

TOWARDS A RESILIENT DROUGHT MANAGEMENT SYSTEM (1072)

Joachim Vercruysse^{1*}, Greet Deruyter¹, Luuk Boelens¹, Renaat De Sutter¹

¹ Ghent University, Belgium; *joachim.vercruysse@ugent.be

Abstract. Drought is considered an insidious, complex and multidisciplinary phenomenon due to many interacting influences. This paper focusses on the specific situation in Flanders, Belgium. Although in Flanders, the annual precipitation remains stable, drought impacts are becoming more and more severe. This is partly due to increased water demand, changed water use patterns in combination with outdated legislation and reactive policies, not aimed at resilient water management.

This paper identifies contributing elements, relations and interactions in the drought system of Flanders, through the actor relational approach and demonstrates how this approach might be implemented in the Flemish case. An actor relational approach would allow striving for a more resilient drought management system.

Keywords: resilience, drought, actor relational approach.

1. Introduction

Since 1950, the climate system has changed in such a way that the world has become a different place (Chapagain et al. 2021; IPCC 2014, 2022). Climate change manifests itself in more frequent and severe hazards, causing problems in sectors such as agriculture, economy, energy, water management, etc., thus showing the sensitivity of both natural and human systems to climate change (Boelens et al. 2017; Hervás-Gómez and Delgado-Ramos 2019; IPCC 2014, 2022; Kasting 1989; Kiehl 2011).

Droughts differ from most other natural hazards, as they are not the result of a singular event (Wilhite 2000) with a well delineated onset and end, while their impact increases and accumulates slowly over a considerable time span, and can linger on for many more years after water supply is back to normal. Therefore, droughts are referred to as 'creeping phenomena' (AghaKouchak et al. 2021; Crausbay et al. 2017; Mishra and Singh 2010; Vilonen et al. 2022; Wilhite 2000; Wilhite and Glantz 1985), which often have non-structural impacts over large geographical areas, unlike most natural hazards. This complicates agreeing on definitions and quantification of impacts (Wilhite 2000), since it subsequently gets influenced by human activities (AghaKouchak et al. 2021; Chapagain

et al. 2021; Crausbay et al. 2017; Mishra and Singh 2010; Van Loon et al. 2016).

The occurrence and severity of droughts as well as other climate related hazards are predominant. However, although several regions have been struggling with droughts for many decades, this threat is relatively new for the Flemish region, situated in the north of Belgium, see Figure 60. The annual water availability per capita, in Flanders, ranges from 1,100 m³ to 1,700 m³, which is lower than other European regions often linked to drought, such as Spain, Portugal and Greece. (Flemish Environment Agency 2021b) Moreover, in 2019, the World Resources Institute (WRI) ranked Belgium 23rd among 164 countries studied for drought risk (Gassert et al. 2013). Flanders struggles to achieve the goals from the European water framework directive, especially when droughts occur. These analyses highlight the significance of judicious and efficient utilisation of available water resources and is caused by several factors. For instance, to date, the high population density, 492 people per km², in combination with a total surface area pavement of 15.8%, prevents the penetration of precipitation, thus lowers the potential water supply. Furthermore, historically policies are aimed at avoiding floods, which led to infrastructure dedicated to diverting the water as fast as possible to the sea. This short-term view of dealing with water-related problems leads to a reactive drought policy. Together with the complex government structure, e.g. fragmented structures, and a history of diverting water away, adds to the problem.

As Flanders is subject to human-driven water management, the region is also prone to anthropogenic drought risks. In this paper, the Actor Relational Approach (ARA), will be used to unravel and visualise the driving forces, key actors, factors of importance and their mutual interactions as a step to prioritise water needs and minimise the impact of drought on human society and ecosystems.

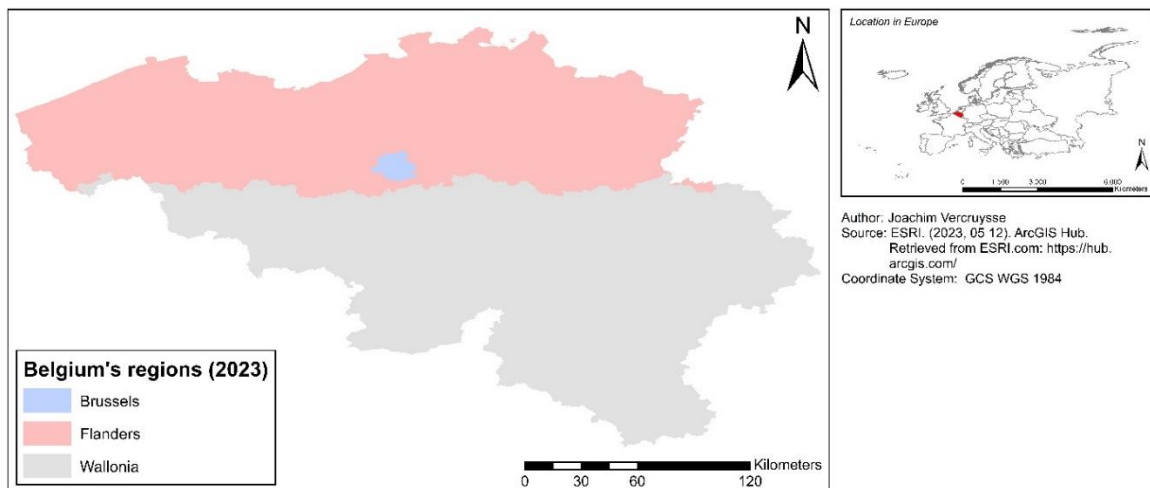


Figure 60. Location of the study area Flanders

2. Drought definition

To date, policy makers and society as a whole become more aware of drought related problems. Furthermore, research on drought development mechanisms, attributing factors, monitoring consequences, etc. progressed significantly over the years. Examples are to be found in the continuous development of drought indices (Bloomfield et al. 2013; Shukla and Wood 2008; Stagge et al. 2015), an improved understanding of the link between drought and atmospheric and ocean drivers (Fleig et al. 2010; Kingston et al. 2015), drought monitoring and forecasting (Sheffield et al. 2014; Trambauer et al. 2015), and the effects of climate change on drought (Prudhomme et al. 2014; Trenberth et al. 2014; Wanders and Wada 2015). Notwithstanding this ever-growing body of drought related research, it is still difficult to determine a precise and universally accepted definition of drought. The literature review of Slette et al. in 2019 points out that researchers use a wide variety of ways to characterise droughts (e.g. reduced precipitation, low soil moisture, reduced streamflow), while a third of the reviewed papers simply equated “dry conditions” with “drought” (Slette et al. 2019). These findings are an indicator for the complexity of “drought”.

Each research discipline uses its own lens to assess the occurrence of drought and incorporates different physical, biological, and/or socioeconomic factors in its definition. Common defined types are grouped as “meteorological” (deficit in precipitation), “agricultural” (soil moisture deficit), “hydrological” (deficit in surface water, storage, and/or groundwater) and “socioeconomic” (deficit in water-dependent economic goods and agricultural products leading to societal impacts). (Dai 2011; Dracup et al. 1980; Mishra and Singh 2010; Wilhite and Glantz 1985). More recently, this traditional classification was expanded with the terms “ecological drought” based in the impacts on ecosystems (Crausbay et al. 2017; Slette et al. 2019), and “human-induced and/or human-modified hydrologic drought” (AghaKouchak et al. 2021; Van Loon et al. 2016). Research has shown that the lack of a precise and objective definition in specific situations is an obstacle to understand drought, which has led to indecisiveness and passivity on the part of managers, policy makers, and others (Wilhite and Glantz 1985).

In this research the definition of the anthropogenic drought will be used. In this respect AghaKouchak et al. (2021), states that while the previous different classifications of droughts offer innovative perspectives about the disparate impacts of drought, the definitions generally treat drought as a product rather than a process. This product-focused approach typically quantifies deficits in water-related variables or water-dependent activities due to natural and climatic variabilities in a certain timeframe. Therefore, these definitions lack a two-way interaction of human activities with changing drought, water stress risks, and/or climate conditions. Subsequently, they do not address effects of a human-induced climate change with local water and land management, and

consequently do not conclude the impacts from the water stress on the environment beyond a specific temporal and spatial domain. (AghaKouchak et al. 2021; Crausbay et al. 2017; Dale 1997) The classic product-oriented definitions lack the complexity to fully understand the interacting elements. Drought is a multidisciplinary phenomenon characterised by processes that involve feedbacks between human activities and nature, which makes this problem a complex system. (AghaKouchak et al. 2021; Boelens 2018; Davids 2021; Van Brussel 2018)

Anthropogenic drought, is here defined as a process that ends up in water stress (societal or environmental), due to feedbacks (in)between human activities, and/or nature (AghaKouchak et al. 2021; Wahl et al. 2018; Zscheischler et al. 2018). The process will then co-evolve (negative or positive), after the drought, leading to water stress or a more resilient system. From that point on, the cycle will repeat itself, since time and drivers will never stop continuing, unless the system becomes stronger. This makes drought a multifaceted, multi-layered and complex issue, which needs an approach that can divert the definition into an operational framework.

3. Actor Relational Approach

The Actor Relational Approach (ARA) for planning is an attitude that evolves depending on specific themes and changing surroundings (Boelens 2010; Tempels 2016). As drought is a complex issue that involves multiple disciplines and sectors (AghaKouchak et al. 2021; Chapagain et al. 2021), the ARA can be used to visually illustrate and understand the problem related to anthropogenic drought as a first step in building drought resilience.

The ARA originates from three components: Actor, Relational, and Approach. The Actor component is based on planning theories such as Actor-Network-Theories (ANT) that focus on the actions of human and non-human actors within a network. The differential system theory of Luhmann posits that society is made up of distinct subsystems that are operationally closed. In planning, the challenge is to intervene in these subsystems and networks with precise tactics that address the interests and behaviours of all actors involved. By understanding the relationships between different actors and systems, planners can use their role to stimulate action and foster collaboration, even in situations where there may be competing interests and viewpoints. (Boelens 2010, 2018)

The Relational component contains post-structuralism and the idea of relational space. Post-structural theorists question the absolute valuations of features such as planning instruments and general wellbeing, meaning that nothing is vast to a subject or space and time, but always relational. This component focuses on the relations between places, their specific uses over time, and how they are organised to understand their quality or

efficiency. (Boelens 2010, 2018)

The Approach component emphasises that the ARA should be flexible and open to other theories. It utilises the strategy of analysing relations in a flexible way and re-evaluating systems since contexts can change over time. (Boelens 2010, 2018) Therefore, the ARA allows systems to irritate and learn from other systems, creating a co-evolutionary perspective, which is helpful for creating a reinforcing effect. Hence, resilience building can be seen as an operational component linking the ARA and anthropogenic drought definition together.

3.1 Resilience

The concept of resilience exists for many years and is relevant across a wide range of disciplines (Grove 2018). Over the past two decades, it has become more prominent within the literature related to environment, natural sciences, social sciences, humanities, and interdisciplinarity (Folke 2016). As a result, there are many definitions of resilience, some of which are contradictory (Chapagain et al. 2021; Davoudi et al. 2013; Davoudi et al. 2012; Fünfgeld and McEvoy 2012; Klein et al. 2003; Meerow and Stults 2016; Rankin et al. 2016; Salata and Yiannakou 2020; Tempels 2016; Woodruff et al. 2022). It is not a new concept, still it is relatively new as a practice and is not yet widely reflected in existing policies or guidelines (Chapagain et al. 2021; Salata and Yiannakou 2020), however, the need for an resilient planning policy is more urgent since the problem worsens. (Salata and Yiannakou 2020)

The three main resilience approaches are Engineering resilience (the ability of a system to return to a stable state after some disturbance or shock (Chapagain et al. 2021; Holling 1996)), Ecological resilience (recognising the intrinsic dynamism of systems and the presence of multiple equilibrium states (Holling 1973; Holling 1996)), and socio-economic resilience. The socio-ecological understanding of resilience emerged from increasing interest in the interlinked dynamics of social and ecological subsystems and their behaviour. It is predicated on the complex nature of these subsystems and the co-evolution between them, which adds to the complexity of the system as a whole. (Berkes et al. 2000; Gual and Norgaard 2010; Tempels 2016) Given that the conditions are constantly changing, resilience is defined not only by the state of the system relative to thresholds, but also by the relationship between the system and its conditions. Under changing conditions, the system must adapt and co-evolve with these conditions in order to be resilient. (Tempels 2016)

The socio-economic approach of resilience is closely related to the anthropogenetic drought definition, in which it is not about a sudden occurrence, but about an ongoing process, creating a new situation that needs to be evaluated depending on each

situation. So far, socio-ecological resilience is not often considered in studies, but is crucial for the transition to adaptive thinking. The major challenge in tackling the issue of drought and resilience is the complexity involved. Overall, the ARA provides a framework for planners to deal with this complex interplay of different entities in systems, e.g. climate change, floods, energy transition, and droughts.

4. Methodological framework

4.1 Understanding drought

Numerous studies highlight the need for a shift towards a more resilient system to mitigate or reduce the impact of climate change and anthropogenic evolutions on the environment. However, a review study conducted in 2019 revealed that 54 percent of the studies on drought considered it to be static and did not account for future developments, indicating a majority on short-term rather than long-term visions (Hagenlocher et al. 2019). Moreover, most estimates of the water status are based on limited historical trends or a snapshot of current conditions, and traditional water accounting approaches lack a dynamic (Chapagain et al. 2021) and relational perspective (Boelens 2023; Boelens et al. 2017). In order to establish a resilient drought management system, it is necessary to understand the interdisciplinary context in which it operates, and to recognise drought as a process instead of an event. The literature review, explained in this paper, leads to the anthropogenic drought definition which clarifies this context.

4.2 Understanding ARA

The ARA theory makes a distinction between actors, factors, institutions, and intermediaries/mediators (Figure).

Actors are those who act, with a minimum of two actors typically involved, a sender and receiver. These actors have their own unique intentions, which can change over time or vary depending on the context. Other actors can also join a context and take over actions or add to the context. (Boelens 2010, 2018)

The context is crucial in understanding the actions of these actors. Some elements or problems urge actors to act, while others constrain them. These contextual elements are regarded as the factors. (Boelens 2010, 2018)

The result of an action, caused by different factors, can also lead to a mutual agreement to act in the future, which can be considered an institution. Institutions can be defined as the rules of the game, whether formal or informal. (Boelens 2010, 2018)

To function as a system, mediators and intermediaries are necessary to connect the actors, factors, and institutions. Intermediaries transfer information without changing it. Mediators, on the other hand, mould information in order to bring actors, factors, or institutions together or apart. These intermediaries/mediators try to enhance the resilience of the system. (Boelens 2010, 2018)

In examining the complex issue of drought, it is important to acknowledge that the world is too complex to be fully understood. Institutions can change in response to circumstances (factors) or human influence (actors). Actors, factors and institutions (re)shape each other in their own environment over time and location. Through co-evolution, actions, within one subsystem, will have indirect effects on other subsystems. This makes a (sub)system a complex multidisciplinary entity that is always incomplete, provisional and unstable, and needs to be continuously reanalysed in a multidisciplinary way. (Boelens 2018)

In the case of drought, a scenario could arise with a water shortage (context) due to a low rainfall rate over a specific period (factor). In such a situation, various water managers (actors) may take actions to safeguard the water supply. This could be achieved through the implementation of legislation (institution), such as a consumption limit. The information on water shortage is communicated through the system via assessment models (intermediaries) or researchers (mediators).

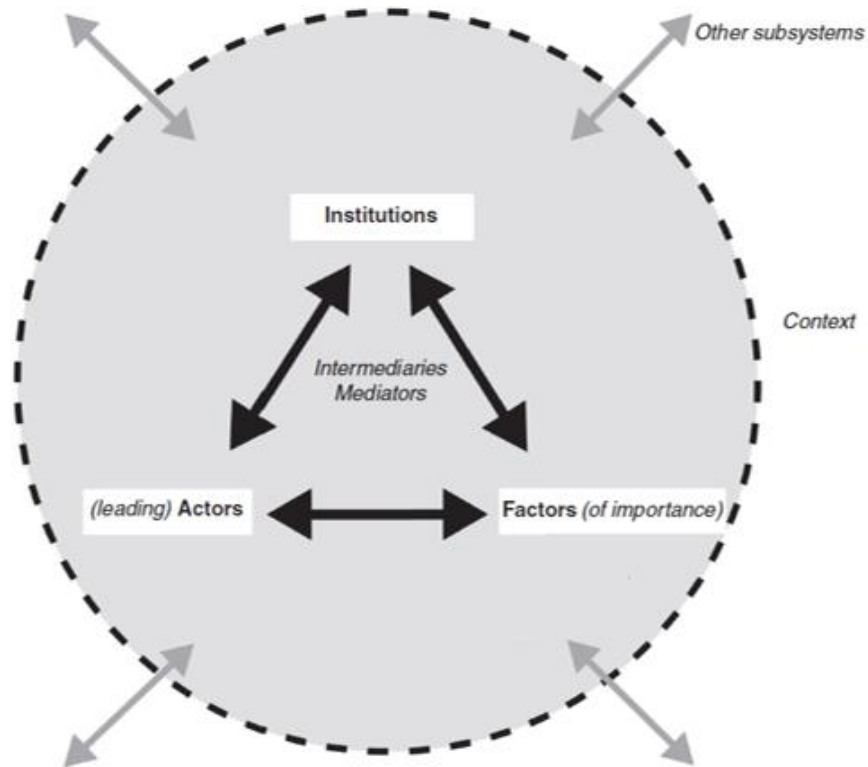


Figure 2. The Actor-Relational Approach – scheme (Boelens, 2018)

Evidently, actors, factors, institutions and intermediaries/mediators are interrelated through actions provoking reactions. It is important to fully comprehend the ARA so that the approach can be operationalised on a study area.

4.3 Understanding the study area

The ARA determines the actors, factors, institutions, and intermediaries/mediators within a known, but evolving context. In the case of this paper, the context is the drought issue in Flanders. Determination of its constituent elements requires a thorough analyses of the specific context. For Flanders, the data acquisition was done through desktop research as a vast amount of detailed legal and other information is offered as free open-source data (e.g., databases, maps, governmental portals, official monitoring data, etc.). However, in most cases, it is recommendable to engage with specialists and stakeholders, conduct surveys, involve citizen science, etc. Throughout the data acquisition process, it is also important to ensure that the level of detail fits the context scale.

4.4 Network Analysis

Analysing and understanding the complex interactions between various actors, factors, institutions, and intermediaries/mediators involved in drought, can be done by using a network analysis tool. In this paper, the program “Gephi”, was used to visualise the relationships between the entities as a network graph. This graph can help to reveal patterns and structures in the relationships between entities, such as who is connected to whom, the strength of the connections, and how information or resources flow through the network. This provides valuable insights into the dynamics of the system and helps identifying opportunities for improving resilience to drought.

5. Results for the case of Flanders

5.1 Actors

From the obtained insights, the main drought actors have been identified as: households, energy, agriculture, trade & services, other industries, and government (within its various layers). These water managers, users and consumers have continuously major impact on the water system, therewith on drought, and provide a global overview of the involved actors. For smaller scales or subsystems, such as concerned communities, most of these actors can be subdivided. Since the actor “government” is closely linked to the ARA-pillar "institution", it is able to bring significant changes to that part. Therefore, the most important actors within “government” will be briefly explained.

5.1.1 Actor, Government

At a regional level, a vital actor within the integral water policy is the "Coordination Commission for Integral Water Policy" (CIW). The CIW prepares the integrated water policy, on which the Flemish government relies and consequently elaborates. For this responsibility, the CIW includes representatives from the Flemish government's policy areas, local water managers, waste and drinking water companies, and a provincial governor. The lead official of the “Flemish Environment Agency” (VMM) chairs the CIW. (Coordination Committee on Integrated Water Policy 2022)

The Flemish government itself consists, on paper, of various departments and agencies with water-related powers, coordinated by the minister for environment. The departments usually support the minister by preparing and maintaining the legislation; the agencies are typically responsible for the implementation of the drought policies. As for water-related issues, the main policy areas are Environment (Flemish Environment Agency; Environment Department; Agency for Nature and Forest; Flemish Land Agency; Public Waste Agency of Flanders), Mobility and Public Works (Department of Mobility and Public Works; Flemish Waterway; Agency for Maritime Services and Coast; Agency for Roads and Traffic), and Agriculture and Fisheries. (Coordination Committee on Integrated Water Policy 2022) In reality, governmental entities receive support from

semi-private and semi-public organisations, contributing to an increase in complexity.

At the basin level, a basin board represents each basin, and the Flemish government provides necessary resources and personnel for its operation. The Flemish minister for environment appoints a basin coordinator recommended by the CIW. The basin council, representing the political level of the basin, includes representatives from the Flemish Region, provinces, sub-basins, and the provincial governor. The basin secretariat manages the basin and prepares draft basin management plans and progress reports. (Coordination Committee on Integrated Water Policy 2022)

At the sub-basin level, water boards are established as a partnership between overlapping water managers. Provinces must take the initiative to establish a water board as overlapping areas are possible. (Coordination Committee on Integrated Water Policy 2022)

Besides overlapping responsibilities between provinces and municipalities, they do still have their own responsibilities within their borders. The provinces manage the second category of unnavigable watercourses (outside the area of the polders and waterways). The provinces state that they play a role in “preventing flooding and decide on environmental and nature permits”. This means that the main focus is floods instead of floods and droughts. The production, distribution, transport and sanitation of drinking water is performed by the drinking water companies. (Coordination Committee on Integrated Water Policy 2022)

Cities and municipalities are then responsible for managing third category watercourses, public canals and municipal canals. They, or a sewer manager appointed by them, take care of the collection of domestic wastewaters. Municipalities are also initiators of local environment plans, responsible for granting environmental permits, applying the water test, etc., influencing the other major water consumers and users. (Coordination Committee on Integrated Water Policy 2022)

5.2 Factors

A significant amount of research has already been conducted on the interactions and influences of factors that contribute to drought. Various studies have focused on defining drought, developing decision-making frameworks. These studies were used to comprehend a vast variety of knowledge and determine the contributing factors. These factors are multi-faceted and can impact the occurrence and severity of drought without requiring any direct action. These factors include:

- weather conditions and the topography of an area, which affect the amount and distribution of precipitation and the flow of surface and groundwater (Abdollahi et al.

- 2019; Bloomfield et al. 2013; Coordination Committee on Integrated Water Policy 2021a, b; Flemish Environment Agency 2021a, b, c, d, e; Mo and Lettenmaier 2016)
- climate change, leading to more frequent and severe droughts, due to changes in precipitation patterns, higher temperatures, and increased evapotranspiration rates (AghaKouchak et al. 2021; Coordination Committee on Integrated Water Policy 2021a, b; Dai 2011; Flemish Environment Agency 2021e; IPCC 2022; Seneviratne et al. 2012)
 - water quality and quantity, impacting the availability and suitability of water resources for different uses (Abdollahi et al. 2019; AghaKouchak et al. 2021; Coordination Committee on Integrated Water Policy 2021a, b; Flemish Environment Agency 2021c, d, e; IPCC 2022)
 - changes in land cover, such as urbanisation or deforestation, can alter the water balance of an area (AghaKouchak et al. 2021; Coutts et al. 2007; Diffenbaugh et al. 2015; Flemish Environment Agency 2021e; IPCC 2022; Van Loon et al. 2016)
 - water management infrastructure, such as dams, irrigation systems, and water allocation systems, can affect water availability and distribution (AghaKouchak et al. 2021; Coutts et al. 2007; Diffenbaugh et al. 2015; Flemish Environment Agency 2021e; IPCC 2022; Van Loon et al. 2016)
 - socioeconomic factors, such as poverty, inequality, and political instability, can impact the vulnerability of communities and their ability to cope with drought impacts (AghaKouchak et al. 2021; Berkes et al. 2000; Flemish Environment Agency 2021e; Gual and Norgaard 2010; IPCC 2022; Madani et al. 2016; Madani and Shafiee-Jood 2020; Mehran et al. 2015; Van Loon et al. 2016)
 - population growth, pressuring the limited water resources (AghaKouchak et al. 2021; Coutts et al. 2007; Diffenbaugh et al. 2015; Flemish Environment Agency 2021e; IPCC 2022; Van Loon et al. 2016)

These factors highlight the complex and multi-dimensional nature of drought. It is important to note that the relative importance can vary depending on the specific context and location of the drought, and understanding these contextual factors is critical for effective drought management.

5.3 Institutions

The current legislation is primarily aimed at the prevention of damage caused by floods. Currently, there is a transition towards also establishing drought policies, however actions and rules are mainly reactive and implemented ad hoc for a limited period, during drought stress. Structural and preventives rules are rare and insufficient.

Belgium itself is since the first state reform, in 1970, divided into several levels: federal (Belgium), regional (Flanders, Brussels, and Wallonia; shown in Figure 60), and provincial and municipal, shown in Figure . This division implies a certain hierarchy for both actors

and institutions. In addition, in Flanders, the water system is divided in ground and surface water. The Integral Water Policy Decree of 18 July 2003 transposes the European Water Framework into Flemish legislation and classifies the water systems based on hydrological, geomorphological, ecological, and functional characteristics. The different levels of water system boundaries within Flanders are flow areas (4), basins (11), sub-basins (102), VHA-zones (264), shown in Figure; and groundwater systems (6), as shown in Figure (Flemish Environment Agency 2020).

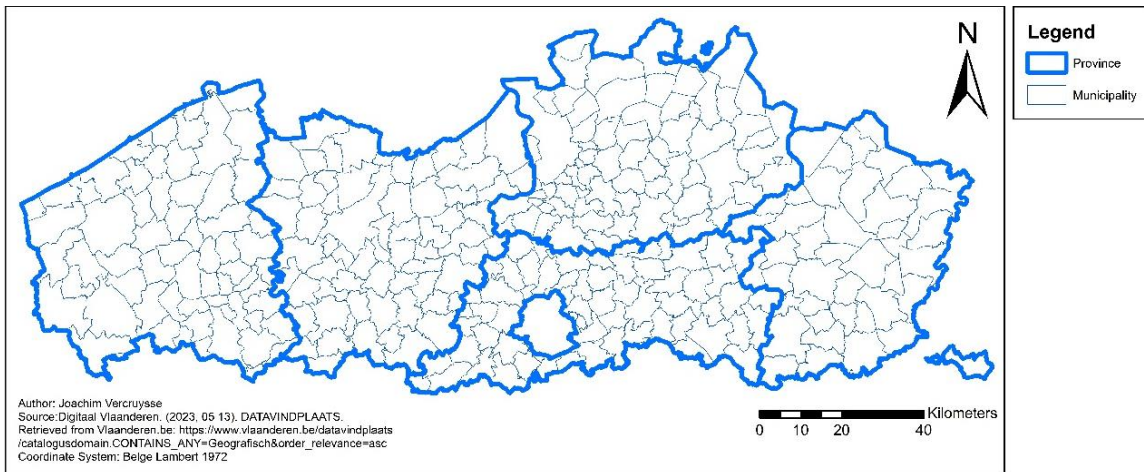


Figure 3. Flemish Provinces and Municipalities

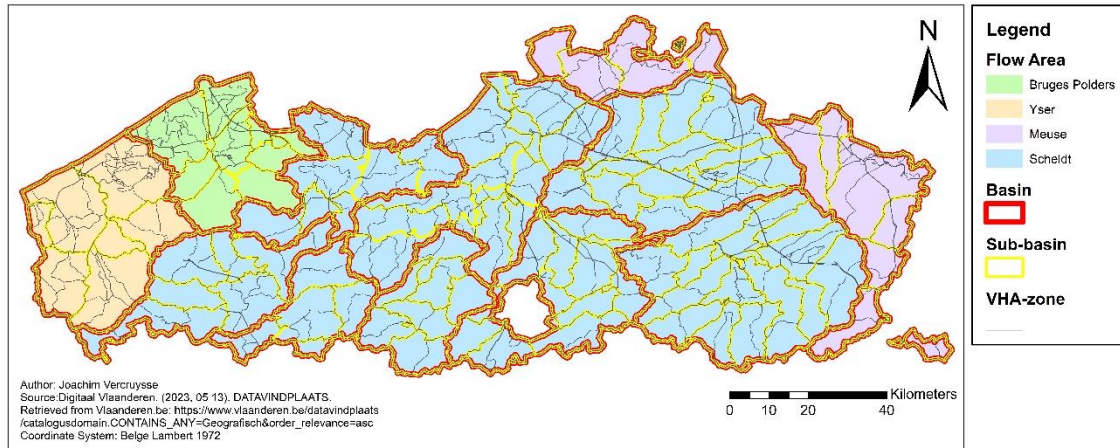


Figure 4. Flemish Flow areas, Basins, Sub-basins and VHA-zones

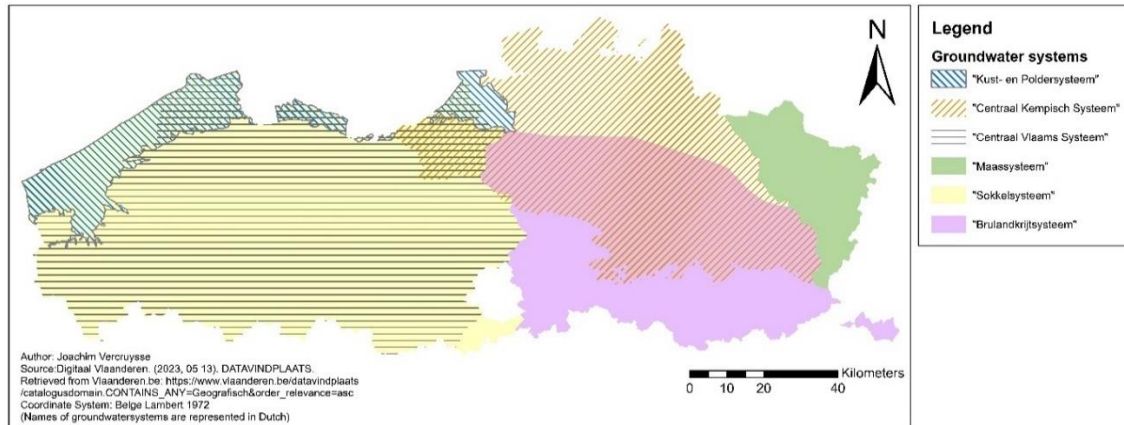


Figure 5. Flemish Groundwater systems

With regard to flooding, this division is a logical and appropriate approach, but it leads to overlapping authorities between different government levels. Therefore, the Flemish government established a general policy vision for integrated water management, in order to coordinate and organise water policy at the level of the Flemish Region. The water policy note outlines the policy framework and provides guidance for drafting flow area management plans. These plans address issues that may lead to a deterioration of the water system or that may hinder its improvement and recovery. Other degree's and legislation were drafted to regulate the amount of consumption and usage of water. (Coordination Committee on Integrated Water Policy 2021c; Flemish Environment Agency 2020) With regard to drought, there is currently no division into different areas, nor is the legislation adapted to droughts.

The following institutional regimes are currently included in the analysis: Belgian National Energy and Climate Plan 2021-2030, National Adaptation Plan, Integral water policy, Water policy note, Flow area management plans, Water Framework Directive and the Floods Directive, Flow areas, Basins, Sub-basins, VHA-zones, Groundwater system, Flemish Climate policy plan, Flemish Adaptation plan, First Enforcement decision: water, Enforcement decision: "Watertoets", Enforcement decision: Financial instruments, Subsidiary Directive Groundwater, Code of good practices, Regional urban development ordinance: rainwater, Drought measurements, Groundwater extraction legislation, Blue Deal, Extra norms for environment license and Other Decree's.

In this list, currently considered in the analysis, is it apparent that several of these legislations were made entirely in function of flood prevention and therefore outdated. The drought measures were added recently, but implemented as non-enforced and reactive measures. This adds to the drought problem, and addressing this issue will be crucial in the transition towards a resilient drought policy.

5.4 Intermediaries/mediators

The intermediaries/mediators bridge the different pillars of the ARA. These are various research institutions and universities, as well as reports produced on measurements and predictions, or internet portals providing climate predictions and scenarios, etc.

In Flanders, a significant number of intermediaries and mediators are active in monitoring and reporting on environmental factors such as rainfall, ground and surface water levels, and temperature across various locations. These environmental factors are continuously monitored at different measuring points, and the data collected is then stored and made accessible on the internet. For instance, on “Waterinfo.be”, a range of time series data can be accessed, providing an overview of the various monitoring activities.

Following the dissemination of monitored data, research institutions, such as the VMM and “Hydrologic Information Centre” (HIC), provide translations of this data into various reports. These reports are made available on “Waterinfo.be” and are categorised into status reports, annual reports, flood-storm and drought reports, and tide tables. Furthermore, the VMM also reports on the conditions of water, air, and climate, combined with the emissions of various actors (households, energy, agriculture, trade & services, and other industries) on their own platform. This information is based on the same data from “Waterinfo.be”, combined with usage and consumption figures from these actors. Additionally, the VMM has conducted research into tools that represent the impact of various natural disasters and allow users to see how the drought problem could evolve. This could encourage a change in mindset towards resilient water management practices. However, it is worth noting that the tools mainly focus on natural causes, and little attention was paid to the impact of human actors. This means that even though the tool does propose actions that actors can take to improve the situation, it does not give feedback from all causes.

Recently, in 2022, the intermediary “reactive assessment framework” was developed to advise the provincial governor. Based on the outcome of the framework, the governor can decide which actions has to be taken to prevent water scarcity. This framework takes the water use and consumption from actors, as well as factors and institutions into account. The used data is mostly an average from the period of 2005-2019, and provides little insight into future trends. Therefore, the reactive nature of the tool does not promote long-term, resilient solutions to address water scarcity, and is limited.

Even though Flanders conducts extensive monitoring and produces many reports to reflect progress, the challenge, in this area, lies in applying this knowledge within the legislative framework.

5.5 Combining knowledge

All actors, factors, institutions, and intermediaries/mediators were brought together in a social network analysis program called "Gephi". In this program, the relationships between components were connected, thereby revealing the previously discussed aspects.

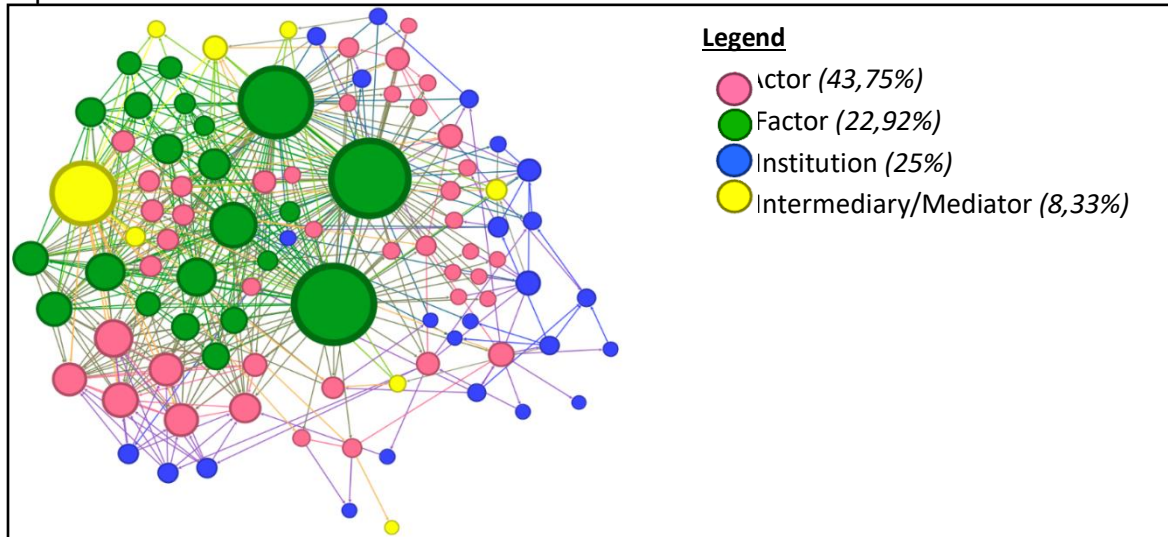


Figure 6. Case study network analysis, the proportion of the circles gives an indication of the degree of importance in the system. In more detail, it is possible to zoom in and highlight key elements. Figure shows an example, zooming in on the institution “*flow area management plans*” and where each direct link can be captured. This allows for an easier interpretation of the complex entity for the spatial planner and lights up connections that may not previously be visible.

Flanders is managed at different levels: federal, provincial, and municipal. However, these levels do not correspond to the water areas, which often results in overlaps and conflicts of interest between actors and institutions.

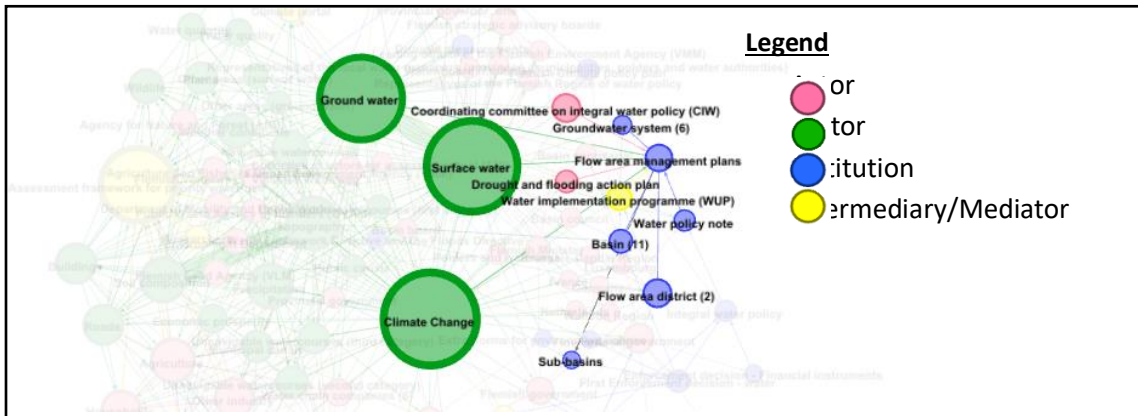


Figure 7. Detailed perspective from the network analysis

Remarkably, most relationships are found between actors, factors, and one intermediary (assessment framework). This highlights the importance of these components. Factors set everything in motion, thus influencing many components and triggering actions. The many relationships among actors can also be traced back to the various conflicts of interest, leading to additional connections. Despite their low population, intermediaries/mediators rank high in terms of importance, confirming that a wealth of data is available and that much is at stake.

An interesting finding is that legislation is mainly focused on flooding, with little attention given to other aspects of the water system. Nonetheless, 25 percent of the population in the system is constituted by institutions that can influence the drought system. When looking at the relationships, it is noted that legislation has little to no power compared to other components. Changes in factors or developments within them do not lead to changes in policy, unless there is an acute problem. Reactive measures will then be taken for a limited time, but they are not enforced, thereby weakening their impact and not evolving on a long-term basis.

6. Discussion

The research conducted in this study has focused on key aspects while acknowledging that not all possible dimensions could be thoroughly examined due to the clarity and scope of this paper. It is evident that actors and factors exhibit numerous interrelationships and interdependencies, although the influence of legislation appears to be limited. The research methodology employed in this paper provides valuable insights into the system, enabling a better understanding of the various relationships and facilitating a more proactive approach. Previously, many studies focused within a delineated aspect of drought, not considering the implications of other remaining aspects within the issue of drought (Chapagain et al. 2021; Hagenlocher et al. 2019;

Slette et al. 2019). This method will change this by dividing a complex issue into several components and combining the relationships and influences, that the components exert on each other, within one system. It allows changing elements to be adjusted over time, thus obtaining a more resilient result.

However, it is important to investigate whether different scales have an impact on the obtained results. Determining whether a global perspective, a detailed analysis at large scale or a site-specific approach, would yield more nuanced insights is an important aspect that warrants further investigation. Such exploration is essential to accurately visualise and comprehend the system, thereby empowering relevant authorities to undertake targeted and effective actions.

Furthermore, it would be beneficial to explore how a network analysis, based on the ARA, can be geographically represented, as this aspect has not been addressed in the present paper. Incorporating geographic information into the analysis can potentially offer additional contextual information and enhance the overall understanding of the system dynamics. This geographical perspective may clarify the spatial distribution of actors, their interactions and the influence of geographical factors and institutions on the system's resilience. It thus may contribute to a more comprehensive understanding of anthropogenic drought.

7. Conclusion

Numerous studies have emphasised the necessity of transitioning towards a more resilient system that can effectively mitigate the impacts of climate change and human-driven factors. To evolve towards a resilient drought management system, it is essential to establish a structured context. Drought, as a highly multidisciplinary problem, is often overlooked as a process interconnected with various underlying causes. This paper established a proper definition, through literature review, stating that the anthropogenic drought definition should be used to comprehend to problem properly.

Solely using the definition is difficult, since the system is too complex. By translating the anthropogenic drought definition into the actor relational approach, the system can be conceptualised more operational. The ARA splits the interrelated elements into actors, factors, institutions, and intermediaries/mediators, and allows to be visualised in a network analysis program, like "Gephi". Therewith it gives new insights for possible solutions, since it analyses the intense interrelationships between human and non-human elements within a specific institutional setting, towards a resilient drought management system.

For the case of Flanders, only the most important components were used. Nevertheless we note that the system has overlapping authorities and remains highly complex. Yet,

important relationships between connections became clear in the network analysis, which were not obvious from the desktop research. The most relationships were found between the actors, factors, and one intermediary (assessment framework). Despite institutions have the second largest representation in the system, we note that the degree of importance is low. This since the reactive measures are not maintained. Subsequently, the fixed measures are outdated and fixated on floods, thereby weakening the impact of the group institutions.

In summary, employing network analysis to visualise the relationships between actors, factors, institutions, and intermediaries/mediators through a network analysis, provides a powerful method for understanding the intricate interactions within a drought system. Planners and policymakers can utilise this method to strive towards a more resilient system and formulate policy recommendations for further elaboration.

References

- Abdollahi, Khodayar, Alireza Bazargan and Gordon McKay. 2019. "Water Balance Models in Environmental Modeling." *Handbook of Environmental Materials Management*:16.
- AghaKouchak, Amir, Ali Mirchi, Kaveh Madani, Giuliano Di Baldassarre, Ali Nazemi, Aneseh Alborzi, Hassan Anjileli, Marzi Azarderakhsh, Felicia Chiang and Elmira Hassanzadeh. 2021. "Anthropogenic drought: Definition, challenges, and opportunities." *Wiley Online Library*.
- Berkes, Fikret, Carl Folke and Johan Colding. 2000. *Linking social and ecological systems: management practices and social mechanisms for building resilience*: Cambridge University Press.
- Bloomfield, John P., Christopher R. Jackson and Marianne E. Stuart. 2013. "Changes in groundwater levels, temperature and quality in the UK over the 20th century: an assessment of evidence of impacts from climate change."
- Boelens, Luuk. 2010. "Theorizing practice and practising theory: Outlines for an actor-relational-approach in planning." *Planning theory* 9(1):28-62.
- Boelens, Luuk. 2018. "Moving Towards a Flat Ontology of Institutional Innovation Actor-Relational Lessons Learned from Early Water Management Perspectives." In *The Routledge handbook of institutions and planning in action*: Routledge.
- Boelens, Luuk. 2023. ed. Joachim Vercruyse.
- Boelens, Luuk, Georges Allaert and Chloé Walot. 2017. *Adapt for life: Coöperatie In Planning UA*.
- Chapagain, Ashok, Colin Strong, Gregg Brill, Jason Morrison, John H. Matthews, Kari Davis and Sandra Ruckstuhl. 2021. "Water Resilience Assessment Framework." ISBN: 978-1-940148-17-5.
- Coordination Committee on Integrated Water Policy. 2021a. "Draaiboek coördinatie

waterschaarste en droogte."

- Coordination Committee on Integrated Water Policy. 2021b. "Evaluatierapport waterschaarste en droogte 2020."
- Coordination Committee on Integrated Water Policy. 2021c. "Integrated water Policy in Flanders."
- Coordination Committee on Integrated Water Policy. 2022. "Wie doet wat in het Vlaamse waterbeleid." integraalwaterbeleid.be: Coordination Committee on Integrated Water Policy,.
- Coutts, Andrew M, Jason Beringer and Nigel J Tapper. 2007. "Impact of increasing urban density on local climate: Spatial and temporal variations in the surface energy balance in Melbourne, Australia." *Journal of Applied Meteorology and Climatology* 46(4):477-493.
- Crausbay, Shelley D., Aaron R. Ramirez, Shawn L. Carter, Molly S. Cross, Kimberly R. Hall, Deborah J. Bathke, Julio L. Betancourt, Steve Colt, Amanda E. Cravens and Melinda S. Dalton. 2017. "Defining ecological drought for the twenty-first century." *Bulletin of the American Meteorological Society* 98(12):2543-2550.
- Dai, Aiguo. 2011. "Drought under global warming: a review." *Wiley Interdisciplinary Reviews: Climate Change* 2(1):45-65.
- Dale, Virginia H. 1997. "The relationship between land-use change and climate change." *Ecological applications* 7(3):753-769.
- Davids, Peter. 2021. "Rethinking floodlabel: a situational approach to homeowner involvement in flood risk management." Ghent University.
- Davoudi, Simin, Elizabeth Brooks and Abid Mehmood. 2013. "Evolutionary Resilience and Strategies for Climate Adaptation." *Planning Practice & Research* 28(3):307-322.
- Davoudi, Simin, Keith Shaw, Jamila L. Haider, Allyson E. Quinlan, Garry D. Peterson, Cathy Wilkinson, Hartmut Fünfgeld, Darryn McEvoy, Libby Porter and Simin Davoudi. 2012. "Resilience: A Bridging Concept or a Dead End? "Reframing" Resilience: Challenges for Planning Theory and Practice Interacting Traps: Resilience Assessment of a Pasture Management System in Northern Afghanistan Urban Resilience: What Does it Mean in Planning Practice? Resilience as a Useful Concept for Climate Change Adaptation? The Politics of Resilience for Planning: A Cautionary Note." *Planning Theory & Practice* 13(2):299-333.
- Diffenbaugh, Noah S., Daniel L. Swain and Danielle Touma. 2015. "Anthropogenic warming has increased drought risk in California." *Proceedings of the National Academy of Sciences* 112(13):3931-3936.
- Dracup, John A., Kil Seong Lee and Edwin G. Paulson Jr. 1980. "On the definition of droughts." *Water resources research* 16(2):297-302.
- Fleig, Anne K., Lena M. Tallaksen, Hege Hisdal, Kerstin Stahl and David M. Hannah. 2010. "Inter-comparison of weather and circulation type classifications for hydrological drought development." *Physics and Chemistry of the Earth, Parts A/B/C* 35(9-12):507-515.

- Flemish Environment Agency. 2020. "Vlaamse Hydrografische Atlas - Zones, 12 maart 2020." ed. Vlaamse Milieumaatschappij - Afdeling Operationeel Waterbeheer: Agentschap Informatie Vlaanderen.
- Flemish Environment Agency. 2021a. "Drinkwaterbalans voor Vlaanderen - 2020."
- Flemish Environment Agency. 2021b. "Droogte."
- Flemish Environment Agency. 2021c. "Impact droogte op grondwater."
- Flemish Environment Agency. 2021d. "Impact droogte op waterlopen."
- Flemish Environment Agency. 2021e. "Uitwerking van een reactief afwegingskader voor prioritair watergebruik tijdens waterschaarste - Eindrapport."
- Folke, Carl. 2016. "Resilience (republished)." *Ecology and society* 21(4).
- Fünfgeld, Hartmut and Darryn McEvoy. 2012. "Resilience as a useful concept for climate change adaptation?" *Planning theory and practice* 13(2):324-328.
- Gassert, Reig, Luo and Maddocks. 2013. "Aqueduct country and river basin rankings: a weighted aggregation of spatially distinct hydrological indicators." Washington, DC.
- Grove, Kevin. 2018. *Resilience*: Routledge.
- Gual, Miguel A and Richard B Norgaard. 2010. "Bridging ecological and social systems coevolution: A review and proposal." *Ecological economics* 69(4):707-717.
- Hagenlocher, Michael, Isabel Meza, Carl C Anderson, Annika Min, Fabrice G Renaud, Yvonne Walz, Stefan Siebert and Zita Sebesvari. 2019. "Drought vulnerability and risk assessments: state of the art, persistent gaps, and research agenda." *Environmental Research Letters* 14(8):083002.
- Hervás-Gómez, Carmen and Fernando Delgado-Ramos. 2019. "Drought management planning policy: From Europe to Spain." *Sustainability* 11(7):1862.
- Holling, Crawford S. 1973. "Resilience and stability of ecological systems." *Annual review of ecology and systematics*:1-23.
- Holling, Crawford Stanley. 1996. "Engineering resilience versus ecological resilience." *Engineering within ecological constraints* 31(1996):32.
- IPCC. 2014. "Climate Change 2014: Synthesis Report." Geneva, Switzerland.
- IPCC. 2022. "Climate Change 2022: Impacts, Adaptation and Vulnerability." Geneva, Switzerland.
- Kasting, James F. 1989. "Long-term stability of the Earth's climate." *Global and planetary change* 1(1-2):83-95.
- Kiehl, Jeffrey. 2011. "Lessons from Earth's past." *Science* 331(6014):158-159.
- Kingston, Daniel G., James H. Stagge, Lena M. Tallaksen and David M. Hannah. 2015. "European-scale drought: understanding connections between atmospheric circulation and meteorological drought indices." *Journal of climate* 28(2):505-516.
- Klein, Richard J.T., Robert J. Nicholls and Frank Thomalla. 2003. "Resilience to natural hazards: How useful is this concept?" *Global environmental change part B: environmental hazards* 5(1):35-45.
- Madani, Kaveh, Amir AghaKouchak and Ali Mirchi. 2016. "Iran's socio-economic drought:

- challenges of a water-bankrupt nation." *Iranian studies* 49(6):997-1016.
- Madani, Kaveh and Majid Shafiee-Jood. 2020. "Socio-hydrology: a new understanding to unite or a new science to divide?" *Water* 12(7):1941.
- Meerow, Sara and Melissa Stults. 2016. "Comparing Conceptualizations of Urban Climate Resilience in Theory and Practice." *Sustainability* 8(7):701.
- Mehran, Ali, Omid Mazdiyasn and Amir AghaKouchak. 2015. "A hybrid framework for assessing socioeconomic drought: Linking climate variability, local resilience, and demand." *Journal of Geophysical Research: Atmospheres* 120(15):7520-7533.
- Mishra, Ashok K and Vijay P Singh. 2010. "A review of drought concepts." *Journal of hydrology* 391(1-2):202-216.
- Mo, Kingtse C. and Dennis P. Lettenmaier. 2016. "Precipitation deficit flash droughts over the United States." *Journal of Hydrometeorology* 17(4):1169-1184.
- Prudhomme, Christel, Ignazio Giuntoli, Emma L Robinson, Douglas B Clark, Nigel W Arnell, Rutger Dankers, Balázs M Fekete, Wietse Franssen, Dieter Gerten and Simon N Gosling. 2014. "Hydrological droughts in the 21st century, hotspots and uncertainties from a global multimodel ensemble experiment." *Proceedings of the National Academy of Sciences* 111(9):3262-3267.
- Rankin, A., M. Bång, M. Sainz, J. Radianti, J. Brage, S. Rosenqvist, L. Lebaka and J. Hernantes. 2016. "D1.1 Survey Report on World-Wide Approaches."
- Salata, Konstantina-Dimitra and Athena Yiannakou. 2020. "The quest for adaptation through spatial planning and ecosystem-based tools in resilience strategies." *Sustainability* 12(14):5548.
- Seneviratne, Nicholls, Easterling, Goodess, Kanae, Kossin, Luo, Marengo, McInnes, Rahimi, Reichstein, Sorteberg, Vera and Zhang. 2012. "Changes in climate extremes and their impacts on the natural physical environment." In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge University Press, Cambridge, UK, and New York, NY, USA: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC).
- Sheffield, Justin, Eric F Wood, Nathaniel Chaney, Kaiyu Guan, Sara Sadri, Xing Yuan, Luke Olang, Abou Amani, Abdou Ali and Siegfried Demuth. 2014. "A drought monitoring and forecasting system for sub-Sahara African water resources and food security." *Bulletin of the American Meteorological Society* 95(6):861-882.
- Shukla, Shraddhanand and Andrew W Wood. 2008. "Use of a standardized runoff index for characterizing hydrologic drought." *Geophysical research letters* 35(2).
- Slette, Ingrid J, Alison K Post, Mai Awad, Trevor Even, Arianna Punzalan, Sere Williams, Melinda D Smith and Alan K Knapp. 2019. "How ecologists define drought, and why we should do better." *Global Change Biology* 25(10):3193-3200.
- Stagge, James H, Lena M Tallaksen, Lukas Gudmundsson, Anne F Van Loon and Kerstin Stahl. 2015. "Candidate distributions for climatological drought indices (SPI and SPEI)." *International Journal of Climatology* 35(13):4027-4040.

- Tempels, Barbara. 2016. "Flood resilience: a co-evolutionary approach: residents, spatial developments and flood risk management in the Dender Basin." Ghent University.
- Trambauer, P, M Werner, HC Winsemius, S Maskey, E Dutra and S Uhlenbrook. 2015. "Hydrological drought forecasting and skill assessment for the Limpopo River basin, southern Africa." *Hydrology and Earth System Sciences* 19(4):1695-1711.
- Trenberth, Kevin E, Aiguo Dai, Gerard Van Der Schrier, Philip D Jones, Jonathan Barichivich, Keith R Briffa and Justin Sheffield. 2014. "Global warming and changes in drought." *Nature Climate Change* 4(1):17-22.
- Van Brussel, Suzanne. 2018. "The art of governing in the complex mobility transition: the value of adding an Orgware agenda." Ghent University.
- Van Loon, Anne F., Kerstin Stahl, Giuliano Di Baldassarre, Julian Clark, Sally Rangecroft, Niko Wanders, Tom Gleeson, Albert I. J. M. Van Dijk, Lena M. Tallaksen, Jamie Hannaford, Remko Uijlenhoet, Adriaan J. Teuling, David M. Hannah, Justin Sheffield, Mark Svoboda, Boud Verbeiren, Thorsten Wagener and Henny A. J. Van Lanen. 2016. "Drought in a human-modified world: reframing drought definitions, understanding, and analysis approaches." *Hydrol. Earth Syst. Sci.* 20(9):3631-3650.
- Vilonen, Leena, Maggie Ross and Melinda D Smith. 2022. "What happens after drought ends: synthesizing terms and definitions." *New Phytologist*.
- Wahl, Thomas, Sally Brown, Ivan D Haigh and Jan Even Øie Nilsen. 2018. "Coastal sea levels, impacts, and adaptation." MDPI.
- Wanders, Niko and Yoshihide Wada. 2015. "Human and climate impacts on the 21st century hydrological drought." *Journal of hydrology* 526:208-220.
- Wilhite. 2000. "Drought as a natural hazard: concepts and definitions."
- Wilhite and Glantz. 1985. "Understanding: the drought phenomenon: the role of definitions." *Water international* 10(3):111-120.
- Woodruff, Sierra C., Sara Meerow, Missy Stults and Chandler Wilkins. 2022. "Adaptation to Resilience Planning: Alternative Pathways to Prepare for Climate Change." *Journal of Planning Education and Research* 42(1):64-75.
- Zscheischler, Jakob, Seth Westra, Bart JJM Van Den Hurk, Sonia I Seneviratne, Philip J Ward, Andy Pitman, Amir AghaKouchak, David N Bresch, Michael Leonard and Thomas Wahl. 2018. "Future climate risk from compound events." *Nature Climate Change* 8(6):469-477.