The Design of an Assessment Framework for the Drought Resilience of a Region

The case of Twente, the Netherlands

Master Thesis

Faculty of Engineering Technology

Civil Engineering and Management

Y.F. (Ype) Willemsen

July 26, 2023

UNIVERSITY OF TWENTE.

Page intentionally left blank.

The Design of an Assessment Framework for the Drought Resilience of a Region

The case of Twente, the Netherlands

Thesis presented for the degree of
Master of Science

July 26, 2023

Final version

Defended on 02 August 2023

Author's details:

Author	Y.F. (Ype) Willemsen BSc.
Email address	Y.f.willemsen@alumnus.utwente.nl
University	University of Twente
Programme	Civil Engineering and Management
Track	Integrated Water Management

Graduation committee:

Dr. M.S. (Maarten) Krol[1]

[1]University of Twente,
Faculty of Engineering Technology,
Department of Civil Engineering and Management

Dr. Ir. J. (Joanne) Vinke-de Kruijf[1]

Dr. L. (Lara) Wöhler[1]

Cover picture obtained from Universitat International de Catalunya (2018).

Preface

In front of you lies the final report of my master thesis "*The Design of an Assessment Framework for the Drought Resilience of a Region: The case of Twente, the Netherlands"*. This thesis marks the finalisation of my time as a Civil Engineering and Management student at the University of Twente. Being born below mean sea water level in the Zaan-region just north of Amsterdam and relatively close to the North Sea-coast, a life in the Netherlands without the constant presence of water has long been unfathomable for me. Being grasped by the interested in how in the world it was possible that I could safely grow up in an area that lies so low without a single thread of fear, I decided to study civil engineering at the University of Twente. I started the bachelor of Civil Engineering in 2016 and the first few years didn't change much in my perspective. I learned that in the Netherlands the presence of water was indeed more or less a given, and I learned which options one can choose from if they wish to deal with it. The severe drought in the summer of 2018 was the first time I realized that in the Netherlands we too can have a water deficit. During the preparation for my bachelor thesis, for which I was meant to go to Cape Town, South Africa to look at how the city of Cape Town could better adapt to drought through spatial planning, my mind opened to the threats of drought (even though it had to be cancelled due to the Covid-19 pandemic). After the 2018 drought turned into a multiannual drought with growing consequences for all kinds of functions, my perspective (that in the Netherlands the 'only' water-related issue lies in how we can keep the water out) changed: also in the Netherlands we can have significant issues with too little water. However, similar to how I felt as a kid that had no idea how it was possible that the water was kept out, I now had no idea how one could hope to keep enough water in when it simply stops raining for months on end. My interest in drought management was initiated and during my master Civil Engineering and Management this interest only swelled. Through this thesis, I had the opportunity to follow that interest and dig deep in drought management.

However, I couldn't have done it alone. First of all, I would like to thank my supervisors at the University of Twente, Maarten, Joanne and Lara. Thank you for your clarifying insights and guidance on how I could conduct this thesis. Thank you for all the feedback you have given for this thesis. Also thank you for always welcoming me for questions and being there to help me through motivational downs. Moreover, I would like to thank Ulf Stein and Jenny Tröltzsch from thinktank and research institute Ecologic Institute, who especially in the starting phase of my thesis helped me tremendously with their time and valuable insights and welcoming me as a guest in their office in Berlin. I also want to thank all the interviewees for their time and our interesting discussions on drought management in Twente.

In the past 7-ish years, I have had a wonderful time as a UT-student in Enschede. I had the opportunity to partake in a multitude of extra-curricular activities. From being a full-time board member at the study association for UT's civil engineering students and organizing a ton of amazing things, to contributing to educational policy in among others the Faculty Council and in the University Committee on Education, and to helping in a variety of research projects giving me the opportunity to get in touch with all kinds of people in the field of civil engineering. I want to thank everyone that was part of these years, from my close friends to the great staff within the Department of Civil Engineering with whom I worked in these extra-curricular activities. You made my time in Enschede unforgettable.

Finally, I want to thank my family and girlfriend for all their support throughout the years. It has been really wonderful to pursue my ambitions throughout my student life, knowing that they were always there to support me, be it related to the study or not. Thank you so much for that.

I hope you will find this report as interesting and enjoyable to read as I found it to write it.

Ype Willemsen
Enschede, July 2023

Summary

Background information

As a consequence of climate change, the likelihood increases that the Netherlands, historically a water-rich country, will experience more frequent and more severe droughts, causing significant degradation in social, economic and environmental functions. In order to capture the significant uncertainties of droughts, both regarding their meteorological characteristic as well as their social, economic and environmental impacts, drought *resilience* of a region is seen as key-element in the policy development for drought management. However, a field problem arises when policy-makers or consultants try to translate this theoretical idea of regional drought resilience into practice: there is no comprehensive understanding of what drought resilience of a region entails, also resulting in the absence of a readily available tool that can provide sound guidance on policies towards a drought resilient region.

Research objective and methodology

To reduce this identified field problem, the main objective of this study was formulated as '*Design an assessment framework that provides a comprehensive understanding of the drought resilience of a region as a tool to guide drought management policies'.* To achieve this objective, design science methodology was employed based on the design cycle by Wieringa (2014), consisting of three distinctive design phases: a problem investigation phase, a design phase, and a validation phase. The implementation and evaluation phases of the full design cycle are not considered in this study.

Problem investigation phase

In the problem investigation, a literature study is conducted on regional drought resilience. Therein, it is identified that the resilience of a region to any kind of disturbance consists of several distinct phases: the region can be *prepared* before the disturbance, the region can *absorb* the disturbance through minimizing the detrimental effects of the disturbance on the functionalities of the region, the region can *recover* from those detrimental effects back to the state of its functionalities before the disturbance, and the region can *adapt* to improve its resilience to the disturbance after lessons were learned from the disturbance. In another literature study into the currently existing frameworks for resilience assessment, it is identified that there is a hiatus in scientific literature on what drought resilience of a region means in practice and that none of the (very) limited number of resilience assessment frameworks (RAFs) that state they can (also) assess for drought resilience is suitable for the assessment of a region, or incomprehensive in their inclusion of resilience theory. Lastly, in a third literature study, a set of 24 design requirements is developed. These are structured under six general design requirements, which stipulate that there should be 1) *credibility*, 2) *legitimacy*, and 3) *salience* of the framework elements and the assessment procedure within the framework, 4) proper *visualisation* of the framework and its assessment results, 5) proper incorporation of the framework within its *context of use*, and 6) a proper level of *flexibility* in the application the framework.

Design phase

In the design phase, a first design of the assessment framework is developed. For this there is built upon the existing base of literature, through the identification of one existing RAF that can be used as a theoretical base for the to-be-designed assessment framework for regional drought resilience. Based on a verification of this existing RAF against the design requirements, necessary adaptations are identified and incorporated into the design of the assessment framework. Most importantly, this entails the adaptation of the existing RAF to the drought context, through i.e. the development of a comprehensive set of drought resilience indicators, instead of its original set of flood resilience indicators. Moreover, the assessment procedure and the visualisation of its results are structured such that the assessment yields concrete guidance towards improved drought resilience of the region, through a combination of quantitative and in-depth qualitative information. As final part of the design phase, a recommended procedure-of-use is developed. This procedure-of-use consists of four distinct

phases: the assessment preparation, the assessment conduction and the follow-up phases, as well as an optional phase in which an ex-ante policy evaluation is conducted. The preparation phase includes the definition of the region and relevant stakeholders, the relative importance of framework elements, the indicator's scoring methods and setting up indicator maturity indices. In the conduction phase, the information is gathered through the earlier defined methods and reported following a structured assessment and reporting method. In the follow-up phase, gaps in current policies are defined based on the assessment results and new or adapted policies should be drafted based thereupon. The ex-ante policy evaluation can be conducted both with or without a baseline from an earlier assessment.

Validation phase

In the validation phase, the Absorb-phase of the designed assessment framework is applied in a case study in the Dutch region of Twente. In this case study, the preparation and conduction phases of the recommended procedure-of-use are followed, utilizing document studies and a total of nineteen expert interviews with various relevant stakeholders to assess the drought resilience of Twente. Employing the gained experiences from the case study, the framework is (partially) validated with an evaluation against the design requirements. From this, it is concluded that the design requirements for the framework's credibility and visualisation are (mostly) met. However, the design requirements for the framework's salience are only partially met, while the design requirements for the framework's legitimacy are mostly not met. As the validation phase consisted of only one case study which did not cover the follow-up phase, neither the (feasibility of the) framework's incorporation in its context of use nor its flexibility are validated in this study. Following this validation, a significant number of points of improvements are identified. A common denominator in these is the lack of participation from prospective users in the design cycle. It would have added greatly to the framework's validity if prospective users participated in setting the design requirements and participated in an evaluation of the framework and its assessment results. Moreover, the case study showed that even a partial application of the framework is already rather laborious. For full application of the designed assessment framework, significant resources are likely required, especially regarding the required time investment. This reduces the framework's usability and thus salience.

Conclusion

This study presents a design for an assessment framework for the drought resilience of a region, including a recommended procedure-of-use to ensure proper framework implementation. Through this assessment framework, also a comprehensive overview of aspects that are relevant for the drought resilience of a region is established. To develop the design, an extensive literature study on drought resilience and resilience assessment is conducted, guiding the formulation of design requirements and the adaptation of an existing RAF into the design of an assessment framework for the drought resilience of a region. One out of four phases within this designed assessment framework, being the Absorb-phase, is applied in a case study in Twente, providing experience with the framework's performance. Based thereupon, an evaluation on the framework's usability is executed, leading to several points of improvement for the designed assessment framework.

Recommendations for further research

Based on this study, recommendations for future research are formulated. Future research is recommended to conduct additional loops of the design cycle, which include more participation from the framework's prospective users in both the definition of new or adapted design requirements as well as for the validation of the design. Moreover, future research is recommended to look into how the laboriousness of the framework can be reduced (i.e. simplified) while maintaining its comprehensiveness, to accommodate for prospective users with low resources available. Moreover, future research should analyse the implementation and evaluation of the designed assessment framework in practice to complete the design science methodology applied in this study.

Samenvatting

Achtergrondinformatie

Als gevolg van de klimaatverandering neemt de kans toe dat Nederland, van oudsher een waterrijk land, vaker te maken zal krijgen met ernstige droogteperioden, met aanzienlijke impact op de sociale, economische en ecologische functies. Om rekening te houden met de grote onzekerheden die droogte met zich meebrengt, zowel wat betreft de meteorologische kenmerken van droogte alsook de sociale, economische en ecologische effecten, wordt droogteveerkracht van een regio gezien als een sleutelelement in de beleidsontwikkeling voor droogtebeheer. Er doet zich echter een veldprobleem voor wanneer beleidsmakers of adviseurs dit theoretische idee van droogteveerkracht van een regio in de praktijk proberen te brengen: er is geen alomvattend begrip van wat de droogteveerkracht van een regio inhoudt, wat tevens resulteert in het ontbreken van een direct beschikbaar instrument dat een degelijke leidraad kan bieden voor beleid dat gericht is op een droogteveerkrachtige regio.

Onderzoeksdoel en methode

Om dit vastgestelde veldprobleem te verkleinen, is de hoofddoelstelling van deze studie geformuleerd als *'Ontwerp een beoordelingsraamwerk dat een alomvattend inzicht geeft in de droogteveerkracht van een regio als hulpmiddel voor het sturen van droogtebeheerbeleid'*. Om dit doel te bereiken is een ontwerpwetenschappelijke methodologie gebruikt op basis van de ontwerpcyclus van Wieringa (2014), bestaande uit drie verschillende ontwerpfasen: een fase waarin het probleem wordt onderzocht, een ontwerpfase en een validatiefase. De implementatie- en evaluatiefasen van de volledige ontwerpcyclus zijn in dit onderzoek buiten beschouwing gelaten.

Probleemanalysefase

In de probleemanalyse is een literatuurstudie uitgevoerd naar de droogteveerkracht van een regio. Daarin is vastgesteld dat de veerkracht van een regio bij elk soort verstoring bestaat uit verschillende fasen: de regio kan worden *voorbereid* vóór de verstoring, de regio kan de verstoring *absorberen* door de nadelige effecten van de verstoring op de functionaliteiten van de regio te minimaliseren, de regio kan *herstellen* van die nadelige effecten tot de staat van haar functionaliteiten vóór de verstoring, en de regio kan zich *aanpassen* om haar veerkracht tegen de verstoring te verbeteren door lessen te trekken uit de verstoring. In een andere literatuurstudie naar de reeds bestaande raamwerken voor het beoordelen van veerkracht, is vastgesteld dat er een hiaat is in de wetenschappelijke literatuur over wat droogteveerkracht van een regio in de praktijk betekent en dat geen van het (zeer) beperkte aantal veerkrachtbeoordelingsraamwerken (VBRs) dat zegt (ook) droogteveerkracht te kunnen beoordelen geschikt is voor de beoordeling van een regio, of onvolledig is in hun opname van de theorie over veerkracht. Tot slot is in een derde literatuurstudie een set van 24 ontwerpeisen ontwikkeld. Deze zijn gestructureerd onder zes algemene ontwerpeisen, die bepalen dat er sprake moet zijn van 1) credibiliteit, 2) legitimiteit, en 3) gebruiksvriendelijkheid van de raamwerkelementen en de beoordelingsprocedure binnen het raamwerk, 4) een goede visualisatie van het raamwerk en de beoordelingsresultaten, 5) een goede inpassing van het raamwerk binnen de gebruikscontext, en 6) een juiste mate van flexibiliteit in de toepassing van het raamwerk.

Ontwerpfase

In de ontwerpfase wordt een eerste ontwerp van het beoordelingsraamwerk ontwikkeld. Hiervoor is voortgebouwd op de bestaande literatuur door een bestaande VBR te identificeren die kan worden gebruikt als theoretische basis voor het te ontwerpen beoordelingsraamwerk voor droogteveerkracht van een regio. Op basis van een toetsing van deze bestaande VBR aan de ontwerpeisen worden noodzakelijke aanpassingen geïdentificeerd en verwerkt in het ontwerp van het beoordelings-raamwerk. De belangrijkste hiervan is de aanpassing van de bestaande VBR aan de droogtecontext, d.w.z. de ontwikkeling van een uitgebreide set indicatoren voor de droogteveerkracht, in plaats van de oorspronkelijke set indicatoren voor de overstromingsveerkracht. Bovendien zijn de

beoordelingsprocedure en de visualisatie van de resultaten gestructureerd zodat de beoordeling door een combinatie van kwantitatieve en diepgaande kwalitatieve informatie concrete aanwijzingen oplevert voor een betere droogteveerkracht van de regio. Als laatste onderdeel van de ontwerpfase is een aanbevolen gebruiksprocedure ontwikkeld. Deze bestaat uit vier afzonderlijke fasen: de voorbereiding van de beoordeling, de beoordeling zelf en de opvolging van de resultaten, evenals een optionele fase waarin een ex ante beleidsevaluatie wordt uitgevoerd. De voorbereidingsfase omvat de definitie van de regio en relevante belanghebbenden, het relatieve belang van specifieke raamwerkelementen, de scoremethoden voor de indicators en het opstellen van beoordelingscriteria voor de indicatoren. In de uitvoeringsfase wordt de informatie verzameld via de eerder gedefinieerde methoden en gerapporteerd volgens de gestructureerde beoordelings- en rapportageprocedure. In de opvolgingsfase worden de hiaten in het huidige beleid gedefinieerd op basis van de beoordelings-resultaten en op basis daarvan moet nieuw of aangepast beleid worden opgesteld. De ex ante beleidsevaluatie kan zowel met als zonder een referentiepunt van een beoordeling worden uitgevoerd.

Validatiefase

In de validatiefase is de Absorptie-fase van het ontworpen beoordelingsraamwerk toegepast in een casestudy in de Nederlandse regio Twente. In deze casestudy zijn de voorbereidings- en beoordelings-fasen van de aanbevolen gebruiksprocedure gevolgd, waarbij gebruik is gemaakt van documentstudies en in totaal negentien expertinterviews van verschillende relevante belanghebbenden om de droogteveerkracht van Twente te beoordelen. Met behulp van de ervaringen uit de casestudy is het raamwerk (gedeeltelijk) gevalideerd met een toetsing aan de ontwerpeisen. Hieruit blijkt dat (grotendeels) wordt voldaan aan de ontwerpeisen voor de credibiliteit en visualisatie van het raamwerk. Aan de ontwerpeisen voor de gebruiksvriendelijkheid van het raamwerk wordt echter slechts gedeeltelijk voldaan, terwijl aan de ontwerpeisen voor de legitimiteit van het raamwerk grotendeels niet wordt voldaan. Aangezien de validatiefase uit slechts één casestudy bestond die de opvolgingsfase niet omvatte, zijn de (haalbaarheid van de) integratie van het raamwerk in de gebruikscontext en de flexibiliteit van het raamwerk in deze studie niet gevalideerd. Naar aanleiding van deze validatie is een aanzienlijk aantal verbeterpunten geïdentificeerd. Een gemene deler hierin is het gebrek aan participatie van toekomstige gebruikers in de ontwerpcyclus. Het zou de validiteit van het raamwerk sterk hebben vergroot als toekomstige gebruikers een actieve rol hadden in het opstellen van de ontwerpeisen en hadden deelgenomen aan een evaluatie van het raamwerk en de beoordelingsresultaten. Bovendien toont de casestudy aan dat zelfs een gedeeltelijke toepassing van het raamwerk al vrij bewerkelijk is. Voor een volledige toepassing van het ontworpen beoordelings-raamwerk zijn waarschijnlijk aanzienlijke middelen nodig, vooral wat betreft de vereiste tijdsinvestering. Dit vermindert de gebruiksvriendelijkheid van het raamwerk.

Conclusie

Deze studie presenteert een ontwerp voor een beoordelingsraamwerk voor de droogteveerkracht van een regio, inclusief een aanbevolen gebruiksprocedure voor goede implementatie van het raamwerk. Door middel van dit beoordelingsraamwerk is ook een uitgebreid overzicht opgesteld van aspecten die relevant zijn voor de droogteveerkracht van een regio. Voor de ontwikkeling van het ontwerp is een uitgebreide literatuurstudie uitgevoerd over droogteveerkracht en de beoordeling hiervan, die als leidraad dient voor de formulering van ontwerpeisen en de aanpassing van een bestaande RAF in het ontwerp van een beoordelingsraamwerk voor de droogteveerkracht van een regio. Een van de vier fasen binnen dit ontworpen beoordelingsraamwerk, de Absorptie-fase, is toegepast in een casestudy in Twente, waarbij ervaring is opgedaan met de prestaties van het raamwerk. Op basis daarvan is een evaluatie uitgevoerd op prestaties van het raamwerk, resulterende in verschillende verbeterpunten.

Aanbevelingen voor vervolgonderzoek

Op basis van deze studie zijn aanbevelingen voor toekomstig onderzoek geformuleerd. Toekomstig onderzoek wordt aanbevolen om een (of meerdere) extra lussen van de ontwerpcyclus uit te voeren, waarbij de toekomstige gebruikers van het raamwerk meer worden betrokken bij zowel het definiëren van nieuwe of aangepaste ontwerpeisen als bij de validatie van het ontwerp. Bovendien wordt voor toekomstig onderzoek aanbevolen om te kijken hoe de bewerkelijkheid van het raamwerk kan worden verminderd (d.w.z. vereenvoudigd) met behoud van de volledigheid, om tegemoet te komen aan toekomstige gebruikers met weinig beschikbare middelen. Bovendien zou toekomstig onderzoek de implementatie- en evaluatiefasen van het ontworpen beoordelingsraamwerk in de praktijk kunnen analyseren om de in deze studie toegepaste ontwerpwetenschappelijke methodologie te voltooien.

Table of Content

List of Abbreviations

CoBRA	-	Community Based Resilience Assessment framework
RAF	-	Resilience Assessment Framework
RDO	-	Regionaal DroogteOverleg (Dutch)
SES	-	Social-Ecological System
SMM MM	-	Smart Mature Resilience Maturity Model
VBR	-	Veerkrachtbeoordelingsraamwerk (Dutch)

List of Figures

List of Tables

1. Introduction

1.1. Problem context

Many regions worldwide face severe water management challenges. These often occur from extreme weather events, which result in floods or droughts. Due to climate change, such extreme events are set to happen more frequently, with higher intensity, and with a longer duration (Huang et al., 2015; IPCC, 2021; National Academies of Sciences, 2016; Naumann et al., 2021). The water management challenges in the Netherlands are no exception to this. On the one hand, floods will occur more frequently (Rannow et al., 2010). A prime example is the flood of July 2021 in the southern Dutch province of Limburg, which caused approximately €400 million in damages and the displacement of some 700 households (NLTimes, 2021). Simultaneously, the country is becoming more susceptible to severe, consecutive drought hazards (Bartholomeus et al., 2023). A recent example is the summer of 2018 (see Figure 1), which will be remembered as one of the driest in measured history as a result of a prolonged heatwave and extremely low precipitation (Brakkee et al., 2022). Coupled with additional dry summers in 2019 and 2020 and insufficient winter precipitation as compensation, this drought hazard event had severe multi-annual social, economic and environmental impacts. This was due to the large spatiotemporal extent and the many cascading effects, such as water extraction restrictions impacting agriculture and industry, reduced or halted shipping through major waterways, significant salt water intrusion in coastal areas and in areas surrounding salt mines, and significant (property) damages due to land subsidence and foundational pile rot (Brakkee et al., 2022; Grillakis, 2019; Wens et al., 2019). Moreover, extreme environmental damages from depleted soil moisture and groundwater levels occurred (Brakkee et al., 2022; Van Hussen et al., 2019).

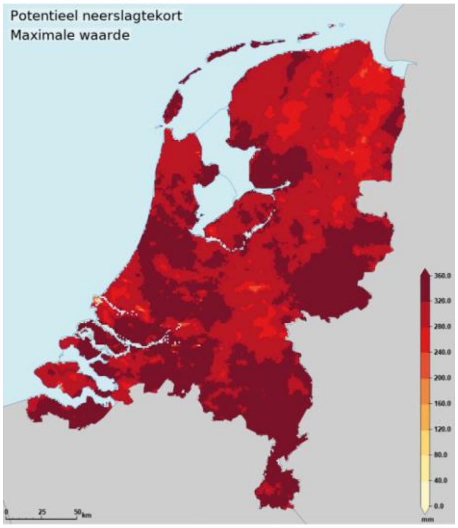

Figure 1 Maximal potential precipitation deficit during 2018 drought (KNMI, 2018, p. 23).

Following the increased likelihood of severe drought events such as the 2018-2020 consecutive drought in the Netherlands, drought-induced damages and water use conflicts are set to worsen as well. Hence, it becomes increasingly relevant to lower the risk and effects of drought events. To do so, a comprehensive and proactive drought management (policy) approach is key (Tong, 2021; Wilhite, 2002). Furthermore, in the past decade, several researchers have stressed the importance of incorporating resilience thinking into such a comprehensive drought management approach (Crossman, 2018; Sivakumar et al., 2014; Wilhite, 2011; Wilhite et al., 2014; Ziervogel, 2019). '*Resilience*' is often used to define how well a system, i.e. a region, can prepare for, withstand, recover from and adapt after disturbances such as stresses and shocks (Carpenter et al., 2001; Hauge Simonsen et al., 2014; Meerow et al., 2016). This goes further than the earlier proposed risk management approach (Wilhite, 2002) focussing on planning and reducing vulnerabilities, and going significantly further than the historically more traditional reactive drought (crisis) management (Bazza, 2002; Wilhite, 1992, 2011). Resilience management (or management and policies towards resilience building) puts additional emphasis on speeding recovery and facilitating adaptation or transformation compared to risk management (Linkov et al., 2014). This notion has also found its way into international drought policy guidelines according to which the regions worldwide should become more resilient to severe droughts (UNCCD, 2019; World Bank, 2019).

An assessment framework for the drought resilience of a region can provide guidance to stakeholders with an interest in the drought management of a region (i.e. policy makers within municipalities, safety regions, water boards and provinces or consultants from consultancy and engineering firms) on the state of the region's drought resilience, in order to create policies to be(come) more drought resilient (Arbon et al., 2014; Frankenberger et al., 2013; Khazai et al., 2015; Sellberg et al., 2015). However, when such stakeholders try to assess the drought resilience of a region, they quickly find there is no comprehensive scientific guidance on what drought resilience of a region means in practice and that there is no comprehensive overview of relevant aspects for a region to be as resilient as possible to droughts. In this absence of scientific guidance, these stakeholders tend to have deviating and incomprehensive ideas on what it means for a region to be resilient to droughts.

1.2. State of the Art

Resilience and resilience assessment are growing fields of interest in the academic world (Sharifi, 2016). Over time, the understanding of the concept of 'resilience' changed significantly (Mujjuni et al., 2021). Especially in the past decades, 'resilience' has seen a significant rise in interest within the academic world (Mujjuni et al., 2021; Sharifi, 2016). However, despite this increased interest in the topic, or perhaps because of it, consensus on a harmonized definition of the concept of 'resilience' is still absent (Brand & Jax, 2007; Hosseini et al., 2016; Meerow et al., 2016; Mujjuni et al., 2021) and the specific definition is highly subject to perspectives (Kim & Lim, 2016). Moreover, despite the increased interest in resilience assessment and the emergence of a large number of resilience assessment frameworks (RAFs) in the past two decades, there is a hiatus in the scientific literature of research into the operationalisation of drought resilience (Tong, 2021). Of the +/- 85 resilience assessment frameworks reviewed in four recent review studies (Büyüközkan et al., 2022; Schipper & Langston, 2015; Sharifi, 2016; Tong, 2021), only very few assessment frameworks state they can (also) assess for drought resilience. However, these are not aimed at the regional level (and instead at households, a community, or specific types of vegetation), incomprehensive in their theoretical base (with consideration of only a part of the resilience phases), and/or aimed at historically dry and impoverished regions, leading to different points of interest for regional drought resilience. As such, a readily available drought resilience assessment framework applicable for the Dutch context is absent.

1.3. Problem statement

Due to the increased likelihood of more frequent and severe droughts in the Netherlands, which historically is relatively water-rich, the importance of good drought management increases (Huang et al., 2015; IPCC, 2021; National Academies of Sciences, 2016; Naumann et al., 2021). To capture the significant uncertainties of droughts, both within the meteorological characteristics of droughts as well as their social, economic and environmental impacts, improving the drought *resilience* of a region is seen as key-element in drought management (Tong, 2021; UNCCD, 2019; Wilhite, 2002; World Bank, 2019). To incorporate resilience thinking in the drought management of a region, it is beneficial to provide stakeholders with an interest in the drought management of a region (i.e. policy makers within municipalities, safety regions, water boards and provinces or consultants from consultancy and engineering firms) with additional guidance on the practical operationalisation of drought resilience, in the form of an assessment framework (Arbon et al., 2014; Linkov et al., 2014; Sellberg et al., 2015).

However, despite the existence of a significant number of resilience assessment frameworks, very few focus on drought resilience and none focus on drought resilience of a relatively water-rich and affluent region (such as a region in the Netherlands) (Büyüközkan et al., 2022; Schipper & Langston, 2015; Sharifi, 2016; Tong, 2021). This leads to a relatively splintered base of information on the relevant elements to improve regional drought resilience and by extension on what it means in practice for such a region to be drought resilient. As such, a practical field problem arises. In the absence of strong scientific guidance, stakeholders with an interest in regional drought management, i.e. policy makers within municipalities, safety regions, water boards and provinces or consultants from consultancy and engineering firms, tend to have deviating and/or incomprehensive ideas on what it means to be(come) resilient to droughts as a region. This challenges these policy makers to design and test comprehensive (sets of) policies for drought management from a drought resilience building perspective.

1.4. Research objective

In order to reduce the identified field problem, a comprehensive assessment framework consisting of relevant elements towards regional drought resilience is to be designed. This framework can serve as an indicative tool for (drought) policy makers to guide them in finding the required focal points for (improved) drought management and conduct ex-ante policy assessments. As such, the main research objective for this study is as follows:

'***Design an assessment framework that provides a comprehensive understanding of the drought resilience of a region as a tool to guide drought management policies.'***

To reach this objective, design science methodology (i.e. van Aken (2013))is employed, structured by the Design Cycle from Wieringa (2014). The main objective is obtained through several sub-objectives:

1. *Investigate the current state of resilience assessment frameworks for regional drought resilience.*
    - 1.1. *Synthesise literature on drought resilience.*
    - 1.2. *Synthesize literature on resilience assessment frameworks.*
    - 1.3. *Develop a set of design requirements for the to-be-designed assessment framework.*
2. *Design a framework which is suitable for assessment of drought resilience of a region.*
    - 2.1. *Identify the most relevant existing RAF to adopt as theoretical base.*
    - 2.2. *Adapt the existing RAF such that it complies with the design requirements*
    - 2.3. *Formulate a procedure-of-use for the designed assessment framework.*
3. *Validate the designed assessment framework*
    - 3.1. *Conduct a case study and assess the drought resilience in that region*
    - 3.2. *Conduct an evaluation based on the gained experience*

1.5. Research scope

This study focuses on the design of an assessment framework for drought resilience of a historically water-rich and affluent region, such as a region in the Netherlands. This assessment framework is not designed for a specific target group, i.e. a water board or municipality, but instead for generic audience of stakeholders with an interest in drought management of a region. Examples of such stakeholders could be policy makers within municipalities, safety regions, water boards and provinces, but could also be consultants from engineering firms.

The employed design methodology consists of several distinct phases, being the problem investigation phase, the design phase, the validation phase, the implementation phase and the evaluation phase (Wieringa, 2014). However, only the first three phases (which are collectively called the 'Design Cycle') are conducted in this study, as this research's objective is to *design* an assessment framework and not to *implement* it.

As part of the framework's validation, it is partially applied in a case study in the Dutch region of Twente. Twente has been chosen as it is a region that is profoundly vulnerable to droughts, following its high sandy soil profile and the absence of options to direct water from the Dutch national water network (Dutch: Rijkshoofdwaternet) towards a significant part of the region (Honing et al., 2023; Van den Eertwegh et al., 2021). To conduct this case study, relevant sectors and stakeholders for the drought resilience of Twente are identified. All these sectors and stakeholders have participated in the case study, giving the case study a broad backing. However, the scope for the case study is to test framework design and this study does not intend to conduct and present a full assessment of Twente's drought resilience. The case study results presented in this report will therefor also be only of indicative nature and most focus will be on the case study *process*.

For this study, the main type of drought that is considered is a meteorological drought, which in essence is a precipitation deficit (Wilhite & Glantz, 1985). However, as a meteorological drought can (indirectly) result in agricultural, hydrological and socioeconomic droughts (Wilhite & Glantz, 1985), these can be seen as potential 'effects' from the meteorological drought and are thereby also considered, albeit inexplicably. The assessment framework assesses the drought policy domain as well as the physical domain. In this, it is assumed that for many aspects, the physical domain can be influenced through drought policies.

1.6. Report outline

This report is structured into 7 chapters and slightly deviates from the 'traditional' report structure of introduction → method chapter → results chapter → discussion and conclusions. After this introductory chapter, the second chapter explains the research method as it is applied in this study. Thereafter, the results of each phase of the design methodology are presented in separate chapters. The third chapter investigates the problem, leading to design requirements. Thereafter, a design for the assessment framework for drought resilience of a region is proposed in the fourth chapter, based on an existing RAF. In the fifth chapter, the designed assessment framework is partially validated through a case study in the Dutch region of Twente. The research method and its results are discussed in the sixth chapter, after which in the seventh chapter final conclusions are drawn and recommendations for further research are proposed. See Figure 2 for a schematisation of this outline.

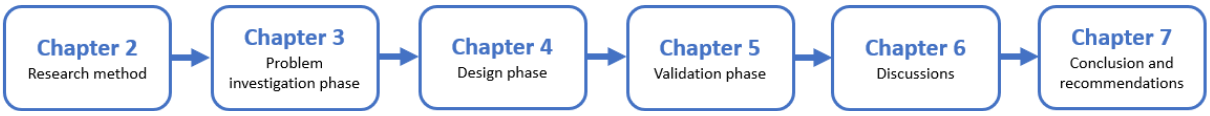

Figure 2 Schematisation of the report outline.

2. Research method

This chapter describes the design science methodology that is employed in this study. First, the design science methodology itself is introduced. In the subsequent sections, there is elaborated on the specific methods employed per phase of the study.

2.1. Design Science as overarching research method

This research addresses a field problem. To overcome a field problem, a method founded in design science is especially useful (van Aken, 2004). The value of design science lays in that it produces a solution concept that can address the field problem not only for one specific case, but which can be generalized to other cases as well (idem.). Hence, design-science research is used to achieve this research's (sub)objective(s). To structure such a design research, Wieringa (2014) developed the Engineering Cycle. In this Engineering Cycle, several distinct phases are followed in an iterative manner during the development of the design (Wieringa, 2014). The cycle starts with a Problem investigation Phase (Phase A) where the field problem's context is investigated and design requirements for a solution are formulated. Based thereupon, a first design is developed in the Design Phase (Phase B). Next, this design is validated in the Validation Phase (Phase C). After validation, the cycle returns to Phase A until the design meets the design criteria to a satisfactory level. Afterwards, it can be implemented in practice, i.e. by its prospective users (Phase D). As last step in the cycle, the design is evaluated based on its performance during implementation (Phase E). Afterwards, the cycle is started again to further improve the design.

This study follows the first three phases of the Engineering Cycle, which combined are also called the Design Cycle (Wieringa, 2014). In Phase A, literature studies are conducted on drought resilience and resilience assessment frameworks, which are synthesized into design requirements. In Phase B, a first design of the assessment framework is developed. For this there is built upon the existing base of literature, through the identification of one existing RAF that can be used as a theoretical base for the to-be-designed assessment framework for regional drought resilience. Based on a verification of this existing RAF against the design requirements, necessary adaptations are identified and incorporated into the design of the assessment framework. In Phase C, the designed assessment framework is partially applied in a case study in the Dutch region of Twente. Employing the gained experiences from the case study, the framework is (partially) validated with an evaluation against the design requirements. The proposed overall research method is visualized in Figure 3. The black and dotted elements indicate the parts of the Engineering Cycle that are not part of this study, while the blue are.

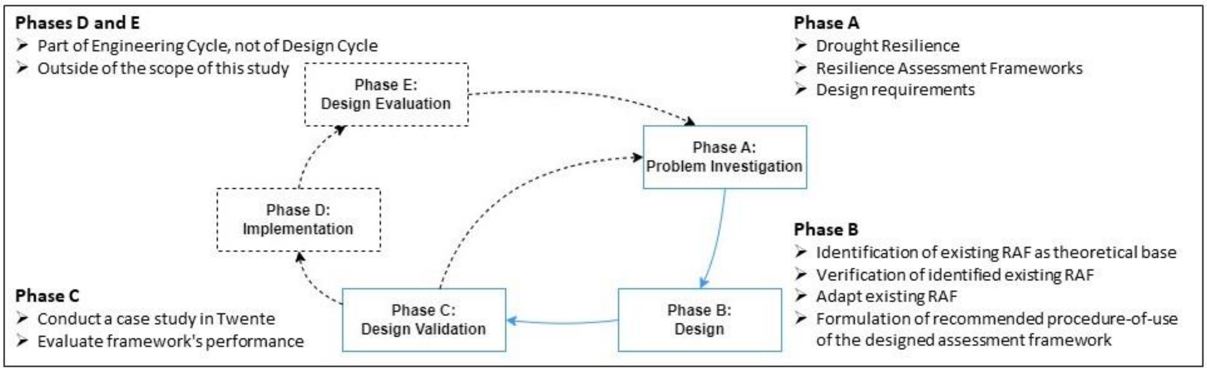

Figure 3 Visualisation of the overarching research method, adapted from the Design Cycle Approach by Wieringa (2014).

2.2. Problem investigation phase

In the sections below, specific methods employed in the problem investigation phase are described.

2.2.1. Regional Drought Resilience

A literature study was conducted on the concept of resilience. The aim of this literature study was to identify what the key-elements are of a 'resilient region'. As a starting point of this literature study, the Google Scholar search engine was used, with simple search terms such as 'review resilience', 'review (regional) drought resilience' and 'what is regional drought resilience?'. In addition, review studies on resilience literature were searched through the Scopus search engine, with similar search terms. This way, several relevant review studies were identified providing information on how resilience is understood in different perspectives and how that translates to the drought resilience of a region. The information from these review studies has been synthesized to come to a delineation and definition of a drought resilient region.

2.2.2. Resilience Assessment Frameworks

A literature study was conducted on the benefits of resilience assessment and how this assessment of the resilience of a certain entity, i.e. a region, can then be conducted. For this, there was made use of the Scopus search engine with 'Resilience Assessment Frameworks' as search term and 'review' as document type. In addition, the Google Scholar search engine was used with search terms such as 'why conduct resilience assessment?' or 'benefits of resilience assessments'. Several relevant studies were identified providing information on the potential reasons for resilience assessments and the different ways resilience can be assessed. The information from these studies has been synthesized.

2.2.3. Design Requirements for a Regional Drought Resilience Assessment Framework

A first understanding on what is required to have a 'good' RAF was already established in the previous literature studies into regional drought resilience and into why it is relevant to assess resilience and how this assessment can be conducted. To further this first understanding, a literature study was conducted on what makes a 'good' resilience assessment framework. Based thereupon, design requirements could be drafted. During this literature study, it was identified that a key-element for any 'good' RAF is the incorporation of knowledge-coproduction, both in its design as well as in its application. An existing study was identified that paid specific attention to the role of knowledge-coproduction in the design and application of indicator-based assessment frameworks, of which a RAF could be an example. This study proposed a set of six general design requirements. To come from these general design requirements for indicator-based frameworks to more specific and applicable design requirements to achieve the theoretically 'ideal' assessment framework for drought resilience of a relatively water-rich and affluent region, further literature study has been conducted. For this, an iterative approach was carried out using the reference lists of articles to find additional relevant literature, starting with the previously mentioned study. In addition, the Reference-function in the query-string of the Scopus search-engine was used to find more recent articles referencing useful literature with additional insights. By applying this approach, a broad array of literature has been found and scanned in a relatively time-efficient manner. This resulted in a set of theoretical requirements for both the design and implementation of an assessment framework for drought resilience of a relatively water-rich and affluent region.

2.3. Design phase

In the sections below, specific methods employed in the design phase are described.

2.3.1. Identification of the most relevant existing RAF to use as theoretical base of the to-be-designed assessment framework for regional drought resilience

There is a significant pool of various existing RAFs. Even though there is no readily available RAF for the drought resilience of a relatively water-rich and affluent region, it is assumed that there can be drawn from existing RAFs to use as (theoretical) base of the to be designed assessment framework. especially holds for the more general theory on the resilience of a region, being considered a complex SES, as well as for the structure of the RAF. If this is indeed the case, the required design-time can be shortened. In order to identify the potentially relevant RAFs to use as (theoretical) base of the to-be-designed assessment framework, a literature study was conducted on existing RAFs. In this literature study, an inventory was made of RAFs that state they could (also) assess for drought. This literature study was firstly based on four recent review studies of RAFs that had already been identified in the earlier literature study on RAFs. This way, a first set of six potentially relevant RAFs to use as the theoretical base were identified. Thereafter, an additional literature study was conducted to identify any missing potentially relevant RAFs. This entailed a search through the search engines of Scopus and Google Scholar, using identifiers "'resilien*' AND 'drought' AND 'framework'" or switching 'framework' for 'index', and looking at the most recent 100 results in both search engines. This way, two additional potential candidate frameworks were identified. These eight potential candidate frameworks have been compared based on how well they incorporated a comprehensive perspective on the (drought) resilience of a region. Based on this comparison, one existing RAF has been identified as being the most relevant to use as (theoretical) base for the to be designed assessment framework: the Resilience Diagnostic Tool (RDT) by Wardekker et al. (2020).

2.3.2. Verification of the RDT on the design requirements

To identify the points of attention in which the RDT needs adaptation, the researcher qualitatively verified to what extent the RDT already complies with the developed set of design requirements. This verification was conducted using the six general design criteria: credibility, legitimacy, salience, visualisation, context of use, and flexibility. The verification is guided by the specific design requirements, but these are not separately verified. The verification was informed by the journal article that presented the RDT (Wardekker et al., 2020) including its supplementary data, as well as the articles building up to the RDT (Wardekker, 2018; Wardekker et al., 2010, 2016). Moreover, a very brief literature study was conducted to find already existing reviews or critiques of the RDT. For this the Scopus search engine was used, in which Wardekker et al. (2020) was put in the Reference-function of the query-string. However, no reviews or critiques were found this way. The verification resulted in a list of main points of improvement for the RDT to better comply with the design requirements.

2.3.3. Adaptations to the RDT based on its verification

Based on the points of improvement arisen from its verification, the RDT is adapted. For most points, the adaptations were quite straightforward. However, two adaptations need further explanation.

- Especially the adaptation of the indicators to suit the regional drought resilience context was more complicated. To make these adaptations, there was made use of a review of pertinent literature. To do this, three different approaches have been used. The first was an iterative approach, using (the reference lists of) previously found assessment frameworks as starting points. Several thus found resilience frameworks held a richness of general indicators that also hold for regional drought resilience (apart from several useful indicators from the RDT itself, also i.e. Urquijjo et al. (2017) formed an important source). Secondly, in the Scopus and Google Scholar search engines, search terms similar to 'How to measure/quantify/operationalize

Operationalisation X' (with 'X' being one of the operationalisations) were used to identify indicators for specific operationalised principles. Thirdly, using the Google search engine statistical and census data were pinpointed to identify which public data was easily available. These were thereafter compared with census-based resilience measurement literature (i.e. Cutter et al., 2010; Lee & Yoo, 2021; Meza et al., 2019; Milman & Short, 2008; van Ginkel et al., 2018) to find those available indicators which are known to affect (drought) resilience either positively or negatively.

- To achieve an improved visualisation method of the assessment results, a brief literature study on existing RAFs was conducted as inspiration on the types of information that are deemed useful for policy makers and how these are visualised. For this, the found RAFs in the problem investigation phase of this study were revisited. No additional RAFs were sought.

2.3.4. The designed regional drought resilience assessment framework

Based on the adaptations to the RDT, a design for the regional drought resilience assessment framework is proposed, including a recommended procedure-of-use. This is in essence a synthesis of the previous sections and the recommended procedure-of-use includes four distinct phases: preparation phase (before the assessment), conduction phase (the actual assessment), follow-up phase (translating the assessment results into new policies) and an optional ex-ante policy evaluation (to evaluate the effects of a specific potential policy on the region's drought resilience).

2.4. Validation phase; Application in Twente

In the sections below, specific methods employed in the validation phase are described.

2.4.1. Applying the framework in a case study in Twente

The case study only included the preparatory phase and the assessment conduction phase, while omitting the follow-up phase of the recommended procedure-of-use. An ex-ante policy evaluation was also not conducted. Moreover, as the designed assessment framework is rather extensive, it was not viable to conduct a case study applying the full framework. Hence, it was decided that only one phase of the framework would be put to the test. For no specific reason, the Absorb-phase was chosen.

2.4.1.1. Preparation phase

As first preparatory step in the case study, a document analysis was conducted to achieve improved overview of the Twente region and how drought is currently managed within Twente. For this, policy and evaluation documents on water and drought management from regional stakeholders were used, such as from the Safety Region Twente, the water board Vechtstromen and the province Overijssel.

As second preparatory step in the case study, an overview of relevant stakeholders that should be considered when drafting drought management policies was created. For this study, 'relevant stakeholders' are considered as being a stakeholder or a sector of stakeholders that is or should be involved in (policy development for) water and drought management practices within the region, either as a direct decision maker or as an indirect sounding board. To obtain a general overview of who such relevant stakeholders are, the researcher participated in an expert workshop which had the aim to identify stakeholders and sectors that should participate in issues concerning drought and water use conflicts in Germany[1]. The workshop concluded that discussions on drought management policies

[1] The researcher participated in a two-day workshop organised by the Ecologic Institute and the BMUV (the German Federal Ministry for Environment, Nature Conservation and Nuclear Safety) in Berlin in November 2022. The workshop was called the Wasserverfügbarkeit und Wassernutzungskonflikte in Deutschland: Klimawandelfolgen und Lösungsstrategien and was part of the German WADKlim-project (funded by the German Environment Agency UBA) which focusses on drought and water use conflicts in Germany. In this workshop a significant number of stakeholders from the German water management domain participated and one of the aims was to identify the sectors and types of stakeholders that should participate in drought management issues.

should not only include the governmental column, but also the drinking water company, nature management sector, industry and economy, and the agricultural sector. Thereafter the identified relevant sectors and types of stakeholders have been specified into the relevant stakeholders with knowledge of the drought management practices within the Twente region. To do so, there was made use of the previously conducted document analysis on drought management in Twente. In addition, there was made use of the extensive overview of stakeholders involved in water management in the neighbouring Salland region (which is a result of an ongoing PhD research project on the link between water management and climate adaptation in the region of Salland). This overview of relevant stakeholders in the Twente region served as starting point to find interviewees.

As third preparatory step in the case study, data availability was researched to find out which indicators of the Absorb-phase could be assessed in a quantitative manner using credible open data sources, and for which indicators input from regional experts was required. For this, the Google search engine was used, with simple search terms where the specific indicator and "Twente" were put together. Moreover, the Dutch governmental Bureau of Statistics (CBS) was scanned to find relevant statistics.

2.4.1.2. Assessment conduction phase

For the indicators that could be assessed through credible open data sources, specific scoring mechanisms were set op based on the specifics of the available data. In Appendix B these scoring mechanisms are presented. Interviews with regional experts from relevant stakeholders were used for the other indicators. Based on the overview of relevant stakeholders in the Twente region, interviewees within these stakeholders were sought. For their identification, there was made use of snowball sampling, sending requests for referrals to designated contact persons of the stakeholders and checking social media accounts of the stakeholders (i.e. LinkedIn). Based thereupon, twenty interviews took place. Nineteen of these are included in the results of the case study. One interview turned out to be with someone who had insufficient knowledge to assess the indicators, but did have useful referrals. An overview of the interview participants is presented in Table 1. All interviewees had significant professional experience in functions related to drought or resilience within their own sector.

Table 1 Overview of interviewed stakeholders in the case study.

#	Stakeholder (governments)
I1	Waterboard Vechtstromen
I2	Province Overijssel
I3	Rijkswaterstaat Oost
I4	Safety Region Twente
I5	Fire brigade Twente
I6	Municipality Enschede
I7	Municipality Hellendoorn
I8	Municipality Hengelo
I9	Municipality Oldenzaal
I10	Municipality Rijssen-Holten
I11	Municipality Wierden

#	Stakeholder type (non-governments)
I12	Drinking water company Vitens
I13	Nature management organisation 1
I14	Nature management organisation 2
I15	Interest group industry and economy 1
I16	Interest group industry and economy 2
I17	Industry party with significant water use
I18	Interest group for agriculture 1
I19	Interest group for agriculture 2

The specific background of the interviewee was used to decide which indicators would be discussed during the interview. An overview of relevant stakeholders per indicator as applied in the case study is presented in Appendix B. All interviews lasted approximately one hour, were held in Dutch and were recorded for later transcription. At the start of each interview a short presentation by the researcher gave some background on the study and explained an overview of the designed assessment framework to provide interviewees a better idea of what types of information they were asked to provide and in what manner. Thereafter a discussion was held per selected indicator to provide these types of information.

Once all interviews were conducted and quantitative indicators were scored, the results were processed. To do so, the structured assessment method and the structured visualization method as described in Section 4.3 were applied.

2.4.2. Validation phase; Lessons learned from application

Based on the experience gained in applying the framework in a case study as validation, lessons learned for the framework and its application are formulated through a self-evaluation by the author. For this, there is made use of the earlier developed set of design requirements. The evaluation is done through qualitatively assessing each of the general design criteria based on how the framework was applied in the case study. The evaluation is guided by the specified design requirements, but these are not separately assessed. This results in an overview of points in which the designed assessment framework is already strong, and where it can or should be improved, both for the framework's content, as well as for the process of application. Moreover, points that require further research are thusly identified. For each of the general design requirements, a final score for the assessment is given. These are either 'not met', 'mostly not met', 'partially met', 'mostly met', or 'met'.

3. Results Problem Investigation Phase

In the section below, the results of the problem investigation are presented. This is the first phase of the design cycle. It aims to obtain an improved oversight on what (regional drought) resilience is and why an assessment framework for the drought resilience of a region has to be designed. Additionally, based on this investigation it is illuminated how this designed assessment framework should look like.

3.1. Regional Drought Resilience

'Resilience' is a broad and complex term. Especially in the past decades, the topic of 'resilience' has seen a significant rise in interest within the academic world (Mujjuni et al., 2021; Sharifi, 2016). However, despite this increased study on the topic, or perhaps because of it, consensus on a harmonized understanding and definition of the concept is still absent (Brand & Jax, 2007; Hosseini et al., 2016; Meerow et al., 2016; Mujjuni et al., 2021) and it's understanding changed significantly over time (Manyena et al., 2019; Mujjuni et al., 2021). In the 1910s resilience was understood as the ability of an object to persist and maintain function during a disturbance (Schlink, 1919). During the 1970s, this understanding changed towards resilience being the ability of an entity to absorb changing conditions (Holling, 1973). Thereafter, the understanding of resilience further changed into the ability of something, i.e. an object, community or system, to prevent, anticipate, cope, bounce back from, learn from and transform after a disturbance (Manyena et al., 2019). In the present, several distinct perspectives exist on what 'resilience' entails, and the specific definition of resilience is highly subject to these perspectives and the context in which it is applied (Kim & Lim, 2016). In an engineering perspective, resilience is about resisting the disturbance while retaining functionality as much as possible and about returning to one singular steady state as quickly as possible (Kim & Lim, 2016). Yet, in an ecological perspective, multiple steady states can occur, and resilience is more about the capabilities of a system to reorganize and absorb a disturbance (idem.). In an evolutionary or ecological system perspective, the notion of a steady state is absent (idem.) and socioecological resilience relates to the capacity of the socioecological system (SES) to achieve quasi-stationary equilibria in which the system shows recovery to the original state in the short-term, but in the long-term can continuously change, adapt and improve based on human agency and system intervention through i.e. policy development in response to (undesired) disturbances (Folke et al., 2016; Nelson et al., 2007). This adaptive capacity for SES includes the capability of human systems (opposed to i.e. ecological systems) to anticipate and prepare for disturbances (Davoudi et al., 2013). In addition to the different perspectives, the definition of resilience is often strictly suited to the system and disturbance at hand (Büyüközkan et al., 2022; Kim & Lim, 2016).

To include resilience building as key-element in drought policy development, an understanding of drought resilience for a region should first be achieved and defined (Taşan-Kok et al., 2013). There can be drawn from existing scientific literature to do so, as common patterns can be observed within the diverging perspectives on and definitions of 'resilience'. Functional definitions of resilience (*what does it do?*) dominate literature, opposed to ontological definitions (*what is it?*) (Mujjuni et al., 2021). Such a functional definition incorporates a set of capacities a system can have, demonstrating the different temporal phases of a disturbance to the system (Mujjuni et al., 2021). The core capacities in resilience literature are 'preparedness', 'absorption', 'recovery', 'adaptability' (Linkov et al., 2014), which can be increased through the five major forms of capital, being social, economic, physical, human, and natural capital (Mayunga, 2007). The manner in which these capacities act throughout the phases of the disturbance determine the resilience process (see Figure 4) and the impact of the disturbance on the system (Linkov et al., 2014; Mujjuni et al., 2021).

In this study, a region is regarded as an adaptive and complex SES, in which urban and rural contexts are combined and where social, economic, ecological, political, technological, and physical components are strongly interlinked (Petrosillo et al., 2018). To come to a definition for drought resilience of such a region, different resilience perspectives are integrated. The definition that is used in this study entails a quick recovery from a disturbance to the desired state (engineering resilience), the ability to absorb and persist the disturbance (ecological resilience) and the ability of an SES to prepare before and adapt and improve after a disturbance has passed (socioecological resilience):

'Regional Drought Resilience entails the region's ability to prepare for, absorb, recover from, and adapt after drought-induced effects in a timely manner, for both the region's urban and rural context, and its social, economic, ecological, cultural, political, technological and physical components.'

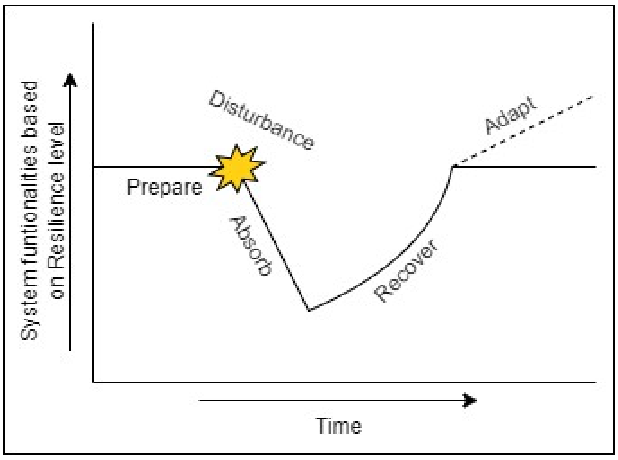

Figure 4 The resilience process of a system, adapted from Linkov et al. (2014, p. 407).

3.2. Resilience Assessment Frameworks

Simultaneously with the rise in interest in the concept of resilience of the academic world, also the interest in ways to assess the resilience of an entity rose (Sharifi, 2016). Through a resilience assessment, *understanding* of ways to *improve* the resilience of a system to a certain hazard can be harvested through *assessing* certain system characteristics (Quinlan et al., 2016; Sharifi, 2016; Tong, 2021). Reasons for conducting resilience assessment or measurement include but are not limited to benchmarking performance (the current 'resilience status', or resilience maturity level) of systems with discussions and lesson-drawing between system-stakeholders as a consequence (Arbon et al., 2014), as an (indicative) ex-ante decision support system which can help identifying vulnerable areas that need to be strengthened (Frankenberger et al., 2013) or prioritized when allocating limited resources (Khazai et al., 2015; Sellberg et al., 2015), and as an (indicative) ex-post decision support systems which can aid organizations that have previously undertaken resilience and/or disaster risk reduction activities to monitor the effectiveness of these activities (Khazai et al., 2015; Renschler et al., 2010). In the past two decades, a wide range of tools have been developed to operationalize the complex term of 'resilience' (as shown in reviews by Schipper and Langston (2015), Sharifi (2016) and Tong (2021)).

These frameworks can be broadly divided into resilience *measurement* frameworks and resilience *assessment* frameworks (Levine, 2014; Quinlan et al., 2016; Wardekker et al., 2020). In brief, resilience measurement frameworks try to *quantify* the resilience of a certain entity through simplified quantifiable models or indices, while resilience assessment frameworks focus on increasing the understanding of a system and its dynamics relevant to resilience through either solely *qualitative* assessment, or through a combination of quantitative and qualitative assessments (idem.). Resilience measurement tools have the advantage of high precision (if transparently designed and applied), repeatability and easy connection with policy tools such as cost benefit analyses, but the disadvantage of (the risk of) oversimplification to a narrow set of indicators and to only those elements of a system that are easy to quantify (i.e. over-dependency on census data) (Wardekker et al., 2020). Resilience assessment tools have the advantage of promoting learning while conducting the assessment, providing a broader view on the relevant dynamics of the system, and maintaining a richer information base in the process, yet have the disadvantage that results are often less clear for decision makers and could take significantly longer than the measurement tools to conduct (Wardekker et al., 2020). Both types of tools typically employ indicators to come to assessment/measurement results (Tong, 2021). These indicators can be more abstract and kept in theory (i.e. the resilience principles are the indicators), or more operationalised (specific indicators providing information on what a resilience principle means in practice).

RAFs typically differ in their (Tong, 2021):

- Topic (what is assessed to what type(s) of disturbance);
- Spatial scale (i.e. district, city, region, country, community);
- Territory of assessment (i.e. coastal, fluvial, mountains, non-specific);
- Characteristics of assessment (which resilience capacities and/or principles are considered, i.e. preparedness, absorption, recovery, adaptation);
- Dimensions of assessment (i.e. the included domains, i.e. social, economy, ecology);
- The applied methods for information gathering and assessment (qualitative, quantitative, or mixed methods, i.e. document analyses, surveys, interviews, workshops, or a Delphi method).

3.3. Design requirements

Knowledge co-production and stakeholder participation have an important role in both the process of development of a RAF as well as in the process of its implementation (Sharifi, 2016; Singletary et al., 2022; Staron et al., 2015). A set of six general design requirements for indicator-based assessment framework, such as a RAF, has been identified by Vargas-Farías (2019). This set focusses on the important role of knowledge co-production in such frameworks. It has been used in this study as a frame with scientific footing to structure specific design requirements that ensure the quality and uptake (i.e. potential usage in policy development) of the (to-be-designed) resilience assessment framework. This set stipulates that there should be 1) *credibility*, 2) *legitimacy*, and 3) *salience* of the framework elements and the assessment procedure within the framework, 4) proper *visualisation* of the framework and its assessment results, 5) proper incorporation of the framework within its *context of use*, and 6) a proper level of *flexibility* in the framework (Vargas-Farías, 2019). In practice, there are often trade-offs between the first three general design requirements credibility, legitimacy and salience (Cash et al., 2003; Lehtonen, 2015). This holds especially true for assessment frameworks targeting early science-policy dialogues such as for ex ante policy evaluations where stakeholders from different domains are brought together (Cash et al., 2003). Consequentially, focus should not lie on one specific criterium, as it is of importance that a balance between them remains. In the sections below, a line of argumentation is discussed leading to the specific design requirements for an assessment framework for drought resilience of a region, based on the set of six general indicators by Vargas-Farías (2019).

3.3.1.Credibility

For the assessment framework to be *credible*, stakeholders should perceive the framework elements and the knowledge based thereupon as meeting their standards of scientific plausibility and technical adequacy (Cash et al., 2003; Jensen & Wu, 2018). For this, each assessment framework element should be coherent with scientific literature on drought resilience for a region (OECD, 2008; Sharifi, 2016) and the assessment framework as a whole should be comprehensive enough to accurately represent this scientific literature with an integrative vision (Cash et al., 2003; Jensen & Wu, 2018). The data on which the assessment is based and informs the framework elements (i.e. the indicators) should come from a source that is trusted (Cash et al., 2003; Jensen & Wu, 2018) and be produced sufficiently recently, i.e. no older than five years (Jensen & Wu, 2018; OECD, 2008; UN-Water, 2006).

3.3.2. Legitimacy

The assessment framework needs *legitimacy* if it is to be accepted by stakeholders (Cash et al., 2003; Jensen & Wu, 2018). This is largely a function of the process of framework development. Legitimacy describes '*how "fair" an information producing process is and whether it considers appropriate values, concerns, and perspectives*' (Cash et al., 2003, p. 2). For this to be true, first of all the assessment procedure and the relationships between framework elements should be transparent and understandable for an audience with little to no experience in resilience theory (Jensen & Wu, 2018; Staron et al., 2015; UN-Water, 2006; Zakkar & Sedig, 2017). Moreover, during the development of the assessment framework, a representative sample of the relevant regional stakeholders should be included such that their different perspectives are incorporated (Cash et al., 2003; Dunn & Bakker, 2009; Sullivan, 2002). In addition, the relevant regional stakeholders should agree upon the score-thresholds of the framework elements as well as on their relative importance or weighting (idem.).

3.3.3. Salience

Salience relates to the relevance and usability of the framework to the relevant regional stakeholders, i.e. the framework's end-users (Cash et al., 2003). For the framework to have 'relevance', the framework elements used to assess the drought resilience of the region should first of all be relevant to the region's specific context (Dunn & Bakker, 2009; OECD, 2003; van Beek & Arriens, 2016). Water availability for industry could for example be highly relevant in one region, while being less relevant in another region. The same holds for salt water intrusion. Moreover, the data that populates the framework elements should be according to the appropriate spatial scale and the region's specific context (Cash et al., 2003; Jensen & Wu, 2018). For the framework to have 'usability', both the procedure of implementation of the assessment framework should be workable and the assessment results should have utility (Cash et al., 2003). For the prior, the framework elements as well as the assessment procedure should be self-explanatory and simple to understand and interpret for an audience with little to no experience in resilience theory (OECD, 2008). Moreover, the data that is used for the assessment should be easily accessible through publicly available data or at a reasonable cost/benefit ratio (Dunn & Bakker, 2009; Jensen & Wu, 2018; van Beek & Arriens, 2016). For the latter, the framework should be able to provide concrete The assessment results should provide concrete guidance on the current state of drought resilience in the region, what the bottlenecks are and how these can be improved (Khazai et al., 2015; Quinlan et al., 2016; Staron et al., 2015). In addition, the utility of the assessment results increases when the assessment procedure produces a combination of quantitative information for a quick overview of assessment results and more in-depth qualitative information (Hunt & Watkiss, 2011; Sharifi, 2016; Singletary et al., 2022; Staron et al., 2015). This as some stakeholders may i.e. need only a quick overview of the assessment results, while others require in-depth information with concrete guidance. Furthermore, when the aim of the assessment framework is policy development, it is highly relevant for the framework to be able to assess the effect of policy interventions on the current state of the drought resilience in the region (Ferraro, 2009; Wardekker et al., 2016). Simultaneously, foreseen developments, i.e. current or upcoming policies not yet in full effect, or ongoing societal shifts, can have an effect on the current state of drought resilience of the region. As a form of counterfactual thinking, it is highly relevant that the framework can reflect on such foreseen developments affecting the current state of the drought resilience in the region if no further policy interventions are implemented (Ferraro, 2009; OECD, 2003).

3.3.4. Visualisation

Communicating the assessment framework and its results to the relevant regional stakeholders can be difficult, due to the inherent complexity of the resilience-related scientific literature and the diversity of stakeholders and their differing needs (Staron et al., 2015; Zakkar & Sedig, 2017). As the significant amount of information contained in the assessment can easily be lost in transmittance (Hoekstra et al., 2018; Sharifi, 2016), proper visualisation of both the framework's analytical base and its results are key to prevent information loss (Hoekstra et al., 2018; Staron et al., 2015). Proper visualisation also enables the framework to be engageable for stakeholders leading to improved uptake of the results in policy development (Voinov et al., 2016) as well as provide improved learning among stakeholders (Zakkar & Sedig, 2017). To accommodate this 'proper' visualisation, the visualisation of the assessment framework and its results should first of all be able to visualize the large amounts of information that make the assessment framework credible, legitimate and salient (Hoekstra et al., 2018; Staron et al., 2015; Voinov et al., 2016; Zakkar & Sedig, 2017). These assessment results have to be presented in such a way that it provides inspiriting guidance for policy development (Sharifi, 2016), but is not overwhelming for the readers (Staron et al., 2015; Zakkar & Sedig, 2017).

3.3.5. Context of Use

Conducting a resilience assessment will have little to no use if it is not properly incorporated in its context of use, enabling a direct link of the assessment results to the policy development (Jensen & Wu, 2018; Sharifi, 2016). In order to create this link between the assessment and policy development, the end-users' ownership of the assessment framework should be created (Lang et al., 2012; Sharifi, 2016). To do so, these end-users should not only be considered for, but also be part of the development of the assessment process (Bremer et al., 2022; Hegger et al., 2012; Lang et al., 2012). Thereafter, the users of the framework should develop action plans informed by the assessment results that are directly linked to the policy development and decision-making process (Sharifi, 2016).

3.3.6. Flexibility

As no two regions are identical, the potential value of the assessment framework and its results decreases if the framework is overly stiff (Sharifi, 2016). In order to remain sufficiently flexible, several aspects are important to be accommodated. First of all, the relevant regional stakeholders will differ on a case-to-case basis and additional stakeholders may be identified during the assessment procedure. The framework should be flexible enough to accommodate this (Bressers et al., 2016). Secondly, the properties of framework elements (i.e. relative importance, accessible data sources, score-thresholds) vary based on the demands of the region's specific context and new information that arises during the assessment procedure may inform required adaptations to these properties. The framework should be flexible enough to accommodate this (Bressers et al., 2016; Constas et al., 2022).

3.3.7. Overview of design requirements

Table 2 presents an overview of the – in total 24 – thusly identified specific design requirements.

Table 2 Design requirements for indicator-based resilience assessment frameworks, including key references.

General design requirement	Specific design requirement	Key references
Credibility	Each framework element is coherent with scientific literature on drought resilience for a region.	(OECD, 2008; Sharifi, 2016)
	The assessment framework as a whole is comprehensive enough to accurately and integratedly represent drought resilience.	(Cash et al., 2003; Jensen & Wu, 2018)
	Data informing framework elements comes from trusted sources.	(Cash et al., 2003; Jensen & Wu, 2018)
	Data informing framework elements is updated regularly or from a sufficiently recent source, i.e. no older than five years.	(Jensen & Wu, 2018; OECD, 2008; UN-Water, 2006)
	Uncertainty of the assessment results is incorporated in the assessment procedure.	(Carstensen & Lindegarth, 2016; Melo-Aguilar et al., 2022; Stoessel, 1994)

General design requirement	Specific design requirement	Key references
Legitimacy	The assessment procedure and the relationships between framework elements is transparent and understandable for an audience with little to no experience in resilience theory.	(Jensen & Wu, 2018; Staron et al., 2015; UN-Water, 2006; Zakkar & Sedig, 2017)
	There is a representative sample of relevant regional stakeholders included in the development of the combined set of indicators.	(Cash et al., 2003; Dunn & Bakker, 2009; Sullivan, 2002)
	The score-thresholds of the different framework elements is agreed upon by the relevant regional stakeholders.	(Cash et al., 2003; Dunn & Bakker, 2009; Sullivan, 2002)
	The relative importance of framework elements is agreed upon by the relevant regional stakeholders.	(Cash et al., 2003; Dunn & Bakker, 2009; Sullivan, 2002)
Salience	Framework elements are relevant to the region's specific context	(Dunn & Bakker, 2009; OECD, 2003; van Beek & Arriens, 2016)
	Framework elements are populated with data according to the selected spatial scale and the region's specific context	(Cash et al., 2003; Jensen & Wu, 2018)
	Framework elements and the assessment procedure are self-explanatory and simple to understand and interpret for an audience with little to no experience in resilience theory.	(OECD, 2008)
	Data for framework elements is easily accessible through publicly available data or at reasonable cost/benefit ratio	(Dunn & Bakker, 2009; Jensen & Wu, 2018; van Beek & Arriens, 2016)
	The assessment results should provide concrete guidance on the current state of drought resilience in the region, what the bottlenecks are and how these can be improved.	(Khazai et al., 2015; Quinlan et al., 2016; Staron et al., 2015)
	The assessment procedure produces a combination of quantitative information providing a quick overview of assessment results and more in-depth qualitative information.	(Hunt & Watkiss, 2011; Sharifi, 2016; Singletary et al., 2022; Staron et al., 2015)
	The assessment framework should be able to assess the effect of policy interventions on the current state of framework elements	(Ferraro, 2009; Wardekker et al., 2016)
	The assessment framework should be able to reflect on the expected effects of the foreseen developments affecting the current state of the framework elements	(Ferraro, 2009; OECD, 2003)
Visualisation	The assessment framework visualises the significant amounts of information as required for the framework to be credible, legitimate and salient.	(Hoekstra et al., 2018; Staron et al., 2015; Voinov et al., 2016; Zakkar & Sedig, 2017)
	The framework presents information in an inspiriting manner.	(Sharifi, 2016)
	The framework presents information in a manner that is not overwhelming.	(Staron et al., 2015; Zakkar & Sedig, 2017)
Context of Use	The end-user(s) are not only considered for, but also part of the development of the assessment framework.	(Bremer et al., 2022; Hegger et al., 2012; Lang et al., 2012)
	The output of the framework is linked with the rest of the policy decision making process to make action plans.	(Sharifi, 2016)
Flexibility	The relevant regional stakeholders are determined on a case-to-case bases and remain flexible during the assessment procedure to accommodate new information.	(Bressers et al., 2016)
	The properties of the framework elements (i.e. relative importance, accessible data sources, score-thresholds) should be determined on a case-to-case basis and remain flexible during the assessment procedure to accommodate new information.	(Bressers et al., 2016; Constas et al., 2022)

4. Results Design phase

In the sections below, the results of the Design phase are presented. This is the second phase of the design cycle. It aims to identify an existing RAF to use as base for the to-be-designed assessment framework for regional drought resilience. This existing RAF is then verified based on the design requirements, after which points of improvement are drafted. Based on these points, adaptations to the RAF are made. In the end of this chapter, the design is presented, including a recommended procedure-of-use to ensure high quality assessment results.

4.1. Identification of the most relevant existing RAF to use as theoretical base for the to-be-designed assessment framework for regional drought resilience

In total, eight existing RAFs have been identified as being potentially relevant to use as a (theoretical) base of the to-be-designed assessment framework for regional drought resilience. In four recent review studies on resilience assessment frameworks (Büyüközkan et al., 2022; Schipper & Langston, 2015; Sharifi, 2016; Tong, 2021), only six (out of +/- 80) different RAFs were identified that mentioned they could also assess for drought resilience (Joerin et al., 2014; Labaka et al., 2019; Oriangi et al., 2020; Siebeneck et al., 2015; UNDP, 2014; Wardekker et al., 2020). However, only one of these, the Community Based Resilience Analysis (CoBRA) conceptual framework by the United Nations Development Programme, or the UNDP, has a specific focus on drought (UNDP, 2014). By conducting the additional literature study, two additional potentially relevant RAFs were identified. These are the (unnamed) drought resilience measurement framework by Lee and Yoo (2021) and the Composite Index for Disaster Resilience by Cutter et al. (2010). The eight thusly found frameworks are presented in Table 3, including a comparison on their resulting product type, their resilience type, resilience definition, the respective hazard for which they were developed, and the included resilience process phases from Linkov et al. (2014). Based on the comparison, only the Climate Disaster Resilience Index (CDRI) by Joerin et al. (2014), the Smart Mature Resilience Maturity Model (SMM MM) by Labaka et al. (2019) and the Resilience Diagnostic Tool (RDT) by Wardekker et al. (2020) include all the required resilience phases Linkov et al. (2014) and therefore have a usable theoretical footing. These three RAFs also include rich stakeholder-based information, opposed to the high dependency on rather bleak census data such as the Composite Index (Cutter et al., 2010) and the Natural Hazard Community Resilience Framework (Siebeneck et al., 2015). However, only the SMM MM (Labaka et al., 2019) and RDT (Wardekker et al., 2020) are RAFs able to process complex regional SESs opposed to household or community resilience of the other frameworks. When taking a more detailed look into the background of both the SMM MM and RDT, it becomes clear that the RDT was constructed with a firmer footing in a more comprehensive combination of literary strands on system resilience. The different resilience phases are better represented by the RDT than by the SMM MM, even though both include all phases. From the rationale above, it was concluded that the RDT is the most relevant framework to consider as base for a regional drought resilience assessment framework.

Table 3 Overview of relevant frameworks found in literature. Res. = Resilience. Possible resilience phases taken from Tong (2021), being Prepare, Absorb, Recover, Adapt, and Transform.

Framework	Source	Product type	Res. type	Resilience definition	Focus area	Res. phases
Composite Index for Disaster Resilience	(Cutter et al., 2010)	Comparative measurement tool with list of 36 relevant census indicators for quantitative measurement in an American context	Community/ Social	*"Resilience is as a set of capacities that can be fostered through interventions and policies, which in turn help build and enhance a community's ability to respond and recover from disasters"*	Unspecified disasters	Prepare, Absorb, Recover
UN CoBRA Framework	(UNDP, 2014)	Methodological framework in the extreme drought and poverty context of the Horn of Africa	Community/ Social	None specified.	Food scarcity due to extreme drought	Absorb, Recovery
Climate Disaster Resilience Index	(Joerin et al., 2014)	Absolute assessment tool with 125 indicators for general community resilience, based on survey results, in an Indian context	Community/ Social	*"The resilience of an urban community depends on its capacity to create the ideal environment, which is most capable of minimising the probability of shocks and has the greatest ability to respond to disaster situations."*	Natural hazards, incl. drought	Prepare, Absorb, Recovery, Adapt
Natural Hazard Community Resilience Framework	(Siebeneck et al., 2015)	Comparative measurement tool with list of 25 relevant census indicators for quantitative measurement in a Thai context	Community/ Social	None specified.	Natural hazards, incl. drought	Absorb, Recovery,
Smart Mature Resilience Maturity Model	(Labaka et al., 2019)	Absolute assessment tool in the form of a maturity model over four dimensions, focussing on resilience building in a Spanish context	Urban/SES	*"The ability of a city or urban region to resist, absorb, adapt to and recover from acute shocks and chronic stresses to keep critical services functioning, and to monitor and learn from on-going processes through city and cross-regional collaboration, to increase adaptive abilities and strengthen preparedness by anticipating and appropriately responding to future challenges"*	Policymaking for flood and drought	Prepare, Absorb, Recover, Adapt
Resilience Diagnostic Tool	(Wardekker et al., 2020)	Absolute multi-layered assessment tool operationalizing a comprehensive literary database on complex socioecological urban system resilience through semi-quantitative indicators, also enabling some ex-ante policy evaluation, in a western urban context	Urban/ SES	*"A resilient system can tolerate disturbances (events and trends) through characteristics or measures that limit their impacts, by reducing or counteracting the damage and disruption, and allow the system to respond, recover, and adapt quickly to such disturbances."*	Policymaking for climate change hazards, incl. drought	Prepare, Absorb, Recover, Adapt
Household Resilience Framework	(Oriangi et al., 2020)	Absolute measurement tool based on a list of 9 indicators, including census and perceived likelihood survey data, In the context of Uganda.	Household/ Social	*"Household resilience is the capacity of a household to prepare, recover and adapt or change its source of income or livelihood if needed when faced with climate change shocks and stresses"*	Flood and drought	Prepare, Absorb, Recover
Drought Resilience Framework	(Lee & Yoo, 2021)	Comparative measurement tool with 29 (semi-)quantitative indicators in the context of South Korea.	Community/ Social	None specified.	Drought	Prepare, Absorb, Recovery

4.2. Verification of the RDT

The RDT is first briefly explained. Thereafter, the verification results of the RDT are discussed.

4.2.1. Explanation of the RDT

Wardekker et al. (2020) have developed the RDT as a diagnostic tool to support policymaking which promotes resilience of a complex socioecological urban system to different climate change related disturbances. It *'diagnoses choices made in resilience-building, making them transparent and explicit, and facilitates reflection on their consequences and consistency between goals and means'* (Wardekker et al., 2020, p2). As such, it was specifically developed to be able to conduct assessments of the broad governance system, incorporating policies, strategies, measures, and institutional contexts in the realm of resilience. The RDT was designed and validated using several case studies concerning urban flood resilience. These case studies were the outer-dike areas of the Dutch municipality of Rotterdam (Wardekker et al., 2010), a wetland area within the Dutch Vechtstreek (Wardekker et al., 2016) and the Dutch municipality of Rotterdam as a whole (Wardekker et al., 2020). The RDT is constructed using four different layers which are linked with each other in a tree-structure. The most generic layer (Layer 1, Phases) consists of the four broad, temporal phases of a disturbance on the system, akin to the phases from Linkov et al. (2014). These are then further elaborated into a set of ten general resilience principles (or characteristics) valid for a regional system as the second more specified layer (Layer 2, General Resilience Principles). These general resilience principles are further detailed using a total of 34 operationalized principles (Layer 3, Operationalised Principles), as Wardekker et al. (2020) named them. However, this layer is in fact not yet an actual operationalization of the principles and only a mere direction towards such an operationalization, which could harbour confusion by the potential framework-users. Despite this non-intuitive labelling of this third layer, the terminology remains in this thesis due to coherence with pertinent literature. In order to actually assess the resilience of a given region, concrete indicators were defined for all specified principles (Layer 4, Indicators). This fourth layer is specific for a certain disturbance. The above is visualised in Figure 5. During an assessment cycle of the RDT, only the indicators (Layer 4) are directly scored through a 5-point Likert-scale. The indicators are then given a relative weighting compared to the other indicators under the overlaying resilience operationalisation (Layer 3). Thereafter, the indicator scores are summed to produce an indirect score for these overlaying resilience operationalisation (Layer 3). Similarly, the resilience operationalisations are given a relative weighting, producing indirect scores for the resilience principles (Layer 2) and in turn the resilience phases (Layer 1). A singular resilience score of the region is not obtained through the RDT.

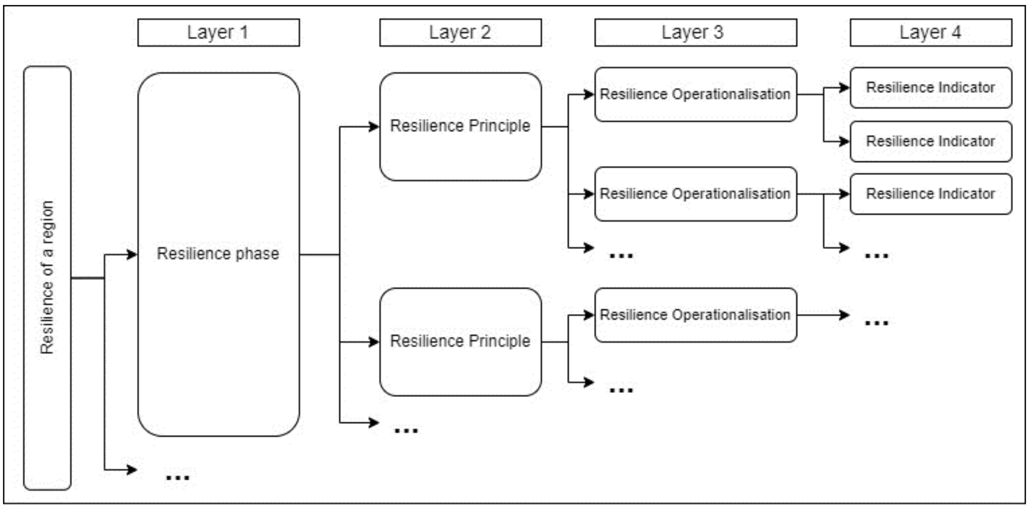

Figure 5 Tree-structure of the RDT by Wardekker et al. (2020).

4.2.2. Verification of the RDT

In the sections below, the verification of the RDT on the design requirements is discussed per general design requirement. Thereafter, an overview of the found points of improvement is presented. Between brackets, the identified points of improvement are numbers (with C = credibility, L = Legitimacy, S = Salience, V = Visualisation, CoU = Context of Use, and F = Flexibility).

Credibility

The RDT is constructed through a very broad and comprehensive scientific literature study, combining different perspectives with the aim of assessing the resilience of a SES. In the RDT, the first three layers (Resilience phases, Resilience principles and Resilience operationalisations) are for unspecified climate related disturbances to a complex SES. These are seen as highly credible, also in the context of regional drought resilience. The fourth layer (indicators) is however developed for a specific disturbance. As the RDT was validated using several case studies concerning urban flood resilience, the set of indicators in the RDT is also specific for urban flood resilience and not aligned with scientific literature on drought resilience. As such, especially the fourth layer should be adapted to suit the context of drought resilience for the framework to be credible (**C1**). Furthermore, in all case studies on which the RDT (or its forebears) was applied, there was made use of regional experts (i.e. in-depth interviews, workshops). Even though this unavoidably bears some subjectivity, regional experts are seen as a trusted data source. Lastly, uncertainty is not accounted for in the RDT, decreasing its credibility (**C2**).

Legitimacy

In the case study conducted by Wardekker et al. (2020), stakeholders perceived the layered structure approach as beneficial for their understanding of resilience, which resulted in a high transparency of the framework, aiding in its legitimacy. Simultaneously, in the discussion of that same case study, it was stated that several specific operationalisations were very similar. This had a negative effect on the perceived complexity of the RDT by the case study participants and thus on its legitimacy (**L1**). Representative samples of the relevant regional stakeholders are included in the development of the framework elements through the different case studies of (the forebears of) the RDT, finetuning the contents with each round. However, as the indicators (Layer 4) will be largely adapted as they are for the most part not relevant for regional drought resilience, no representative sample has been included in the development of the indicators for Layer 4 (**L2**). Lastly, during the case studies of the RDT, the score-thresholds as well as the relative importance of the different framework elements are discussed and agreed upon during workshop sessions with a representative sample of relevant regional stakeholders, improving the legitimacy of the assessment procedure.

Salience

Firstly, in the assessment procedure of the RDT, the framework elements are provided with a relative weighting. This provides an opportunity to ensure that all framework elements are relevant to the region's specific context improving the frameworks salience, as the irrelevant elements can be given a relative weighting of nil. Similarly, the data that populates the framework elements are selected on a case-to-case basis, with mostly regional experts as source, improving salience of the used data. Whether or not this form of data gathering is considered to be at a reasonable cost/benefit ratio largely depends on the available resources of the study. Secondly, during the case study of the RDT in Wardekker et al. (2020), the participating stakeholders had difficulties understanding (the underlying resilience theory of) the RDT, needing significant explanation thereupon. As such, it is concluded that the framework itself was not sufficiently self-explanatory for the audience and the theory should be better explained within the framework (**S1**). Additionally, in the case studies it proved laborious to refer to certain framework elements, both during the assessment as well as in the text. This complicated the assessment procedure, negatively impacting the salience (**S2**). Moreover, even though in the case study in Wardekker et al. (2020) the score-thresholds as well as the relative importance of the different framework elements are discussed and agreed upon during workshop sessions, no guidance is given as to how this should be done, nor on how an outcome of this could look like. As such, these elements of the assessment procedure are not self-explanatory (**S3, S4**). Thirdly, the RDT does provide concrete guidance on the current state of (flood) resilience in the region, what the bottlenecks are and how these can be improved. This is done through a combination of radar diagrams with quantitative results and textual clarification for each framework elements on its bottlenecks. Similarly, the RDT has shown in the different case studies that it is able to assess the effects of policy interventions on the current state of framework elements. However, in none of the case studies it has shown to be able to reflect on foreseen developments affecting the current state of the framework elements. As such, this is an uncertain factor for the framework's salience (**S5**).

Visualisation

The RDT visualised its results through radar diagrams and accompanying textual clarification (Wardekker et al., 2020). However, especially the textual clarification is not clearly structurally incorporated in the assessment procedure, potentially leaving only the radar diagrams as result visualisation. A radar diagram in itself is a good tool to visualize a relatively small amount of quantitative information in a simple manner for a diverse audience (Sharifi, 2016). However, having solely this one radar diagram as visualization of the assessment results insufficiently captures the richness of information that is accumulated by applying the framework. Hence, a more structured and extensive approach for the visualisation of the assessment results should be formulated (**V1**). Missing types of information that should be visualised are the relative importance of framework elements, data sources, uncertainty in assessment results and a reflection on the foreseen development affecting the current state of the framework elements.

Context of Use

As the incorporation of a RAF in its context of use is highly specific to that RAF, potential points of improvement for the RDT in this regard will not inform the incorporation of a newly designed RAF, i.e. the regional drought resilience assessment framework, in its context of use in any way. As such, the verification of the RDT on its incorporation into its context of use is left out of this study.

Flexibility

The relevant regional stakeholders during the case studies of the RDT were determined on a case-to-case basis and involved in the assessment procedure accordingly, which is positive for the flexibility. The case studies did not provide information on the flexibility of the RDT's assessment procedure in involving additional stakeholders if new information identified additional relevant regional stakeholders. As such, this is an uncertain factor for the framework's flexibility. Similarly, the properties of the framework elements (i.e. relative importance, accessible data sources, score-thresholds) are determined on a case-to-case basis and can therefore be considered to be flexible. However, again no information is provided on the extent the assessment procedure can accommodate new information on these properties, making it an additional uncertain factor for the framework's flexibility. Moreover, the framework's users have flexibility in their way of data gathering, dependent on their available resources. However, it would be better if these users are provided with guidance as to what a certain availability of resources means for possible assessment approaches (**F1**).

Overview of RDTs main points of improvement

Based on the sections above, eleven points of improvements for the RDT have been formulated based on the six general design requirements. An overview of these is presented in Table 4.

Table 4 Points of improvement of the RDT by Wardekker et al. (2020) based on verification against design requirements.

#	Points of improvement of the RDT per general design requirement
C1	Adapt Layer 4 (Indicators) such that it is comprehensive for the regional drought resilience context.
C2	Incorporate uncertainty in the assessment results.
L1	Combine operationalisations with significant overlap to reduce frameworks' complexity.
L2	Include a representative sample of relevant regional stakeholders in the development of the combined set of indicators in the context of regional drought resilience.
S1	To make the framework elements more self-explanatory, their definitions should become more understandable for an audience with little experience in resilience theory.
S2	Simplify referencing to specific framework elements.
S3	To make the assessment procedure more self-explanatory, guidance should be provided on setting up the score-thresholds of the different framework elements.
S4	To make the assessment procedure more self-explanatory, guidance should be provided on defining the relative importance of the different framework elements.
S5	Information should be gathered to reflect on the foreseen developments affecting the current state of the framework elements.
V1	Formulate a more structured and extensive approach for the visualisation of the assessment results that harbours the significant base of information from the assessment procedure. Missing types of information that should be visualised are the relative importance of framework elements, data sources, uncertainty in assessment results and a reflection on the foreseen development affecting the current state of the framework elements.
CoU	None identified.
F1	Guidance should be provided as to what different availability of resources means for possible assessment approaches

4.3. Adaptations to the RDT based on its verification; Towards a design of the regional drought resilience assessment framework

In the text below, the adaptations of the original RDT towards the design of the regional drought resilience assessment framework are discussed. This covers the following aspects: adaptations to the layered structure and its contents, inclusion of a coding system for easier referencing of specific framework components, formulation of a structured assessment method, and formulation of a structured visualisation method of framework results. In the text, there is referred to specific points of improvement for the credibility (C), Legitimacy (L), Salience (S), Visualisation (V), Context of Use (CoU) and Flexibility (F) from the previously discussed verification of RDT. At the end of this section, an overview is provided of which points of improvement of the RDT are covered by these adaptations.

4.3.1. Adaptations to the layered structure and its contents

In the case study conducted by Wardekker et al. (2020), stakeholders perceived the layered structure approach as beneficial for their personal understanding of resilience and resulted in a high transparency of the framework, aiding in its *legitimacy*. Hence, the layered structure of design is identical to the RDT, with the layers being Phases (Layer 1), Principles (Layer 2), Operationalisations (Layer 3) and Indicators (Layer 4). The content of Layer 1 and Layer 2 also remained identical to the RDT and only some relatively small adaptations were made to Layer 3, i.e. phrasing or combining some operationalisations that were overlapping to reduce complexity (**L1**). This way, the total number of operationalisations reduced from 35 in the RDT to 31 in the designed regional drought resilience assessment framework. A significant number of the indicators (Layer 4) proposed by the RDT were however specific for urban flood resilience and were as such inadequate for the context of regional drought resilience. As such, Layer 4 was significantly adapted and filled with drought-related indicators (**C1**). Through a review of pertinent literature, a total of 85 substantive indicators for regional drought resilience were developed, with 1 to 5 underlying indicators for each resilience operationalisation (Layer 3). To make the framework more self-explanatory, each of these indicators is transformed into a statement including an explanation on (the relevancy of) the indicator, such that the framework's users don't need to be experts in the field of resilience (**S1**).

4.3.2. Inclusion of a coding system for specific framework elements

For easier reference to specific framework elements (**S2**), each element has been given a four-digit code (i.e. [1234] or [ABCD]). The four digits relate to the four layers of the framework, i.e. the first digit relates to a specific phase from Layer 1, while the third digit relates to a specific operationalisation from Layer 3. See also Figure 6.

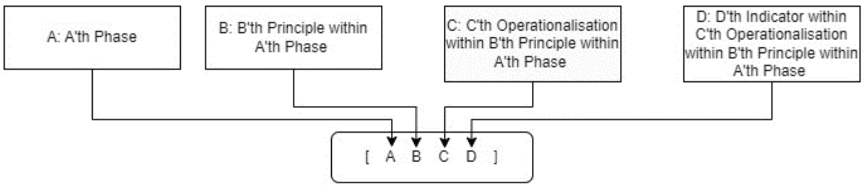

Figure 6 Visualisation of the codes for framework components.

4.3.3. Formulation of a structured assessment method

The original RDT did not give guidelines on how the different indicators should be assessed and scored and what types of information are required by the framework. The information for each of the indicators is gathered through three different types of knowledge:

1. A numerical score on the current state of the indicator within the region to obtain a direct and clear insight on which indicators really deserve attention.
2. A textual clarification on the current state including what is already happening regarding the specific indicator and what the current bottlenecks and areas for improvement are.
3. An indication on the expected effect of foreseen developments on the current state of the indicator, including some reasoning (**S5**). Such developments can i.e. be existing policies that currently are not yet fully executed, upcoming policies, societal shifts or otherwise deviations from the current situation. This impact can be either negative ("-1", leading to a "-"), neutral ("0", leading to a "o"), or positive ("+1", leading to a "+").

With regards to the final scores of the indicative expected effect of foreseen developments on the current state of an indicator, the scores of the combined sources of that indicator are averaged (i.e. three interviewees expect a positive effect and two expect a neutral effect, leads to an average expected effect of $\frac{3\times(+1)+2\times(+0)}{5} = +0.6$). Thereafter, the following holds:

$$Final\ score\ Indicative\ Effect\ Foreseen\ Developments\ \text{"}x\text{"}\ (-, o, +):$$

$$Average\ Score\ x < -0.5 \rightarrow \text{x} = \text{"-"}, else\ if$$

$$Average\ Score - 0.5 \leq \text{"}x\text{"} < +0.5 = \text{"o", else if}$$

$$Average\ score\ \text{"}x\text{"} \geq\ +0.5 = \text{" + "}.$$

Furthermore, uncertainty in the assessment results should be accounted for (**C2**). As such, the standard deviations are to be calculated for the numerical scores of framework elements, as well as of the indication on the expected effect of foreseen developments on the current state of the framework elements. These standard deviations are dependent on the number of sources on which the scores are based (i.e. number of expert interviews or publicly available sources). Moreover, some guidance for pathways under different resource availabilities is given in a recommended procedure-of-use that accompanies the framework itself (**F1**).

4.3.4. Formulation of a structured visualisation and reporting method for assessment results

A structured visualisation method of the framework results has been formulated (**V1**). Based on the brief literature study on the types of information that are deemed useful for policy makers and how these are visualized, several techniques with significant benefit for visualisation are identified. These are among others the use of radar diagrams and colouring schemes (Bachmair et al., 2016; Buitenhuis et al., 2020; Cutter et al., 2010; Gupta et al., 2010; Joerin et al., 2014; Khazai et al., 2015; Sharifi, 2016; van Ginkel et al., 2018) and having a multi-layered results section with a layer where the reader can get a quick overview and when interest is sparked, an explanatory layer with more in-depth knowledge on the most important bottlenecks and points of improvement (Bressers et al., 2016; Buitenhuis et al., 2020; Hunt & Watkiss, 2011; Villamayor-Tomas, 2018). In addition, to increase the transparency and thus legitimacy of the framework results, also the relative weights of each indicator, the indicator assessment methods and its sources should be presented (Eraydin, 2016; Kammouh et al., 2019; Karamouz et al., 2016), as well as the standard deviations and the number of scores that form the eventual average scores in the framework should be presented (Cutter et al., 2010; Eraydin, 2016; Karamouz et al., 2016; Khatibi et al., 2019; Nemec et al., 2014).

With this in mind, the structured visualization method of framework results prescribes that there should be three types of result visualisation, with increasing levels of detail:

1. Radar diagrams are presented for the different framework layers. These radar diagrams will give the reader a first quick overview of the current state and bring focus points. The radar diagrams should include the following information: (Code of) the framework element, Average score of that element including its standard deviation, and the impact of the foreseen changes (+, o, or -). The radar diagrams for the resilience phase and resilience principle layer show their complete layer. For the operationalization phase and indicator phase, the radar diagrams would become too complex if they were to combine all scores. Hence, for full implementation of the framework, these would get subdivided radar diagrams per resilience phase. This results in having ten radar diagrams: one showing the results of the resilience phase layer, one showing the results of the resilience principle layer, four showing the results of the resilience operationalization layer (one per resilience phase), and four showing the results of the resilience indicator layers (one per resilience phase).
2. The indicator layer is presented in a Dashboard Table. In addition to the radar diagrams, these Dashboard Tables will also have an intuitive coloured scheme (with red = poor/negative, yellow = average/neutral and green = good/positive) for the average score and if applicable (i.e. when assessed through interviews) the standard deviation and the number of received scores on which the average current score is based, as well as for the impact of foreseen developments on the current score of the indicator. The relative weighting should also be presented in this Dashboard Table. These Dashboard Tables give better insight in how the radar diagrams are constructed and provides further clarity on which indicators are already well-performing and which need attention.
3. A Textual Indicator Assessment Report is provided for each assessed indicator. Here, the bottlenecks and points of improvement for each indicator are summarized to provide the policy makers with concrete guidance on how the indicators can be improved. Additionally, the reasoning behind the foreseen impacts of current developments on the current state of indicators are discussed here.

4.3.5. Feedback to RDT's points of improvement

Through the adaptations described above, most of the RDT's points of improvement as identified in its verification are covered in the new designed regional drought resilience assessment framework. An overview of these is presented in Table 6.

Table 5 Covered points of improvement for the RDT based on incorporated adaptations.

Point of improvement of the RDT	Covered?
C1	Yes
C2	Yes
L1	Yes
L2	No
S1	Yes
S2	Yes
S3	No
S4	No
S5	Yes
V1	Yes
F1	Yes

4.4. The designed regional drought resilience assessment framework and how to apply it

A design of the assessment framework for regional drought resilience has been developed, including a recommended procedure of use. First, the designed assessment itself is further presented. Thereafter, the recommended procedure-of-use for the assessment framework is elaborated upon.

4.4.1. The designed assessment framework

In Figure 7, the tree-structure of the different layers of the resulting regional drought resilience assessment framework are schematised. It shows the four layers: 1) phase; 2) principle; 3) operationalization; 4) indicator.

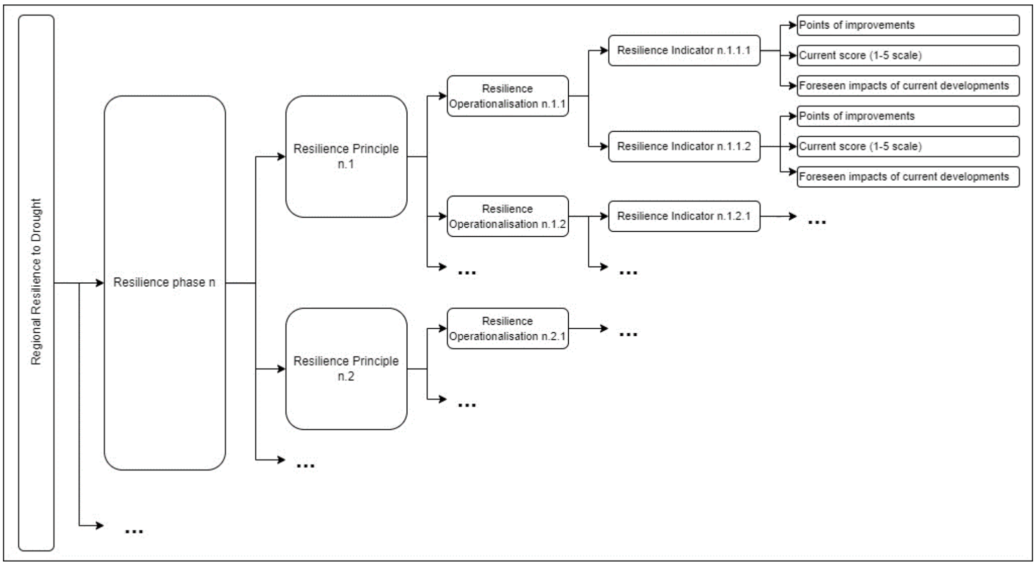

Figure 7 Tree-structure of the design of the Assessment Framework for Regional Drought Resilience.

The thusly designed regional drought resilience assessment framework is presented in Table 6. Appendix A presents the framework including explanations as to why each indicator is relevant to consider for the drought resilience to a region. These explanations can be used during implementation.

Table 6 The design of the assessment framework for the drought resilience of a region, with different colours (blue, green, yellow and orange) representing the differing resilience phases.

Phase	Principle	Operationalisation	Indicators	Key references
[1000] Plan/Prepare	[1100] Anticipation and Foresight	[1110] Building knowledge regional drought vulnerability	[1111] Existence of regional climate scenarios	(Godschalk, 2003; Gunderson, 2009; Lu & Stead, 2013)
			[1112] Assessment of regional drought vulnerability	(Cutter et al., 2008; Davoudi et al., 2013; Linkov et al., 2014; Lu & Stead, 2013; Tyler & Moench, 2012)
			[1113] Mapping critical functions during drought hazard	(Godschalk, 2003)
		[1120] Continuous monitoring of slow variables	[1121] Continuous monitoring of environmental factors	(Carpenter et al., 2001)
			[1122] Continuous monitoring of human factors	(Gober et al., 2016)
			[1123] Continuous monitoring and evaluation for drought-protective infrastructure	(Chelleri et al., 2015; Davoudi et al., 2013; Lu & Stead, 2013)
		[1130] Information management and sharing	[1131] Access of institutions to scientific information and data relating to droughts	(Gupta et al., 2010; Moench, 2014; Pahl-Wostl, 2007; Tyler & Moench, 2012)
			[1132] Effective mechanisms for (drought) information storage and sharing are present	(Pahl-Wostl, 2007)
			[1133] Presence of platforms of exchange among drought-related actors	(Moench, 2014; van den Brink et al., 2014)
	[1200] Preparedness and Planning Ahead	[1210] Public awareness, risk communication, education and training	[1211] Credible and correct drought information is disclosed via various channels	(Lu & Stead, 2013; Schipper & Langston, 2015)
			[1212] Educating the public with guidance documents to minimize impact of drought hazards	(Gupta et al., 2010; Norris et al., 2008; Schipper & Langston, 2015)
			[1213] Develop drought risk communication strategies for affected stakeholders through targeted campaigns	(Norris et al., 2008)
		[1220] Response and emergency management	[1221] Multiple and reliable communication technologies to for disseminating information	(ARUP, 2014; Norris et al., 2008)
			[1222] Presence of drought hazard guidance documents for the authorities	(Raadgever et al., 2018)
			[1223] Presence of reliable drought early warning systems	(Raadgever et al., 2018; Sharafi et al., 2020; Wilhite, 2002)
		[1230] Preparedness of drought prone economic sector for adverse events	[1231] Information on drought-related risks is available for drought prone economic sectors	(Godschalk, 2003; Orhan, 2016)
			[1232] Presence of exchange networks for drought prone economic sectors	(Lonsdale et al., 2010; Sutton & Tierney, 2006)
			[1233] Drought is factored in the business practice of drought prone economic sectors	(Lonsdale et al., 2010; Orhan, 2016; Sutton & Tierney, 2006)
			[1234] Drought prone economic sectors have drought insurance	(Khatibi et al., 2019; Meza et al., 2019)
	[1300] Homeostasis	[1310] Preservation and restoration of regulating ecosystem services	[1311] Policies are in place for natural areas and ecosystem conservation	(Biggs et al., 2012; Orimoloye et al., 2021)
			[1312] Ecosystem services are valuated in drought policies based on their ecological, socio-cultural and economic value	(Biggs et al., 2012; Sekercioglu, 2010; Small et al., 2017)
			[1313] Policies are in place to create or increase urban greenery	(Biggs et al., 2012; Wardekker et al., 2010)
		[1320] Integrated planning, coordination and collaboration	[1321] Human resources in drought management are adequate	(Urquijo et al., 2017; Wilhite, 2002)
			[1322] Integrating drought management in other policy domains is mainstreamed	(ARUP, 2014; Runhaar et al., 2009; Smit & Wandel, 2006; Uittenbroek et al., 2013)
			[1323] There are sufficient bridging mechanisms between drought management and other policy domains	(Kern et al., 2019; Raadgever et al., 2018)
		[1330] Inclusiveness and equity standards	[1331] Support of government authorities for vulnerable population is adequate and aims at social equity	(Norris et al., 2008; Tyler & Moench, 2012; Zarafshani et al., 2016)
			[1332] There is an appropriate level of transparency and accountability in policy-making processes	(Folke, 2006; Gupta et al., 2010; Lebel et al., 2006; van den Brink et al., 2014)

Phase	Principle	Operationalisation	Indicators	Key references
			[1333] Ex-ante policy assessments with a focus on the distributional consequences is appropriately mainstreamed	(Adger et al., 2005; Helming et al., 2011)
		[1340] Clearly defined stakeholder responsibilities	[1341] Responsibility for drought management is legally and clearly defined	(Gupta et al., 2010; Raadgever et al., 2018; van den Brink et al., 2014)
			[1342] The definition of responsibilities in drought management is sufficiently transparent	(de Bruijn, 2004; Raadgever et al., 2018)
			[1343] Stakeholders are sufficiently aware of their responsibilities and roles in drought management	(Bruneau et al., 2003; Gupta et al., 2010; van den Brink et al., 2014)
		[1350] Quick notification of disturbances	[1351] Information on (oncoming) droughts can be gathered in a timely manner	(Lu & Stead, 2013; Raadgever et al., 2018; Wilhite et al., 2014)
			[1352] Drought information dissemination to relevant stakeholders has an appropriate rapidity	(Lu & Stead, 2013; Raadgever et al., 2018; Wilhite et al., 2014)
[2000] Absorb	[2100] Robustness and Buffering	[2110] Measures and installations towards low water demand	[2111] There is sufficient presence of (structural) measures and installations to decrease water demand	(Crossman, 2018; Mens, 2015)
			[2112] There is a functioning process of periodical assessment and improvement of present (structural) measures and installation to reduce water demand	(Cutter et al., 2013; Mens, 2015)
		[2120] Creating buffer capacities	[2121] The baseline water stress during a dry year is absent	(Meza et al., 2019; van Ginkel et al., 2018)
			[2122] Sustainable water storage capacity exceeds demand under drought conditions	(Crossman, 2018; Mens, 2015)
			[2123] The regional water sources are sufficient quality	(Meza et al., 2019; van Ginkel et al., 2018)
			[2124] There is a sufficiently large regional financial buffer	(Cutter et al., 2010; Meza et al., 2019)
		[2130] Impact and risk reducing spatial planning and planning practice	[2131] Drought risk is sufficiently embedded in spatial planning	(Godschalk, 2003; Hoa & Vinh, 2018; Tyler & Moench, 2012)
			[2132] There is sufficient attention to drought and its effects in laws and regulations	(Fu & Tang, 2013; Godschalk, 2003)
			[2133] Drought resilience is actively and sufficiently incorporated in nature management strategies	(Fu & Tang, 2013; Kooyers, 2015)
			[2134] The region has (a high percentage of areas with) permeable soils	(Debusk & Wynn, 2011; Kavdir et al., 2014)
	[2200] Redundancy	[2210] Institutional redundancy with overlapping functions and roles	[2211] Presence of a multilevel polycentric drought governance system	(Aligica & Tarko, 2012; Biggs et al., 2012; Bródy et al., 2018; Carlisle & Gruby, 2019; Nelson et al., 2007; Pahl-Wostl et al., 2020; Villamayor-Tomas, 2018)
			[2212] The regional drought governance system is well-coordinated	Morisson et al. 2023, Pahl-Wostl and Knieper 2023]
		[2220] Technological redundancy in important functions and services	[2221] There is a sufficient level of redundancy mechanisms for and in drought-sensitive critical infrastructure and networks	(Tyler & Moench, 2012)
			[2222] There is a sufficient level of redundancy within ecosystem services	(Orimoloye et al., 2021; Sekercioglu, 2010; Turkelboom et al., 2013)
		[2230] Compart-mentalization and modularity	[2231] There is a sufficient level of institutional modularity (self-reliance) of parties within the drought governance system to decrease or prevent high-risk cascading effects between parties	(Biggs et al., 2012; Tyler & Moench, 2012)
			[2232] There is a sufficient level of compartmentalization within drought-sensitive critical infrastructure to avoid cascading drought effects	(Biggs et al., 2012; Tyler & Moench, 2012)

Phase	Principle	Operationalisation	Indicators	Key references
	[2300] Diversity	[2310] Functional diversity	[2311] The water supply portfolio has a sufficient level of diversification	(Gonzales & Ajami, 2019; Tran et al., 2023)
	[2300] Diversity	[2310] Functional diversity	[2312] There is a sufficient level of spatial distribution of drought-sensitive critical infrastructure, industry and services across the region	(Edwards et al., 2019; Pahl-Wostl, 2007; Tyler & Moench, 2012)
	[2300] Diversity	[2320] Economic diversity	[2321] There is a low regional economic dependency on sectors vulnerable to drought	(Coulson et al., 2020; Cutter et al., 2010; Meza et al., 2019)
	[2300] Diversity	[2320] Economic diversity	[2322] There is a sufficient level of economic diversity within sectors vulnerable to drought	(Swarnam et al., 2018; Tamburini et al., 2020)
	[2300] Diversity	[2330] Institutional diversity	[2331] There is a just level of institutional disciplinary variety within the drought governance system	(Biggs et al., 2012; Folke et al., 2005; Grêt-Regamey et al., 2019; Urquijo et al., 2017)
	[2300] Diversity	[2330] Institutional diversity	[2332] There is an appropriate level of institutional managerial disparity within the drought governance system	(Edwards et al., 2019; Pahl-Wostl, 2007; Tyler & Moench, 2012)
	[2300] Diversity	[2330] Institutional diversity	[2333] There is an appropriate level of institutional balance within the drought governance system	(Stirling, 2007)
	[2300] Diversity	[2330] Institutional diversity	[2334] There is sufficient presence of effective drought-centred partnerships and platforms for sectoral and cross-sectoral networking between different stakeholder groups	(ARUP, 2014; Folke et al., 2005)
[3000] Recover	[3100] Flatness	[3110] Institutional decentralization and autonomy	[3111] Local and regional governing bodies have appropriate legal capabilities to make autonomous decisions, authorize plans and legislate tailor-made policies and measures	(Biggs et al., 2012; Lebel et al., 2006; Raadgever et al., 2018; Tanner et al., 2009)
[3000] Recover	[3100] Flatness	[3110] Institutional decentralization and autonomy	[3112] Local and regional governing bodies have sufficient financial independence	(Knüppe & Pahl-Wostl, 2013; Lebel et al., 2006)
[3000] Recover	[3100] Flatness	[3120] Broad and inclusive stakeholder participation	[3121] Non-governmental stakeholders are sufficiently and actively involved from an early stage in policy-making for drought	(ARUP, 2014; Biggs et al., 2012; van den Brink et al., 2014; Wardekker et al., 2010)
[3000] Recover	[3100] Flatness	[3120] Broad and inclusive stakeholder participation	[3123] There is a high societal trust in governing authorities	(Brown, 2022; Wheeler et al., 2017)
[3000] Recover	[3100] Flatness	[3130] Room for autonomous change	[3131] Drought prone economic sectors are sufficiently guided autonomous drought adaptation	(Schelfaut et al., 2011; Tuihedur Rahman et al., 2021; Wardekker et al., 2010)
[3000] Recover	[3100] Flatness	[3130] Room for autonomous change	[3132] The public has sufficient guidance on how to mitigate drought impacts through small-scale measures on private property	(Schelfaut et al., 2011; Tuihedur Rahman et al., 2021; Wardekker et al., 2010)
[3000] Recover	[3100] Flatness	[3130] Room for autonomous change	[3133] The public has sufficient opportunity to form legal voluntary organizations for small-scale autonomous projects	(Tyler & Moench, 2012)
[3000] Recover	[3200] High Flux	[3210] Availability of and access to resources	[3211] The mechanisms for financial support after drought-induced damages are sufficiently swift to apply for	(ARUP, 2014; Tyler & Moench, 2012; van den Brink et al., 2014)
[3000] Recover	[3200] High Flux	[3210] Availability of and access to resources	[3213] The mechanisms providing supportive resources and assistance to vulnerable population in drought-struck areas are sufficiently swift	(Godschalk, 2003)
[3000] Recover	[3200] High Flux	[3210] Availability of and access to resources	[3214] The influence of corruption is negligible in regional drought management	(Brown, 2022; Meza et al., 2019)
[3000] Recover	[3200] High Flux	[3220] Social, institutional and	[3221] There is sufficient presence of partnerships and networks with an explicit role for the drought context	(Biggs et al., 2012; Norris et al., 2008; Tyler & Moench, 2012; van den Brink et al., 2014)

Phase	Principle	Operationalisation	Indicators	Key references
		environmental networks	[3222] There is a sufficient level of social cohesion within and between communities	(de Bruijn, 2004; Folke, 2006; Norris et al., 2008)
			[3223] Governing authorities sufficiently and actively aim to improve social networks within and between communities	(Biggs et al., 2012; Norris et al., 2008; Tyler & Moench, 2012; van den Brink et al., 2014)
			[3224] Environmental areas have a sufficiently high connectivity	(Biggs et al., 2012; Folke, 2006; Gunderson, 2009; Holling, 2001)
		[3230] Having options for flexibility in response	[3231] The human resources within the drought governance system can cope with changing conditions sufficiently well	(ARUP, 2014; Moench, 2014; Tyler & Moench, 2012)
[4000] Adapt	[4100] Learning and Reflectivity	[4110] Capacity to reflect and learn from past experiences in drought management policy	[4111] Lessons learnt from previous drought hazards are comprehensively formulated and documented in accessible reports	(Cutter et al., 2008; Gunderson, 2009; Schipper & Langston, 2015; van den Brink et al., 2014)
			[4112] The performance of drought management plans and strategies are continuously evaluated and lessons learnt are formulated in accessible reports	(Cutter et al., 2013; Gupta et al., 2010; Lonsdale et al., 2010)
			[4113] Emerging drought management research is continuously monitored to learn lessons from	(Lonsdale et al., 2010)
			[4114] Learning outputs continuously inform drought management policy changes, plans, strategies and standards	(Davoudi et al., 2013; Schipper & Langston, 2015; Tyler & Moench, 2012)
		[4120] Experimentation and innovation	[4121] There are sufficient opportunities for safe-failure of experiments in order to innovate in alternative approaches and policy designs	(Biggs et al., 2012; Folke, 2006; Lonsdale et al., 2010)
			[4122] Drought management policies are informed by innovations in alternative approaches and policy designs	(Davoudi et al., 2013; Folke, 2006; Schipper & Langston, 2015; Tyler & Moench, 2012)
	[4200] Flexibility	[4210] Institutional flexibility	[4211] There is sufficient flexibility in the organizational structure of the drought governance system	(Lonsdale et al., 2010; Pahl-Wostl, 2007; van Buuren et al., 2015)
			[4212] There is sufficient flexibility in the content agenda of the drought governance system	(Lonsdale et al., 2010; Pahl-Wostl, 2007; van Buuren et al., 2015)
			[4213] There is sufficient flexibility in the processes within the drought governance system	(Lonsdale et al., 2010; Pahl-Wostl, 2007; van Buuren et al., 2015)
		[4220] Flexibility in spatial planning	[4221] Spatial planning is sufficiently flexible to accommodate adaptations based on new insights	(Hurlimann & Wilson, 2018; van Buuren et al., 2013; Vinh & Van, 2020)
			[4222] Convertibility is sufficiently integrated in the strategic design of the urban environment	(Hurlimann & Wilson, 2018; van Buuren et al., 2013; Vinh & Van, 2020; Wardekker et al., 2010)
		[4230] Flexibility in measures	[4231] No- and low-regret measures are sufficiently employed in drought adaptation	(Bryan et al., 2019; Henao Casas et al., 2022; Wilhite, 1992)
			[4232] Long-term effects of measures are sufficiently well considered and prevented	(Huntjens et al., 2010; Wardekker et al., 2010)

4.4.2. The Procedure of Use of the designed assessment framework

To be able to implement the framework, several steps have to be taken. These steps are divided in four phases: preparation phase (before assessment), conduction phase (the actual assessment), follow-up phase (connecting assessment results to existing policies) and an optional ex-ante policy evaluation phase. Figure 8 presents an overview of these. In the paragraphs below, the different steps are elaborated. This provides clarity on how the assessment framework should be implemented, and guides the framework's users to assessment results of high quality.

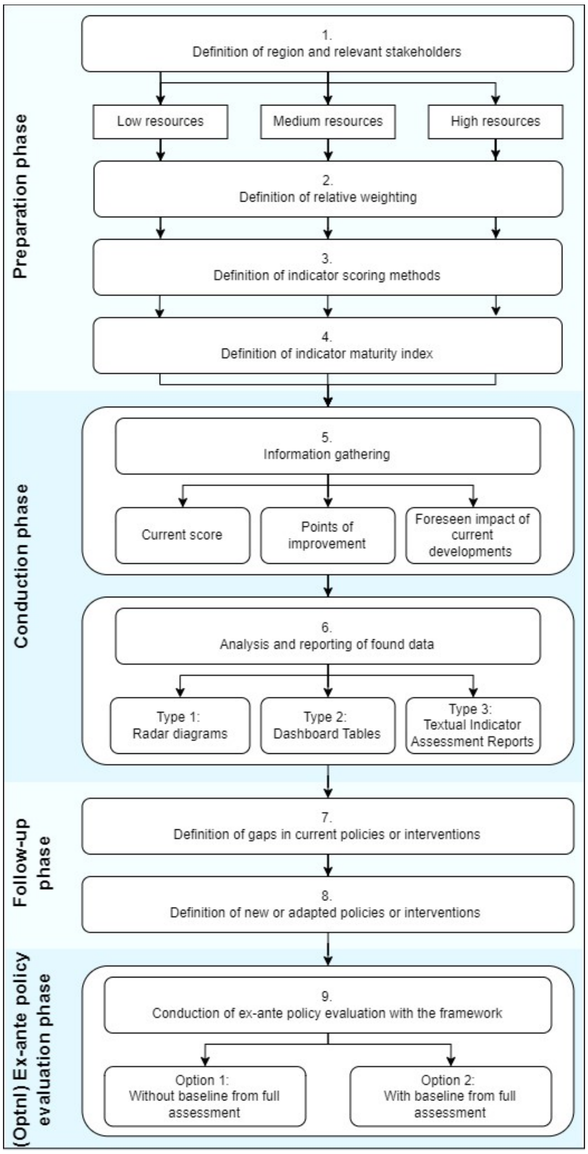

Figure 8 Overview of the recommended procedure of use.

Preparation phase

1. **Definition of region and relevant stakeholders:** The first step of the framework's procedure-of-use is defining the region and conducting a preliminary analysis of the drought governance system (being the organisation in which policy on drought management is developed, and the stakeholders therein). This results in an improved understanding of how the region 'works', as well as an inventory of relevant stakeholders within the defined region including these stakeholders' formal roles.
2. **Definition of relative importance and weighting:** As second step, the relative importance of each framework element within its own framework layer (being the specific phases, principles, operationalisations and indicators) is defined on a case-to-case basis. In one region the

importance of a specific indicator could be significantly larger than the importance of that same indicator in a different region. Through the definition of the relative importance of each framework element, agreement can be reached on the weight of each framework element when translating the indicator scores into scores of the higher framework layers. This relative weight also holds for the translation of the indicative scores of the foreseen impact of current developments on the current indicator scores into the higher framework layers. This definition process can be done in a variety of ways, dependent on the user's available resources in terms of time, personnel and finances. For this, the developed framework offers a great flexibility in its usage. Below three illustrative pathways are given.

   a. **Low resources:** The relative weighting can be kept at default (all elements get equal weights), the expert applying the framework could define relative weighting based on the user's own experience in and knowledge of the region or the expert applying the framework could ask some direct colleagues for their opinions.
   b. **Medium resources:** The relative weighting is defined through a brief participation approach, i.e. a single workshop session with a varied group of regional experts.
   c. **High resources:** The relative weighting is defined as part of a Delphi method with significant stakeholder participation.

3. **Definition of indicator scoring method:** The data availability for specific indicators can vary significantly dependant on the case study region. Hence, on a case-to-case basis the framework indicators are checked on their data availability for the required information. Based thereupon, the indicator's scoring method is defined. Indicator's scoring methods could be based on publicly available (semi)quantitative data, as long as it is from credible and legitimate sources. If such (semi)quantitative data is not available, there is chosen for qualitative data from regional experts from relevant stakeholders. Indicators can be scored in a variety of ways (i.e. with differing indicator scoring methods), dependent on the user's available resources. Below three illustrative pathways are given.
   a. **Low resources:** In case there is only little resources available, the expert applying the framework could for example assess each indicator based purely on the expert's own knowledge of the region, or i.e. based on a single internal workshop.
   b. **Medium resources:** With more resources available, the approach as taken by low resources can be improved upon through a broader range of in-depth input through participatory processes with regional experts. Dependent on the exact amount of available resources, this can take the form of i.e. translating the indicators into an online survey for regional experts to fill in, conducting interviews with relevant experts, or organizing one or multiple workshop sessions with relevant experts.
   c. **High resources:** With significant resources available, a Delphi method or even an extensive research on each of the indicator could become an option.
4. **Definition of indicator maturity index:** Region-specific contexts may influence what is required for a certain indicator score to be achieved (what does it mean to have a score of 2/5, or indeed 5/5?). Hence, on a case-to-case basis a definition for each scoring value for each indicator is defined. This can be done through developing a resilience maturity index for each indicator. Again, there are various ways this could be implemented during the application of the assessment framework, dependent on the user's available resources.
   a. **Low resources:** No indicator maturity index is defined for the qualitative indicators and the scoring is based on subjective reasoning, or an indicative indicator maturity index is developed by the framework's user's own experience in and knowledge of the region, or the user could ask some direct colleagues for their opinions.
   b. **Medium resources:** The indicator maturity index is developed through a brief participation approach, i.e. a single workshop session with several regional experts from a variety of backgrounds decreasing subjectivity within the maturity index.
   c. **High resources:** The indicator maturity index is defined as part of a Delphi method with significant stakeholder participation.

Conduction phase

5. **Information gathering:** Based on the chosen method of assessment for the specific indicators, the actual information is gathered. Three types of information are gathered per indicator:
    a. **Numerical score for the current state of the indicator**
    b. **Current bottlenecks and points of improvement per indicator**
    c. **Foreseen impact of current developments on current score of indicator**
6. **Analysis and reporting of found data:** Based on the defined relative weighting and the structured visualisation method, the gathered information is analysed and reported. The assessment report visualises the assessment results through three types of result visualisation:
    a. **General overview through radar diagrams (quantitative)**
    b. **More specific overview through Dashboard Tables (quantitative)**
    c. **Detailed assessment through Textual Indicator Assessment Reports (qualitative)**

Follow-up phase

7. **Definition of gaps in current policies or interventions:** Once the assessment of regional drought resilience has been conducted and analysed and an assessment report has been drafted, the policy-makers in the drought domain define gaps in current policies or interventions based on the assessment results. This considers the flaws of the employed assessment procedure. The assessment procedure will i.e. always present a simplified picture and, especially when participatory approaches are employed, will likely have at least some degree of bias. In addition, the assessment results can yield new questions that need further clarification before these gaps can be properly defined.
8. **Definition of new policies or interventions:** After defining the gaps in current policies or interventions, new adapted policies and interventions are to be defined. This answers the question how the found bottlenecks will be improved.

Ex-ante policy evaluation phase

9. **Generic ex-ante policy evaluation through framework:** An aim of the application of the assessment framework could be to conduct an ex-ante policy evaluation. Policies can improve some indicators, while deteriorating others. Similarly, a policy could have a positive effect on some indicators, while having no effect at all on others. Such an ex-ante policy evaluation can be done either with or without a baseline from a full assessment with the framework.
    a. **Without baseline from full assessment with the framework:** if the region has not been assessed through earlier appliance of the framework, the framework can serve as a guiding tool for relevant aspects in drought management. In the ex-ante policy evaluation, the proposed policy is assessed by evaluating how it will likely influence specific indicators based on its foreseen impact. Such an ex-ante policy evaluation doesn't harbour any numerical assessment scores, but does provide the user with a generic overview of potential (side-)effects (i.e. trade-offs, co-benefits) of the proposed policy and a 'direction of change' for the drought resilience of the region.
    b. **With baseline from full assessment with the framework:** if the region has been assessed through earlier appliance of the framework, a baseline will be present for each indicator, including the points of improvement. If this is the case, an ex-ante policy evaluation provides the user with not only a generic overview of potential (side-)effects of proposed policies, but the proposed policy can also directly be evaluated on the extent to which it benefits identified bottlenecks and points of improvement towards regional drought resilience.

5. Results validation phase

In the sections below, the results of the validation phase are outlined. For this, first the results of the case study are presented. This presentation follows the steps from the recommended procedure-of-use. After presenting the results of the case study, the validation of the assessment framework based on the experience gained in the case study is elaborated on.

5.1. Applying the assessment framework in a case study in Twente

5.1.1. Preparation phase

Step 1: Definition of the region and relevant stakeholders; Introducing Twente

Twente lies in the east of the Netherlands and encompasses the easternmost part of the province Overijssel. The borders of Twente are defined by the German counties of Grafschaft Bentheim on the north east and Kreis Borken to the southeast, the Salland region to the west and northwest, and the Achterhoek region to the southwest. Twente consists of 14 municipalities, covering an area of 1500 km^2. See Figure 9 for an outline of the region. The region is characterized by its mixed urbanity, with some areas of high urbanity and a large share with very low urbanity (CBS, 2023b; Sival et al., 2022). Almelo, Hengelo and Enschede are the main cities, housing about 50% of the total population (CBS, 2023a). The rural areas are characterized by a combination of agriculture and nature areas (Sival et al., 2022), among which fifteen Natura2000 areas (Ministerie LNV, 2023). Within the agricultural sector, the majority of the land is used for livestock farming, while arable farming and horticulture are less common (Sival et al., 2022). Furthermore, a significant part of the industrial sector in Twente is dependent on the Twentekanaal for logistics (Sival et al., 2022). Twente also has several large water consumers within the food and processing industry, requiring high quality water (Sival et al., 2022).

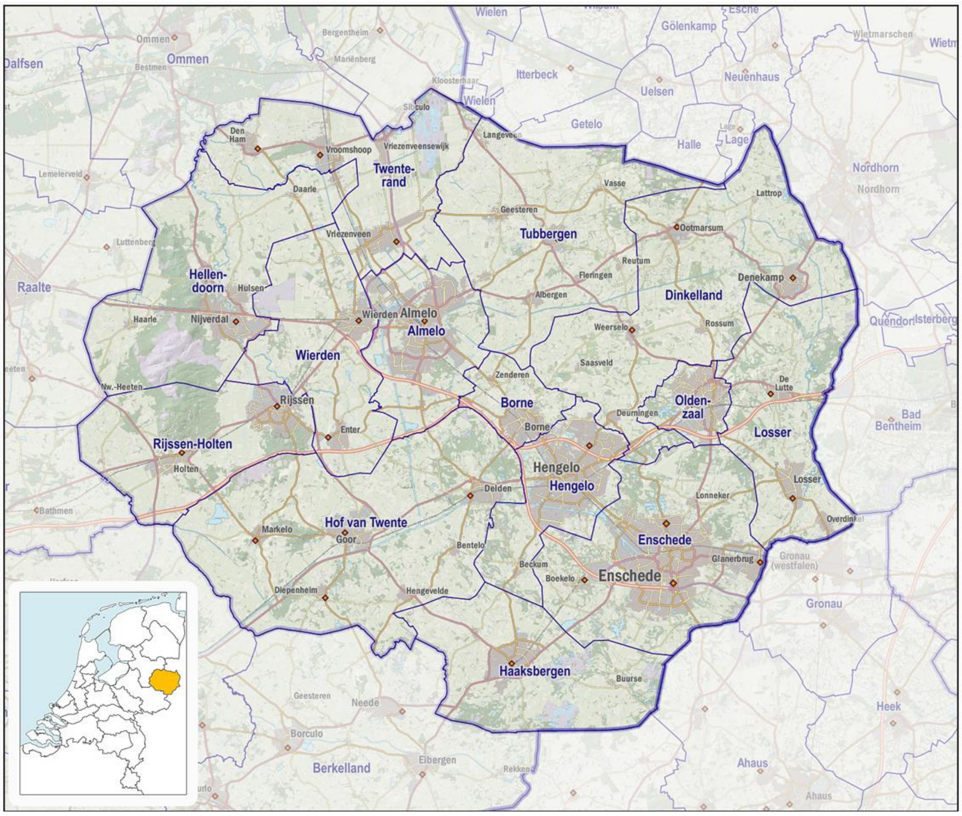

Figure 9 Outline of the case study region of Twente. Source: (Van Aalst, 2017)

Twente is a relatively high-lying region with a sloping character and consisting mainly out of sandy soils, with loamy soils in the east (Oldenzaal-Enschede axis) (Goijer et al., 2012; Van den Eertwegh et al., 2021). Due to these relatively high differences in elevation, it is very difficult to transport water across the region and only a rather small part of Twente consists of 'water supply areas' (Dutch: wateraanvoergebieden), which are areas that can be reached and supplied with water from the Dutch national water network (Dutch: Rijkshoofdwaternet) (Goijer et al., 2012). Twente has two small rivers with the Regge and Dinkel and the Twentekanaal links the urban areas of Twente with the IJssel river. In addition, Twente has a significant number of natural brooks. Apart from the Twentekanaal, Twente is dependent on precipitation for its water supply (Sival et al., 2022), and especially the natural brooks tend to fall dry during the summer period. In the past decades, the water system of Twente has been significantly redesigned to prevent flooding and lowering the groundwater level to enable the presence of all functions (Van Tuinen et al., 2022). To do so, naturally meandering brooks, creeks and streams were straightened, continuous drainage systems were installed and planned land consolidation (Dutch: 'ruilverkaveling') took place (idem.). This has resulted in a drop of the average groundwater level of 40 to 50 cm (Van Tuinen et al., 2022) and the regional precipitation reaching the IJsselmeer with a delay-time of only 3 days (Honing et al., 2023). In their study to calculate the regional water balance, Van Tuinen et al. (2022) showed that Twente has a higher water consumption than its natural water supply, both on an annual timescale as well as during the hydrological summer, and both during an average hydrological year as well as during a dry meteorological year. An important element in this high water consumption is the discharge to the Dutch national water network during water surpluses. When the discharge of water surpluses is excluded, it becomes apparent that on annual timescale the natural water supply far exceeds the annual water consumption both for an average year as well as for a dry meteorological year. During the hydrological summer the water consumption of an average meteorological year barely exceeds the natural water supply, yet far exceeds it during a dry meteorological year. See also Table 7. As only a rather small part of Twente falls within the water supply area, this (significant) overconsumption can only be partially covered by the Dutch national water network. Therefore, an extended period of meteorological drought can quickly transform into an agricultural and socio-economic drought. With that in mind, it is of high importance that the region of Twente is or becomes (more) resilient to droughts.

Table 7 Water balance of the Twente region, with comparisons of the natural water supply to the water consumption including and excluding surplus discharges to the Dutch national water network. Source: van Tuinen et al. (2022).

Timescale	**Annual**		**Hydrological summer**	
Type of meteorological year	**Average**	**Dry**	**Average**	**Dry**
Ratio water consumption / natural water supply	104%	125%	125%	185%
Ratio water consumption excl. surplus discharge / natural water supply	64%	82%	101%	155%

Under normal conditions, responsibility of water management within Twente is divided among different stakeholders (Provincie Overijssel, 2023). The responsibilities of the main stakeholders are summarized in Table 8. The organisation surrounding water management during times of (imminent) drought crises in the Netherlands consists of six regional drought councils (Dutch: Regionaal DroogteOverleg, or RDO) (WMCN-LCW, 2021). The region of Twente falls within jurisdiction of two of these: RDO-Twentekanalen and RDO-Gelderland. Within these RDOs, the relevant (departments of) Rijkswaterstaat, waterboards, provinces and drinking water company discuss and decide on drought management and crisis strategies. Stakeholders from outside of the governmental column are neither under normal nor under crisis conditions judicially connected to water and drought management.

Table 8 Summarized responsibilities of water and drought management within Twente. Source: Provincie Overijssel (2023)

Stakeholder	Responsibility in brief
Rijkswaterstaat	Water quality and water division of the Dutch national water network (in the Twente region this is only the Twentekanaal)
Province Overijssel	Create and implement regional water policies and water quality and licensing authority (i.e. for drinking water) for deep groundwater
Waterboard Vechtstromen	Water quality and quantity of surface water and waterways of regional significance and rural shallow groundwater
Municipalities	Create and implement municipal water policies, water quality of urban shallow groundwater, waste water treatment, and supply of potable water to households (which in practice is put at the regional drinking water company Vitens)

Step 2: Definition of relative importance and weighting

For the case study, all framework elements were given equal relative importance. Consequentially, the scores of the indicators (Layer 4) under a specific operationalisation (Layer 3) are simply averaged to obtain a score for that specific operationalisation. The same holds for the translation of operationalisation scores (Layer 3) into scores for the resilience principles (Layer 2), as well as for the translation of these resilience principle scores (Layer 2) into scores for the resilience phases (Layer 1).

Step 3: Definition of indicator scoring mechanism

During the search for the availability of data on the region of Twente, it was found that six out of the 24 indicators in the Absorb-phase of the assessment framework had credible and open-source data available. In Appendix B the scoring mechanisms of the indicators with credible open-source data available are presented. The other eighteen indicators were assessed through interviewees with regional experts from the relevant stakeholders.

Step 4: Definition of indicator maturity index

For the case study, indicator maturity indices were only defined for the indicators that were assessed through quantitative data sources, as part of their scoring mechanism. However, no indicator maturity indices were defined for the indicators that were assessed through interviews with regional experts from the relevant stakeholders.

5.1.2. Conduction phase

Step 5: Information gathering

The information to fill in the Absorb-phase of the assessment framework was gathered as prescribed in the defined indicator scoring mechanisms.

Step 6: Analysis and reporting of found data

In the section below, assessment results of the Absorb-phase of the assessment framework are presented, following the structured visualisation and reporting method for assessment results.

Radar diagrams with score overviews

A quick overview of the framework results is presented through radar diagrams. The results for Twente are elaborated on below. Within these radar diagrams, the impact of foreseen developments is presented in brackets behind the framework element (i.e. 'Redundancy (+)). This expected effect of the foreseen developments can be positive (+), neutral (o), negative (-) or unknown (unknown) in case no information was gathered during the framework's application.

Figure 10 shows the results of the case study on resilience phase layer. With a Resilience Score of 2.9 (on a 1-5 scale), the Absorb phase of Twente is found to be sufficient, but with significant room for improvement. In addition, on this radar diagram it is immediately visible that there is quite some uncertainty in the found score, with a medium to high standard deviation. As a phase overall, foreseen developments have a neutral effect on the current score of the Absorbing capacity of Twente.

Figure 11 zooms in on the resilience principles layer. Here it is visible that the different resilience principles all lie rather close to each other, with scores of 2.8, 2.9 and 3.1 for Robustness and Buffering, Redundancy, and Diversity respectively. The most uncertainty lies in the score of the Redundancy principle, whereas the Robustness and Buffering principle has a relatively low uncertainty. In addition, following the foreseen impact of current developments, it is visible that the score of the robustness and buffering principle will likely increase, whereas they have a neutral effect on the other two principles of the Absorb-phase.

Figure 12 presents the operationalization layer. This layer shows larger differentiations in the scores of the operationalizations, as well as in their uncertainties. From the case study it is apparent that the measures towards low water demand, institutional redundancy, the modularity to mitigate cascading effects, the economic diversity, the institutional diversity are all sufficient with scores between 3.1 and 3.5. On the other hand, especially the functional redundancy in important functions and services need attention, with a score of 1.7. When looking at the uncertainty of these scores, it is clear that there is significant uncertainty in the operationalizations of institutional redundancy, functional diversity and institutional diversity. The case study did not provide any information on the foreseen impact of current developments on the score of the economic diversity. These current developments have either a positive or neutral foreseen impact on the current scores of the other operationalizations.

Figure 13 presents the indicator layer. This layer shows significant differentiation, both in current scores as well as in the uncertainty within these scores. Several indicators score very high (i.e. [2112] on assessment of and innovation within measures reducing water demand and [2134] on the soil permeability for infiltration of precipitation). However, other indicators score very low (i.e. [2222] on the presence of redundancy in ecosystem services and [2131] on the incorporation of drought risk in spatial planning). Similarly, there are significant differences in the uncertainty within the indicator scores. The case study provided no information on the foreseen impact of current developments on current scores of six indicators, whereas the other indicators all have either positive or neutral impacts.

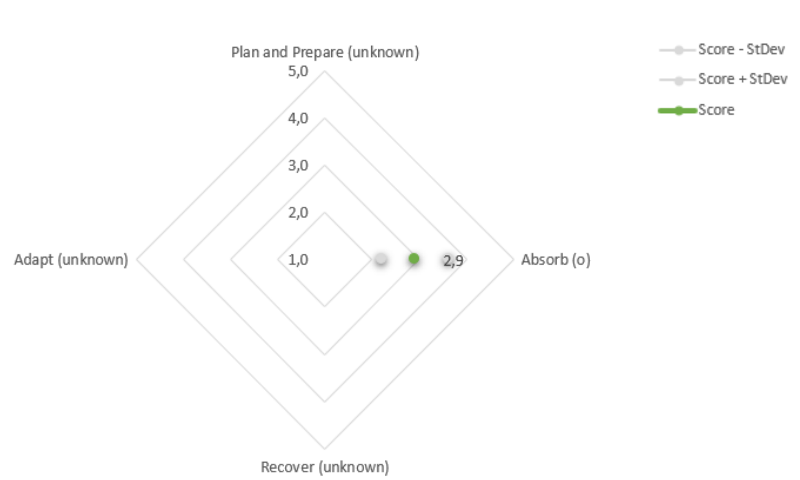

Figure 10 Radar diagram of the case study results of resilience phase layer. (-), (o) and (+): negative, neutral or positive foreseen impacts of developments to current state.

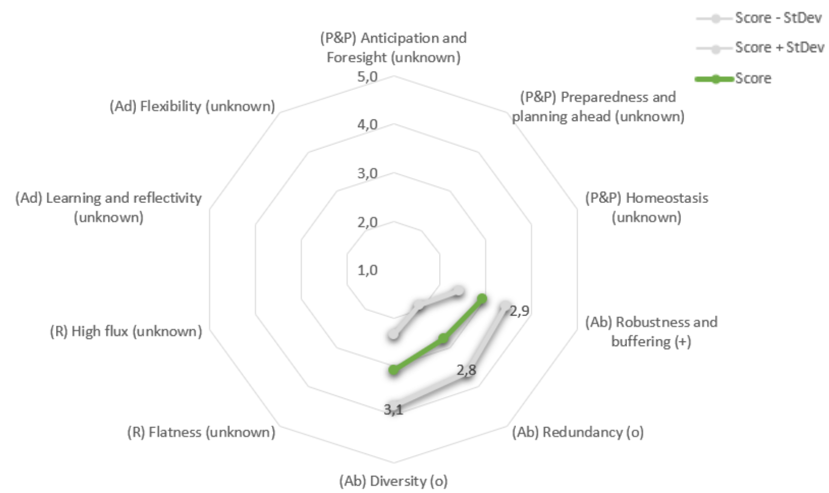

Figure 11 Radar diagram of the case study results of resilience principle layer. (-), (o) and (+): negative, neutral or positive foreseen impacts of developments to current state.

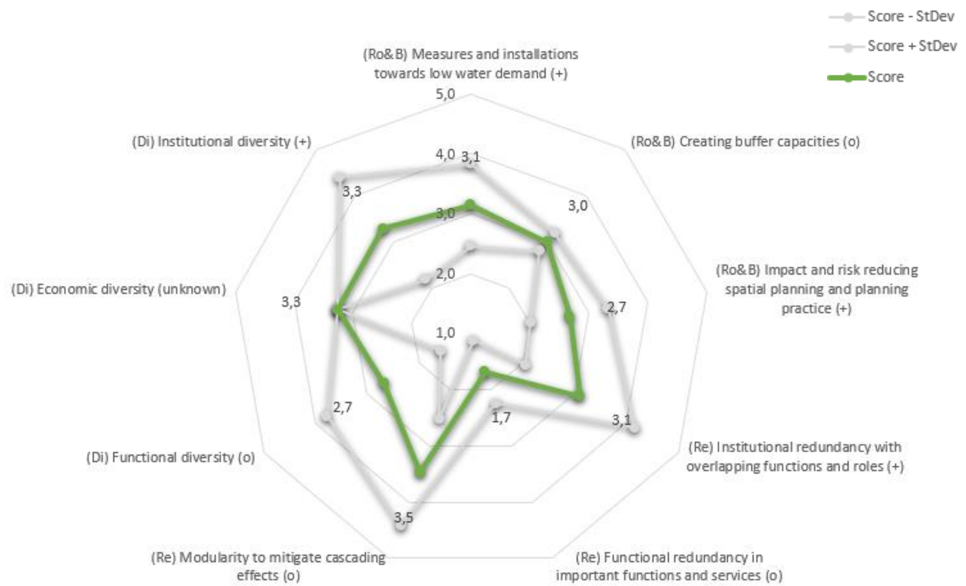

Figure 12 Radar diagram of the case study results of operationalization layer (Absorb phase). (-), (o) and (+): negative, neutral or positive foreseen impacts of developments to current state.

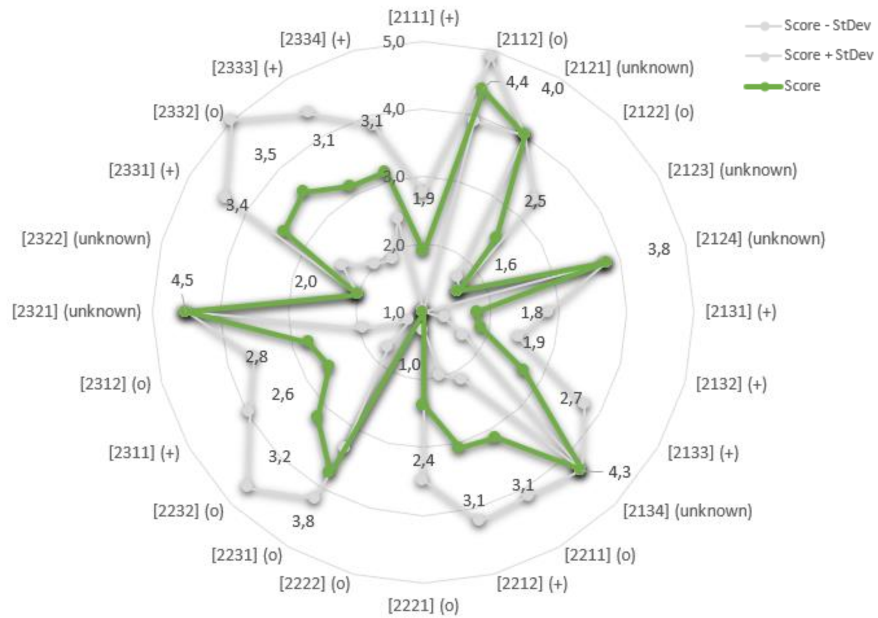

Figure 13 Radar diagram of the case study results of indicator layer (Absorb phase). (-), (o) and (+): negative, neutral or positive foreseen impacts of developments to current state.

Dashboard Tables with score overviews

In the Dashboard Table, further detail is given on the results presented in the radar diagrams, with the full indicator names, as well as their structure under the three higher layers, the indicator's relative weight under their respective operationalisation and their scoring method. In addition, the indicator's final scores, standard deviations and the indicative foreseen impact of current developments have been given a colour scheme. This way, key bits of information, such as the indicators that really need attention, or which indicator scores have a relatively high uncertainty, can be easily differentiated.

Table 9 presents the Dashboard Table of the resilience indicator layer. Here it becomes apparent that the indicators have been attached with equal relative weighting for their respective operationalisation scores. Furthermore, it becomes clear that all the indicators with an unknown foreseen impact of current developments, are indicators that have been quantitatively assessed through credible data sources, instead of through interviews with regional experts. In addition, it is clearly visible that there are certain indicators that have been assessed by quite some interviewees (i.e. [2111], [2131], [2132], and [2334]), while other indicators were assessed by a limited number of interviewees (i.e. [2222], [2312] and [2332]). The reason these indicators were assessed by only few interviewees, was twofold. Indicator [2222] on the redundancy within ecosystem services was very specific, leading to the expected regional expertise on that indicator (i.e. the indicator's relevance) to lie within only a small group of stakeholders, in this case the water board and nature management organisations. As there were only three interviewees from these stakeholders, the number of interviewees assessing this indicator is naturally low as well. Still, the indicators [2312] on the spatial distribution of drought-sensitive critical infrastructure, industry and services across the region and indicator [2132] on the institutional managerial disparity of the drought governance system were expected to be relevant for a broader group of stakeholders, yet still had a low number of interviewees assessing them. The reason for this was that many of the interviewees simply had no knowledge of the state of these indicators within the region, even though interviewees mentioned these indicators were indeed relevant to have a better understanding of. In addition, about half of the indicators harbour significant uncertainty (standard deviations ≥ 1.0), of which the most severe are indicators [2232], [2311], [2332]. The reason for this was again twofold. The primary contributor was the differing understanding among interviewees on the 'meaning' of certain scores for an indicator. Moreover, standard deviations increased as some interviewees gave their assessment based on their understanding of the system as a whole, whereas others gave their assessment based on their understanding of how well their own sector or stakeholders was doing with regards to the indicator. To obtain more credible, legitimate and salient assessment results, further assessment of specific indicators could be required, if these indicators are either assessed by a low number of regional experts or harbour significant uncertainty.

Textual Indicator Assessment Report (indicative)

In the Textual Indicator Assessment Report, additional information on bottlenecks and points of improvement of the current state are discussed, as well as which developments are foreseen and why these developments will likely have a positive, neutral or negative impact on the current state.

Table 10 provides an *indicative* Textual Indicator Assessment Report. This textual report is only presented for one single indicator, as it surpasses the purpose of this study to present the in-depth information on all indicators from the case study. Based on the assessment of this indicator, a total of fourteen concrete bottlenecks and points of improvement for the attention to drought and its effects in laws and regulations. In addition, several developments are expected to impact the current state.

Table 9 Case study results Dashboard Table on indicator layer of the Absorb-phase. In the colour scheme, green = good/positive, yellow = average/neutral, and red = poor/negative.

Phase	Principle	Operationalisation	Indicators	Rel. Weight	Scoring method	Final score	Stand. Dev.	Effect foreseen developments (-, o, +)
[2000] Absorb	[2100] Robustness and Buffering	[2110] Structural measures and installations towards low water demand	[2111] There is sufficient presence of (structural) measures and installations to decrease water demand	0.5	(9) Interviews	1.9	0.9	+0.9 = +
			[2112] There is a smooth-running process of periodical assessment and improvement of present (structural) measures and installation to reduce water demand	0.5	(5) Interviews	4.4	0.5	+0.3 = o
		[2120] Creating buffer capacities	[2121] The baseline water stress during a dry year is absent	0.25	Document	3.2	(-)	Unknown
			[2122] The sustainable water storage capacity within the region exceeds demand under drought conditions	0.25	(15) Interviews	2.5	0.8	+0.4 = o
			[2123] The available regional water sources are of sufficient quality	0.25	Documents	1.6	(-)	Unknown
			[2124] There is a sufficiently large regional financial buffer	0.25	Documents	3.8	(-)	Unknown
		[2130] Impact and risk reducing spatial planning and planning practice	[2131] Drought risk is sufficiently embedded in spatial planning	0.25	(15) Interviews	1.8	1.0	+1.0 = +
			[2132] There is sufficient attention to drought and its effects in laws and regulations	0.25	(9) Interviews	1.9	0.6	+0.9 = +
			[2133] Drought resilience is actively and sufficiently incorporated in nature management strategies	0.25	(7) Interviews	2.7	1.0	+1.0 = +
			[2134] The region has (a high percentage of areas with) permeable soils	0.25	Documents	4.3	(-)	Unknown
[2000] Absorb	[2200] Redundancy	[2210] Institutional redundancy with overlapping functions and roles	[2211] The regional drought governance system is polycentric and multilevel with an appropriate level of decentralisation and division of autonomy	0.5	(7) Interviews	3.1	1.0	+0.4 = o
			[2212] The regional drought governance system is well-coordinated	0.5	(12) Interviews	3.1	1.1	+0.8 = +
		[2220] Functional redundancy in important functions and services	[2221] There is a sufficient level of redundancy mechanisms for and in drought-sensitive critical infrastructure and networks	0.5	(8) Interviews	2.4	1.1	+0.3 = o
			[2222] There is a sufficient level of redundancy within ecosystem services	0.5	(2) Interviews	1.0	0.0	+0.0 = o
		[2230] Modularity to mitigate cascading effects	[2231] There is a sufficient level of institutional modularity (self-reliance) of parties within the drought governance system to decrease or prevent high-risk cascading effects between parties	0.5	(8) Interviews	3.8	0.4	+0.3 = o
			[2232] There is a sufficient level of compartmentalization within drought-sensitive critical infrastructure to avoid cascading drought effects	0.5	(5) Interviews	3.2	1.5	+0.3 = o
[2000] Absorb	[2300] Diversity	[2310] Functional diversity	[2311] The water supply portfolio has a sufficient level of diversification	0.5	(5) Interviews	2.6	1.4	+0.8 = +
			[2312] There is a sufficient level of spatial distribution of drought-sensitive critical infrastructure, industry and services across the region	0.5	(4) Interviews	2.8	0.8	+0.0 = o
		[2320] Economic diversity	[2321] There is a low regional economic dependency on sectors vulnerable to drought	0.5	Documents	4.5	(-)	Unknown
			[2322] There is a sufficient level of economic diversity within sectors vulnerable to drought	0.5	Documents	2.6	(-)	Unknown
		[2330] Institutional diversity	[2331] There is a just level of institutional disciplinary variety within the drought governance system	0.25	(16) Interviews	3.4	1.0	+0.8 = +
			[2332]There is an appropriate level of institutional managerial disparity within the drought governance system	0.25	(2) Interviews	3.5	1.5	+0.0 = o
			[2333] There is an appropriate level of institutional balance within the drought governance system	0.25	(7) Interviews	3.1	1.2	+0.5 = +
			[2334] There is sufficient presence of effective drought-centred partnerships and platforms for networking and knowledge exchange between different stakeholder groups, both sectoral as well as cross-sectoral	0.25	(15) Interviews	3.1	0.7	+0.9 = +

Table 10 Indicative Textual Indicator Assessment Report for indicator [2132].

Indicator
[2132] There is sufficient attention to drought and its effects in laws and regulations ***Explanation***: Laws and Regulations can play an important role in achieving a higher level of drought resilience, through for example drought-proof building codes and spatial regulations. These include both structural safety for the built environment itself, as well as 'spatial/environmental safety' where the built environment aids in water scarcity prevention in its direct vicinity.
Assessment method
This indicator was assessed based on ***interviews*** with regional experts. In total, nine interviewees gave information on and a score for this indicator. Their scores have been averaged for a final score. These include (Interview number in brackets): - 1 Waterboard (I01) - 5 Municipalities (I06, I08, I09, I10, I11) - 2 Interest groups for industry and economy (I15, I16) - 1 Interest group for agriculture (I19)
Current state bottlenecks and points of improvement
Higher level preparatory laws and regulations (i.e. European, national): 1. (I06, I11) The prevention of detrimental drought effects is considered to a very limited extent in the current higher laws and regulations (i.e. European, national), giving local governments a free pass and allowing discrepancies to arise between different local governments in the same region. By narrowing this scope of work within higher laws and regulations, every lower-level government will be obliged to deal with drought and better results can emerge from regional partnerships. 2. (I11) Potential improvements in drought adaptation in the built environment are held back by potentially outdated current higher laws and regulations. To solve this problem, an inventory needs to be made of what opportunities exist in the built environment and what legal problems municipalities encounter in wanting to introduce them on a large scale. Then, at regional, provincial and national level, we can look at how best to solve these problems. 3. (I06) Recently, the national guideline for climate-adaptive and green built environment (in Dutch: 'Maatlat voor Klimaat-adaptieve groene Gebouwde Omgeving'). This guideline is non-committal and rather generic. The knowledge and information from this guideline need to trickle down to all lower levels of government and thereafter become mandatory. 4. (I09, I15, I19) Currently, drought is not included in any formal national construction standard (i.e. NEN-norms), except for land subsidence which may be caused by drought. Through more explicit inclusion of drought risks in such standards, it can be ensured that drought is considered and there is a minimal incorporation of drought risk aversion that municipalities and property developers must adhere to. ***Regional and local preparatory laws and regulations:*** 5. (I01, I15, I19) The 'Watertoets' from the waterboard is the instrument that is seen as the best suited instrument in existing laws and regulations to match the functions to the water system and project developers are obliged to conduct a Watertoets for all new development plans. The specific rules within the Watertoets are however mostly based on the prevention of flooding and relatively little attention goes to drought. Therefore, the Watertoets is likely less effective than could be in a drought context. 6. (I01, I15) Another element that decreases the potential effectiveness of the Watertoets is the fact that it is advisory and thereby largely non-committal. Even though within Twente a negative advice from the Watertoets is quite influential in the project development plans, there are significantly different experiences in other regions within the Netherlands. Legally, municipalities and project developers can often go on with their plans even after negative advise from the Watertoets, which is thus still seen as a risk, also for Twente. To counter this, a positive 'advice' from the Watertoets should be a legal prerequisite instead of its non-committal current legal state. 7. (I06, I08, I10, I15, I16) Most if not all municipalities have laws and regulations within their zoning plans on water-related topics, such as a minimal infiltration or water storage capacity. However, these are mostly if not entirely based on preventing flooding and the benefit for drought is seen as only a bycatch. Despite the significant increase of interest in drought in urban planning and some adaptations to the rules and regulations within the zoning plans, specific rules and regulations for drought are (near) non-existent. There should be an inventory of possible rules and regulation specifically for drought, or at least with an explicit role for drought next to the prevention of flooding, to ensure drought is included in all construction activities. 8. (I06) As improvements for drought are only seen as a bycatch in current local laws and regulations from the zoning plans, they either have no quantitative numerical values or have differing values between municipalities. These values should be standardized throughout the region. 9. (I08, I09) There is a range of municipal laws and regulations for areas that are newly developed that to some extent include drought risks. However, laws and regulations that focus on (required adaptations to) the current built up areas are missing. This is especially the case for areas that are not publicly owned.

10. (I16, I19) There are no laws and regulations whatsoever that aim at systematically reducing water demand in industry and/or agriculture. Therefore, there is no legal incentive for these sectors to invest in reducing their water demand. A steering mechanism to achieve this could be the introduction of tiered pricing where large consumers pay a higher price per cubic meter of water consumption.
11. (I19) There are currently no laws and regulations in place that aim at creating a sustainable agricultural sector that is less drought-prone. A step towards this could for example be obligations or prohibitions of crop choices based on the local or regional water system.

Laws and regulations for during acute drought crises:

12. (I01, I15) In an acute drought crisis situation, the legal national water displacement sequence streamlines which functions are prioritized for their water demand. However, this displacement sequence is only relevant for the water supply areas (or in Dutch the 'wateraanvoergebieden', those areas in the Netherlands that can be reached and supplied by Rijkswaterstaat from the Dutch national water network). There is no such displacement sequence for the non-water supply areas (which are entirely dependent on precipitation and groundwater), other than a provision in the Drinking Water Act (in Dutch: Drinkwaterwet), which stipulates that drinking water has priority over industry. As Twente is almost entirely a non-water supply area, current prioritization is much less structured and therefore likely not optimal. A formal and legal displacement sequence for non-water supply areas is seen as key-element in better laws and regulations for drought in Twente.
13. (I10) There are laws and regulations in place that prevent over-abstraction of water in vulnerable areas (i.e. surrounding nature reserves). In addition, during an acute drought crisis, further water extraction bans can be put in place for i.e. agriculture and industry. However, there are no functioning steering mechanisms in place through which these water extraction limitations can be properly enforced.
14. (I10, I19) There are currently no laws and regulations whatsoever that aim at the reduction of household water demand during acute drought crises. Governments (i.e. municipalities or waterboards) can only incentivise through creating more social awareness and thereby building social pressure. This however does not give a sufficiently large effect.

Final indicator score

Based on Assessment Method, a **final score of 1.9** (on a scale of 1-5) was obtained, with a **standard deviation of 0.9**.

Foreseen impacts of current developments

Almost all interviewees mentioned they saw developments that would likely have a **positive** impact on the current state of this indicator. Their reasoning for this is described below.

1. (I01, I10, I15) Several interviewees mentioned the current developments surrounding the Environment and Planning Act (in Dutch: 'Omgevingswet') as well as the National Strategy on Spatial Planning and the Environment (in Dutch: 'Nationale Omgevingsvisie', or 'NOVI') as an important development. This national legislation should come into effect quite soon and is expected to be highly influential. Spatial planning is expected to be a key-element in this legislation. There is a strong lobby to make a paradigm shift from a water system that is managed to accommodate the wished-for functions (in Dutch: 'Peil volgt functie') to an allocation of functions based on the water system (in Dutch: 'Functie volgt peil'), in which drought has an important role. Based on this new national legislation, legislation on lower governmental levels will be adapted and eventually will lead to better incorporation of drought risk in laws and regulations.
2. (I09, I11) Other interviewees mostly mentioned the increasing awareness and urgency for especially the drinking water safety as a catalysator for forced incorporation of drought risk reduction in laws and regulations.
3. (I01, I15) There is also more and more awareness that the current national water displacement sequence is not sufficient for the entirety of the Netherlands and that something similar should be created for the non-water supply areas (in Dutch: 'niet-wateraanvoergebieden'). Several stakeholders, i.e. waterboards and provinces, have already taken first steps towards this.
4. (I06) In addition, the national government is currently assessing how the national guideline for climate-adaptive and green built environment (in Dutch: 'Maatlat voor een Klimaat-adaptieve groene Gebouw Omgeving') can be legally secured and made compulsory. Thereafter, lower levels of government will have to translate this national guideline to their own levels.
5. (I16) There are no current developments with a foreseen impact on the current state of this indicator with regards to water demand reduction in industry.
6. (I19) For agriculture, especially the current developments surrounding water quality regulations are of interest (specifically the 7th Action Program Nitrate Guideline, or in Dutch: '7e Actieprogramme Nitraatrichtlijn'). An important element in this will likely be the prohibition of cultivation of certain types of crops based on the local or regional water system. This is mainly aimed at the prevention of (further) water quality deterioration, but will likely also be linked with water quantity aspects and therefore with the development of drought-related legislation in the agriculture sector.

5.2. Validation of the assessment framework based on its application in Twente

Table 11 summarises the self-evaluation per (general) design requirement and whether these are or are not (partially) met. It provides the positive aspects of the designed assessment framework and lists the points of improvement. These points of improvement mostly relate to two different things: the procedure surrounding the assessment, and points where further validation is required before conclusions can be properly made. The case study provided very little points of improvement for the content of the designed assessment framework.

Table 11 Validation of the designed assessment framework against design requirements based on the experience from the case study application in Twente.

Design req.	Type	Remarks	Met?
Credibility	Positive	All framework elements are based on relevant peer-reviewed scientific literature incorporating different perspectives on the resilience of a region to droughts, ensuring the comprehensiveness of the framework as a whole and the coherence of framework elements with the relevant scientific literature. During the case study this was confirmed by the interviewees for the indicators in the Absorb-phase. Moreover, as a part of the assessment procedure is to define the indicator's scoring methods, the credibility of the data used to assess the framework's elements is also ensured. Additionally, the assessment procedure also incorporates the uncertainty in assessment results.	Met
	Improvements	1. Some regional experts interviewed for the case study proved to be more knowledgeable on certain indicators than others that assessed the same indicator. Scores of both 'types' of interviewees were considered equal in the final indicator score. The credibility of the assessment results could improve if a differentiation in how much 'weight' an expert has in the final score of an indicator based on their level of expertise is possible, in case of multiple assessors. 2. The manner in which the uncertainty is currently incorporated in the assessment is not validated by prospective users.	
Legitimacy	Positive	During the case study, the framework's structure was understandable and clear for all regional experts participating in the interviews, among whom policy makers from prospective users, with or without prior knowledge on resilience theory. The indicators of the Absorb-phase were also generally well-understood by the interviewees.	Mostly not met
	Improvements	1. Prospective users of the assessment framework were not part of its development whatsoever, nor has there been an evaluation of the assessment framework or its results with them. As such, it is unclear to what extent these prospective users perceive the framework to have appropriate values, concerns and perspectives. 2. During the case study multiple regional experts could have comparable qualitative assessments of the current state of an indicator, yet gave differing numerical scores, leading to relatively subjective numerical scores with significant standard deviations. As such, the case study showed the importance of providing the regional experts that assess the indicators with at least some guidance on the indicator maturity (what a certain score for a certain indicator 'means' for the region).	

Design req.	Type	Remarks	Met?
Salience	Positive	As part of the assessment procedure, relative weightings are assigned to all framework elements, ensuring that all considered elements are relevant to the region's specific context. Similarly, indicator scoring methods need to be determined on a case-to-case basis, ensuring that the used data is according to the region's spatial scale and context. Additionally, through the recommended procedure-of-use and the explanations provided for each indicator (which were deemed clear and understandable for all interviewees), the assessment framework and how it should be applied is deemed to be self-explanatory. Moreover, the assessment incorporates both quantitative and in-depth qualitative knowledge, translated into concrete guidance on the current state of drought resilience in the region as well as on current bottlenecks therein and how these bottlenecks can be improved upon. The case study also showed that it was relatively easy for regional experts to reflect on the expected effect of foreseen developments on the current state of the indicators, implying it will likely also be relatively easy for these regional experts to use the assessment framework for ex-ante policy evaluations.	Partially met
	Improvements	1. The main and most important point of attention to improve the salience of the assessment framework is regarding its workability. Even the partial assessment as conducted in the case study proved to be very laborious. Only a relatively small number of indicators could be assessed through public data and documents, while for the rest regional expertise was required. However, only about ten indicators could be assessed per hour of interview, while in total the designed framework has 85 indicators. Ideally multiple regional experts assess each indicator, quickly increasing the workload for the applier of the assessment framework. As such, when only little resources are available, the feasibility of conducting a proper assessment with the current design is questionable. 2. It was not evaluated with prospective users of the assessment framework whether the assessment framework and its procedure-of-use was indeed sufficiently self-explanatory, nor whether the assessment results provided sufficient guidance on the current state of drought resilience in the region and how it can be improved. 3. In the case study it proved difficult for many regional experts to translate their local knowledge to regional knowledge and/or their specialized knowledge to general knowledge on the general state of the indicator in the region. Examples are experts from municipalities having no clear overview of the current state in the region, or experts from a specific sector having little knowledge on how other sectors are dealing with the same issues. This leads to potential bias in the assessment results, especially if the participating stakeholders are somewhat skewed (i.e. the number of regional experts per sector). 4. A relatively small improvement to the content of the assessment framework relates to the possibility to reflect on the expected effect of foreseen developments on the current state of an indicator. Many regional experts automatically distinguished between short- and long-term foreseen developments. However, the applied version could only include the foreseen developments as a whole, missing out on potentially relevant information.	

<table>
<tr><th>Design req.</th><th>Type</th><th>Remarks</th><th>Met?</th></tr>
<tr><td rowspan="2">Visualisation</td><td>Positive</td><td>To ensure the assessment framework was not overwhelming, it has been visually broken down into more bite-sized pieces through a distinct colour scheme. In this scheme, each of the different resilience phases has its own colour (blue, green, yellow and orange), and each resilience principle within these phases has been given their own opacity of the phase's colour (dark, light). This was deemed clear by the regional experts participating in the interviews. Moreover, also the assessment results have been broken down into more bite-sized pieced through the instalment of three different 'levels' of detail in the assessment results.</td><td rowspan="2">Mostly met</td></tr>
<tr><td>Improvements</td><td>1. The manner in which the framework results are visualised are not validated with prospective users.
2. Due to the extensiveness of the assessment framework, a full assessment report including Textual Indicator Assessment Reports for all assessed indicators will still be extremely lengthy and therefore potentially overwhelming. To counteract this lengthiness, a reporting mode could be developed in which the readers/viewers of the report can more easily decide what types of information they require. For this purpose, an online tool in which the user can simply select the required information could be a good idea. In addition, such a tool could easily include further theoretical background on the framework elements and the reasoning why they are relevant for regional drought resilience, which is beneficial for increasing the readers' understanding of resilience.</td></tr>
<tr><td rowspan="2">Context of Use</td><td>Positive</td><td>Two distinct steps in the recommended procedure-of-use of the assessment framework refer to the framework's incorporation in the context of use. First, gaps in current policies and interventions are to be defined based on the assessment results. Thereafter, new or adapted policies and interventions should be developed. As such, if this recommended procedure-of-use is followed, the assessment framework should be well-incorporated in its context of use.</td><td rowspan="2">Not validated</td></tr>
<tr><td>Improvements</td><td>1. The case study did not cover the follow-up steps after the assessment was conducted. Also, no other validation of these steps took place. As such, it is unknown to what extent the theoretical incorporation of the assessment framework in its context of use are feasible.</td></tr>
<tr><td rowspan="2">Flexibility</td><td>Positive</td><td>Specific contexts hampering the assessment framework's applicability in differing cases are avoided by the recommended procedure-of-use of the assessment framework, through the definition of relevant stakeholders for the region's assessment, relative weighting, indicator scoring methods and an (indicative) indicator maturity index. Moreover, multiple pathways for differing available resources are indicatively covered in the recommended procedure-of-use. The framework is thus designed in such a way that it can be readily applied in different regions.</td><td rowspan="2">Not validated</td></tr>
<tr><td>Improvements</td><td>1. The assessment framework has only been applied in one case study. As such, it is only expected to be appropriately flexible for different regions of similar sizes, but this has not been validated through appliance in multiple case studies.</td></tr>
</table>

6. Discussion

This chapter discusses the findings of the study. First, the theoretical and practical contribution of the study are discussed (Section 6.1). Thereafter, there is reflected upon the limitations of the research method (Section 6.2) and the sensitivity of the assessment framework to specific contexts of other cases and domains (Section 6.3).

6.1. Theoretical and practical contribution of this research

This study has contributed to the current body of literature on drought resilience as well as to the practical field on drought management in multiple ways, as discussed below.

This study took a first step towards the design of an assessment framework for the drought resilience of a region, including a recommended procedure-of-use for this assessment framework. The problem investigation identified a knowledge gap in the current body of literature, which was the absence of a comprehensive overview of elements that are relevant for the drought resilience of a region and thus should be considered during the development of drought-related policies. This also led to the identification of a field problem concerning the absence of a readily-available tool that can aid in the policy development towards regional drought resilience. Consequentially, policy-makers and consultants working on drought management lack sufficient (scientifically proven) guidance as to what it means *in practice* for a region to be resilient to droughts and how they can improve it. Through the design of an assessment framework for the drought resilience of a region, the knowledge gap was filled. Moreover, through implementing the assessment framework through its recommended procedure-of-use, policy-makers and consultants working on drought management can obtain significant guidance on what elements they should consider during policy development, what the points of improvement in the region are and how these points can indeed be improved upon. This can be characterized by a quote from an interviewee from an interest group for industry and economy within Twente (*Interview 16*):

"The emerging problem of freshwater shortages in the eastern Netherlands due to more frequent periods of prolonged drought has been discussed with all kinds of different parties for an incredibly long time. Nevertheless, a lot of companies, but also different governments, still do not realise all the different knobs they can turn to become less sensitive to these periods of prolonged drought. This study provides a much clearer picture of what you can do to facilitate this, both in the physical domain and in the policy or operational domain. Just by asking these questions, companies and governments will look at it more emphatically."

In addition, a by-product of this study is an overview of design requirements for any to-be-designed RAF based on theoretical good-practice. This overview can be used by researchers and practitioners in the resilience domain as starting point for their specific needs and requirements for a new RAF.

Moreover, through the implementation of the designed assessment framework for regional drought resilience in the Dutch region of Twente, this study resulted in an extensive information-base and indicative guidance for Twente on how its regional drought resilience can be improved. This can be characterized by a quote from an interviewee with a joint function at the regional water board as well as an interest group for industry and economy within Twente (*Interview 15*):

"Using the qualitative information provided by the wide range of stakeholders involved in the assessment of the different indicators of this framework, we will for the first time see a comprehensive regional picture emerging concerning the balance of water demand and water supply and where the problems lie in this respect. Through this assessment, concrete guidance is given on emerging points of improvement for the drought management within Twente. This, in addition to the scientific literature in which the framework is grounded, is extremely interesting."

6.2. Reflection on limitations of the research method

A first limitation of the applied research method, relates to its adaptation of the Design Cycle by Wieringa (2014). For proper application of the Design Cycle, the design process follows multiple loops of the cycle (Wieringa, 2014). In subsequent loops, the points of evaluation after the validation of a design are followed by a new problem investigation, informing new or adapted design requirements and from there redesigning the earlier developed assessment framework to fit these new or adapted design requirements. In this research, only a single loop of the Design Cycle has been taken. Consequentially, potential refinements and adjustments to the framework, i.e. from the case study in the validation phase, have not been translated into a renewed design, nor did it inform new or adapted design requirements.

A second important limitation to the applied research method, relates to the lack of participation in the design of the assessment framework from prospective users of the assessment framework, i.e. policy-makers and consultants working in the drought management domain. The points where the lack of stakeholder participation has likely limited the quality of this study, are discussed below.

- The design requirements were not developed in cocreation with prospective users, and instead fully based on scientific literature on theoretical good-practice of designing a RAF. Although this resulted in a set of design requirements with strong theoretical footing, this negates potential case-specific requirements prospective users may have (i.e. specific types of information or the employment of specific participatory approaches could be required). As such, the set of thus developed design requirements is seen as a very good starting point for the design requirements of the assessment framework for regional drought resilience, but could potentially benefit significantly from a second loop in which the evaluation of the design informs a new or adapted set of design requirements in a more participatory manner.
- Prospective users of the assessment framework also did not participate in the design of the assessment framework and its recommended procedure-of-use, and instead this was done purely through a literature study. For the framework itself, this was a deliberate choice, as it was expected that none of these prospective users already had the comprehensive understanding on drought resilience of a region necessary to developed the first design of the assessment framework. However, also the design of the recommended procedure-of-use was based on scientific literature, even though prospective users could certainly have. This was mostly due to constraints in the available resources for this study. As such, some design requirements were considered more thoroughly for this design than others, which is clearly visible in the validation, where the credibility requirements are largely met, yet the assessment framework's legitimacy and salience for the prospective users receive lower assessments.
- The validation of the designed assessment framework and its procedure-of-use was partially based on comments from case study interviewees, but mostly based on the researcher's own perception on how well the assessment framework performed during the case study. Despite significant effort to have a critical take on the design, this could still have resulted in researcher's bias (Drisko, 1997; Noble & Smith, 2015). Therefore, it would have been beneficial to not only conduct a 'self-evaluation', but also employ an explicitly participatory approach with one or multiple prospective users of the assessment framework in which the framework and its (case study) results are discussed. This could i.e. be in the form of a small workshop with several policy-makers from the regional water board. This could also directly inform new or adapted design requirements for a new loop of the DCA, as previously mentioned.

There are also several limitations to the method that has been applied for the indicative case study in Twente specifically, as discussed below.

- The most prevalent one is that only a part of the designed assessment framework has been implemented. This was a necessary concession due to the required time-investment for a full implementation and it was justifiable looking at the indicative scope of the case study. Nevertheless, it still resulted in a lack of information on the remainder of the assessment framework.
- In addition, to find participants for the case study, there was made use of snowball sampling where the researcher started with a number of initial contacts ('seeds'). Based on their experience and networks, these seeds then recommend other potential participants. Due to its flexibility, networking characteristics and the inherent incentive to participate in the study when a 'known seed' from a potential participant's own network recommends said potential participant, snowball sampling proved a useful and convenient approach to find participants for the case study. This approach however also has a clear downside. As a network-based convenience sampling approach, it can be viewed negatively for not producing samples that meet criteria of random samples in the statistical sense and foster potential selection bias as well as a lack of external validity, generalisability and representativeness (Parker et al., 2020). An attempt has been made to counteract this potential selection bias through clearly defining the types of stakeholders that are relevant to do a proper assessment with the framework, as well as through making an inventory of relevant stakeholders that fit within these types for the case study region and ensuring each of the types of identified stakeholders had multiple participants. Nevertheless, a case could be made for a degree of selection bias due to a skewed participation of stakeholders, where some stakeholder types had more participants than others (i.e. the municipalities had six participants, while the agricultural sector only had two). As the scope of the case study was to be indicative and provide experience with the implementation of the designed assessment framework and not so much in conducting a full and proper assessment for the case study region, this remaining risk of potential selection bias was deemed acceptable.

6.3. Reflection on the sensitivity of the assessment framework to contexts

Specific contexts that could hamper framework-applicability are integrated in the procedure-of-use of the assessment framework, through the definition of relative weighting, indicator scoring methods and an (indicative) indicator maturity index. Thereby, the framework is designed in such a way that it can be readily applied in different regions. However, as was already stressed in the validation phase, the assessment framework and its procedure-of-use has only been applied to a single case: the Twente region. As such, even though the assessment framework is expected to have a quite flexible application, this has not been properly validated and no concrete conclusions can be drawn with regards to its sensitivity to the regional contexts. Still, one important limiting factor to the flexibility of the assessment framework can already be delineated: the size of the region. Based on the experience from the case study, it is expected that the designed assessment framework can readily be applied in regions of similar sizes and contexts as Twente, which is a NUTS3-level region[2], i.e. safety regions or water boards, to assess the drought resilience of their territory. However, based on the experience from the case study, it can also be deduced that the main factor of interest is the extent of differentiation within the regional context. If there are significant differences within a region, which is more likely to be the case in a larger region, the assessment framework is likely to generalize the information, as was already visible in the translation of municipal information to the regional scale in the case study. This will have an adverse effect on the usability of the assessment results. This could

[2] The NUTS classification is a hierarchical system for dividing the territory of the EU and the UK (Eurostat, 2021). There are three regional NUTS-levels: NUTS1 (multiple Dutch provinces together), NUTS2 (a Dutch province), and NUTS3 (smaller regions, i.e. Twente).

be the case if the region has multiple water systems or if it has significantly different drought governance systems. Similarly, for rather small regions it could be that important dynamics of the socioecological system (SES) with significant impact on the small region are not considered, as these dynamics fall outside of the spatial scope. It is yet to be seen what the spatial limits of application of the proposed assessment framework are.

With regards to the flexibility of application of the assessment framework in other resilience domains (being not 'drought'), Tyler et al. (2016) reason that the creation of a universal set of resilience assessment indicators that are applicable to all sectors and geographic locations is impossible, as climate adaptation and resilience building inherently require localized and context-specific responses. Following this argument, it is difficult to design a framework applicable to multiple sectors and resilience domains. Nevertheless, the proposed assessment framework does lend itself to some extent for application in other domains. This is mostly due to the strong footing in generally applicable resilience theory for socioecological systems (i.e. regions) of the first, second and third framework layers (resilience phases, principles and operationalisations respectively). Similarly, to the RDT by Wardekker et al. (2020), the specification towards a specific resilience domain is only made in the fourth layer (indicators). This enables relatively simple transition of this proposed assessment framework for the drought resilience domain to other resilience domains: as long as the to-be-assessed aspect is a socioecological system (i.e. not a community, household, financial system or engineered structure), only the fourth framework layer is required to be adapted. Although this will still take a significant period of time, this required transition also serves as an opportunity. Multiple studies have however shown added benefit in defining a set of indicators in a participatory manner, as this process builds local/regional capacity in terms of understanding resilience, shared understanding of concepts and measurements and establishes a common platform for future planning and monitoring of policy and interventions (Cash et al., 2003; Dunn & Bakker, 2009; Sullivan, 2002; Tyler et al., 2016).

7. Conclusion and recommendations

7.1. Conclusion

To achieve the objective, being '*Design an assessment framework that provides a comprehensive understanding of the drought resilience of a region as a tool to guide drought management policies*', design science methodology was employed, consisting of three distinctive design phases: the problem investigation, design, and validation phases.

In the problem investigation, it was identified that even though there is significant knowledge on resilience and even though a significant number of RAFs exist, there is indeed no readily available comprehensive assessment framework for the drought resilience of a region. Moreover, in the problem investigation phase a set of 24 design requirements was developed for an assessment framework that can assess the regional drought resilience. These design requirements were structured under six general design requirements. These stipulate that there should be 1) *credibility*, 2) *legitimacy*, and 3) *salience* of the framework elements and the assessment procedure within the framework, 4) proper *visualisation* of the framework and its assessment results, 5) proper incorporation of the framework within its *context of use*, and 6) a proper level of *flexibility* in the framework.

An existing RAF, namely the Resilience Diagnostic Tool (RDT) by Wardekker et al. (2020), was identified as being a fitting theoretical base to build the design upon. The RDT was adapted based on the points for improvement that were identified while verifying the RDT against the design requirements. This resulted in an assessment framework with four distinct layers connected through a tree-structure. The first layer captures the four different resilience phases, being 'prepare', 'absorb', 'recover' and 'adapt'. These are specified into ten resilience principles. These resilience principles are in turn specified into 31 policy theme operationalisations, which are specified into 85 drought resilience indicators. As final part of the design phase, a recommended procedure-of-use was developed. This gives guidance on how the framework should be applied and consists of four distinct phases: the assessment preparation phase, the assessment conduction phase, the follow-up phase and an optional phase in which an ex-ante policy evaluation is conducted.

The Absorb-phase of the designed assessment framework was applied in a case study in the Dutch region of Twente. For this, the preparation and conduction phases of the recommend procedure-of-use were followed. Using the thus gained experience on the usability of the (Absorb-phase of the) framework, it was concluded that design requirements for the framework's credibility and visualisation are (mostly) met. However, the design requirements for the frameworks salience are only partially met, while the design requirements for the framework's legitimacy are mostly not met. As this validation phase consisted of only one case study that only followed the first six steps of the procedure-of-use (and thus no follow-up steps with the assessment results have been undertaken), the (feasibility of the) incorporation of the assessment framework in its context of use, as well as the framework's flexibility, were not validated in this study. Following this validation, a significant number of points of improvements were identified. A common denominator in these was the lack of participation from prospective users in the total design cycle. It would have added greatly to the framework's credibility, legitimacy and salience if prospective users participated in setting the design requirements and participated in an evaluation of the framework and its assessment results. Moreover, an element significantly impacting the salience of the assessment framework was that the assessment framework, is very laborious to apply. For full application of the designed assessment framework, significant resources are likely required, especially in the time investment. This reduces the framework's usability.

To conclude, this study is structured through appliance of design science methodology. Theoretical design requirements are developed based on scientific literature on good-practice for RAFs. Guided by these design requirements, an existing RAF has been adapted into the design of an assessment framework for the drought resilience of a region. One out of four phases within this designed assessment framework has been applied in a case study in Twente, providing experience with its performance. Based thereupon, an evaluation on the framework's usability took place, leading to several important points of improvement for the designed assessment framework.

7.2. Recommendations for further research

Multiple recommendations for further research can be distilled from this study.

It is recommended to conduct additional research in which prospective users play an important participative role. First off, it would be highly relevant if these prospective users could participate in the validation of the assessment framework to come to better informed points of improvement. Moreover, it is recommended to conduct a new loop of the Design Cycle during which the prospective users should obtain a more participative role in the development of design requirements. In this new loop, also the complete assessment framework should be applied, instead of only one out of four phases, as was done in this study with the Absorb-phase.

Furthermore, considering the laboriousness that the case study, in which only $1/4^{th}$ of the framework was applied, it would be highly relevant to investigate a manner in which the designed assessment framework can be applied if resources are low. How can the framework be simplified, without it losing its comprehensiveness?

Lastly, this study excluded the implementation and evaluation phases of the design cycle by Wieringa (2014). Once the adapted requirements are verified and met, it is recommended to complete the engineering cycle and analyse the implementation and evaluation of the designed assessment framework in practice.

Bibliography

Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R., & Rockström, J. (2005). Social-Ecological Resilience to Coastal Disasters. *Science*, *309*(5737), 1036–1039. https://doi.org/10.1126/science.1112122

Aligica, P. D., & Tarko, V. (2012). Polycentricity: From Polanyi to Ostrom, and Beyond. *Governance*, *25*(2), 237–262. https://doi.org/10.1111/j.1468-0491.2011.01550.x

Arbon, P., Gebbie, K., Cusack, L., Perera, S., & Verdonk, S. (2014). Developing a model and tool to measure community disaster resilience. *Australian Journal of Emergency Management*, *29*(4), 1216. www.torrensresilience.org

ARUP. (2014). *City Resilience Framework*.

Bachmair, S., Svensson, C., Hannaford, J., Barker, L. J., & Stahl, K. (2016). A quantitative analysis to objectively appraise drought indicators and model drought impacts. *Hydrology and Earth System Sciences*, *20*(7), 2589–2609. https://doi.org/10.5194/hess-20-2589-2016

Bartholomeus, R. P., van der Wiel, K., van Loon, A. F., van Huijgevoort, M. H. J., van Vliet, M. T. H., Mens, M., Muurling-van Geffen, S., Wanders, N., & Pot, W. (2023). Managing water across the flood-drought spectrum – experiences from and challenges for the Netherlands. *Cambridge Prisms: Water*, 1–22. https://doi.org/10.1017/wat.2023.4

Bazza, M. (2002). Water Resources Planning and Management for Drought Mitigation. *Regional Workshop on Capacity Building on Drought Mitigation in the Near East*, 1–10. https://www.droughtmanagement.info/literature/FAO_water_resources_planning_management_drought_mitigation_2002.pdf

BDO. (2022). *BDO-Benchmark Nederlandse Gemeenten 2022*. www.linkedin.com/company/bdo-nederland

Biggs, R., Schlüter, M., Biggs, D., Bohensky, E. L., Burnsilver, S., Cundill, G., Dakos, V., Daw, T. M., Evans, L. S., Kotschy, K., Leitch, A. M., Meek, C., Quinlan, A., Raudsepp-Hearne, C., Robards, M. D., Schoon, M. L., Schultz, L., & West, P. C. (2012). Toward principles for enhancing the resilience of ecosystem services. In *Annual Review of Environment and Resources* (Vol. 37, pp. 421–448). Annual Reviews Inc. https://doi.org/10.1146/annurev-environ-051211-123836

Brakkee, E., Van Huijgevoort, M. H. J., & Bartholomeus, R. P. (2022). Improved understanding of regional groundwater drought development through time series modelling: The 2018-2019 drought in the Netherlands. *Hydrology and Earth System Sciences*, *26*(3), 551–569. https://doi.org/10.5194/hess-26-551-2022

Brand, F. S., & Jax, K. (2007). *Focusing the Meaning(s) of Resilience: Resilience as a Descriptive Concept and a Boundary Object* (Vol. 12, Issue 1). and Society. https://www.jstor.org/stable/26267855

Bremer, S., Wardekker, A., Baldissera Pacchetti, M., Bruno Soares, M., & van der Sluijs, J. (2022). Editorial: High-Quality Knowledge for Climate Adaptation: Revisiting Criteria of Credibility, Legitimacy, Salience, and Usability. *Frontiers in Climate*, *4*. https://doi.org/10.3389/fclim.2022.905786

Bressers, H., Bressers, N., Kuks, S., & Larrue, C. (2016). The governance assessment tool and its use. In *Governance for Drought Resilience: Land and Water Drought Management in Europe* (pp. 45–66). Springer International Publishing. https://doi.org/10.1007/978-3-319-29671-5_3

Bródy, L. S., Chelleri, L., Baró, F., & Ruiz-Mallen, I. (2018). Enhancing Community Resilience in Barcelona: Addressing Climate Change and Social Justice Through Spaces of Co-Management. In A. Galderisi & A. Colucci (Eds.), *Smart, Resilient and Transition Cities: Emerging Approaches and Tools for A Climate-Sensitive Urban Development* (pp. 203–208). Elsevier. https://www.elsevier.com/books/smart-resilient-and-transition-cities/galderisi/978-0-12-811477-3

Brown, F. (2022). *Governance for Resilience: How Can States Prepare for the Next Crisis?* CarnegieEndowment.org

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W. A., & von Winterfeldt, D. (2003). A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. *Earthquake Spectra*, *19*(4), 733–752. https://doi.org/10.1193/1.1623497

Bryan, K., Ward, S., Barr, S., & Butler, D. (2019). Coping with Drought: Perceptions, Intentions and Decision-Stages of South West England Households. *Water Resources Management*, *33*(3), 1185–1202. https://doi.org/10.1007/s11269-018-2175-2

Buitenhuis, Y., Candel, J. J. L., Termeer, K. J. A. M., & Feindt, P. H. (2020). Does the Common Agricultural Policy enhance farming systems' resilience? Applying the Resilience Assessment Tool (ResAT) to a farming system case study in the Netherlands. *Journal of Rural Studies*, *80*, 314–327. https://doi.org/10.1016/j.jrurstud.2020.10.004

Büyüközkan, G., Ilıcak, Ö., & Feyzioğlu, O. (2022). A review of urban resilience literature. *Sustainable Cities and Society*, *77*, 103579. https://doi.org/10.1016/j.scs.2021.103579

Carlisle, K., & Gruby, R. L. (2019). Polycentric Systems of Governance: A Theoretical Model for the Commons. *Policy Studies Journal*, *47*(4), 921–946. https://doi.org/10.1111/psj.12212

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From Metaphor to Measurement: Resilience of What to What? *Ecosystems*, *4*(8), 765–781. https://doi.org/10.1007/s10021-001-0045-9

Carstensen, J., & Lindegarth, M. (2016). Confidence in ecological indicators: A framework for quantifying uncertainty components from monitoring data. *Ecological Indicators*, *67*, 306–317. https://doi.org/10.1016/j.ecolind.2016.03.002

Cash, D., Clark, W. C., Alcock, F., Dickson, N., Eckley, N., & Jäger, J. (2003). Salience, Credibility, Legitimacy and Boundaries: Linking Research, Assessment and Decision Making. *KSG Working Paper Series*. https://doi.org/10.2139/ssrn.372280

CBS. (2017). *Bodemgebruik; uitgebreide gebruiksvorm, per gemeente*. https://www.cbs.nl/nl-nl/cijfers/detail/70262ned

CBS. (2020). *Landbouw; Bedrijven met verbredingsactiviteiten, hoofdbedrijfstype, regio*. https://opendata.cbs.nl/#/CBS/nl/dataset/80807ned/table

CBS. (2021a). *Regionale kerncijfers; nationale rekeningen 2021*. https://www.cbs.nl/nl-nl/cijfers/detail/84432NED

CBS. (2021b). *Toegevoegde waarde veehouderij en agrocomplex 2018-2021*. https://www.cbs.nl/nl-nl/maatwerk/2022/47/toegevoegde-waarde-veehouderij-en-agrocomplex-2018-2021

CBS. (2023a). *Bevolking op 1 januari en gemiddeld; geslacht, leeftijd en regio*. https://opendata.cbs.nl/#/CBS/nl/dataset/03759ned/table?dl=39E0B

CBS. (2023b). *Kerncijfers wijken en buurten 2020*. https://opendata.cbs.nl/#/CBS/nl/dataset/84799NED/table?searchKeywords=stedelijkheid

Chelleri, L., Waters, J. J., Olazabal, M., & Minucci, G. (2015). Resilience trade-offs: addressing multiple scales and temporal aspects of urban resilience. *Environment and Urbanization*, *27*(1), 181–198. https://doi.org/10.1177/0956247814550780

Constas, M. A., d'Errico, M., & Pietrelli, R. (2022). Toward Core Indicators for Resilience Analysis: A framework to promote harmonized metrics and empirical coherence. *Global Food Security*, *35*. https://doi.org/10.1016/j.gfs.2022.100655

Coulson, N. E., McCoy, S. J., & McDonough, I. K. (2020). Economic diversification and the resiliency hypothesis: Evidence from the impact of natural disasters on regional housing values. *Regional Science and Urban Economics*, *85*. https://doi.org/10.1016/j.regsciurbeco.2020.103581

Crossman, N. D. (2018). *Drought Resilience, Adaptation and Management Policy (DRAMP) Framework*.

Cutter, S. L., Ahearn, J. A., Amadei, B., Crawford, P., Eide, E. A., Galloway, G. E., Goodchild, M. F., Kunreuther, H. C., Li-Vollmer, M., Schoch-Spana, M., Scrimshaw, S. C., Stanley, E. M., Whitney, G., & Zoback, M. Lou. (2013). Disaster resilience: A national imperative. *Environment: Science and Policy for Sustainable Development*, *55*(2), 25–29. https://doi.org/10.1080/00139157.2013.768076

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, *18*(4), 598–606. https://doi.org/10.1016/j.gloenvcha.2008.07.013

Cutter, S. L., Burton, C. G., & Emrich, C. T. (2010). Disaster Resilience Indicators for Benchmarking Baseline Conditions. *Journal of Homeland Security and Emergency Management*, *7*(1), 51. https://doi.org/10.2202/1547-7355.1732

Davoudi, S., Brooks, E., & Mehmood, A. (2013). Evolutionary Resilience and Strategies for Climate Adaptation. *Planning Practice and Research*, *28*(3), 307–322. https://doi.org/10.1080/02697459.2013.787695

de Bruijn, K. M. (2004). Resilience indicators for flood risk management systems of lowland rivers. *International Journal of River Basin Management*, *2*(3), 199–210. https://doi.org/10.1080/15715124.2004.9635232

Debusk, K. M., & Wynn, T. M. (2011). Storm-Water Bioretention for Runoff Quality and Quantity Mitigation. *Journal of Environmental Engineering*, *137*(9), 800–808. https://doi.org/10.1061/(ASCE)EE.1943-7870.0000388

Drisko, J. W. (1997). Strengthening Qualitative Studies and Reports. *Journal of Social Work Education*, *33*(1), 185–197. https://doi.org/10.1080/10437797.1997.10778862

Dunn, G., & Bakker, K. (2009). *Canadian approaches to assessing water security: an inventory of indicators. Policy report*. Program on Water Governance, University of British Columbia.

Edwards, B., Gray, M., & Hunter, B. (2019). The social and economic impacts of drought. *Australian Journal of Social Issues*, *54*(1), 22–31. https://doi.org/10.1002/ajs4.52

Eraydin, A. (2016). Attributes and Characteristics of Regional Resilience: Defining and Measuring the Resilience of Turkish Regions. *Regional Studies*, *50*(4), 600–614. https://doi.org/10.1080/00343404.2015.1034672

Eurostat. (2021). *NUTS background*. https://ec.europa.eu/eurostat/web/nuts/background

Ferraro, P. J. (2009). Counterfactual thinking and impact evaluation in environmental policy. *New Directions for Evaluation*, *2009*(122), 75–84. https://doi.org/10.1002/ev.297

Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change*, *16*(3), 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002

Folke, C., Biggs, R., Norström, A. v., Reyers, B., & Rockström, J. (2016). Social-ecological resilience and biosphere-based sustainability science. *Ecology and Society*, *21*(3). https://doi.org/10.5751/ES-08748-210341

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. In *Annual Review of Environment and Resources* (Vol. 30, pp. 441–473). https://doi.org/10.1146/annurev.energy.30.050504.144511

Frankenberger, T., Mueller, M., Spangler, T., & Alexander, S. (2013). *Community Resilience: Conceptual Framework and Measurement Feed the Future Learning Agenda*. https://www.agrilinks.org/sites/default/files/resource/files/FTF%20Learning_Agenda_Community_Resilience_Oct%202013.pdf

Fu, X., & Tang, Z. (2013). Planning for drought-resilient communities: An evaluation of local comprehensive plans in the fastest growing counties in the US. *Cities*, *32*, 60–69. https://doi.org/10.1016/j.cities.2013.03.001

Gober, P., Sampson, D. A., Quay, R., White, D. D., & Chow, W. T. L. (2016). Urban adaptation to mega-drought: Anticipatory water modeling, policy, and planning for the urban Southwest. *Sustainable Cities and Society*, *27*, 497–504. https://doi.org/10.1016/j.scs.2016.05.001

Godschalk, D. R. . (2003). Urban Hazard Mitigation: Creating Resilient Cities. *Natural Hazards Review*, *4*(3), 136–143. https://doi.org/10.1061/(ASCE)1527-6988(2003)4:3(136)

Goijer, I., Heuven, A., Luijendijk, J., Overbeek, M., & Runhaar, H. (2012). *Zoetwatervoorziening Oost Nederland - Gevolgen van droogte voor het waterbeheer - Kenmerk R001-4798994IGO-kzo-V03-NL*.

Gonzales, P., & Ajami, N. K. (2019). Goal-based water trading expands and diversifies supplies for enhanced resilience. *Nature Sustainability*, *2*(2), 138–147. https://doi.org/10.1038/s41893-019-0228-z

Grêt-Regamey, A., Huber, S. H., & Huber, R. (2019). Actors' diversity and the resilience of social-ecological systems to global change. *Nature Sustainability*, *2*(4), 290–297. https://doi.org/10.1038/s41893-019-0236-z

Grillakis, M. G. (2019). Increase in severe and extreme soil moisture droughts for Europe under climate change. *Science of the Total Environment*, *660*, 1245–1255. https://doi.org/10.1016/j.scitotenv.2019.01.001

Gunderson, L. (2009). *Comparing ecological and human community resilience: CARRI research report 5*.

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P., Nooteboom, S., & Bergsma, E. (2010). The Adaptive Capacity Wheel: A method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science and Policy*, *13*(6), 459–471. https://doi.org/10.1016/j.envsci.2010.05.006

Hauge Simonsen, S., Biggs, R., Schlüter, M., Schoon, M., Bohensky, E., Cundill, G., Dakos, V., Daw, T., Kotschy, K., Leitch, A., Quinlan, A., Peterson, G., Moberg, F., Anderies, M., Armitage, D., Baggio, J., Bennett, E., Biggs, D., Bodin, Ö., … Kommunikation, M. (2014). *Applying resilience - Seven principles for building resilience in social ecological systems*.

Hegger, D., Lamers, M., Van Zeijl-Rozema, A., & Dieperink, C. (2012). Conceptualising joint knowledge production in regional climate change adaptation projects: success conditions and levers for action. *Environmental Science & Policy*, *18*, 52–65. https://doi.org/10.1016/j.envsci.2012.01.002

Helming, K., Diehl, K., Bach, H., Dilly, O., König, B., Kuhlman, T., Pérez-Soba, M., Sieber, S., Tabbush, P., Tscherning, K., Wascher, D., & Wiggering, H. (2011). *Ex Ante Impact Assessment of Policies Affecting Land Use, Part A: Analytical Framework* (Vol. 16, Issue 1). and Society.

Henao Casas, J. D., Fernández Escalante, E., Calero Gil, R., & Ayuga, F. (2022). Managed Aquifer Recharge as a Low-Regret Measure for Climate Change Adaptation: Insights from Los Arenales, Spain. *Water (Switzerland)*, *14*(22). https://doi.org/10.3390/w14223703

Hoa, N. T., & Vinh, N. Q. (2018). The notions of resilience in spatial planning for drought - Flood coexistence (DFC) at regional scale. *IOP Conference Series: Earth and Environmental Science*, *143*(1). https://doi.org/10.1088/1755-1315/143/1/012066

Hoekstra, A. Y., Buurman, J., & van Ginkel, K. C. H. (2018). Urban water security: A review. In *Environmental Research Letters* (Vol. 13, Issue 5). Institute of Physics Publishing. https://doi.org/10.1088/1748-9326/aaba52

Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, *4*(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

Holling, C. S. (2001). *Understanding the Complexity of Economic, Ecological, and Social Systems*. *4*(5), 390–405. https://doi.org/10.1007/s10021-00

Honing, D., Pezij, M., Klopstra, D., Berendrecht, W., & Arts, M. (2023). *Quick scan droogte IJsselvallei, Managementsamenvatting (PR4757.10)*.

Hosseini, S., Barker, K., & Ramirez-Marquez, J. E. (2016). A review of definitions and measures of system resilience. *Reliability Engineering and System Safety*, *145*, 47–61. https://doi.org/10.1016/j.ress.2015.08.006

Huang, S., Krysanova, V., & Hattermann, F. (2015). Projections of climate change impacts on floods and droughts in Germany using an ensemble of climate change scenarios. *Regional Environmental Change*, *15*(3), 461–473. https://doi.org/10.1007/s10113-014-0606-z

Hunt, A., & Watkiss, P. (2011). Climate change impacts and adaptation in cities: A review of the literature. *Climatic Change*, *104*(1), 13–49. https://doi.org/10.1007/s10584-010-9975-6

Huntjens, P., Pahl-Wostl, C., & Grin, J. (2010). Climate change adaptation in European river basins. *Regional Environmental Change*, *10*(4), 263–284. https://doi.org/10.1007/s10113-009-0108-6

Hurlimann, A., & Wilson, E. (2018). Sustainable urban water management under a changing climate: The role of spatial planning. *Water (Switzerland)*, *10*(5). https://doi.org/10.3390/w10050546

IPCC. (2021). *Climate Change 2021 - The Physical Science Basis Summary for Policymakers*. www.ipcc.ch

Jensen, O., & Wu, H. (2018). Urban water security indicators: Development and pilot. *Environmental Science and Policy*, *83*, 33–45. https://doi.org/10.1016/j.envsci.2018.02.003

Joerin, J., Shaw, R., Takeuchi, Y., & Krishnamurthy, R. (2014). The adoption of a Climate Disaster Resilience Index in Chennai, India. *Disasters*, *38*(3), 540–561. https://doi.org/10.1111/disa.12058

Kammouh, O., Zamani Noori, A., Cimellaro, G. P., & Mahin, S. A. (2019). Resilience Assessment of Urban Communities. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, *5*(1). https://doi.org/10.1061/ajrua6.0001004

Karamouz, M., Zeynolabedin, A., & Olyaei, M. A. (2016). Regional Drought Resiliency and Vulnerability. *Journal of Hydrologic Engineering*, *21*(11). https://doi.org/10.1061/(asce)he.1943-5584.0001423

Kavdir, Y., Zhang, W., Basso, B., & Smucker, A. J. M. (2014). Development of a new long-term drought resilient soil water retention technology. *Journal of Soil and Water Conservation*, *69*(5), 154A-160A. https://doi.org/10.2489/jswc.69.5.154A

Kern, F., Rogge, K. S., & Howlett, M. (2019). Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies. *Research Policy*, *48*(10). https://doi.org/10.1016/j.respol.2019.103832

Khatibi, S. A., Golkarian, A., Mosaedi, A., & Sojasi Qeidari, H. (2019). Assessment of Resilience to Drought of Rural Communities in Iran. *Journal of Social Service Research*, *45*(2), 151–165. https://doi.org/10.1080/01488376.2018.1479342

Khazai, B., Bendimerad, F., Cardona, O. D., Carreño, M. L., Barbat, A. H., & Burton, C. G. (2015). *A guide to measure urban risk resilience. Principles, Tools and Practice of Urban Indicators*. Earthquakes and MEgacities Initiative, Inc.

Kim, D., & Lim, U. (2016). Urban Resilience in Climate Change Adaptation: A Conceptual Framework. *Sustainability*, *8*(4), 405. https://doi.org/10.3390/su8040405

KNMI. (2018). *De droogte van 2018: Een analyse op basis van het potentiele neerslagtekort | 117162*. www.knmi.nl

Knüppe, K., & Pahl-Wostl, C. (2013). Requirements for adaptive governance of groundwater ecosystem services: Insights from Sandveld (South Africa), Upper Guadiana (Spain) and Spree (Germany). *Regional Environmental Change*, *13*(1), 53–66. https://doi.org/10.1007/s10113-012-0312-7

Kooyers, N. J. (2015). The evolution of drought escape and avoidance in natural herbaceous populations. In *Plant Science* (Vol. 234, pp. 155–162). Elsevier Ireland Ltd. https://doi.org/10.1016/j.plantsci.2015.02.012

KWR. (2018). *Grondwaterkwaliteit - Totaalkaarten alle voorkomende stoffen per stofgroep in 2016 en 2018, diep en ondiep*. https://www.arcgis.com/apps/dashboards/64b0f96fa1f74729b060150cfb403fca

Labaka, L., Maraña, P., Giménez, R., & Hernantes, J. (2019). Defining the roadmap towards city resilience. *Technological Forecasting and Social Change*, *146*, 281–296. https://doi.org/10.1016/j.techfore.2019.05.019

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science*, *7*(S1), 25–43. https://doi.org/10.1007/s11625-011-0149-x

Lebel, L., Anderies, J. M., Campbell, B., Folke, C., Hatfield-Dodds, S., & Lebel, L. ; (2006). *Governance and the Capacity to Manage Resilience in Regional Social-Ecological Systems Repository Citation*. https://digitalcommons.library.umaine.edu/sms_facpub

Lee, C. W., & Yoo, D.-G. (2021). Evaluation of drought resilience reflecting regional characteristics: Focused on 160 local governments in Korea. *Water*, *13*(1873). https://doi.org/10.3390/w13131873

Lehtonen, M. (2015). Indicators: Tools for informing, monitoring or controlling? In *The Tools of Policy Formulation: Actors, Capacities, Venues and Effects* (pp. 76–99). Edward Elgar Publishing Ltd. https://doi.org/10.4337/9781783477043.00015

Levine, S. (2014). *Assessing resilience: why quantification misses the point*.

Linkov, I., Bridges, T., Creutzig, F., Decker, J., Fox-Lent, C., Kröger, W., Lambert, J. H., Levermann, A., Montreuil, B., Nathwani, J., Nyer, R., Renn, O., Scharte, B., Scheffler, A., Schreurs, M., & Thiel-Clemen, T. (2014). Changing the resilience paradigm. In *Nature Climate Change* (Vol. 4, Issue 6, pp. 407–409). Nature Publishing Group. https://doi.org/10.1038/nclimate2227

Lonsdale, K. G., Gawith, M. J., Johnstone, K., Street, R. B., West, C. C., & Brown, A. D. (2010). *Attributes of Well-Adapting Organisations A report prepared by UK Climate Impacts Programme for the Adaptation Sub-Committee*.

Lu, P., & Stead, D. (2013). Understanding the notion of resilience in spatial planning: A case study of Rotterdam, The Netherlands. *Cities*, *35*, 200–212. https://doi.org/10.1016/j.cities.2013.06.001

Manyena, B., Machingura, F., & O'Keefe, P. (2019). Disaster Resilience Integrated Framework for Transformation (DRIFT): A new approach to theorising and operationalising resilience. *World Development*, *123*. https://doi.org/10.1016/j.worlddev.2019.06.011

Mayunga, J. S. (2007). Understanding and Applying the Concept of Community Disaster Resilience - A Capital-Based Aproach. *Economics*. https://doi.org/10.1146/annurev.energy.32.051807.090348

Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning*, *147*, 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011

Melo-Aguilar, C., Agulles, M., & Jordà, G. (2022). Introducing uncertainties in composite indicators. The case of the Impact Chain risk assessment framework. *Frontiers in Climate*, *4*(1019888). https://doi.org/10.3389/fclim.2022.1019888

Mens, M. (2015). *System robustness analysis in support of flood and drought risk management*. IOS Press. https://doi.org/10.3990/1.9781614994817

Meza, I., Hagenlocher, M., Naumann, G., Vogt, J., & Frischen, J. (2019). *Drought vulnerability indicators for global-scale drought risk assessments: global expert survey results report. EUR29824EN JRC117546* (I. Meza, M. Hagenlocher, G. Naumann, J. Vogt, & J. Frischen, Eds.). https://doi.org/doi:10.2760/73844

Milman, A., & Short, A. (2008). Incorporating resilience into sustainability indicators: An example for the urban water sector. *Global Environmental Change*, *18*(4), 758–767. https://doi.org/10.1016/j.gloenvcha.2008.08.002

Ministerie LNV. (2023). *https://natura2000.nl/gebieden/overijssel*. Natura2000 Gebieden Overijssel.

Moench, M. (2014). Experiences applying the climate resilience framework: Linking theory with practice. *Development in Practice*, *24*(4), 447–464. https://doi.org/10.1080/09614524.2014.909385

Mujjuni, F., Betts, T., To, L. S., & Blanchard, R. E. (2021). Resilience a means to development: A resilience assessment framework and a catalogue of indicators. *Renewable and Sustainable Energy Reviews*, *152*. https://doi.org/10.1016/j.rser.2021.111684

National Academies of Sciences, E. and M. (2016). *Attribution of Extreme Weather Events in the Context of Climate Change*. National Academies Press. https://doi.org/10.17226/21852

Naumann, G., Cammalleri, C., Mentaschi, L., & Feyen, L. (2021). Increased economic drought impacts in Europe with anthropogenic warming. *Nature Climate Change*, *11*(6), 485–491. https://doi.org/10.1038/s41558-021-01044-3

Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to environmental change: contributions of a resilience framework. *Annual Review of Environment and Resources*, *32*, 395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348

Nemec, K. T., Chan, J., Hoffman, C., Spanbauer, T. L., Hamm, J. A., Allen, C. R., Hefley, T., Pan, D., & Shrestha, P. (2014). Assessing resilience in stressed watersheds. *Ecology and Society*, *19*(1). https://doi.org/10.5751/ES-06156-190134

NLTimes. (2021, June 21). *Flood damage i nValkenbyrg estimated at €400 million; 700 families discplaced*. https://nltimes.nl/2021/07/21/flood-damage-valkenburg-estimated-eu400-million-700-families-displaced

Noble, H., & Smith, J. (2015). Issues of validity and reliability in qualitative research. In *Evidence-Based Nursing* (Vol. 18, Issue 2, pp. 34–35). BMJ Publishing Group. https://doi.org/10.1136/eb-2015-102054

Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness. *American Journal of Community Psychology*, *41*(1–2), 127–150. https://doi.org/10.1007/s10464-007-9156-6

OECD. (2003). *Environmental Indicators Development, Measurement and Use*. https://www.oecd.org/env/indicators-modelling-outlooks/24993546.pdf

OECD. (2008). *Handbook on constructing composite indicators : methodology and user guide*. OECD.

Orhan, E. (2016). Building community resilience: Business preparedness lessons in the case of Adapazari, Turkey. *Disasters*, *40*(1), 45–64. https://doi.org/10.1111/disa.12132

Oriangi, G., Albrecht, F., di Baldassarre, G., Bamutaze, Y., Mukwaya, P. I., Ardö, J., & Pilesjö, P. (2020). Household resilience to climate change hazards in Uganda. *International Journal of Climate Change Strategies and Management*, *12*(1), 59–73. https://doi.org/10.1108/IJCCSM-10-2018-0069

Orimoloye, I. R., Zhou, L., & Kalumba, A. M. (2021). Drought disaster risk adaptation through ecosystem services-based solutions: Way forward for south africa. In *Sustainability (Switzerland)* (Vol. 13, Issue 8). MDPI. https://doi.org/10.3390/su13084132

Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. *Water Resources Management*, *21*(1), 49–62. https://doi.org/10.1007/s11269-006-9040-4

Pahl-Wostl, C., Knieper, C., Lukat, E., Meergans, F., Schoderer, M., Schütze, N., Schweigatz, D., Dombrowsky, I., Lenschow, A., Stein, U., Thiel, A., Tröltzsch, J., & Vidaurre, R. (2020). Enhancing the capacity of water governance to deal with complex management challenges: A framework of analysis. *Environmental Science and Policy*, *107*, 23–35. https://doi.org/10.1016/j.envsci.2020.02.011

Parker, C., Scott, S., & Geddes, A. (2020). Snowball Sampling. *SAGE Research Methods Foundations*. https://doi.org/http://dx.doi.org/10.4135/

Petrosillo, I., Aretano, R., & Zurlini, G. (2018). Socioecological systems. In *Encyclopedia of Ecology* (pp. 419–425). Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.09518-X

Provincie Overijssel. (2020). *Kwaliteit oppervlaktewater kaderrichtlijn water*. Geoportaal Provincie Overijssel. https://www.geoportaaloverijssel.nl/metadata/service/2e27c65f-1149-46f2-965d-673998be8dd5

Provincie Overijssel. (2023). *Water en Klimaat*. Https://Www.Overijssel.Nl/Onderwerpen/Water-En-Klimaat. https://www.overijssel.nl/onderwerpen/water-en-klimaat

Quinlan, A. E., Berbés-Blázquez, M., Haider, L. J., & Peterson, G. D. (2016). Measuring and assessing resilience: broadening understanding through multiple disciplinary perspectives. *Journal of Applied Ecology*, *53*(3), 677–687. https://doi.org/10.1111/1365-2664.12550

Raadgever, T., Booister, N., & Steenstra, M. K. (2018). Flood risk management strategies. In *Flood Risk Management Strategies and Governance* (pp. 93–100). Springer International Publishing. https://doi.org/10.1007/978-3-319-67699-9_8

Rannow, S., Loibl, W., Greiving, S., Gruehn, D., & Meyer, B. C. (2010). Potential impacts of climate change in Germany-Identifying regional priorities for adaptation activities in spatial planning. *Landscape and Urban Planning*, *98*(3–4), 160–171. https://doi.org/10.1016/j.landurbplan.2010.08.017

Renschler, C. S., Frazer, A. E., Arendt, L. A., Cimellaro, G.-P., Reinhorn, A. M., & Bruneau, M. (2010). *A Framework for Defining and Measuring Resilience at the Community Scale: The PEOPLES Resilience Framework. Technical Report MCEER-10-0006*. http://mceer.buffalo.edu

Runhaar, H., Driessen, P. P. J., & Soer, L. (2009). Sustainable urban development and the challenge of policy integration: An assessment of planning tools for integrating spatial and environmental planning in the Netherlands. *Environment and Planning B: Planning and Design*, *36*(3), 417–431. https://doi.org/10.1068/b34052

Schelfaut, K., Pannemans, B., van der Craats, I., Krywkow, J., Mysiak, J., & Cools, J. (2011). Bringing flood resilience into practice: The FREEMAN project. *Environmental Science and Policy*, *14*(7), 825–833. https://doi.org/10.1016/j.envsci.2011.02.009

Schipper, E. L. F., & Langston, L. (2015). *A comparative overview of resilience measurement frameworks: analyzing indicators and approaches - ODI Working paper 422*. https://doi.org/10.13140/RG.2.1.2430.0882

Schlink, F. J. (1919). The concept of resilience with respect to indicating instruments. *Journal of the Franklin Institute*, *187*(2), 147–169.

Sekercioglu, C. H. (2010). Ecosystem functions and services. In N. S. Sodhi & P. R. Ehrlich (Eds.), *Conservation Biology for All* (pp. 45–72). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199554232.003.0004

Sellberg, M. M., Wilkinson, C., & Peterson, G. D. (2015). Resilience assessment: a useful approach to navigate urban sustainability challenges. *Ecology and Society*, *20*(1), art43. https://doi.org/10.5751/ES-07258-200143

Sharafi, L., Zarafshani, K., Keshavarz, M., Azadi, H., & van Passel, S. (2020). Drought risk assessment: Towards drought early warning system and sustainable environment in western Iran. *Ecological Indicators*, *114*, 106276. https://doi.org/10.1016/j.ecolind.2020.106276

Sharifi, A. (2016). A critical review of selected tools for assessing community resilience. *Ecological Indicators*, *69*, 629–647. https://doi.org/10.1016/j.ecolind.2016.05.023

Siebeneck, L., Arlikatti, S., & Andrew, S. A. (2015). Using provincial baseline indicators to model geographic variations of disaster resilience in Thailand. *Natural Hazards*, *79*(2), 955–975. https://doi.org/10.1007/s11069-015-1886-4

Singletary, L., Koebele, E., Evans, W., Copp, C. J., Hockaday, S., & Rego, J. J. (2022). Evaluating stakeholder engagement in collaborative research: co-producing knowledge for climate resilience. *Socio-Ecological Practice Research*, *4*(3), 235–249. https://doi.org/10.1007/s42532-022-00124-8

Sivakumar, M. V. K., Stefanski, R., Bazza, M., Zelaya, S., Wilhite, D., & Magalhaes, A. R. (2014). High Level meeting on national drought policy: Summary and major outcomes. *Weather and Climate Extremes*, *3*, 126–132. https://doi.org/10.1016/j.wace.2014.03.007

Sival, M., Fischer, L., Rouweler, J., Ter Riet, N., & Smelt, F. (2022). *Regionaal Risicoprofiel Twente 2022*. https://www.vrtwente.nl/over-de-veiligheidsregio/documenten

Small, N., Munday, M., & Durance, I. (2017). The challenge of valuing ecosystem services that have no material benefits. *Global Environmental Change*, *44*, 57–67. https://doi.org/10.1016/j.gloenvcha.2017.03.005

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, *16*(3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Staron, M., Niesel, K., & Meding, W. (2015). Selecting the Right Visualization of Indicators and Measures - Dashboard Selection Model. In A. Kobyliński, B. Czarnacka-Chrobot, & J. Świerczek (Eds.), *Software Measurement - IWSM Mensura 2015, LNBIP 230* (pp. 130–143). Springer International Publishing Switzerland. https://doi.org/10.1007/978-3-319-24285-9

Stirling, A. (2007). A general framework for analysing diversity in science, technology and society. *Journal of the Royal Society Interface*, *4*(15), 707–719. https://doi.org/10.1098/rsif.2007.0213

Stoessel, E. T. (1994). The alliance between uncertainty and credibility. *The Leading Edge*, *13*(4), 270–272. https://doi.org/https://doi.org/10.1190/1.1437019

Sullivan, C. (2002). Calculating a Water Poverty Index. *World Development*, *30*(7), 1195–1210. https://doi.org/https://doi.org/10.1016/S0305-750X(02)00035-9

Sutton, J., & Tierney, K. (2006). Disaster Preparedness; Concepts, Guidance and Research. In *Assessing Disaster Preparedness Conference*. Fritz Institute. http://www.colorado.edu/hazards

Swarnam, T. P., Velmurugan, A., Ravisankar, N., Singh, A. K., & Zamir Ahmed, S. K. (2018). Diversification of Island Agriculture – A Viable Strategy for Adaptation to Climate Change. In *Biodiversity and Climate Change Adaptation in Tropical Islands* (pp. 553–575). Elsevier. https://doi.org/10.1016/B978-0-12-813064-3.00020-X

Tamburini, G., Bommarco, R., Wanger, T. C., Kremen, C., van der Heijden, M. G. A., Liebman, M., & Hallin, S. (2020). Agricultural diversification promotes multiple ecosystem services without compromising yield. *Science Advances*, *6*(45). https://doi.org/10.1126/sciadv.aba1715

Tanner, T., Mitchell, T., Polack, E., & Guenther, B. (2009). Urban Governance for Adaptation: Assessing Climate Change Resilience in Ten Asian Cities. *IDS Working Papers*, *2009*(315), 01–47. https://doi.org/10.1111/j.2040-0209.2009.00315_2.x

Taşan-Kok, T., Stead, D., & Lu, P. (2013). Chapter 3 Conceptual Overview of Resilience: History and Context. In A. Eraydin & T. Taşan-Kok (Eds.), *Resilience Thinking in Urban Planning, GeoJournal Library: Vol. GEJL 106* (pp. 39–51). Springer. https://doi.org/10.1007/978-94-007-5476-8_3

Tong, P. (2021). Characteristics, dimensions and methods of current assessment for urban resilience to climate-related disasters: A systematic review of the literature. *International Journal of Disaster Risk Reduction*, *60*, 102276. https://doi.org/10.1016/j.ijdrr.2021.102276

Tran, D., Borisova, T., & Beggs, K. (2023). The Cost of Alternative Water Supply and Efficiency Options under Uncertainty: An Application of Modern Portfolio Theory and Chebyshev's Inequality. *Earth*, *4*(1), 40–65. https://doi.org/10.3390/earth4010003

Tuihedur Rahman, H. M., Albizua, A., Soubry, B., & Tourangeau, W. (2021). A framework for using autonomous adaptation as a leverage point in sustainable climate adaptation. *Climate Risk Management*, *34*, 100376. https://doi.org/10.1016/j.crm.2021.100376

Turkelboom, F., Raquez, P., Dufrêne, M., Raes, L., Simoens, I., Jacobs, S., Stevens, M., de Vreese, R., Panis, J. A. E., Hermy, M., Thoonen, M., Liekens, I., Fontaine, C., Dendoncker, N., van der Biest, K., Casaer, J., Heyrman, H., Meiresonne, L., & Keune, H. (2013). Chapter 18 CICES Going Local: Ecosystem Services Classification Adapted for a Highly Populated Country. In *Ecosystem Services: Global Issues, Local Practices* (pp. 223–247). Elsevier Inc. https://doi.org/10.1016/B978-0-12-419964-4.00018-4

Tyler, S., & Moench, M. (2012). A framework for urban climate resilience. In *Climate and Development* (Vol. 4, Issue 4, pp. 311–326). https://doi.org/10.1080/17565529.2012.745389

Tyler, S., Nugraha, E., Nguyen, H. K., Nguyen, N. Van, Sari, A. D., Thinpanga, P., Tran, T. T., & Verma, S. S. (2016). Indicators of urban climate resilience: A contextual approach. *Environmental Science and Policy*, *66*, 420–426. https://doi.org/10.1016/j.envsci.2016.08.004

Uittenbroek, C. J., Janssen-Jansen, L. B., & Runhaar, H. A. (2013). Mainstreaming climate adaptation into urban planning: Overcoming barriers, seizing opportunities and evaluating the results in two Dutch case studies. *Regional Environmental Change*, *13*(2), 399–411. https://doi.org/10.1007/s10113-012-0348-8

UNCCD. (2019). *Drought Resilience, Adaptation and Management Policy Framework: Supporting Technical Guidelines*.

UNDP. (2014). *Community Based Resilience Analysis (CoBRA) Conceptual Framework and Methodology*. https://www.undp.org/library/cobra-conceptual-framework

Universitat International de Catalunya. (2018). *New International Master in City Resilience Design and Management*. https://masteremergencyarchitecture.uic.es/2018/07/10/new-international-master-in-city-resilience-design-and-management/

UN-Water. (2006). *UN-Water Task Force on Monitoring; Water Monitoring, Mapping Existing Global Systems and Initiatives Background Document*. http://www.pacificwater.org/userfiles/file/UNW_MONITORING_REPORT.pdf

Urquijo, J., Pereira, D., Dias, S., & De Stefano, L. (2017). A methodology to assess drought management as applied to six European case studies. *International Journal of Water Resources Development*, *33*(2), 246–269. https://doi.org/10.1080/07900627.2016.1174106

Van Aalst, J. W. (2017). *2017-Ro5-Twente.jpg*. Wikimedia Commons.

van Aken, J. E. (2004). Management Research Based on the Paradigm of the Design Sciences: The Quest for Field-Tested and Grounded Technological Rules. *Journal of Management Studies*, *41*(2), 219–246. https://doi.org/10.1111/j.1467-6486.2004.00430.x

van Aken, J. E. (2013). Design Science: Valid Knowledge for Socio-technical System Design. In M. Helfert & B. Donnellan (Eds.), *Communications in Computer and Information Science* (Vol. 388, pp. 1–13). Springer. https://doi.org/10.1007/978-3-319-04090-5

van Beek, E., & Arriens, W. L. (2016). Water Security: Putting the Concept into Practice. *TEC Background Papers, Global Water Partnership (GWP)*, *20*. https://aquadoc.typepad.com/files/gwp_tec20_web.pdf

van Buuren, A., Driessen, P. P. J., van Rijswick, M., Rietveld, P., Salet, W., Spit, T., & Teisman, G. (2013). Towards adaptive spatial planning for climate change: Balancing between robustness and flexibility. *Journal for European Environmental and Planning Law*, *10*(1), 29–53. https://doi.org/10.1163/18760104-01001003

van Buuren, A., Keessen, A. M., van Leeuwen, C., Eshuis, J., & Ellen, G. J. (2015). Implementation arrangements for climate adaptation in the netherlands: Characteristics and underlying mechanisms of adaptive governance. *Ecology and Society*, *20*(4). https://doi.org/10.5751/ES-07704-200411

van den Brink, M., Meijerink, S., Termeer, C., & Gupta, J. (2014). Climate-proof planning for flood-prone areas: assessing the adaptive capacity of planning institutions in the Netherlands. *Regional Environmental Change*, *14*, 981–995. https://doi.org/10.1007/s10113-012-0401-7

Van den Eertwegh, G., De Louw, P., Witte, J. P., Van Huijgevoort, M., Bartholomeus, R., Van Deijl, D., Van Dam, J., Hunink, J., America, I., Pouwels, J., Hoefsloot, P., & De Wit, J. (2021). *Droogte in zandgebieden Zuid-, Midden- en Oost-Nederland*. https://publications.deltares.nl/WeL2855.pdf

van Ginkel, K. C. H., Hoekstra, A. Y., Buurman, J., & Hogeboom, R. J. (2018). Urban Water Security Dashboard: Systems Approach to Characterizing the Water Security of Cities. *Journal of Water Resources Planning and Management*, *144*(12). https://doi.org/10.1061/(asce)wr.1943-5452.0000997

Van Hussen, K., Van De Velde, I., Läkamp, R., Van Der Kooij, S., & Hekman, A. (2019). *Economische schade door droogte in 2018*. https://www.ecorys.com/nl/nederland/latest-news/eerste-economische-effecten-van-droogte-2018-beeld

Van Tuinen, E. S. J., Benninga, H. F., & van Houwelingen, J. (2022). *Waterbalans Overijssel, deelopdracht: Twents Waternet - Referentie 127291/22-010.643*. https://klimaatadaptatienederland.nl/actueel/actueel/nieuws/2022/twente-waterbasis-geeft-richting-aanpak-droogte/

Vargas-Farías, A. (2019). *Towards an Action Perspective for Urban Water Security: Design and Use of Indicators as a Boundary Object* [MSc Thesis, University of Twente/Deltares]. http://purl.utwente.nl/essays/80024

Villamayor-Tomas, S. (2018). Polycentricity in the water–energy nexus: A comparison of polycentric governance traits and implications for adaptive capacity of water user associations in Spain. *Environmental Policy and Governance*, *28*(4), 252–268. https://doi.org/10.1002/eet.1813

Vinh, N. Q., & Van, T. T. (2020). Chapter 3 Resilient Spatial Planning for Drought-Flood Coexistence ('DFC'): Outlook Towards Smart Cities. In R. Roggema & A. Roggema (Eds.), *Smart and Sustainable Cities and Buildings* (Vol. 1, pp. 27–40). Springer Nature Switzerland AG. https://doi.org/https://doi.org/10.1007/978-3-030-37635-2

Voinov, A., Kolagani, N., McCall, M. K., Glynn, P. D., Kragt, M. E., Ostermann, F. O., Pierce, S. A., & Ramu, P. (2016). Modelling with stakeholders – Next generation. *Environmental Modelling & Software*, *77*, 196–220. https://doi.org/10.1016/j.envsoft.2015.11.016

Wardekker, A. (2018). Resilience Principles as a Tool for Exploring Options for Urban Resilience. *Solutions*, *9*(1). https://www.thesolutionsjournal.com/article/resilience-principles-tool-exploring-options-

Wardekker, A., de Jong, A., Knoop, J. M., & van der Sluijs, J. P. (2010). Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. *Technological Forecasting and Social Change*, *77*(6), 987–998. https://doi.org/10.1016/j.techfore.2009.11.005

Wardekker, A., Wildschut, D., Stemberger, S., & van der Sluijs, J. P. (2016). Screening regional management options for their impact on climate resilience: an approach and case study in the Venen-Vechtstreek wetlands in the Netherlands. *SpringerPlus*, *5*(1), 750. https://doi.org/10.1186/s40064-016-2408-x

Wardekker, A., Wilk, B., Brown, V., Uittenbroek, C., Mees, H., Driessen, P., Wassen, M., Molenaar, A., Walda, J., & Runhaar, H. (2020). A diagnostic tool for supporting policymaking on urban resilience. *Cities*, *101*. https://doi.org/10.1016/j.cities.2020.102691

Wens, M., Johnson, J. M., Zagaria, C., & Veldkamp, T. I. E. (2019). Integrating human behavior dynamics into drought risk assessment—A sociohydrologic, agent-based approach. *WIREs Water*, *6*(4). https://doi.org/10.1002/wat2.1345

Wheeler, S. A., Hatton MacDonald, D., & Boxall, P. (2017). Water policy debate in Australia: Understanding the tenets of stakeholders' social trust. *Land Use Policy*, *63*, 246–254. https://doi.org/10.1016/j.landusepol.2017.01.035

Wilhite, D. A. (1992). Preparing for Drought: A guidebook for develhping countries. In *UNEP* (Issue 1).

Wilhite, D. A. (2002). Combating Drought through Preparedness. *Natural Resources Forum*, *26*(4), 275–285.

http://digitalcommons.unl.edu/droughtfacpubhttp://digitalcommons.unl.edu/droughtfacpub/36

Wilhite, D. A. (2011). Breaking the Hydro-Illogical Cycle: Progress or Status Quo for Drought Management in the United States. *European Water*, *34*, 5–18. http://drought.unl.edu/Planning/HydroillogicalCycle.aspx

Wilhite, D. A., & Glantz, M. H. (1985). Understanding the Drought Phenomenon: The Role of Definitions. *Water International*, *10*(3), 111–120. https://doi.org/10.1080/02508068508686328

Wilhite, D. A., Sivakumar, M. V. K., & Pulwarty, R. (2014). Managing drought risk in a changing climate: The role of national drought policy. *Weather and Climate Extremes*, *3*, 4–13. https://doi.org/10.1016/j.wace.2014.01.002

WMCN-LCW. (2021). *Landelijk draaiboek waterverdeling en droogte; Informatie-uitwisseling en afstemming van maatregelen en communicatie*. www.helpdeskwater.nl.

World Bank. (2019). *Assessing Drought Hazard and Risk: Principles and Implementation Guidance*. https://www.gfdrr.org/en/publication/assessing-drought-hazard-and-risk

Zakkar, M., & Sedig, K. (2017). Interactive visualization of public health indicators to support policymaking: An exploratory study. *Online Journal of Public Health Informatics*, *9*(2). https://doi.org/10.5210/ojphi.v9i2.8000

Zarafshani, K., Sharafi, L., Azadi, H., & Van Passel, S. (2016). Vulnerability assessment models to drought: Toward a conceptual framework. In *Sustainability (Switzerland)* (Vol. 8, Issue 6). MDPI. https://doi.org/10.3390/su8060588

Ziervogel, G. (2019). *Unpacking the Cape Town Drought: Lessons learned. Report for Cities Support Programme Undertaken by African Centre for Cities*.

Appendices

Appendix A – The designed Assessment Framework for Regional Drought Resilience including indicator explanations

In the subsequent sections, the assessment framework for regional drought resilience is presented, including indicator explanations. For this, each resilience principle and their accompanying operationalisations and indicators are presented in their own sub-appendix.

Appendix A.1 Anticipation and Foresight Principle

Table A. 1 Identified indicators for the [1100] Anticipation and Foresight principle.

Phase	Principle	Operationalisation	Indicators	Explanation	Key references
[1000] Plan/Prepare	[1100] Anticipation and Foresight	[1110] Building knowledge about disturbance, exposure, vulnerability	[1111] Existence of regional climate scenarios	Regional climate scenarios and modelling of their effects are the core of further predictions of trends and patterns regarding droughts. Having these scenarios gives improved understanding on the likelihood of drought occurrence and development in the region.	(Godschalk, 2003; Gunderson, 2009; Lu & Stead, 2013)
			[1112] Assessment of regional drought vulnerability	With in-depth studies of economic, social and environmental (cascading) effects of drought hazards with special attention to critical functions (i.e. potable water network, road-, rail- and water safety infrastructure, medical facilities, communication lines, high-impact industry), there is a solid understanding to base contingency plans on.	(Cutter et al., 2008; Davoudi et al., 2013; Linkov et al., 2014; Lu & Stead, 2013; Tyler & Moench, 2012)
			[1113] Mapping critical functions during drought hazard	Mapping of vulnerable economic and environmental assets and critical functions in drought-prone areas can serve as a first priority establishment.	(Godschalk, 2003)
		[1120] Continuous monitoring of slow variables	[1121] Continuous monitoring of environmental factors	With regard to the natural factors, one can think of geological, atmospheric and oceanic phenomena. The El Niño and La Niña effects and land subsidence could be examples.	(Carpenter et al., 2001)
			[1122] Continuous monitoring of human factors	With regard to human factors, one can think of water extraction and pollution affecting water availability and quality.	(Gober et al., 2016)
			[1123] Continuous monitoring and evaluation for drought-protective infrastructure	With regard to drought protective infrastructure, one can think of green infrastructure, water reservoirs and water network linkages.	(Chelleri et al., 2015; Davoudi et al., 2013; Lu & Stead, 2013)
		[1130] Information management and sharing	[1131] Access of institutions to scientific information and data relating to droughts	The available drought hazard-related knowledge and information should be independently and swiftly accessible to all relevant parties, i.e. government agencies and research institutions, in order to set out best steps and make strategic policy choices.	(Gupta et al., 2010; Moench, 2014; Pahl-Wostl, 2007; Tyler & Moench, 2012)
			[1132] Effective mechanisms for (drought) information storage and sharing are present	To accomplish effective information management for the more tangible forms of knowledge, effective, open and shared information management tools which facilitate integration (i.e. data archives, open access, reports, policy documents) should be in present.	(Pahl-Wostl, 2007)
			[1133] Presence of platforms of exchange among drought-related actors	More intangible forms of knowledge benefit from platforms of exchange, such as brainstorm sessions and workshops, among relevant parties (i.e. policy officials, municipal representatives, project coordinators, …), as a discussion table bringing people and their ideas together.	(Moench, 2014; van den Brink et al., 2014)

Appendix A.2 Preparedness and Planning Ahead Principle

Table A. 2 Identified indicators for the [1200] Preparedness and Planning Ahead principle.

Phase	Principle	Operationali-sation	Indicators	Explanation	Key references
[1000] Plan/Prepare	[1200] Preparedness and Planning Ahead	[1210] Public awareness, risk communication, education and training	[1211] Credible and correct drought information is disclosed via various channels	In order to create awareness, the disclosure of credible and correct information on drought risk, both in general and in specific for a potentially upcoming drought, via various channels should be standard practice by respective governance institutions to households and community organizations	(Lu & Stead, 2013; Schipper & Langston, 2015)
			[1212] Educating the public with guidance documents to minimize impact of drought hazards	Increasing the mitigation capability of the population is achieved through effective and broad drought risk training and with the provision of scripts for action and guidance documents in case a drought hazard occurs.	(Gupta et al., 2010; Norris et al., 2008; Schipper & Langston, 2015)
			[1213] Develop drought risk communication strategies for affected stakeholders through targeted campaigns	Apart from understanding the system and the drought, there should be targeted drought risk communication strategies in place for affected stakeholders, i.e. residents, industry, to ensure they are received.	(Norris et al., 2008)
		[1220] Response and emergency management	[1221] Multiple and reliable communication technologies to for disseminating information	(Emergency) measures need to be communicated with the public in order to get a timely response. This is best done with multiple different ICTs.	(ARUP, 2014; Norris et al., 2008)
			[1222] Presence of drought hazard guidance documents for the authorities	Drought hazard guidance documents for the authorities, i.e. regional drought hazard management plans, drought hazard mitigation plans, emergency response plans and contingency plans, are key in adequate management.	(Raadgever et al., 2018)
			[1223] Presence of reliable drought early warning systems	Reliable early warning systems are essential to provide enough lead time to take actions and extend the window of opportunity for important decisions	(Raadgever et al., 2018; Sharafi et al., 2020; Wilhite, 2002)
		[1230] Preparedness of drought prone economic sector for adverse events	[1231] Information on drought-related risks is available for drought prone economic sectors	Economic sectors prone to droughts (i.e. agricultural and forestry) are provided with information to foster an understanding of drought-related threads, associated risks and vulnerabilities in the business operation as well as opportunities	(Godschalk, 2003; Orhan, 2016)
			[1232] Presence of exchange networks for drought prone economic sectors	The participation of drought prone economic sectors in formal or informal networks of knowledge exchange can facilitate spread and uptake of information and networks can broaden the potential action possibilities.	(Lonsdale et al., 2010; Sutton & Tierney, 2006)
			[1233] Drought is factored in the business practice of drought prone economic sectors	Drought prone economic sectors (i.e. agricultural and forestry) factor the impacts of drought hazards into their business practice (i.e. in business continuity and contingency plans).	(Lonsdale et al., 2010; Orhan, 2016; Sutton & Tierney, 2006)
			[1234] Drought prone economic sectors have drought insurance	The drought insurance ratio is seen as a good proxy to find to what extent economic sectors are preparing their sectors for drought, decreasing vulnerability and increasing resilience.	(Khatibi et al., 2019; Meza et al., 2019)

Appendix A.3 Homeostasis Principle

Table A. 3 Identified indicators for the [1300] Homeostasis principle.

Phase	Principle	Operationalisation	Indicators	Explanation	Key references
[1000] Plan/Prepare	[1300] Homeostasis	[1310] Preservation and restoration of regulating ecosystem services	[1311] Policies are in place for natural areas and ecosystem conservation	Ecosystem services have a stabilizing effect for the desired regime and prevent tipping over critical thresholds. Through policies towards conservation of natural areas and ecosystems, threats to these ecosystem services, such as overexploitation, pollution, habitat destruction, introduction of invasive species and deforestation, are decreased.	(Biggs et al., 2012; Orimoloye et al., 2021)
			[1312] Ecosystem services are valuated in drought policies based on their ecological, socio-cultural and economic value	Ecosystem services are commonly perceived as free public goods, frequently leading to the 'tragedy of the commons'. Their values, if valued at all, are based on economic marginal value and are therefore often drastically underestimated when the service becomes scarcer. Ecosystem services should therefore not only be valued based on their economic value, but also on their ecological value and socio-cultural value.	(Biggs et al., 2012; Sekercioglu, 2010; Small et al., 2017)
			[1313] Policies are in place to create or increase urban greenery	Especially in urban environments ecosystem services are often neglected or deteriorating. By having specific policies towards creating more urban greenery (i.e. green parks, green roofs, urban canopy cover), these ecosystem services are directly improved.	(Biggs et al., 2012; Wardekker et al., 2010)
		[1320] Integrated planning, coordination and collaboration	[1321] Human resources in drought management are adequate	Human resources in terms of number, skills and continuity have a significant impact on how well a region is prepared for drought. All these aspects should be adequate for proper drought management practices.	(Urquijo et al., 2017; Wilhite, 2002)
			[1322] Integrating drought management in other policy domains is mainstreamed	Integration of drought management practices with other policy domains, i.e. spatial planning, drainage plans, urban development, ensure cross-sectoral collaboration and make for more effective outcomes. For this, mainstreaming the incorporation of the drought policies in these other policy domains is key. Ideally, there is a common underlying vision between the different policy domains with an explicit role for drought.	(ARUP, 2014; Runhaar et al., 2009; Smit & Wandel, 2006; Uittenbroek et al., 2013)
			[1323] There are sufficient bridging mechanisms between drought management and other policy domains	If policy domains are to be integrated, they need to function well together: one missing link may hamper implementation of all others. As such, bridging mechanisms, such as specific actors, policies, legislation and other tools and instruments, that link and align the different strategies, are essential.	(Kern et al., 2019; Raadgever et al., 2018)
		[1330] Inclusiveness and equity standards	[1331] Support of government authorities for vulnerable population is adequate and aims at social equity	Certain groups of the population are particularly vulnerable to drought effects, based on i.e. age, health or economic welfare. To facilitate these (marginalized) groups and achieve equity, government authorities should 1) know who are vulnerable and where they live, and 2) provide them with supportive resources and assistance, i.e. tailor-made mitigation programs based on specific needs, and legal rights and entitlements.	(Norris et al., 2008; Tyler & Moench, 2012; Zarafshani et al., 2016)
			[1332] There is an appropriate level of transparency and accountability in policy-making processes	Processes surrounding policy-making and financial expenditures of governing authorities should be transparent to the public. Additionally, it should have accountability mechanisms which the public can use to counter poor performance or (perceived) unjust allocation of risks and benefits. Such accountability mechanisms have shown to incentivise policy-makers to reduce destabilizing conflicts and strengthen weak links in society. It thus exhibits a stabilizing effect.	(Folke, 2006; Gupta et al., 2010; Lebel et al., 2006; van den Brink et al., 2014)
			[1333] Ex-ante policy assessments with a focus on the distributional consequences is appropriately mainstreamed	Proper ex ante policy assessments with an explicit focus on the distributional consequences (regarding uneven social and spatial impacts) of the potential implementation of drought management policies and measures, should be appropriately mainstreamed in policy-making processes.	(Adger et al., 2005; Helming et al., 2011)
		[1340] Clearly defined	[1341] Responsibility for drought management is legally and clearly defined	There are many governing authorities and other stakeholders involved in drought management. These should have legally-binding and clearly defined responsibilities, tasks and roles. This includes the legal financial liability in case damages due to drought effects occur.	(Gupta et al., 2010; Raadgever et al., 2018; van den Brink et al., 2014)

Phase	Principle	Operationali-sation	Indicators	Explanation	Key references
		stakeholder responsibilities	[1342] The definition of responsibilities in drought management is sufficiently transparent	The defined distribution of responsibilities, tasks and roles of governing authorities and other stakeholders involved in drought management should be sufficiently transparent for these stakeholders as well as for stakeholders not directly involved in drought management	(de Bruijn, 2004; Raadgever et al., 2018)
			[1343] Stakeholders are sufficiently aware of their responsibilities and roles in drought management	The distribution of responsibilities, tasks and roles in drought management are not only defined in a clear, legally binding and transparent manner, but all involved stakeholders are also aware of their own and other's responsibilities, tasks and roles. This also holds for the general public.	(Bruneau et al., 2003; Gupta et al., 2010; van den Brink et al., 2014)
		[1350] Quick notification of disturbances	[1351] Information on (oncoming) droughts can be gathered in a timely manner	Especially before and during acute drought crises, the information on (oncoming) droughts should be gathered in a timely manner, i.e. through a comprehensive drought early warning system. , to widen the window of opportunity for appropriate policy decisions.	(Lu & Stead, 2013; Raadgever et al., 2018; Wilhite et al., 2014)
			[1352] Drought information dissemination to relevant stakeholders has an appropriate rapidity	Especially before and during acute drought crises, the gathered information on (oncoming) droughts should be disseminated to relevant stakeholders in a timely manner. That way, the window of opportunity to make appropriate policy decisions is as wide as possible and adaptations to the SES can be made to maintain its functions.	(Lu & Stead, 2013; Raadgever et al., 2018; Wilhite et al., 2014)

Appendix A.4 Robustness and Buffering Principle

Table A. 4 Identified indicators for the [2100] Robustness and Buffering principle.

Phase	Principle	Operationalisation	Indicators	Explanation	Key references
[2000] Absorb	[2100] Robustness and Buffering	[2110] Measures and installations towards low water demand	[2111] There is sufficient presence of (structural) measures and installations to decrease water demand	The robustness to droughts can be improved through (structural) measures and installations decreasing water demand. This includes all of industrial, agricultural, environmental and household water demand. These can be in the form of physical measures such as continuous water leak detectors, water levees, highly efficient irrigation systems, evaporation-blockers in freshwater lakes, water-reuse facilities, but also social behavioural measures through i.e. communication strategies.	(Godschalk, 2003; Mens, 2015)
			[2112] There is a functioning process of periodical assessment and improvement of present (structural) measures and installation to reduce water demand	To ensure the reduced water demand through the (structural) measures and installations is maintained, they have periodic assessments and improvements where possible. This could be in the form of periodic assessments of the efficiency of the water distribution network and the system of weirs, but also of steering on innovations for further water demand reduction.	(Cutter et al., 2013; Mens, 2015)
		[2120] Creating buffer capacities	[2121] The baseline water stress during a dry year is absent	To assess the possibility to create a water buffer capacity, the baseline water stress during a dry year is seen as a highly relevant proxy. The lower the baseline water stress is, the more water there is available to create the buffer capacity. In order to calculate the water stress, the water balance provides information on the water demand and the renewable supply.	(Meza et al., 2019; van Ginkel et al., 2018)
			[2122] Sustainable water storage capacity exceeds demand under drought conditions	If there is a large water buffer within the region, a period of drought will have less impact on the region's functionalities. However, for this to happen, there must also be sufficient sustainable water storage capacity in the region. Water storage capacity can be improved through, among other things, adapted water level management, natural soil management (such as steering for higher concentration of organic matter), additional surface storage (rain barrels, ponds, inundation-proof built environment) and artificial recharge of aquifers (or Managed Aquifer Recharge, such as with green infrastructure or additional infiltration basins).	(Crossman, 2018; Mens, 2015)
			[2123] The regional water sources are sufficient quality	The water quality of the available volumetric water buffer (both surface water and ground water) within the region should be sufficient to use for the intended functions.	(Meza et al., 2019; van Ginkel et al., 2018)
			[2124] There is a sufficiently large regional financial buffer	A high financial buffer capacity is relevant as drought can have severe economic impacts across a region, and as such is related to how well the population could handle economic downturn due to drought hazards. This can be both directly in i.e. agriculture, forestry, shipping, and indirectly i.e. due to property damages from land subsidence.	(Cutter et al., 2010; Meza et al., 2019)
		[2130] Impact and risk reducing spatial planning and planning practice	[2131] Drought risk is sufficiently embedded in spatial planning	Certain land use practices can be unsustainable in areas with higher drought risks. By embedding these drought risks in the spatial planning, these risks are directly mitigated, making the system more robust than otherwise would be the case. This can be i.e. through land consolidation when functions vulnerable to droughts are situated in areas vulnerable to drought, as well as in the design of the (public) spaces.	(Godschalk, 2003; Hoa & Vinh, 2018; Tyler & Moench, 2012)
			[2132] There is sufficient attention to drought and its effects in laws and regulations	Laws and Regulations can play an important role in achieving a higher level of drought resilience, through for example drought-proof building codes and spatial regulations. These include both structural safety for the built environment itself, as well as 'spatial/environmental safety' where the built environment aids in water scarcity prevention in its direct vicinity. For the prior, safety standards to combat drought-induced effects (such as from land subsidence) on critical infrastructure (i.e. dikes, roads, canals and subsurface infrastructure) or high-rise buildings are relevant. For the latter, it could include quotas water infiltration within the project's surface area or norms for water-efficient facilities in and around the built environment.	(Fu & Tang, 2013; Godschalk, 2003)
			[2133] Drought resilience is actively and sufficiently	Drought resilience of nature should be an explicit element in nature management strategies. This ensures that the nature is managed in such a way that it can better withstand droughts and better recover after the drought has passed. This can be done in various ways, for instance through conscious groundwater level	(Fu & Tang, 2013; Kooyers, 2015)

Phase	Principle	Operationali-sation	Indicators	Explanation	Key references
			incorporated in nature management strategies	management, but also by planting drought-resistant vegetation. This applies to both nature reserves and public green spaces.	
			[2134] The region has (a high percentage of areas with) permeable soils	Infiltration of precipitation leads to increased (ground)water storage and slows down the water outflow from the region. For infiltration, a permeable soil is a necessity. The higher the percentage of impermeable soils a region has, the less water can infiltrate to recharge the groundwater storage and the quicker water flows out of the region.	(Debusk & Wynn, 2011; Kavdir et al., 2014)

Appendix A.5 Redundancy Principle

Table A. 5 Identified indicators for the [2200] Redundancy principle.

Phase	Principle	Operationalisation	Indicators	Explanation	Key references
[2000] Absorb	[2200] Redundancy	[2210] Institutional redundancy with overlapping functions and roles	[2211] Presence of a multilevel polycentric drought governance system	The drought governance system should be somewhat decentralised to the local and regional level and thus have multiple decision-making centres ('polycentric') at different levels of government ('multilevel'). Each of these decision-making centres has an appropriate degree of autonomy on drought management. This autonomy should also be suitably embedded in the authority of the higher level of government, ensuring overlap of roles and functions. If this is the case, higher levels of government have a well-functioning monitoring function to establish minimum requirements, and lower levels of government have the freedom to go beyond these minimum requirements based on their own ambitions.	(Aligica & Tarko, 2012; Biggs et al., 2012; Bródy et al., 2018; Carlisle & Gruby, 2019; Nelson et al., 2007; Pahl-Wostl et al., 2020; Villamayor-Tomas, 2018)
			[2212] The regional drought governance system is well-coordinated	For a governance system to work adequately, it is dependent on strong and clear vertical as well as horizontal coordination such that collaboration is fostered and every stakeholder knows its role, function, rights and responsibilities within that system, and acts upon them.	Morisson et al. 2023, Pahl-Wostl and Knieper 2023]
		[2220] Technological redundancy in important functions and services	[2221] There is a sufficient level of redundancy mechanisms for and in drought-sensitive critical infrastructure and networks	Drought has many (indirect) chain effects. This is particularly important in drought-prone critical infrastructure and networks, such as communication lines, transport networks, drinking water distribution network or underground infrastructure networks. In the presence of functional redundancy in systems, these chain effects can be mitigated. Functional redundancy in critical infrastructure ensures 'safe failure' of system components, where alternative components can take over the function of the failed component. In drought, for example, this could mean a highly interconnected water distribution network, where local problems can be solved through other components and it does not cause larger service interruptions.	(Tyler & Moench, 2012)
			[2222] There is a sufficient level of redundancy within ecosystem services	Ecosystem services refer to the direct and indirect benefits an ecosystem has on humanity. Within an ecosystem, different flora and fauna have different functions. Through environmental policies focused on redundancy within these functions, the different ecosystem services can be maintained for a prolonged period of time during a drought hazard, even though some flora and/or fauna may not survive the drought. Examples of ecosystem services that may come under pressure due to prolonged droughts and its consequential ecological damages include: regulation of soil and water quality, regulation of local and regional climates, regulation of soil erosion, preservation of wildlife habitat, shielding from sight and sound pollution, nature tourism, preservation of cultural heritage.	(Orimoloye et al., 2021; Sekercioglu, 2010; Turkelboom et al., 2013)
		[2230] Compart-mentalization and modularity	[2231] There is a sufficient level of institutional modularity (self-reliance) of parties within the drought governance system to decrease or prevent high-risk cascading effects between parties	If an organisation (e.g. water board or a municipality) within the drought management system (the organisation in which parties involved in drought management are contained and organized, either directly in decision-making or indirectly as a sounding board) cannot perform its functions and roles for whatever reason, this may affect what another organisation can do in its functions and roles. This may be because, for example, the drought management-related available capacities (human and/or financial capital) at one organisation is (strongly) affected by what another organisation can make available. By incorporating a sufficient level of institutional modularity or self-reliance (and thereby reducing dependency between organisations) within the drought governance system, these negative effects are mitigated or even avoided.	(Biggs et al., 2012; Tyler & Moench, 2012)
			[2232] There is a sufficient level of compartmentalization within drought-sensitive critical infrastructure to avoid cascading drought effects	In the presence of sufficiently compartmentalised systems within critical infrastructure (such as communication lines, transport networks, drinking water distribution network or underground infrastructure networks), the effects of a failing system (sub)component can remain controlled within that specific (sub)component (e.g. by closure), without having negative effects on other (sub)components. This way, cascading (indirect) effects of drought are mitigated or prevented.	(Biggs et al., 2012; Tyler & Moench, 2012)

Appendix A.6 Diversity Principle

Table A. 6 Identified indicators for the [2300] Diversity principle.

Phase	Principle	Operationalisation	Indicators	Explanation	Key references
[2000] Absorb	[2300] Diversity	[2310] Functional diversity	[2311] The water supply portfolio has a sufficient level of diversification	The most important function to maintain during a drought is the water supply. Having a potentially highly diverse water supply portfolio, significantly improves the region's ability to absorb the drought hazard. The water supply portfolio could be extended through additional water transport modes coming in from other regions, or with alternative water sources within the region.	(Gonzales & Ajami, 2019; Tran et al., 2023)
			[2312] There is a sufficient level of spatial distribution of drought-sensitive critical infrastructure, industry and services across the region	Due to the spatial distribution of drought-sensitive critical infrastructure, industry and services across the region, they differ in potential exposure and vulnerability to the drought hazard. Critical infrastructure includes i.e. communication, transport networks, water use distribution network or infrastructure grids. Critical industry includes i.e. industry of high regional economic importance and which is sensitive to drought or water scarcity. Critical services include i.e. the fire brigade and physical and mental health services.	(Edwards et al., 2019; Pahl-Wostl, 2007; Tyler & Moench, 2012)
		[2320] Economic diversity	[2321] There is a low regional economic dependency on sectors vulnerable to drought	Drought hazards will have a smaller impact on a diversified regional economy than an economy that is dependent on drought-prone sectors (i.e. agriculture, forestry).	(Coulson et al., 2020; Cutter et al., 2010; Meza et al., 2019)
			[2322] There is a sufficient level of economic diversity within sectors vulnerable to drought	Drought hazards will have a smaller impact on drought-prone sectors if these establish economic diversity within their business-practices with revenue sources that are less drought-prone. An example could be through broadening activities such as towards the tourism-sector or subsidized ecosystem services.	(Swarnam et al., 2018; Tamburini et al., 2020)
		[2330] Institutional diversity	[2331] There is a just level of institutional disciplinary variety within the drought governance system	An appropriate degree of diversity of disciplinary background (different government levels, but also sectors with high drought interests) of stakeholders within the drought management system (the organisation in which parties involved in drought management are contained, either directly in decision-making or indirectly as a sounding board) leads to great diversity and creativity in solutions. In this way, the different disciplinary backgrounds of the parties can fill knowledge gaps, make connections and identify challenges. In addition, the broad representation ensures that all interests are considered in these solutions. Moreover, this broad stakeholder involvement also increases institutional memory, which helps in finding new solutions.	(Biggs et al., 2012; Folke et al., 2005; Grêt-Regamey et al., 2019; Urquijo et al., 2017)
			[2332] There is an appropriate level of institutional managerial disparity within the drought governance system	A specific administrative structure within an organisation can lead to a particular form of solution-oriented and strategic thinking. By having an appropriate degree of administrative inequality within organisations in the drought governance system, a more diverse palette of ideas can be put forward, possibly leading to better solutions. This administrative inequality can take the form of the organisations' sizes, cultures, experience levels of human capital, funding mechanisms and internal structures, among others.	(Edwards et al., 2019; Pahl-Wostl, 2007; Tyler & Moench, 2012)
			[2333] There is an appropriate level of institutional balance within the drought governance system	The various parties within the drought management system must have an appropriate degree of balance in order to function optimally and reduce the likelihood of neglecting certain interests. In essence, this means establishing an agreed and fair "evenness" of the numerical number of parties from each sector within the decision-making centres, as well as the power of the parties present within them.	(Stirling, 2007)
			[2334] There is sufficient presence of effective drought-centred partnerships and platforms for networking and knowledge exchange between different stakeholder groups, both sectoral as well as cross-sectoral	The interaction, knowledge exchange and collaboration between different stakeholder groups (both within their own sector and cross-sectoral, e.g. governments, academia, industry, agricultural sector, NGOs and citizens) are crucial for effective decision-making in times of uncertainty and change. This is best operationalised through both formal and informal collaboration between these stakeholder groups, with appropriate and sufficient platforms for acquaintance and knowledge exchange (such as periodic workshops, brainstorming sessions and symposia).	(ARUP, 2014; Folke et al., 2005)

Appendix A.7 Flatness Principle

Table A. 7 Identified indicators for the [3100] Flatness principle.

Phase	Principle	Operationali-sation	Indicators	Explanation	Key references
(3000) Recover	[3100] Flatness	[3110] Institutional decentralization and autonomy	[3111] Local and regional governing bodies have appropriate legal capabilities to make autonomous decisions, authorize plans and legislate tailor-made policies and measures	The adaptive capacity for quick recovery is higher when the legal authority to make autonomous decisions, authorize plans and legislate tailor-made policies and measures is appropriately decentralized to local and regional governing levels. Such an appropriate level of decentralization allows for policy-making that is tailored to the local/regional situation. In addition, with their decentralized structure, the local and regional governing bodies are able to appropriately respond to differing scales of the drought through applying knowledge suitable for specific socioecological, geographical and environmental contexts. Therefore, they can develop locally-informed and scale-specific action and interventions.	(Biggs et al., 2012; Lebel et al., 2006; Raadgever et al., 2018; Tanner et al., 2009)
			[3112] Local and regional governing bodies have sufficient financial independence	Apart from the legal authority to make autonomous decisions, authorize plans and legislate tailor-made policies and measures that comes with an appropriate level of decentralization to the local and regional governing bodies, these bodies should also have sufficient financial independence to do so.	(Knüppe & Pahl-Wostl, 2013; Lebel et al., 2006)
		[3120] Broad and inclusive stakeholder participation	[3121] Non-governmental stakeholders are sufficiently and actively involved from an early stage in policy-making for drought	Participatory policy-making is an important element in creating flatness for quick recovery from a drought hazard. Active and early involvement of non-governmental stakeholders in drought policy-making results in a shared understanding of issues. Such a shared understanding is the starting point for coordinated action, mobilization of resources and self-organization in case of a (drought) hazard. Furthermore, it can result in a feeling of shared ownership which safeguards ongoing and sustained action from communities after the implementation of policies and measures.	(ARUP, 2014; Biggs et al., 2012; van den Brink et al., 2014; Wardekker et al., 2010)
			[3123] There is a high societal trust in governing authorities	In order to have a broad participation and maintain stakeholder participation, a high level of societal trust in the governing authorities is required. Societal trust directly impacts the willingness of citizens and other stakeholders to come to compromises and comply with demands and regulations, which often have short-term sacrifice for longer-term benefit.	(Brown, 2022; Wheeler et al., 2017)
		[3130] Room for autonomous change	[3131] Drought prone economic sectors are sufficiently guided autonomous drought adaptation	One of the key components of flatness is strengthening the capacity of the drought-struck economic sectors to self-organize and self-regulate (i.e. autonomous adaptation). To do so, these economic sectors should have sufficient opportunities to achieve funding and find possible solutions, tools and guidance on how they can mitigate the drought impacts in a manner that is not detrimental for planned adaptation from the formal drought management policies.	(Schelfaut et al., 2011; Tuihedur Rahman et al., 2021; Wardekker et al., 2010)
			[3132] The public has sufficient guidance on how to mitigate drought impacts through small-scale measures on private property	One of the key components of flatness is strengthening the capacity of the public to self-organize and self-regulate through small-scale measures on private property (i.e. autonomous adaptation). To do so, the public should have sufficient opportunities to achieve funding and find possible solutions, tools and guidance on how they can mitigate the drought impacts through such small-scale measures on private property, in a manner that is not detrimental for planned adaptation from the formal drought management policies.	(Schelfaut et al., 2011; Tuihedur Rahman et al., 2021; Wardekker et al., 2010)
			[3133] The public has sufficient opportunity to form legal voluntary organizations for small-scale autonomous projects	Having opportunities to form legal (voluntary) organizations, raise funds and undertake activities based on the emerging local/regional needs, results in a significant increase in bottom-up initiatives and autonomous small-scale projects for drought mitigation. This directly increases the capabilities of the public to self-organise.	(Tyler & Moench, 2012)

Appendix A.8 High Flux Principle

Table A. 8 Identified indicators for the [3200] High Flux principle.

Phase	Principle	Operationali-sation	Indicators	Explanation	Key references
(3000) Recover	[3200] High Flux	[3210] Availability of and access to resources	[3211] The mechanisms for financial support after drought-induced damages are sufficiently swift to apply for	An important element in the recovery of drought struck parties is a swift pay-out through (drought) insurances or contingency funds or damage reimbursement from national, regional or municipal funds. For this to be swift, pre-event arrangements on legal liability of drought-induced damages are required, as well as on the prerequisites to be eligible for the contingency funds.	(ARUP, 2014; Tyler & Moench, 2012; van den Brink et al., 2014)
			[3213] The mechanisms providing supportive resources and assistance to vulnerable population in drought-struck areas are sufficiently swift	The ability of the population to quickly recover from drought-induced effects depend to a great extent on their specific socioeconomic situation. Certain groups within a drought-struck population are especially vulnerable and as such have additional needs, based on i.e. their age, health, or economic welfare. There should be mechanisms in place to provide additional supportive resources and assistance to these groups and these should be sufficiently swift.	(Godschalk, 2003)
			[3214] The influence of corruption is negligible in regional drought management	In order to plan for and respond to disturbances such as drought, governing authorities need to be both willing and able to act. Corruption, which often sears during crises, erodes both the authorities' will to act (through preventing incentives) and its ability to act (through draining of resources and worsening societal trust). As such, controlling and preventing corruption is an essential element in resilience building.	(Brown, 2022; Meza et al., 2019)
		[3220] Social, institutional and environmental networks	[3221] There is sufficient presence of partnerships and networks with an explicit role for the drought context	Through the establishment of strong formal and informal partnerships and networks that have an explicit role for the drought context, drought information sharing is incited, mutual trust is developed, and a flow of resources and ideas is generated more easily. This can i.e. be in the form of drought forums or bilateral aid agreements. This way, the rapidity of recovery is increased.	(Biggs et al., 2012; Norris et al., 2008; Tyler & Moench, 2012; van den Brink et al., 2014)
			[3222] There is a sufficient level of social cohesion within and between communities	Through the establishment of strong formal and informal social networks, the social cohesion within these networks is significantly improved. This leads to an improved flow of resources and ideas within these social networks during hazardous situations. These networks can be improved through local and community-level projects	(de Bruijn, 2004; Folke, 2006; Norris et al., 2008)
			[3223] Governing authorities sufficiently and actively aim to improve social networks within and between communities	To further improve the social cohesion within and between communities, governing authorities should play an important role in connecting to and strengthening existing networks and community-led initiatives. Governing authorities should also sufficiently contribute to the emergence of new social networks.	(Biggs et al., 2012; Norris et al., 2008; Tyler & Moench, 2012; van den Brink et al., 2014)
			[3224] Environmental areas have a sufficiently high connectivity	Having a high connectivity in environmental areas (i.e. nature reserves, but also urban greenery patches) and thereby having accessible biodiversity is pivotal in ecosystem recovery after a disturbance. Connecting habitat patches and landscapes, i.e. through green—blue-infrastructure, ensures that required links between ecosystems are preserved or improved, and the ecosystems can recover more rapidly.	(Biggs et al., 2012; Folke, 2006; Gunderson, 2009; Holling, 2001)
		[3230] Having options for flexibility in response	[3231] The human resources within the drought governance system can cope with changing conditions sufficiently well	The cascading effects of droughts are inherently uncertain. Therefore, also the most appropriate measure during a drought hazard is subject to change under changing conditions. The human resources within the drought governance system should be able to cope with these changing conditions. This can be fostered through i.e. explicit education on leadership, entrepreneurship and skills development in changing conditions.	(ARUP, 2014; Moench, 2014; Tyler & Moench, 2012)

Appendix A.9 Learning and Reflectivity Principle

Table A. 9 Identified indicators for the [4100] Learning and Reflectivity principle.

Phase	Principle	Operationalisation	Indicators	Explanation	Key references
[4000] Adapt	[4100] Learning and Reflectivity	[4110] Capacity to reflect and learn from past experiences in drought management policy	[4111] Lessons learnt from previous drought hazards are comprehensively formulated and documented in accessible reports	Past experiences foster understanding and anticipation of when and where a hazard occurs and what cascading impacts it can have due to system failures, but also on the recovery and adaptation of the region after that event. These experiences can be utilized to enhance preparedness for the following drought hazards, if the lessons learned are comprehensively documented and documented in accessible reports.	(Cutter et al., 2008; Gunderson, 2009; Schipper & Langston, 2015; van den Brink et al., 2014)
			[4112] The performance of drought management plans and strategies are continuously evaluated and lessons learnt are formulated in accessible reports	Each experience from past or present drought management policy can inform future drought management policy plans. Therefore, it is highly relevant that policy-makers monitor the performances of their drought management activities (i.e. the plans and strategies they implemented). Based on this monitoring, comprehensive and accessible lessons learnt need to be drafted.	(Cutter et al., 2013; Gupta et al., 2010; Lonsdale et al., 2010)
			[4113] Emerging drought management research is continuously monitored to learn lessons from	Apart from own past experiences, lessens can also be learnt from emerging research into drought management. It must be mainstreamed by policy-makers to continuously monitor this research field to learn lessons from, such that they always have the most recent knowledge available.	(Lonsdale et al., 2010)
			[4114] Learning outputs continuously inform drought management policy changes, plans, strategies and standards	Although writing the lessons learnt-reports does inform those who made the report, it does not immediately influence the regional resilience at large. To do so and really make use of the available knowledge from past experiences, the lessons learnt must be internalized into the region's drought policy (i.e. planning, implementation activities, preparedness and recovery mechanisms). Effective mechanisms should be in place that ensure iteration and incorporation of new information from the lessons learned in strategies, policy development and decision-making.	(Davoudi et al., 2013; Folke, 2006; Schipper & Langston, 2015; Tyler & Moench, 2012)
		[4120] Experimentation and innovation	[4121] There are sufficient opportunities for safe-failure of experiments in order to innovate in alternative approaches and policy designs	As knowledge on socioecological systems inherently harbours uncertainties, experimentation is of great significance to build resilience. In order to have opportunities to make discoveries and innovate in alternative approaches and designs, it is important that failures are allowed and spaces for safe-failure are created. An important part in this is in the financial support of such experimentation, from small-scale experiments to large research projects.	(Biggs et al., 2012; Folke, 2006; Lonsdale et al., 2010)
			[4122] Drought management policies are informed by innovations in alternative approaches and policy designs	Similar to the learning outputs from past experiences, learning outputs from innovative experiments are only useful once they are internalized in the process of drought policy-making. Effective mechanisms should be in place that ensure measures and policies are informed by the new information from experiments and innovations.	(Davoudi et al., 2013; Folke, 2006; Schipper & Langston, 2015; Tyler & Moench, 2012)

Appendix A.10 Flexibility Principle

Table A. 10 Identified indicators for the [4200] Flexibility principle.

Phase	Principle	Operationalisation	Indicators	Explanation	Key references
[4000] Adapt	[4200] Flexibility	[4210] Institutional flexibility	[4211] There is sufficient flexibility in the organizational structure of the drought governance system	Institutional flexibility is a prerequisite for adaptive governance and organizational learning and counteracts institutional path dependency. Through a sufficiently flexible organizational structure, the drought governance system offers possibilities to adapt the formal and informal rules which arrange the collaboration processes between stakeholders, i.e. mutual agreements and rules of collaboration. Mutual trust between stakeholders is another key-element in this.	(Lonsdale et al., 2010; Pahl-Wostl, 2007; van Buuren et al., 2015)
			[4212] There is sufficient flexibility in the content agenda of the drought governance system	Institutional flexibility is a prerequisite for adaptive governance and organizational learning and counteracts institutional path dependency. Through a sufficiently flexible content agenda, the drought governance system offers possibilities to adapt scope, time horizon and goals of the drought management activities (i.e. plans and strategies) based on new insights from i.e. policy evaluations or changing climate conditions.	(Lonsdale et al., 2010; Pahl-Wostl, 2007; van Buuren et al., 2015)
			[4213] There is sufficient flexibility in the processes within the drought governance system	Institutional flexibility is a prerequisite for adaptive governance and organizational learning and counteracts institutional path dependency. Through sufficiently flexible interaction processes, the decision-making processes can be speeded up or slowed down when wished for. Additionally, there are flexible arrangements that should be open and inclusive to participation from different stakeholders and allow for somewhat fluid stakeholder composition over time, with the aim of learning and changing the focus of the drought governance system.	(Lonsdale et al., 2010; Pahl-Wostl, 2007; van Buuren et al., 2015)
		[4220] Flexibility in spatial planning	[4221] Spatial planning is sufficiently flexible to accommodate adaptations based on new insights	With the emergence of new insights, some functions may prove unsustainable to have in a certain area. To decrease the regional vulnerability to droughts, these functions may need to be adapted. Spatial planning should accommodate for this through sufficient flexibility in terms of the locality and quantity of land-use and space dedicated to particular functions.	(Hurlimann & Wilson, 2018; van Buuren et al., 2013; Vinh & Van, 2020)
			[4222] Convertibility is sufficiently integrated in the strategic design of the urban environment	Adapting the built environment to changing climate conditions often takes significant time and costs due to the high density of complex built up areas with a long design lifetime. Through mainstreaming the incorporation of convertibility and versatility in built environment design, required transformations are much easier to make. This can be done through strategic design for convertible structures and multi-use spaces allowing short/long-term conversions in the use of space and buildings under changing conditions.	(Hurlimann & Wilson, 2018; van Buuren et al., 2013; Vinh & Van, 2020; Wardekker et al., 2010)
		[4230] Flexibility in measures	[4231] No- and low-regret measures are sufficiently employed in drought adaptation	Drought has significant inherent uncertainties, both for the drought itself (where, when and how severe?) as well as in its effects across social, economic and environmental domains. These uncertainties can be somewhat counteracted through the implementation of no- and low-regret measures, which do not require significant funding and are effective for a broad range of possible future scenarios.	(Bryan et al., 2019; Henao Casas et al., 2022; Wilhite, 1992)
			[4232] Long-term effects of measures are sufficiently well considered and prevented	Another element in installing flexibility in measures, is that they should limit the range of future possible measures as little as possible, i.e. through strategic designs exhibiting reversibility measures and structured assessment of solutions for short-term problems to the problems caused in the far future. Through mainstreaming this idea in policy practices, path-dependencies are counteracted. This includes the measures themselves, as well as the financial commitments to these measures.	(Huntjens et al., 2010; Wardekker et al., 2010)

Appendix B – Indicator assessment methods for the Case Study Implementation

In this Appendix, the different indicator assessment methods are elaborated upon. This includes a total of 6 indicators that are quantitatively assessed through credible open data sources. In addition, an overview is presented on which indicators have been asked to which (type of) stakeholders.

Appendix B.1 Indicator [2121] Baseline water stress during dry year is absent

The baseline water stress could be easily calculated using the water balance of Twente (Van Tuinen et al., 2022). For this, the ratio of the total annual water consumption to the annual natural water supply (thus excluding additional water supply through from the Dutch national water network) is used. The final indicator score is calculated as follows:

$$Score_{[2121]} = MIN(\,5\,;5 * \frac{total\ annual\ natural\ water\ supply\ Twente}{total\ annual\ water\ consumption\ Twente})$$

In which the total annual natural water supply for Twente equals 898.7 Mm^3, and the total annual water consumption for Twente equals 1119.9 Mm^3 (Van Tuinen et al., 2022).

$$Score_{[2121]} = MIN\left(\,5\,;5 * \frac{898.7 * 10^6\ m^3}{1119.9 * 10^6\ m^3}\right) = 4.01$$

Appendix B.2 Indicator [2123] The regional water sources are sufficient quality

The water quality score is dependent on two elements: surface water quality and groundwater quality. Both are given their own score. The score for the indicator [2123] as a whole is the average of these two separate scores. The final indicator score is calculated as follows:

$$Score_{[2123]} = 0.5 * (Score_{[2123]_{Surface}} + \ Score_{[2123]_{Ground}})$$

Surface water quality

Province Overijssel periodically assesses the surface water quality (every 3 or 4 years). To do so, Province Overijssel looks at the ecological target gap from the European Water Framework Directive. These results are spatially divided over 6 regions. Twente covers three of these: Region NorthEast Twente (NET), Region SouthEast Twente (SET) and Region West Twente (WT). The surface water quality score equals the average target gap score of these three smaller regions.

$$Score_{[2123]_{Surface}} = MAX\left(\,0\,;\ \left(\frac{Tg_{Score_{NET}} + Tg_{Score_{NET}} + Tg_{Score_{NET}}}{3}\right)\right)$$

$$With\ Tg_{score_i} = MAX\ (\,0\,;\ \ 5 - Average\ target\ gap\ in\ region_i * 20\,)$$

The average target gaps for the three regions are quite similar. Each of the regions have an average target gap of 11-17% (Provincie Overijssel, 2020). See also **Error! Reference source not found.**. For this calculation, the averages are set at 14%. Hence, the score for the surface water quality is as follows:

$$Score_{[2123]_{Surface}} = MAX\left(\,0\,;\ \left(\frac{2.2 + 2.2 + 2.2}{3}\right)\right) = 2.2$$

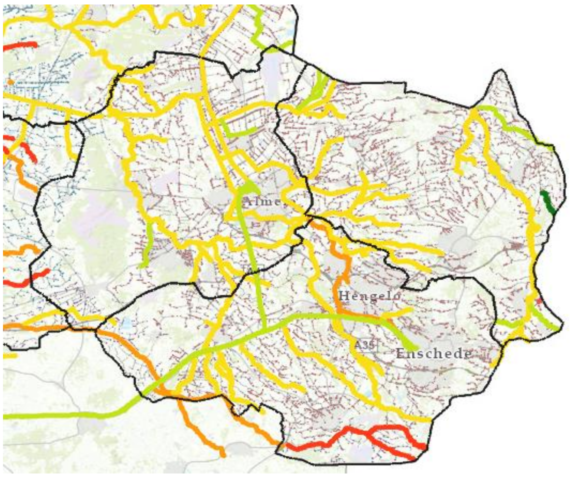

Figure B. 1 Overview of average target gaps from the WFD within Twente (Provincie Overijssel, 2020).

Groundwater quality

Through the National Groundwater Quality Monitoring Network, KWR presents an online report on the groundwater quality in principle every three years (the most recently published is however from 2018) (KWR, 2018). In these, the concentrations of pesticides, medicine and other anthropogenic substances are compared to their reporting threshold as well as their signalling value. This was done through a net of spatially distributed groundwater quality measurement columns. Based on the measurements, the groundwater from that specific measurement column was either graded ‘good’ (below the reporting threshold), ‘medium’ (above the reporting threshold but below the signalling value), or ‘insufficient’ (above the signalling value). To calculate the score for the groundwater quality, the ratio of total measurements within the region is to the number of measurements that are medium/insufficient is used. In this calculation, a measurement column with a ‘medium’ score is seen as half an ‘insufficient column.

$$Score_{[2123]_{Ground}} = 5 * \frac{N_{measurements_{total}} - 0.5 * N_{Measurements_{medium}} - N_{Measurements_{bad}}}{N_{Measurements_{total}}}$$

In total, there are 27 groundwater measurement columns situated within Twente during the 2018 measurement round (KWR, 2018). Only 1 of these was scored ‘good’, 8 scored ‘medium’ and 18 scored ‘insufficient (KWR, 2018). See also **Error! Reference source not found.**. Hence, the score for the groundwater quality is as follows:

$$Score_{[2123]_{Ground}} = 5 * \frac{27 - 0.5 * 8 - 18}{27} = 0.93$$

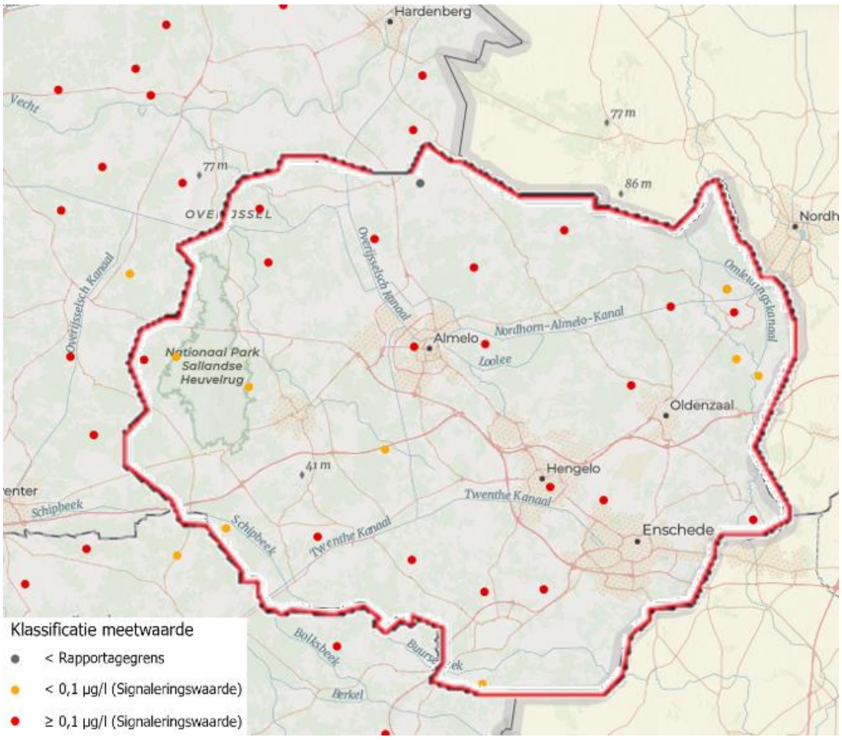

Figure B. 2 Groundwater quality measurement column, adapted from KWR (2018).

Total score water quality indicator [2123]

Following these results for the surface water and groundwater quality, the final indicator score for indicator [2123] is as follows:

$$Score_{[2123]} = 0.5 * \left(Score_{[2123]_{Surface}} + Score_{[2123]_{Ground}}\right) = 0.5 * (2.2 + 0.93) = 1.6$$

Appendix B.3 Indicator [2124] There is a sufficiently large regional financial buffer

To determine the score for the regional financial buffer, there has been made use of the annual benchmark of the financial situation of all Dutch municipalities by the accountancy firm BDO (BDO, 2022). In their 2022 report, BDO looked at the municipalities' annual accounts of the year 2020. In this benchmark, all municipalities receive a numerical score for their financial 'health' and buffer between 1 and 10, based on their solvency, net/adjusted debt ratio, land exploitation, structural exploitation space, and tax capacity. As the financial situation of one municipality is less influential for the region as a whole than the financial situation of another municipality, it has been decided to incorporate the relative population from the CBS (CBS, 2023b) in the final indicator score. This way, a large municipality such as Enschede or Hengelo, have a more significant impact in the final indicator score than a relatively small municipality such as Borne or Losser. The final indicator score is calculated as follows:

$$Score_{[2124]} = SUM_{i=1}^{i=14}(0.5 * \ Score_{BDO_i} * RelativePopulation_i)$$

With 'i' being one of the fourteen municipalities within Twente. See **Error! Reference source not found.** for the scores per municipality. This leads to a final indicator score of:

$$Score_{[2124]} = SUM_{i=1}^{i=14}\left(0.5 * \ Score_{BDO_i} * RelativePopulation_i\right) = 3.81$$

Table B. 1 Regional Financial buffer per municipality, based on BDO (2022).

Municipality	Population	Relative population	BDO Score	Score Economic buffer	Relative score Economic Buffer	Total score
Twente	631000	100%				3.81
Almelo	73000	12%	6	3	0,35	
Borne	24000	4%	3	1,5	0,06	
Dinkelland	26000	4%	9	4,5	0,19	
Enschede	160000	25%	8	4	1,01	
Haaksbergen	24000	4%	7	3,5	0,13	
Hellendoorn	36000	6%	6	3	0,17	
Hengelo (O.)	80000	13%	7	3,5	0,44	
Hof van Twente	35000	6%	10	5	0,28	
Losser	23000	4%	8	4	0,15	
Oldenzaal	32000	5%	8	4	0,20	
Rijssen-Holten	38000	6%	8	4	0,24	
Tubbergen	21000	3%	10	5	0,17	
Twenterand	34000	5%	9	4,5	0,24	
Wierden	25000	4%	9	4,5	0,18	

Appendix B.4 Indicator [2134] The region has (a high percentage of areas with) permeable soils

To determine the percentage of areas with permeable soils in the Twente region, data from the CBS on land use has been used (CBS, 2017). This dataset has data for Twente as a region and differentiates between different types of terrains: 1) traffic area: 2) Built-up area, 3) Semi-built-up area, 4) Recreational area, 5) Agricultural area, 6) Forest and open natural areas, 7) Inland water, and 8) Outer water. As simplification for the case study, terrain types 1 to 3 are seen as impermeable, whereas terrain types 4 to 8 are seen as permeable. The indicator score is calculated using the ratio of the total surface area of permeable soils to the total surface area and is as follows:

$$Score_{[2134]} = 5 * \frac{A_{total_{Twente}}}{A_{recreational} + A_{Agricultural} + A_{Forest} + A_{InlandWater} + A_{OuterWater}}$$

The surface areas are presented in **Error! Reference source not found.**. This leads to a final indicator score of:

$$Score_{[2134]} = 5 * \frac{A_{total_{Twente}}}{A_{recreational} + A_{Agricultural} + A_{Forest} + A_{InlandWater} + A_{OuterWater}} = 4.3$$

Table B. 2 Surface areas of different terrain types in Twente (CBS, 2017).

Terrain type	Surface area (ha)
Total Twente	150377
Recreational	3714
Agriculture	100718
Forest	23417
Inland water	1600
Outer water	0

Appendix B.5 Indicator [2321] There is a low regional economic dependency on sectors vulnerable to drought

To come to a numerical score for the dependency of the region on sectors vulnerable to drought, especially the agricultural sector is of relevance for Twente. The dependency of the regional economy on this sector can be determined through the added value of the agricultural complex (in Dutch: 'agrocomplex') to the total added value in the region. The agricultural complex refers to the direct and indirect set of activities surrounding agriculture and the food industry. This approach lends itself ideally to looking at the interconnectedness of agriculture with the rest of the economy. As a severe drought won't only impact the agricultural sector itself, but also all supporting services to the agricultural sector, this is especially relevant.

The province-level is the most spatially detailed level for which data is available on the agricultural complex. Although not an actual match with the spatial scale of Twente as case study region, the data from the province Overijssel (in which Twente lies) is seen as a sufficiently relevant proxy, assuming the province's data translate quite well to the would-be data for Twente.

In setting a numerical score for the economic dependency on drought prone sectors, or in this case the agricultural sector, it is assumed that if the dependency is 0%, the region receives the highest score (5). If the dependency is ≥25%, the region receives the lowest score (1). All percentages in between result in a gradual range between 1 and 5. This leads to the following formula to be used:

$$Score_{EconomicDiversity} = 5 - \frac{Dep_{AgricultureOverijssel}}{0.25} * 4$$

The added value from the agricultural complex in Overijssel in the year 2021 is €1248 million (CBS, 2021b). The total added value of Overijssel in the year 2021 was €42725 million (CBS, 2021a).

As such, the economic dependency of Overijssel on the agricultural complex is as follows:

$$Dep_{AgricultureOverijssel} = \frac{AddVal_{AgricultureOverijssel}}{AddVal_{TotOverijssel}} = \frac{€1248 * 10^6}{€42725 * 10^6} = 0.029 = 2.9\%$$

This leads to the following score for the economic dependency of the region on drought prone regions:

$$Score_{EconomicDiversity} = 5 - \frac{Dep_{AgricultureOverijssel}}{0.25} * 4 = 5 - \frac{2.9\%}{0.25} * 4 = 4.5$$

Appendix B.6 Indicator [2322] There is a sufficient level of economic diversity within sectors vulnerable to drought

To come to a numerical score for the economic diversification of drought prone sectors, there is looked at the average share of expansion activities (in Dutch 'verbredingsactiviteiten') on the annual revenue of the agricultural sector, based on relatively recent data from the CBS (CBS, 2020). This dataset describes the number of agricultural firms that have a certain type of expansion activity (i.e. agritourism, or agricultural education). Moreover, the dataset describes the share of these expansion activities in the annual revenue of the agricultural firms (low, medium, high). The dataset itself is presented in **Error! Reference source not found.**. Assuming a larger share of expansion activities in the annual revenue of the agricultural firms results in these agricultural firms being less vulnerable to drought, combining these two data types can result in a score for their economic diversification away from drought-prone economic activities. The province-level is the most spatially detailed level the dataset has. Although not an actual match with the spatial scale of Twente as case study region, the data from the province Overijssel (in which Twente lies) is seen as a sufficiently relevant proxy, assuming the province's data translate quite well to the would-be data for Twente.

In setting a numerical score for the economic diversity within drought prone sectors, or in this case the agricultural sector, it is assumed that if expansion activities account for 0% of the total annual revenue within the sector the region receives the lowest score (1). If it accounts for ≥25% of the total annual revenue, the region receives the highest score (5). All percentages in between result in a gradual range between 1 and 5. This leads to the following formula to be used:

$$Score_{EconomicDiversity} = 1 + \frac{Share_{ProportionExpansionActivities}}{0.25} * 4$$

To find the proportion of the expansion activities within the total annual revenue of the agricultural sector, several steps have to be taken. Firstly, the number of agricultural firms that have such expansion activities are summed up. From this, it can be concluded that approximately half of all agricultural firms (49.8%) have at least some expansion activities included in their business operation. Thereafter, it is calculated how many agricultural firms fit within each bracket share of the expansion activities in the annual revenue.

To calculate how many firms that have expansion activities that result in a certain proportion ‘i’ of their total annual revenue (being either low (<10%), medium (10%-50%), or high (>50%)), the following formula is applied:

$$N_{FirmsWithExpansionActivitiesWithRevenueProportion(i)} =$$

$$N_{FirmsWithExpansionActivities} * Share_{FirmsWithRevenueProportion(i)ShareOfExpansionActivities}$$

Table B. 3 Dataset on the expansion activities of agricultural firms in the province Overijssel, based on CBS (2020). *The yellow rows are calculated based on the presented formulas.*

Expansion activity	**Unit**	**Absolute**	**Relative to total**
Total number of agricultural firms in Overijssel	Number	6648	100%
Doorstep sales	Number	566	9%
Storage of goods or animals	Number	281	4%
Agritourism	Number	253	4%
Processing agricultural products	Number	111	2%
Special care farm	Number	77	1%
Aquaculture	Number	3	0%
Contract work for third parties	Number	445	7%
Agricultural nature and landscape management	Number	966	15%
Agricultural childcare	Number	33	0%
Agricultural education	Number	151	2%
Energy production, supply to third parties	Number	428	6%
Total number of agricultural firms with expansion activities	Number	3314	49.8%
Share of expansion activity in annual revenue (<10%)	% of firms that have expansion activities	*(unknown)*	60%
Share of expansion activity in annual revenue (<10%)	Number	1988	30%
Share of expansion activity in annual revenue (10%<50%)	% of firms that have expansion activities	*(unknown)*	22%
Share of expansion activity in annual revenue (10%<50%)	Number	729	11%
Share of expansion activity in annual revenue (>50%)	% of firms that have expansion activities	*(unknown)*	18%
Share of expansion activity in annual revenue (>50%)	Number	597	9%

As the revenue proportions are given in quite broad ranges, these need to be transformed into a singular value per range in order to do calculations towards the total share of expansion activities within the total annual revenue of the agricultural sector. For this, the values in **Error! Reference source not found.** are used.

Table B. 4 Assigned singular values for each original range.

Original Range in Share of expansion activity in annual revenue	**Assigned singular value for the share of expansion activity in annual revenue**
<10%	*5%*
10%-50%	*30%*
>50%	*60%*

Based on this information, the total share of expansion activities within the total annual revenue of the agricultural sector can be determined. With 'i' again being a certain proportion of the total annual revenue (being either low (<10%), medium (10%-50%), or high (>50%)), This is done through the following formula:

$$Share_{ProportionExpansionActivities} = SUM(Share_{FirmsWithRevenueProportion(i)ShareOfExpansionActivities} * P_{AssignedSingularValueForFirmsWithRevenueProportion(i)})$$

This results in the following share of expansion activities within the total annual revenue of the agriculture sector:

$$Share_{ProportionExpansionActivities} = (30\% * 5\%) + (11\% * 30\%) + (9\% * 60\%) = 10.2\%$$

This leads to the following score for the economic diversity within drought prone sectors:

$$Score_{EconomicDiversity} = 1 + \frac{Share_{ProportionExpansionActivities}}{0.25} * 4 = 1 + \frac{10.2\%}{0.25} + 4 = 2.6$$

Appendix B.7 Interview indicator selection

In Table B. 5 an overview is presented on the relevant (types of) stakeholders for each indicator. This scheme served as starting point in deciding which indicators would be discussed during each interview.

Table B. 5 Relevant stakeholder (groups) per indicator as applied in the case study.

Phase	Principle	Policy operationalisation	Indicator	Qual.?	Stakeholder (group) for which indicator is relevant										Total number relevant groups
					1	2	3	4	5	6	7	8	9	10	
Absorb	[2100] Robustness and buffering	[2110] Structural measures and installations towards low water demand	[2111] There is sufficient presence of (structural) measures and installations to decrease water demand	Y	X		X	X	X		X		X	X	7
			[2112] There is a smooth-running process of periodical assessment and improvement of present (structural) measures and installation to reduce water demand	Y	X		X	X	X		X		X	X	7
		[2120] Creating buffer capacities	[2121] The baseline water stress during a dry year is absent	N											
			[2122] The sustainable water storage capacity within the region exceeds demand under drought conditions	Y	X	X	X	X	X	X	X	X	X	X	10
			[2123] The available regional water sources are of sufficient quality	N											
			[2124] There is a sufficiently large regional financial buffer	N											
		[2130] Impact and risk reducing spatial planning and planning practice	[2131] Drought risk is sufficiently embedded in spatial planning	Y	X		X	X		X		X	X	X	7
			[2132] There is sufficient attention to drought and its effects in laws and regulations	Y	X			X		X			X	X	5
			[2133] Drought resilience is actively and sufficiently incorporated in nature management strategies	Y	X	X		X		X		X			5
			[2134] The region has (a high percentage of areas with) permeable soils	N											
	[2200] Redundancy	[2210] Institutional redundancy with overlapping functions and roles	[2211] The regional drought governance system is polycentric and multilevel with an appropriate level of decentralisation and division of autonomy	Y	X		X	X	X	X	X				6
			[2212] The regional drought governance system is well-coordinated	Y	X		X	X	X	X	X	X	X	X	9
		[2220] Functional redundancy in important functions and services	[2221] There is a sufficient level of redundancy mechanisms for and in drought-sensitive critical infrastructure and networks	Y	X	X	X	X	X		X		X		7
			[2222] There is a sufficient level of redundancy within ecosystem services	Y			X					X			2
		[2230] Modularity to mitigate cascading effects	[2231] There is a sufficient level of institutional modularity (self-reliance) of parties within the drought governance system to decrease or prevent high-risk cascading effects between parties	Y	X		X	X	X	X	X	X	X	X	9
			[2232] There is a sufficient level of compartmentalization within drought-sensitive critical infrastructure to avoid cascading drought effects	Y	X	X	X	X			X		X		6
	[2300] Diversity	[2310] Functional diversity	[2311] The water supply portfolio has a sufficient level of diversification	Y	X		X	X	X		X		X		6
			[2312] There is a sufficient level of spatial distribution of drought-sensitive critical infrastructure, industry and services across the region	Y	X			X					X		3
		[2320] Economic diversity	[2321] There is a low regional economic dependency on sectors vulnerable to drought	N											
			[2322] There is a sufficient level of economic diversity within sectors vulnerable to drought	N											
		[2330] Institutional diversity	[2331] There is a just level of institutional disciplinary variety within the drought governance system	Y	X		X	X	X	X	X	X	X	X	9
			[2332]There is an appropriate level of institutional managerial disparity within the drought governance system	Y	X		X	X	X						4
			[2333] There is an appropriate level of institutional balance within the drought governance system	Y	X		X	X	X	X	X				6
			[2334] There is sufficient presence of effective drought-centred partnerships and platforms for networking and knowledge exchange between different stakeholder groups, both sectoral as well as cross-sectoral	Y	X	X	X	X	X	X	X	X	X	X	10
Total number of relevant indicators per stakeholder (group)				**18**	**17**	**5**	**15**	**17**	**12**	**10**	**12**	**8**	**13**	**9**	

Where: Qual. means qualitative and part of case study interviews, and;
1) Safety region, 2) Fire brigade, 3) Waterboard, 4) Province, 5) Rijkswaterstaat, 6s) Municipality, 7) Water company, 8) (Interest groups) Nature management, 9) (Interest groups) Economy and Industry, 10) (Interest groups) Agricultural sector.