. In paragraph 6.1. is assessed how relevant the results are for making the Netherlands resilient to freshwater shortages by 2050. Paragraph 6.2. elaborated on the inclusivity of the explorative research for drought measures for HDSR management challenges. In paragraph 6.3., the research approach of internationally focussed social learning is assessed, wherefrom recommendations for further research arise.

6.1. Relevance

This research aims to contribute to the general policy of the Delta Decision Freshwater in making the Netherlands resilient to freshwater shortages by 2050 through identifying possible DMP improvements for HDSR. By protecting HDSR assets from drought, the authorities' competence to provide water for downstream authorities increases. All of the promising drought measures for HDSR may be extrapolated for use in other water authorities. However, other authorities may be facing different drought issues, such as salinisation and fire-outbreaks (*NOS*, 2020; Salmoral, Ababio, & Holman, 2020), whereby other measures become applicable. For example, drought measures such as AussieGRASS were not suitable for HDSR due to lack of urgency, but could be suitable in authorities where water supply is more difficult to maintain. However, many challenges that HDSR faces are nationally and globally apparent. For example, HDSR's need for complementary water management modelling tools is in line with the globally existing need for MEW systems that assess the societal and economic consequences and costs for drought events of different duration, intensity and return periods (Hannaford et al., 2019). Well integrated cooperation structures and advanced information systems are essential elements to develop coping strategies for a wicked problem such as drought (Berkes, 2009; Huntjens et al., 2011). Thereby, adaptive drought management requires excessive natural resource data (Stone, 2014). However, besides the non-availability of certain water flow data, an underpinning reason for not having operational water accounting systems in place for drought assessment in HDSR seems to be a lack of a common drought perception and an overarching sense of urgency. This result arose from the focus groups with Strategy & communication and Digitalization and is in line with the ongoing discussion on how perceptions of risks influence the management thereof (Bruggeman et al., 2013; Neuvel, 2005). This is also a bottleneck for the purpose and scope of public participation in drought management in HDSR. Identifying drought indicators is therefore an ongoing search (Weijers, 2020). Furthermore, common indicator systems with composite indicators allow homogeneous treatment among different sub-basins. Such a system can be implemented at EU level to strengthen integrated and international management (Hervás-Gámez & Delgado-Ramos, 2019). Beside the ten promising drought measures (chapter 5), a few additional measures arose from the brainstorm focus-groups sessions, such as incorporating the water/drought price into consumer products through a Water Footprint Analysis or a Water Productivity Score (Bastiaanssen & Steduto, 2017). More "quid pro quo" measures to incentivise nature conservation are being developed through for example Key Performance Indicators (Hoes, 2021). Lastly, as drought is an issue that is often caused, and thereby solvable, at the international scale (Büntgen et al., 2021; Teuling et al., 2019), one idea is to ensure the Netherlands of water by getting water entitlements in for example Switzerland. Another development is the reforestation in Western Europe to enhance cloud formation and counteract meteorological drought (IJpelaar, 2021).

6.2. Representativeness

The methodology of this research was to improve drought management in HDSR through explorative research that targets social learning from other countries. I focused on exploring regional adaptation strategies (RAS) at the sub-basin level, framed in the drought problems-oriented scope of HDSR. Since RAS documents are often in the national language, English publications were most accessible.

Nonetheless, many non-Anglo Saxon countries are incorporated in the results, due to scientific literature on these countries' common drought measures. India, Brazil, and Iran have been incorporated in my research for agricultural drought management measures. South Africa, India, and the Philippines have been consulted for civil urgency generation and public involvement. Still, many countries' drought management practices remain unexplored. Therefore, it is important to reflect on whether this method was sufficient to identify the most relevant drought measures for HDSR or if major possibilities were overlooked. An argument to support inclusivity of most relevant measures in this report, is that regional adaptation strategies are bound to the multi-level governance structure of national, European and international regulations (Lebel, Grothmann, & Siebenhüner, 2010). Therefore, the 17 adaptation strategies have already been the result of global social learning. The Netherlands' and UK's governance is influenced by the Water Framework Directive (WFD), the European coordination platform that provides social learning in integrated river basin management (Environment Agency, 2017; Hophmayer-Tokich, 2006). Moreover, the UK has been rapidly improving their adaptive and proactive drought management since the 2018 summer drought and looked at other countries for learning objectives (Hannaford et al., 2019; Salmoral et al., 2020). Similarly, the Canadian drought management is largely inspired by the US, as the US Drought Monitor has been developed into the North American Drought Monitor for Canada (and Mexico) (Lawrimore, Jr, Svoboda, Swail, & Englehart, 2002). This monitor has become an integral part of drought management, including planning, preparedness and mitigation at the local, regional and national levels. Additionally, the global integrated water resource management (IWRM) discourse is influential globally (Carr & Podger, 2012; Watson, Shrubsole, & Mitchell, 2019), and the Conservation Agriculture (CA) paradigm is adopted in Europe, North Africa, South-East Asia and Latin America. Hereby is demonstrated that globalization has already played a large role in the establishment of the 17 drought measures from objective 2. As a final test for representativeness and completeness of the set of identified drought measures I asked Dr. ir. N. Wanders for a check. He is a drought management expert at Utrecht University (https://nikowanders.com/about-me/). He assessed the 17 drought measures and concluded that it is an elaborate collection, whereby only the Blue Deal of Belgium was recommended for further exploration.

6.3. Recommendations: indicators for social learning & managing to learn

The local climate and resulting weather is the main variable in many characteristics of droughts, such as duration, magnitude, and frequency, and thus influences the degree to which meteorological-, hydrological-, soil-moisture and groundwater drought perturbate and affect to the rest of society (Hervás-Gámez & Delgado-Ramos, 2020). Therefore, it is noteworthy that multiple drought measures from countries with different climates than the Netherlands are useful for HDSR. It appears that the complexity of the drought phenomena(van Loon, 2015; van Loon et al., 2016), is exemplified in the aim to manage it. Drought risk is a combination of the vulnerability, hazard, and exposure (Wang, Qiao, Wang, Cao, & Zhang, 2020). Socio-economic and political parameters contribute to this risk, along with climatic and geographic conditions. Especially in urban areas, socio-economic parameters are the main factors contributing to a high vulnerability (Wang et al., 2020). To recapitulate: indicators to identify promising countries for international social learning on drought management cannot be deducted from climate conditions alone, but should be representative of the drought risk that must be managed. Drought vulnerability assessments incorporate social, economic, physical, environmental, and institutional dimensions (Tánago, Urquijo, Blauhut, Villarroya, & Stefano, 2016) to determine a Drought Vulnerability Index (DVI) for regional scales (Zarafshani et al., 2012). Drought problems have to be tackled from an integrated perspective (Pahl-Wostl, 2007), thus creating a European or even global map of such a DVI with a multi-disciplinary team may be useful for future international social learning objectives. If improvement of a regional DVI is due to management improvements, these regions could be the leading innovators to follow for the Netherlands. It should be noted that a limit to such learning is that adaptation always needs to be tailored to the region (Lebel et al., 2010), thus further research is required on implementing the drought measures within HDSR. Case-studies and pilots may therefore be recommended, as adaptive management is “learning to manage by managing to learn” (Pahl-Wostl, 2007).

7. Conclusion

Drought is a relatively newly addressed challenge that requires regional development in HDSR based on the nationally defined goals of Rijkswaterstaat. This research consisted of a literature review of the HDSR drought management challenges, followed by an explorative research of DMPs and scientific papers to create an elaborate list drought measures for HDSR drought challenges. The useability of these theoretically applicable measures was tested for the context of HDSR practicalities through focus-group discussions. By synthesising these results, this research has assessed what HDSR can learn from other countries' drought management measures. Ten suitable drought measures are obtained for HDSR through this internationally focused social learning. These consist of: experimenting with water value for groundwater, WSCPs as a proactive addition to the national water displacement series, diversification with effluent, the MSF-fishway design, a composite indicator within VIDENTE and national models, water accounting within VIDENTE for surface and groundwater, additional water management modelling tools that opt for complementary calculation functionality, instruments that coordinate water frugality measures with provinces, townships, citizens and Vitens, storytelling that generate uniform urgency perceptions amongst experts and non-experts, and community monitoring events complementary to a government drought monitoring system that increase water literacy amongst citizens and stakeholders. Implementation of these measures requires further research, or piloting. Because these measures are the result of a problem-oriented research for HDSR, measures for problems that exist beyond HDSR borders have been eliminated from the results. Nonetheless, these ten measures are extrapolatable to most other water Authorities in the Netherlands with similar drought challenges. This research exhibits an approach to international social learning from a problem oriented perspective. With the uncertainties of climate change development in mind, improving such approaches is essential to increase the capacity for quick innovation towards higher drought resilience. Therefore, further research on applying DVIs for global social learning in drought management is recommended.

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